UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 8,437,712 B2
APPLICATION NO. : 12/084134
DATED : May 7, 2013
INVENTOR(S) : Melis et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page:

The first or sole Notice should read --

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1409 days.

Signed and Sealed this
Tenth Day of February, 2015

Michelle K. Lee

Michelle K. Lee
Deputy Director of the United States Patent and Trademark Office

Office of Petitions: Routing Sheet

PUBS

Application No. 12/084,134

This application is being forwarded to your office for further processing. A decision has been rendered on a petition filed in this application.

- [X] **GRANTED**
- [ ] **DISMISSED**
- [ ] **DENIED**

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/084,134	08/27/2009	Bruno Melis	09952.0468-00000	5280

22852 7590 10/30/2014
FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

EXAMINER	
LE, NHAN T	
ART UNIT	PAPER NUMBER
2649	
MAIL DATE	DELIVERY MODE
10/30/2014	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

UNITED STATES PATENT AND TRADEMARK OFFICE

Commissioner for Patents
United States Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313-1450
www.uspto.gov

In re Patent No. 8,437,712	: DECISION ON REQUEST FOR
Melis et al.	: RECONSIDERATION OF
Issue Date: May 7, 2013	: PATENT TERM ADJUSTMENT
Application No. 12/084,134	: and
Filed: August 27, 2009	: NOTICE OF INTENT TO ISSUE
Atty Docket No.: 09952.0468-00000	: CERTIFICATE OF CORRECTION

This is a decision on the petition filed on October 4, 2013 pursuant to 37 C.F.R. § 1.705(b) requesting that the patent term adjustment indicated on the above-identified patent be corrected to indicate that the term of the above-identified patent is extended or adjusted by one thousand, four hundred and nine (1409) days.

The petition to correct the patent term adjustment indicated on the above-identified patent to indicate that the term of the above-identified patent is extended or adjusted by one thousand, four hundred and nine (1409) days is **GRANTED**.

The Office acknowledges submission of the $200.00 fee set forth in 37 CFR 1.18(e), along with a three-month extension of time so as to make timely this petition. No additional fees are required. Patentee has indicated this patent is not subject to a terminal disclaimer on the third page of this petition.

It is noted in passing the Office agrees the commencement date is April 28, 2008. Patentee sets forth the commencement date as April 28, 2008 on page 2, paragraph B of the petition, but uses a commencement date of April 27, 2008 to calculate the over three-year period. It follows the Office finds the over three-year period which begins on April 29, 2011 (not April 27, 2011) and ends with the issuance of the patent on May 7, 2013 totals 740, not 741 days, and the period of overlap which begins on April 28, 2011 not (April 27, 2011) totals 490, not 491 days. See petition, page 3, paragraphs C and E.

Formula:

"A" delay + "B" delay + "C" delay - overlap - applicant delay = X.

USPTO's Calculation:

1159 + 740 + 0 – 490 – 0 = 1409

<u>Patentee's Calculation</u>:

1159 + 741 + 0 – 491 – 0 = 1409

The application is being forwarded to the Certificates of Branch for issuance of a certificate of correction. The Office will issue a certificate of correction indicating that the term of the above-identified patent is extended or adjusted by **one thousand, four hundred and nine (1409) days.**

Telephone inquiries specific to this matter should be directed to the undersigned at (571) 272-3225.

/Paul Shanoski/
Paul Shanoski
Attorney Advisor
Office of Petitions

Encl: Adjusted PTA calculation
DRAFT Certificate of Correction

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT : 8,437,712 B2

DATED : **May 7, 2013** **DRAFT**

INVENTOR(S) : **Melis et al.**

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the cover page,

[*] Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 USC 154(b) by 923 days

Delete the phrase "by 923 days" and insert – by 1409 days --

Patent Term Adjustments

PTA/PTE Information | Patent Term Adjustment | Patent Term Extension

Application Number*: 12084134 Search Explanation of PTA Calculation Explanation of PTE Calculation

PTA Calculations for Application: 12084134

Application Filing Date	08/27/2009	**OverLapping Days Between (A and B) or (A and C)**	490
Issue Date of Patent	05/07/2013	**Non-Overlapping USPTO Delays**	923
A Delays	673	**PTO Manual Adjustment**	486
B Delays	740	**Applicant Delay (APPL)**	0
C Delays	0	**Total PTA (days)**	1409

* - Sorted Column

File Contents History

Action Number	Action Recorded Date	Action Due Date	Action Code	Action Description	Duration PTO	Duration APPL	Parent Action Number
64	10/21/2014		P028	Adjustment of PTA Calculation by PTO	1159		0
64	10/21/2014		P028	Adjustment of PTA Calculation by PTO	1159		0
63	10/21/2014		P028	Adjustment of PTA Calculation by PTO		673	0
63	10/21/2014		P028	Adjustment of PTA Calculation by PTO		673	0
59.5	05/07/2013	04/28/2011	PTA36M	PTA 36 Months	240		59.4
59	05/07/2013		PTAC	Patent Issue Date Used in PTA Calculation			0
58	04/09/2013		EFDC	Export to Final Data Capture			0
57	04/08/2013		D1935	Dispatch to FDC			0
56	04/08/2013		PILS	Application Is Considered Ready for Issue			0
55	04/05/2013		N084	Issue Fee Payment Verified			0
54	04/05/2013		IFEE	Issue Fee Payment Received			0
53	02/22/2013		FIDC	Finished Initial Data Capture			0
52	01/09/2013		EIDC	Export to Initial Data Capture			0
51	01/08/2013		MN/=.	Mail Notice of Allowance			0
50	01/07/2013		OAR	Office Action Review			0
49	01/07/2013		OAR	Office Action Review			0
48	01/07/2013		IREV	Issue Revision Completed			0
47	01/07/2013		DVER	Document Verification			0
46	01/07/2013		N/=.	Notice of Allowance Data Verification Completed			0
45	01/07/2013		DOCK	Case Docketed to Examiner in GAU			0
44	01/03/2013		EX.R	Reasons for Allowance			0
43	01/03/2013		CNTA	Allowability Notice			0
40	12/07/2012		INHY	case Inherited			0
39	12/07/2012		DOCK	Case Docketed to Examiner in GAU			0
36	12/06/2012		FWDX	Date Forwarded to Examiner			0
34	12/03/2012		INHY	case Inherited			0
33	12/03/2012		DOCK	Case Docketed to Examiner in GAU			0
41	11/30/2012		IDSC	Information Disclosure Statement considered			0
38	11/30/2012		RCAP	Reference capture on IDS			0
37	11/30/2012	11/30/2012	M844	Information Disclosure Statement (IDS) Filed			35
35	11/30/2012		A...	Response after Non-Final Action			0
32	11/30/2012		WIDS	Information Disclosure Statement (IDS) Filed			0
31	08/30/2012	10/27/2010	MCTNF	Mail Non-Final Rejection	673		13
30	08/28/2012		OAR	Office Action Review			0
28	08/16/2012		CTNF	Non-Final Rejection			0
21	01/05/2011		DOCK	Case Docketed to Examiner in GAU			0
20	08/04/2010		DOCK	Case Docketed to Examiner in GAU			0
17	04/25/2010		RCAP	Reference capture on IDS			0
15	01/28/2010		PG-ISSUE	PG-Pub Issue Notification			0
14	10/28/2009		OIPE	Application Dispatched from OIPE			0
12	10/19/2009		PGPC	Sent to Classification Contractor			0
11	10/19/2009		M903	Notice of DO/EO Acceptance Mailed			0
10	10/19/2009		FLRCPT.O	Filing Receipt			0
27	08/27/2009		IDSC	Information Disclosure Statement considered			0
19	08/27/2009		M844	Information Disclosure Statement (IDS) Filed			0
13	08/27/2009		371COMP	371 Completion Date			0
9	08/27/2009		ADDFLFEE	Additional Application Filing Fees			0
8	08/27/2009		INFODSCL	Information Disclosure Statements			0
7	08/27/2009		OATHDECL	A statement by one or more inventors satisfying the requirement under 35 USC 115, Oath of the Applic			0
6	08/27/2009		WIDS	Information Disclosure Statement (IDS) Filed			0
59.4	04/28/2008		COMMN	Commencement Date			0
0.5	10/27/2005		NEFILE	International Filing date			0

Export to: Excel

Office of Petitions: Decision Count Sheet

Mailing Month

Application No. 12084134

12084134

For US serial numbers: enter number only, no slashes or commas. Ex: 10123456
For PCT: enter "51+single digit of year of filing+last 5 numbers", Ex. for PCT/US05/12345, enter 51512345

Deciding Official: Paul Shanoski

Count (1) - Palm Credit 12/084,134

Decision: GRANT

FINANCE WORK NEEDED
Select Check Box for YES

GRANT

Decision Type: 551 - 37 CFR 1.705(d) - PATENT TERM ADJUSTMENT AI

551

Notes:

Count (2)

Decision: n/a

FINANCE WORK NEEDED
Select Check Box for YES

Decision Type: NONE

Notes:

Count (3)

Decision: n/a

FINANCE WORK NEEDED
Select Check Box for YES

Decision Type: NONE

Notes:

Initials of Approving Official (if required)

If more than 3 decisions, attach 2nd count sheet & mark this box

Printed on: *10/29/2014*

PATENT
Attorney Docket No. 09952.0468

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	)
Bruno MELIS et al.	) Group Art Unit: 2649
Patent No. 8,437,712 B2	) Examiner: Le, Nhan T.
Issued: May 7, 2013	) Confirmation No.: 5280
Application No.: 12/084,134	)
Filed: August 27, 2009	) VIA EFS-WEB
For: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT	)

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

APPLICATION FOR PATENT TERM ADJUSTMENT–POST GRANT

In accordance with 37 C.F.R. § 1.705, Applicant hereby applies for patent term adjustment under 35 U.S.C. § 154(b) of an additional 486 days or 1409 days total. This application for patent term adjustment (PTA) is being filed within the three month extended time limit from the May 7, 2013, issue date of the above-identified patent, as required by 37 C.F.R. § 1.705(b), and is accompanied by a three month petition for extension of time and the appropriate fee therefor.

I. STATEMENT OF THE FACTS INVOLVED

A. Correct Patent Term Adjustment

According to information printed on the face of the above-identified issued patent, U.S. Patent No. 8,437,712 B2 is entitled to 923 days of patent term adjustment, which corresponds to the PTA associated with this patent on PAIR. The Patentee, however, has calculated a patent term adjustment of 1409 days based on the following facts.

B. A Delays (Examination Delays)

The national stage requirements where fulfilled in the above-identified application on August 27, 2009, and the national stage commenced under 35 U.S.C. § 371 on April 28, 2008, thirty months after October 27, 2005, when the earliest priority application was filed.

A Non-Final Office Action was mailed on August 30, 2012, resulting in a U.S. Patent and Trademark Office (PTO) A delay of 673 days measured from the date of fulfilling the national stage requirements according to the PTO.

The AIA amended Section 154(b)(1)(A)(i) to start the 14-month period on the day after "the date of commencement of the national stage under section 371 in an international application," instead of on the § 371 Completion Date.
35 U.S.C. § 154(b)(1)(A)(i). Thus, the correct calculation of the PTO's A delay is 1159 days, counted from June 28, 2009 (14 months from the day after the date of commencement of the national stage) to August 30, 2012 (the mailing date of the Non-Final Office Action), instead of the Office's calculation of 673 days, counted from October 27, 2010 (14 months after the "371 Completion Date") to August 30, 2012 (the mailing date of the Non-Final Office Action).

Applicants agree with the Office calculation that there were no Applicant delays.

Based on the facts set forth above, the PTO delay during examination (A delays) is 1159 days, and Applicants' delay during examination is 0 days.

C. B Delays (Three-Year Pendency)

The Patentee and the Office disagree that PTA based on B delay is 740 days. The Patentee believes that the B delays should be 741 days (the period from the day after the date that is three years after the date of commencement of the national stage under section 371 (April 27, 2011) until the date the patent issued (May 7, 2013)). *See* 37 C.F.R. §§ 1.703(b).

D. C Delays

There was no C delay under the circumstances of this patent.

E. Overlapping PTO Days

There are 491 days overlapping days between "A" delays and "B" delays (the period from April 27, 2011 to August 30, 2012). In accordance with 37 C.F.R. § 1.703(f), and *Wyeth v. Kappos*, 591 F.3d 1364 (Fed. Cir. 2010), actual overlapping days may not be counted twice. Accordingly, the overlapping period of 491 days is subtracted from PTA otherwise accumulated under A and B delays.

F. Terminal Disclaimer

The above-identified application is not subject to a Terminal Disclaimer.

G. Reasonable Efforts

There were no circumstances constituting a failure to engage in reasonable efforts to conclude processing of examination of the above-identified application, as set forth in 37 C.F.R. § 1.704, other than those discussed above.

II. PTA DETERMINATION

According to information printed on the face of the above-identified issued patent, this patent is entitled to 923 days of patent term adjustment: 673 days of A delay + 740 days of B Delay - 490 days of overlap - 0 days of Applicant delay. The Patentee disagrees to the extent that A delay should be 1159 days so that overall PTA should be 1409 days: 1159 days of A delay + 741 days of B delay – 491 days of overlap - 0 days of Applicant delay. In view of the foregoing, the Patentee respectfully requests that the current patent term adjustment be reconsidered and adjusted in view of the above remarks.

III. FEE

As required by 37 C.F.R. § 1.705(b)(1), the required $200.00 fee is being charged to our credit card. Please charge any deficiencies to Deposit Account No. 06-0916. If there are any other fees due in connection with the filing of this request, please charge them to Deposit Account No. 06-0916. If a fee is required for an extension of time under 37 C.F.R. 1.136 not accounted for above, such an extension is requested and the fee should also be charged to our deposit account.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: OCT 04 2013

By: ____________
Ernest F. Chapman
Reg. No. 25,961

PATENT
Attorney Docket No. 09952.0468

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	
Bruno MELIS et al.	Group Art Unit: 2649
Patent No. 8,437,712 B2	Examiner: Le, Nhan T.
Issued: May 7, 2013	Confirmation No.: 5280
Application No.: 12/084,134	
Filed: August 27, 2009	**VIA EFS-WEB**

For: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

PETITION FOR EXTENSION OF TIME

Applicant petitions for a three-month extension of time to file an Application for Patent Term Adjustment-Post Grant. A fee of $1,400.00 is being charged to our credit card.

Please grant any additional extensions of time required to enter the attached reply and charge any additional required fees to deposit account 06-0916.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER, L.L.P.

Dated: OCT 04 2013

By:
Ernest F. Chapman
Reg. No. 25,961

Electronic Patent Application Fee Transmittal

Application Number:	12084134
Filing Date:	27-Aug-2009
Title of Invention:	METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT
First Named Inventor/Applicant Name:	Bruno Melis
Filer:	Richard V. Burgujian/Michelle Daniels
Attorney Docket Number:	09952.0468-00000

Filed as Large Entity

U.S. National Stage under 35 USC 371 Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Application for patent term adjustment	1455	1	200	200
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension - 3 months with $0 paid	1253	1	1400	1400
Miscellaneous:				
		Total in USD ($)		**1600**

Electronic Acknowledgement Receipt

EFS ID:	17043498
Application Number:	12084134
International Application Number:	
Confirmation Number:	5280
Title of Invention:	METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT
First Named Inventor/Applicant Name:	Bruno Melis
Customer Number:	22852
Filer:	Richard V. Burgujian/Michelle Daniels
Filer Authorized By:	Richard V. Burgujian
Attorney Docket Number:	09952.0468-00000
Receipt Date:	04-OCT-2013
Filing Date:	27-AUG-2009
Time Stamp:	14:52:22
Application Type:	U.S. National Stage under 35 USC 371

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$1600
RAM confirmation Number	1423
Deposit Account	
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)

1		ADS-PostGrant.pdf	222158 4e03865c65aa80356d90d8dd7cf4b08c7e7847d2	yes	5

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Patent Term Adjustment Petition	1	4
	Extension of Time	5	5

Warnings:

Information:

2	Fee Worksheet (SB06)	fee-info.pdf	32734 6fab3a5572b2943096c2c82c8995fced37526165	no	2

Warnings:

Information:

Total Files Size (in bytes):	254892

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/084,134	05/07/2013	8437712	09952.0468-00000	5280

22852 7590 04/17/2013

FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

ISSUE NOTIFICATION

The projected patent number and issue date are specified above.

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(application filed on or after May 29, 2000)

The Patent Term Adjustment is 923 day(s). Any patent to issue from the above-identified application will include an indication of the adjustment on the front page.

If a Continued Prosecution Application (CPA) was filed in the above-identified application, the filing date that determines Patent Term Adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) WEB site (http://pair.uspto.gov).

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Application Assistance Unit (AAU) of the Office of Data Management (ODM) at (571)-272-4200.

APPLICANT(s) (Please see PAIR WEB site http://pair.uspto.gov for additional applicants):

Bruno Melis, Torino, ITALY;
Alfredo Ruscitto, Torino, ITALY;
Paolo Semenzato, Roma, ITALY;
Renata Mele, Milano, ITALY;
Giuseppe Grassano, Milano, ITALY;

Customer Number 22,852
Attorney Docket No. 09952.0468

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	)	
	)	
Bruno MELIS et al.	)	Group Art Unit: 2649
	)	
Application No.: 12/084,134	)	Examiner: Le, Nhan T.
	)	
Filed: August 27, 2009	)	Confirmation No.: 5280
	)	
For: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT	)	

Mail Stop M Correspondence
Director of the U.S. Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

FEE ADDRESS FOR MAINTENANCE FEE PURPOSES IN ACCORDANCE WITH 37 C.F.R. 1.363

In accordance with the provisions of 37 C.F.R. 1.363, the fee address set forth below is being supplied for purposes of receiving notices, receipts, and other correspondence relating to the payment of maintenance fees:

CPI (Computer Packages Annuity Service, Inc.)
414 Hungerford Drive, Suite 300
Rockville, MD 20850

Payor Number, if assigned 00204

Phone: 301-517-5501
Fax: 301-763-8663
www.computerpackages.com
Gene McCloskey
GMccloskey@computerpackages.com

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated:

By: ______________________
Ernest F. Chapman
Reg. No. 25,961

ARTHUR S. GARRETT
REG. NO. 20,338

Electronic Patent Application Fee Transmittal

Application Number:	12084134
Filing Date:	27-Aug-2009
Title of Invention:	METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT
First Named Inventor/Applicant Name:	Bruno Melis
Filer:	Ernest F. Chapman/Michelle Daniels
Attorney Docket Number:	09952.0468-00000

Filed as Large Entity

U.S. National Stage under 35 USC 371 Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Utility Appl Issue Fee	1501	1	1780	1780
Publ. Fee- Early, Voluntary, or Normal	1504	1	300	300

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**2080**

Electronic Acknowledgement Receipt

EFS ID:	15448919
Application Number:	12084134
International Application Number:	
Confirmation Number:	5280
Title of Invention:	METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT
First Named Inventor/Applicant Name:	Bruno Melis
Customer Number:	22852
Filer:	Ernest F. Chapman/Michelle Daniels
Filer Authorized By:	Ernest F. Chapman
Attorney Docket Number:	09952.0468-00000
Receipt Date:	05-APR-2013
Filing Date:	27-AUG-2009
Time Stamp:	17:01:55
Application Type:	U.S. National Stage under 35 USC 371

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$2080
RAM confirmation Number	4326
Deposit Account	
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)

1		IF-FMTRANS.pdf	204454 f86aeba4efba83bd1e09984b358d8e2e100908be	yes	3
	Multipart Description/PDF files in .zip description				
	Document Description		**Start**		**End**
	Issue Fee Payment (PTO-85B)		1		1
	Change of Address		2		3
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	32260 9ea8e70f497500bfeaa6089105c6d392447f041a	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	236714		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail **Mail Stop ISSUE FEE**
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
or Fax (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

22852 7590 01/08/2013

FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being facsimile transmitted to the USPTO (571) 273-2885, on the date indicated below.

(Depositor's name)

(Signature)

(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/064,134	08/27/2009	Bruno Melis	09952.0468-00000	5280

TITLE OF INVENTION: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT

APPLN. TYPE	SMALL ENTITY	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1770	$300	$0	$2070	04/08/2013

EXAMINER	ART UNIT	CLASS-SUBCLASS
LE, NHAN T	2649	455-101000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

☐ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list

(1) the names of up to 3 registered patent attorneys or agents OR, alternatively,

(2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1. Finnegan, Henderson,
2. Farabow, Garrett &
3. Dunner, L.L.P.

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document has been filed for recordation as set forth in 37 CFR 3.11. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE
1. Telecom Italia S.p.A.
2. Pirelli & C. S.p.A.

(B) RESIDENCE: (CITY and STATE OR COUNTRY)
Both of MILANO, ITALY

Please check the appropriate assignee category or categories (will not be printed on the patent) : ☐ Individual ☒ Corporation or other private group entity ☐ Government

4a. The following fee(s) are submitted:

☒ Issue Fee
☒ Publication Fee (No small entity discount permitted)
☐ Advance Order - # of Copies ______

4b. Payment of Fee(s): **(Please first reapply any previously paid issue fee shown above)**

☐ A check is enclosed.
☒ Payment by credit card. Form PTO-2038 is attached.
☒ The Director is hereby authorized to charge the required fee(s), any deficiency, or credit any overpayment, to Deposit Account Number 06-0916 (enclose an extra copy of this form).

5. **Change in Entity Status** (from status indicated above)

☐ a. Applicant claims SMALL ENTITY status. See 37 CFR 1.27.
☐ b. Applicant is no longer claiming SMALL ENTITY status. See 37 CFR 1.27(g)(2).

NOTE: The Issue Fee and Publication Fee (if required) will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the United States Patent and Trademark Office.

Authorized Signature [signature]

Date April 5, 2013

Typed or printed name Arthur S. Garrett

Registration No. 20,338

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

NOTICE OF ALLOWANCE AND FEE(S) DUE

22852 7590 01/08/2013

FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

EXAMINER	
LE, NHAN T	
ART UNIT	PAPER NUMBER
2649	

DATE MAILED: 01/08/2013

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/084,134	08/27/2009	Bruno Melis	09952.0468-00000	5280

TITLE OF INVENTION: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT

APPLN. TYPE	SMALL ENTITY	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1770	$300	$0	$2070	04/08/2013

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE DOES NOT REFLECT A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE IN THIS APPLICATION. IF AN ISSUE FEE HAS PREVIOUSLY BEEN PAID IN THIS APPLICATION (AS SHOWN ABOVE), THE RETURN OF PART B OF THIS FORM WILL BE CONSIDERED A REQUEST TO REAPPLY THE PREVIOUSLY PAID ISSUE FEE TOWARD THE ISSUE FEE NOW DUE.

HOW TO REPLY TO THIS NOTICE:

I. Review the SMALL ENTITY status shown above.

If the SMALL ENTITY is shown as YES, verify your current SMALL ENTITY status:

A. If the status is the same, pay the TOTAL FEE(S) DUE shown above.

B. If the status above is to be removed, check box 5b on Part B - Fee(s) Transmittal and pay the PUBLICATION FEE (if required) and twice the amount of the ISSUE FEE shown above, or

If the SMALL ENTITY is shown as NO:

A. Pay TOTAL FEE(S) DUE shown above, or

B. If applicant claimed SMALL ENTITY status before, or is now claiming SMALL ENTITY status, check box 5a on Part B - Fee(s) Transmittal and pay the PUBLICATION FEE (if required) and 1/2 the ISSUE FEE shown above.

II. PART B - FEE(S) TRANSMITTAL, or its equivalent, must be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted. If an equivalent of Part B is filed, a request to reapply a previously paid issue fee must be clearly made, and delays in processing may occur due to the difficulty in recognizing the paper as an equivalent of Part B.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Mail Stop ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail **Mail Stop ISSUE FEE**
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INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

22852 7590 01/08/2013

FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

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(Depositor's name)

(Signature)

(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/084,134	08/27/2009	Bruno Melis	09952.0468-00000	5280

TITLE OF INVENTION: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT

APPLN. TYPE	SMALL ENTITY	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1770	$300	$0	$2070	04/08/2013

EXAMINER	ART UNIT	CLASS-SUBCLASS
LE, NHAN T	2649	455-101000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).
   - ☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.
   - ☐ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list
   (1) the names of up to 3 registered patent attorneys or agents OR, alternatively,
   (2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.
   1 ____________________
   2 ____________________
   3 ____________________

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document has been filed for recordation as set forth in 37 CFR 3.11. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE

(B) RESIDENCE: (CITY and STATE OR COUNTRY)

Please check the appropriate assignee category or categories (will not be printed on the patent) : ☐ Individual ☐ Corporation or other private group entity ☐ Government

4a. The following fee(s) are submitted:
- ☐ Issue Fee
- ☐ Publication Fee (No small entity discount permitted)
- ☐ Advance Order - # of Copies ____________________

4b. Payment of Fee(s): **(Please first reapply any previously paid issue fee shown above)**
- ☐ A check is enclosed.
- ☐ Payment by credit card. Form PTO-2038 is attached.
- ☐ The Director is hereby authorized to charge the required fee(s), any deficiency, or credit any overpayment, to Deposit Account Number ____________ (enclose an extra copy of this form).

5. **Change in Entity Status** (from status indicated above)
- ☐ a. Applicant claims SMALL ENTITY status. See 37 CFR 1.27.
- ☐ b. Applicant is no longer claiming SMALL ENTITY status. See 37 CFR 1.27(g)(2).

NOTE: The Issue Fee and Publication Fee (if required) will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the United States Patent and Trademark Office.

Authorized Signature ______________________________ Date ______________________________

Typed or printed name ______________________________ Registration No. ______________________________

This collection of information is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, Virginia 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450.

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UNITED STATES DEPARTMENT OF COMMERCE
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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/084,134	08/27/2009	Bruno Melis	09952.0468-00000	5280

22852 7590 01/08/2013

FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

EXAMINER	
LE, NHAN T	
ART UNIT	PAPER NUMBER
2649	

DATE MAILED: 01/08/2013

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(application filed on or after May 29, 2000)

The Patent Term Adjustment to date is 673 day(s). If the issue fee is paid on the date that is three months after the mailing date of this notice and the patent issues on the Tuesday before the date that is 28 weeks (six and a half months) after the mailing date of this notice, the Patent Term Adjustment will be 673 day(s).

If a Continued Prosecution Application (CPA) was filed in the above-identified application, the filing date that determines Patent Term Adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) WEB site (http://pair.uspto.gov).

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at 1-(888)-786-0101 or (571)-272-4200.

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Notice of Allowability	**Application No.** 12/084,134	**Applicant(s)** MELIS ET AL.	
	Examiner NHAN LE	**Art Unit** 2649	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☒ This communication is responsive to *11/30/2012*.
2. ☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.
3. ☒ The allowed claim(s) is/are *46-48 and 50-68*. As a result of the allowed claim(s), you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see http://www.uspto.gov/patents/init_events/pph/index.jsp or send an inquiry to PPHfeedback@uspto.gov .
4. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).
   a) ☐ All b) ☐ Some* c) ☐ None of the:
   1. ☐ Certified copies of the priority documents have been received.
   2. ☐ Certified copies of the priority documents have been received in Application No. _____ .
   3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

   * Certified copies not received: _____.

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application.
THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.

5. ☐ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.
   ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No./Mail Date _____.

   Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet. Replacement sheet(s) should be labeled as such in the header according to 37 CFR 1.121(d).
6. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1. ☐ Notice of References Cited (PTO-892)
2. ☒ Information Disclosure Statements (PTO/SB/08), Paper No./Mail Date _____
3. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material
4. ☐ Interview Summary (PTO-413), Paper No./Mail Date _____ .
5. ☐ Examiner's Amendment/Comment
6. ☒ Examiner's Statement of Reasons for Allowance
7. ☐ Other _____.

/NHAN LE/ Primary Examiner, Art Unit 2649	01/03/2013

DETAILED ACTION

Allowable Subject Matter

1. Claims 46-48, 50-68 are allowed over the prior art.

The following is an examiner's statement of reasons for allowance:

Claims 46-48, 50-68 are allowed for the reason as stated in the applicant's remarks pages 8-16, filed 11/30/2012.

2. Any comments considered necessary by applicant must be submitted no later than the payment of the issue fee and, to avoid processing delays, should preferably accompany the issue fee. Such submissions should be clearly labeled "Comments on Statement of Reasons for Allowance."

Conclusion

3. Any inquiry concerning this communication or earlier communications from the examiner should be directed to Nhan T. Le whose telephone number is 571-272-7892. The examiner can normally be reached on 08:00-05:00 (Mon-Fri).

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Yuwen Pan can be reached on 571-272-7855. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300. Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/Nhan T Le/
Primary Examiner, Art Unit 2649
Nhan T. Le

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	12084134	MELIS ET AL.
	Examiner	**Art Unit**
	CHARLES CHOW	2618

SEARCHED

Class	Subclass	Date	Examiner
455	101-103, 133-137, 272, 277.1, 277.2, 562.1	01/03/13	NLe
375	299, 347	/	/

SEARCH NOTES

Search Notes	Date	Examiner
Updated East Search	01/03/13	NLe
Double Patenting Search	/	/
Inventor Name Search	/	/

INTERFERENCE SEARCH

Class	Subclass	Date	Examiner
Interference Search, see East Search History	Text	01/03/13	NLe

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Use as many sheets as necessary)				Complete if Known	
				Application Number	12/084,134
				Filing Date	August 27, 2009
				First Named Inventor	Bruno MELIS et al.
				Parent Art Unit	2618
				Parent Examiner Name	Charles Chiang Chow
Sheet	1	of	2	Attorney Docket Number	09952-0468

U.S. PATENTS

Examiner Initials*	Cite No.[1]	Document Number: Number-Kind Code[2] (if known)	Issue or Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
		US-6,438,389 B1	08-2002	Sandhu et al.	
		US-2002/0187813 A1	12-2002	Guo	
		US-6,907,272 B2	06-2005	Roy, Sebastien Joseph Armand	
		US-2005/0181831 A1	08-2005	Doi	
		US-6,992,621	01-2006	Casas et al.	
		US-7,062,294 B1	06-2006	Rogard et al.	
		US-7,155,192	12-2006	Ghassemzadeh et al.	
		US-2007/0093269 A1	04-2007	Leabman	
		US-7,403,748	07-2008	Keskitalo et al.	
		US-7,697,626	04-2010	Wang et al.	
		US-8,185,161	05-2012	Haskell et al.	

U.S. PUBLISHED PATENT APPLICATIONS

Examiner Initials*	Cite No.[3]	Document Number: Number-Kind Code[4] (if known)	Issue or Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
		US-2001/0016504	08-2001	Dam et al.	
		US-2004/0234012	11-2004	Rooyen, Pieter van	
		US-2004/0224655 A1	11-2004	Petrov et al.	
		US-2005/0025271 A1	02-2005	Molish et al.	
		US-2005/0143037	06-2005	Stratis et al.	
		US-2005/0163270 A1	07-2005	Akita et al.	
		US-2005/0227619	10-2005	Lee et al.	
		US-2005/0287692 A1	12-2005	Kim et al.	
		US-2006/0079221	04-2006	Grant et al.	
		US-2007/0080886	04-2007	Thomas et al.	
		US-2007/0205943	09-2007	Nassiri-Toussi et al.	
		US-2010/0322336	12-2010	Nabar et al.	

Note: Submission of copies of U.S. Patents and published U.S. Patent Applications is not required.

FOREIGN PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	Foreign Patent Document: Country Code[5] Number[6] Kind Code[7] (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear	Translation[8]
		WO 02/03568 A1	01-2002	Sampath et al.		
		EP 1267501 A2	12-2002	Guo		
		EP-1475904 A2	11-2004	AMI SEMICONDUCTOR, INC.		

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /N.L./

INFORMATION DISCLOSURE STATEMENT BY APPLICANT				Complete if Known	
				Application Number	12/084,134
				Filing Date	August 27, 2009
				First Named Inventor	Bruno MELIS et al.
				Parent Art Unit	2618
(Use as many sheets as necessary)				Parent Examiner Name	Charles Chiang Chow
Sheet	2	of	2	Attorney Docket Number	09952-0468

FOREIGN PATENT DOCUMENTS

		EP 1489758 A1	12-2004	Doi		
		WO 2006/023247 A1	03-2006	Shtrom et al.		
		WO 2007/019185 A2	02-2007	Leabman		
		WO 2008/064696 A1	06-2008	D'Amico et al.		

NONPATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No.[1]	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation[6]
		"(O)RLANS IN THE FREQUENCY BAND 2400-2483.5 MHz", Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT), ECC Report 57, pages 1-17, (2004)	
		FAHMY ET AL.; "Ad Hoc Networks with Smart Antennas Using IEEE 802.11-Based Protocols", ICC 2002, 2002 IEEE International Conference on Communications, Conference Proceedings, pp. 3144-3148, (2002).	
		European International Search Report for International Application No. PCT/EP2007/011140, mailing date October 28, 2008.	

Examiner Signature	/Nhan Le/	Date Considered	01/03/2013

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /N.L./

Index of Claims	Application/Control No. 12084134	Applicant(s)/Patent Under Reexamination MELIS ET AL.
	Examiner CHARLES CHOW	Art Unit 2618

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIM		DATE								
Final	Original	08/13/2012	01/03/2013							
	1	-	-							
	2	-	-							
	3	-	-							
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	36	-	-							

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	12084134	MELIS ET AL.
	Examiner	**Art Unit**
	CHARLES CHOW	2618

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIM		DATE								
Final	Original	08/13/2012	01/03/2013							
	37	-	-							
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17	63	✓	=							
18	64	✓	=							
19	65	✓	=							
20	66	✓	=							
21	67	✓	=							
22	68	✓	=							

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
S1	160	@ad<"20060101" and (replicat$4 duplicat$4 cop$4) same divers$4 near2 antenna$1 and power	US-PGPUB; USPAT; EPO; JPO; DERWENT	OR	ON	2013/01/03 14:52
S2	1	divers$4 and antenna$1 and two near3 replica$1 and time near3 delay$3 and power near2 level$1 and imbalance and transmission near3 mode$1 and function and path$4.clm.	US-PGPUB; USPAT; EPO; JPO; DERWENT	OR	ON	2013/01/03 16:35
S3	1	(divers$4 and antenna$1 and two near3 replica$1 and time near3 delay$3 and power near2 level$1 and imbalance and transmission near3 mode$1 and function and path$4) and (bruno near2 melis.inv. or alfredo near2 ruscitto.inv. or paolo near2 semenzato.inv. or renata near2 mele.inv. or giuseppe near2 grassano.inv.)	US-PGPUB; USPAT; EPO; JPO; DERWENT	OR	ON	2013/01/03 16:36

EAST Search History (Interference)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
S4	0	divers$4 and antenna$1 and two near3 replica$1 and time near3 delay$3 and power near2 level$1 and imbalance and transmission near3 mode$1 and function and path$4	USPAT; UPAD	OR	ON	2013/01/03 16:37

1/3/2013 4:38:14 PM
C:\Users\nle1\Documents\EAST\Workspaces\12084134.wsp

Issue Classification

Application/Control No.	Applicant(s)/Patent Under Reexamination
12084134	MELIS ET AL.
Examiner	**Art Unit**
NHAN LE	2649

ORIGINAL

CLASS	SUBCLASS
455	101

CROSS REFERENCE(S)

CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)				
455	562.1				
375	299				

INTERNATIONAL CLASSIFICATION

CLAIMED					NON-CLAIMED
H	0	4	B	1 / 02 (2006.01.01)	
H	0	4	B	7 / 02 (2006.01.01)	

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
-	1	-	17	-	33	-	49	19	65						
-	2	-	18	-	34	4	50	20	66						
-	3	-	19	-	35	5	51	21	67						
-	4	-	20	-	36	6	52	22	68						
-	5	-	21	-	37	7	53								
-	6	-	22	-	38	8	54								
-	7	-	23	-	39	9	55								
-	8	-	24	-	40	10	56								
-	9	-	25	-	41	11	57								
-	10	-	26	-	42	12	58								
-	11	-	27	-	43	13	59								
-	12	-	28	-	44	14	60								
-	13	-	29	-	45	15	61								
-	14	-	30	1	46	16	62								
-	15	-	31	2	47	17	63								
-	16	-	32	3	48	18	64								

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 22
/NHAN LE/ Primary Examiner.Art Unit 2649 (Primary Examiner)	01/03/2013 (Date)	O.G. Print Claim(s): 1 — O.G. Print Figure: 27

PATENT
Customer No. 22,852
Attorney Docket No. 09952.0468

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	
Inventors.: Bruno MELIS et al.	Group Art Unit: 2618
Serial No.: 12/084,134	Examiner: Charles Chiang Chow
Filed: August 27, 2009	Confirmation No.: 5280
Title: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

VIA EFS-WEB

Commissioner:

REPLY TO OFFICE ACTION

In reply to the non-final Office Action mailed August 30, 2012, the period for response to which extends to November 30, 2012, please amend the above-identified application as follows:

Amendments to the Claims are reflected in the listing of claims in this paper.

Remarks follow the amendment section of this paper.

AMENDMENTS TO THE CLAIMS:

This listing of claims will replace all prior versions and listing of claims in the application.

Claims 1-45 (Canceled).

46. (Currently Amended) A method of diversity processing at least one signal propagated via at least two diversity antennas comprising the steps of:

propagating at least two replicas of said at least one signal over respective propagation paths coupled to said at least [[to]] <u>two</u> diversity antennas, whereby said replicas are propagated via different antennas;

subjecting at least one of said replicas to a time variable delay; [[and]]

adjusting the power levels of said at least two replicas to produce a level imbalance therebetween<u>;</u>

<u>selectively using one of three or more transmission modes for said at least one signal; and</u>

<u>selecting said level imbalance as a function of a selected transmission mode</u>.

47. (Previously Presented) The method of claim 46, wherein said at least two replicas comprise replicas having respectively higher and lower power levels, and wherein the method comprises the step of subjecting to said time variable delay, said replica having a lower power level.

48. (Previously Presented) The method of claim 46, comprising the step of selecting said level imbalance in the range of 3 to 10 dB.

49. (Canceled)

50. (Currently Amended) The method of claim [[49]] 46, wherein said plurality of transmission modes have respective coding rates and comprises the step of selecting said level imbalance as a function of said coding rates, wherein higher level imbalance values are selected for higher coding rates.

51. (Currently Amended) The method of claim [[49]] 46, comprising the steps of:

selectively varying the transmission mode used; and

adaptively varying said level imbalance as a function of the selected current transmission mode.

52. (Previously Presented) The method of claim 46, comprising the step of subjecting to time variable delays two of said replicas propagating over propagation paths associated with the same of said diversity antennas.

53. (Previously Presented) The method of claim 52, comprising the step of subjecting to time variable delays the replicas propagating over at least two of said propagation paths by:

providing, in the propagation paths for said at least two replicas associated with the same of said diversity antennas, respective distinct propagation portions and a combined propagation portion for said at least two replicas;

subjecting said at least two replicas to a time variable delay over the common portion of said propagation paths; and subjecting one of said at least two replicas to a fixed delay over a respective distinct portion of said propagation paths.

54. (Previously Presented) The method of claim 46, applied to at least one signal transmitted in the form of at least two replicas propagated over respective propagation paths toward said at least two diversity antennas, comprising the step of splitting said at least one signal transmitted to produce said at least two replicas of said at least one signal propagated over respective propagation paths coupled to said at least two diversity antennas.

55. (Previously Presented) The method of claim 54, wherein said splitting is an asymmetric splitting producing said level imbalance between said replicas.

56. (Previously Presented) The method of claim 55, wherein said splitting is a symmetric splitting, and further comprising the step of applying different gains over said respective propagation paths coupled to said at least two diversity antennas to produce said level imbalance between said replicas.

57. (Previously Presented) The method of claim 46, applied to at least one signal received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas, comprising the step of combining said at least two replicas to produce said at least one signal received.

58. (Previously Presented) The method of claim 57, wherein said combining is an asymmetric combining producing said level imbalance between said replicas.

59. (Previously Presented) The method of claim 57, wherein said combining is a symmetric combining, and further comprising the steps of applying different gains to

said respective propagation paths of said replicas from said at least two diversity antennas to produce said level imbalance between said replicas.

60. (Previously Presented) The method of claim 57, applied to at least two signals received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas, comprising the step of splitting at each of said diversity antennas the respective propagation paths of said at least two signals received.

61. (Previously Presented) A system for diversity processing at least one signal propagated via at least two diversity antennas by means of the method of claim 46, comprising:

respective propagation paths for propagating at least two replicas of said at least one signal, said respective propagation paths being coupled to said at least two diversity antennas, whereby said replicas are propagated via different antennas;

at least one time variable delay element for subjecting at least one of said replicas to a time variable delay; and

level adjusting elements arranged on said respective propagation paths to produce a level imbalance between the power levels of said at least two replicas.

62. (Previously Presented) The system of claim 61, comprising respective propagation paths for at least two said replicas having respectively higher and lower power levels, said at least one time variable delay element being arranged on the propagation path of said replica having a lower power level.

63. (Previously Presented) The system of claim 61, wherein said at least one signal is received in the form of at least two replicas propagated over respective

propagation paths from said at least two diversity antennas, comprising at least one combiner for combining said at least two replicas to produce said at least one signal received.

64. (Previously Presented) The system of claim 63, wherein said at least one combiner is an asymmetric combiner producing said level imbalance between said replicas.

65. (Previously Presented) The system of claim 63, wherein said at least one combiner is a symmetric combiner, and further comprising gain elements for applying different gains to said respective propagation paths of said replicas from said at least two diversity antennas of said replicas to produce said level imbalance between said replicas.

66. (Previously Presented) The system of claim 61, wherein said at least one signal transmitted and received by means of said at least two diversity antennas, comprises:

at least one splitter for splitting said at least one signal transmitted to produce at least two replicas transmitted over respective transmission paths toward said diversity antennas; and

at least one combiner for combining said at least two replicas propagated over respective propagation paths from said at least two diversity antennas to produce said at least one signal received,

wherein said at least one splitter and combiner comprise at least one reciprocal element.

67. (Previously Presented) A wireless communication apparatus comprising the system of claim 61.

68. (Currently Amended) A non-transitory computer-readable medium containing a computer program product, loadable into the memory of at least one computer and comprising software code portions capable of performing the method of claim 46.

REMARKS

Applicants submit this Reply to Office Action in response to the non-final Office Action mailed August 30, 2012. Claims 46-68 are pending in this application, of which claim 46 is independent. By this Reply, Applicants have amended claims 46 and 68 and canceled claim 49 without prejudice or disclaimer. No new matter has been added.

First, the Examiner objected to claim 46 because of a typographical error.

Second, the Examiner rejected claims 46, 61, and 68 under 35 U.S.C. § 102(e) as being anticipated by U.S. Patent No. 6,917,597 ("*Schmidl*").

Third, under 35 U.S.C. § 103(a), the Examiner rejected as being unpatentable claims 47 and 62 over *Schmidl* in view of U.S. Patent Publication No. 2004/0266338 ("*Rowitch*"); claim 48 over *Schmidl* in view of U.S. Patent No. 7,450,907 ("*Shurvinton*"); claims 49-51 over *Schmidl* in view of U.S. Patent No. 6,154,652 ("*Park*"); claim 52 over *Schmidl* in view of U.S. Patent No. 5,982,825 ("*Tsujimoto*"); claim 53 over *Schmidl* and *Tsujimoto* and further in view of U.S. Patent No. 7,653,149 ("*Strich*"); claim 54 over *Schmidl* in view of U.S. Patent No. 7,433,713 ("*Haskell*"); claim 55 over *Schmidl*, *Haskell*, and further in view of U.S. Patent Publication No. 2002/0190790 ("*Chen*"); claim 56 over *Schmidl*, *Haskell*, *Chen*, and further in view of U.S. Patent No. 6,658,268 ("*Golemon*"); claims 57, 59, 63, and 65 over *Schmidl* in view of *Haskell*; claims 58 and 64 over *Schmidl*, *Haskell* and *Chen*; rejected claim 60 under 35 U.S.C. § 103(a) as being unpatentable over *Schmidl*, *Haskell*, and *Strich*; claim 66 over *Schmidl*, *Strich*, and further in view of U.S. Patent No. 5,504,465 ("*Yung*"); claim 67 over *Schmidl* in view of U.S. Patent No. 6,259,730 ("*Solondz*").

Objection of Claim

The Examiner objects to informalities of claim 46. By this Reply, Applicants have amended claim 46 to recite, in part, "coupled to said at least two diversity antennas." Accordingly, Applicants respectfully request that the Examiner reconsider and withdraw the objection of claim 46.

Rejection of Claims 46, 61, and 68 Under 35 U.S.C. § 102

The Examiner rejected claims 46, 61, and 68 under 35 U.S.C. § 102(e) as being anticipated by *Schmidl.* In order to properly establish that *Schmidl* anticipates Applicants' claims under 35 U.S.C. § 102, every element of the claims at issue must be found, either expressly or described under principles of inherency, in that single reference. *See* M.P.E.P. § 2131. Furthermore, "[t]he identical invention must be shown in as complete detail as is contained in the . . . claim." *Id.* (quoting *Richardson v. Suzuki Motor Co.*, 868 F.2d 1126, 1236, 9 U.S.P.Q.2d 1913, 1920 (Fed. Cir. 1989)).

Schmidl fails to disclose every element of independent claim 46 as amended. Specifically, *Schmidl* fails to disclose at least, "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in independent claim 46.

In the Office Action, the Examiner concedes, "Schmidl fails to disclose the mode, associated with imbalance." *Office Action* at 6 (under the rejection of now-canceled claim 49 under 35 U.S.C. § 103(a)). In an attempt to cure this deficiency, the Examiner cites to *Park*. The Examiner asserts that *Park* discloses "in handoff-mode, instead of normal-mode, the controller increases the gain amplifier 515, with fast data clock, for the shorter length of orthogonal codes, as higher coding rate, controller increases the gain of amplifier 515, col. 6, lines 48-67." *Id.* The Examiner continues, "the gain of 515 is set higher than the first amplifier 514 in proportional to the converted data rate, mode, in order to compensate for Ber, which is increasing with data rate, as transmission mode, col. 6, lines 8-23, for transmitting the same input data to 511, 911/912." *Id.* The Examiner then concludes, "Therefore, one of ordinary skill in the art at the time of the invention was made would have been obvious to modify Schmidl with Park's technique, such that the gain for different amplifier could be controlled to compensate the coding rate/Ber." *Id.*

Applicants respectfully disagree with the Examiner's characterization of *Park*. However, even assuming, *arguendo*, that the Examiner's characterization of *Park* is accurate, nowhere does *Park* disclose selectively using one of three or more transmission modes and selecting the level imbalance as a function of a selected transmission mode. Rather, *Park* teaches the use of two transmission modes—"handoff mode" and "normal mode"—and provides a higher transmission power in handoff mode than in normal mode. *Park* at col. 6, ll. 48-67. Thus, *Park* fails to disclose at least, "*selectively using one of three or more transmission modes* for said at least one signal; *and selecting said level imbalance as a function of a selected transmission mode*," as recited in independent claim 46.

Accordingly, Applicants respectfully request that the Examiner reconsider and withdraw the rejection of amended independent claim 46 under 35 U.S.C. § 102(b) based on *Schmidl*. Claim 61 and 68 depend from claim 46, and thus, are patentably distinguishable from *Schmidl* for the same reasons as claim 46. As a result, Applicants similarly request that the Examiner reconsider and withdraw the rejection of claims 61 and 68 under § 102(b).

<u>Rejection of Claims Under 35 U.S.C. § 103(a)</u>

Applying 35 U.S.C. § 103(a), the Examiner rejected claims 47-60 and 62-67 as set forth below. However, a *prima facie* case of obviousness, the requirements of which are discussed below, has not been established for each rejected claim.

To establish a *prima facie* case of obviousness, the prior art reference (or references when combined) must disclose all of claim recitations, or the claim rejection must explain why the differences between the prior art and the claim recitations would have been obvious to one of ordinary skill in the art. *See* M.P.E.P. § 2141.

<u>Rejection of Claim 48 Under 35 U.S.C. § 103(a)</u>

Claim 48 stands rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl* in view of *Shurvinton.* Claim 48 depends directly from amended independent claim 46, which is allowable over *Schmidl* for at least the reasons outlined above. *Shurvinton* does not remedy the deficiencies of *Schmidl*, at least because it also fails to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35 U.S.C. § 103(a) rejection of dependent claim 48 cannot be maintained and should be withdrawn.

<u>Rejection of Claims 49-51 Under 35 U.S.C. § 103(a)</u>

Claims 49-51 stands rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl* in view of *Park.* Claim 49 has been canceled, rendering moot its rejection.

Claims 50 and 51 depend directly from amended independent claim 46, which is allowable over *Schmidl* for at least the reasons outlined above. *Park* does not remedy the deficiencies of *Schmidl*, at least because it also fails to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35 U.S.C. § 103(a) rejection of dependent claims 50-51 cannot be maintained and should be withdrawn.

Rejection of Claim 52 Under 35 U.S.C. § 103(a)

Claim 52 stands rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl* in view of *Tsujimoto*. Claim 52 depends directly from amended independent claim 46, which is allowable over *Schimdl* for at least the reasons outlined above. *Tsujimoto* does not remedy the deficiencies of *Schmidl*, at least because it also fails to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35 U.S.C. § 103(a) rejection of dependent claim 52 cannot be maintained and should be withdrawn.

Rejection of Claim 53 Under 35 U.S.C. § 103(a)

Claim 53 stands rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl*, *Tsujimoto*, and further in view of *Strich*. Claim 53 depends directly from amended independent claim 46, which is allowable over *Schimdl* for at least the reasons outlined above. *Tsujimoto* and *Strich* do not remedy the deficiencies of *Schmidl* or *Park*, at least because they also fail to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35 U.S.C. § 103(a) rejection of dependent claim 53 cannot be maintained and should be withdrawn.

Rejection of Claim 54 Under 35 U.S.C. § 103(a)

Claim 54 stands rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl* in view of *Haskell.* Claim 54 depends directly from amended independent claim 46, which is allowable over *Schimdl* for at least the reasons outlined above. *Haskell* does not remedy the deficiencies of *Schmidl*, at least because it also fails to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35 U.S.C. § 103(a) rejection of dependent claim 54 cannot be maintained and should be withdrawn.

Rejection of Claims 55, 58, and 64 Under 35 U.S.C. § 103(a)

Claims 55, 58, and 64 stand rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl*, *Haskell*, and further in view of *Chen*. Claims 55, 58, and 64 depend, either directly or indirectly, from amended independent claim 46, which is allowable over *Schmidl* for at least the reasons outlined above. *Haskell* and *Chen* do not remedy the deficiencies of *Schmidl*, at least because they also fail to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35

U.S.C. § 103(a) rejection of dependent claims 55, 58, and 64 cannot be maintained and should be withdrawn.

Rejection of Claim 56 Under 35 U.S.C. § 103(a)

Claim 56 stands rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl*, *Haskell*, *Chen* and further in view of *Golemon.* Claim 56 depends directly from amended independent claim 46, which is allowable over *Schmidl* for at least the reasons outlined above. *Haskell*, *Chen*, and *Golemon* do not remedy the deficiencies of *Schmidl*, at least because they also fail to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35 U.S.C. § 103(a) rejection of dependent claim 56 cannot be maintained and should be withdrawn.

Rejection of Claims 57, 59, 63, and 65 Under 35 U.S.C. § 103(a)

Claims 57, 59, 63 and 66 stand rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl* in view of *Haskell.* Claim 57, 59, 63 and 66 depend, either directly or indirectly, from amended independent claim 46, which is allowable over *Schimdl* for at least the reasons outlined above. *Haskell* does not remedy the deficiencies of *Schmidl*, at least because it also fails to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35 U.S.C. § 103(a) rejection of dependent claims 57, 59, 63 and 66 cannot be maintained and should be withdrawn.

Rejection of Claim 60 Under 35 U.S.C. § 103(a)

Claim 60 stands rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl*, *Haskell*, and further in view of *Strich*. Claim 60 depends directly from amended independent claim 46, which is allowable over *Schimdl* for at least the reasons outlined above. *Haskell* and *Strich* do not remedy the deficiencies of *Schmidl*, at least because they also fail to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35 U.S.C. § 103(a) rejection of dependent claim 60 cannot be maintained and should be withdrawn.

Rejection of Claim 66 Under 35 U.S.C. § 103(a)

Claim 66 stands rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl*, *Strich*, and further in view of *Yung*. Claim 66 depends directly from amended independent claim 46, which is allowable over *Schmidl* for at least the reasons outlined above. *Strich* and *Yung* do not remedy the deficiencies of *Schmidl*, at least because they also fail to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35 U.S.C. § 103(a) rejection of dependent claim 66 cannot be maintained and should be withdrawn.

Rejection of Claim 67 Under 35 U.S.C. § 103(a)

Claim 67 stands rejected for being unpatentable under 35 U.S.C. § 103(a) over *Schmidl* in view of *Solondz*. Claim 67 depends directly from amended independent claim 46, which is allowable over *Schmidl* for at least the reasons outlined above. *Solondz* does not remedy the deficiencies of *Schmidl*, at least because it also fails to disclose or suggest at least "selectively using one of three or more transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode," as recited in amended independent claim 46. Therefore, the 35 U.S.C. § 103(a) rejection of dependent claim 67 cannot be maintained and should be withdrawn.

Claim Scope

It is to be understood that Applicants are in no way intending to limit the scope of the claims to any exemplary embodiments described in the specification or abstract and/or shown in the drawings. Rather, Applicants believe that they are entitled to have the claims interpreted broadly, to the maximum extent permitted by statute, regulation, and applicable case law.

Conclusion

In view of the foregoing remarks, Applicants respectfully request reconsideration and reexamination of this application, and the timely allowance of the pending claims.

If the Examiner believes that a telephone conversation might advance prosecution of this application, the Examiner is cordially invited to call Applicants' undersigned attorney at (404) 653-6476.

Applicants respectfully note that the Office Action contains a number of assertions concerning the related art and the claims. Regardless of whether those assertions are addressed specifically herein, Applicants respectfully decline to automatically subscribe to them.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: November 30, 2012

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PATENT
Customer No. 22,852
Attorney Docket No. 09952.0468-00000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	)
	)
Bruno MELIS et al.	) Group Art Unit: 2618
	)
Application No.: 12/084,134	) Examiner: Charles Chiang Chow
	)
Filed: August 27, 2009	) Confirmation No.: 5280
	)
For: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT	)

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

VIA EFS WEB

Commissioner:

INFORMATION DISCLOSURE STATEMENT UNDER 37 C.F.R. § 1.97(c)

Pursuant to 37 C.F.R. §§ 1.56 and 1.97(c), Applicants bring to the attention of the Examiner the documents on the attached listing. This Information Disclosure Statement is being filed after the events recited in Section 1.97(b) but, to the undersigned's knowledge, before the mailing date of either a Final action, Quayle action, or a Notice of Allowance. Under the provisions of 37 C.F.R. § 1.97(c), this Information Disclosure Statement is accompanied by a fee of $180.00 as specified by Section 1.17(p).

Applicants respectfully request that the Examiner consider the listed documents and indicate that they were considered by making appropriate notations on the attached form.

This submission does not represent that a search has been made or that no better art exists and does not constitute an admission that each or all of the listed documents are material or constitute "prior art." If the Examiner applies any of the documents as prior art against any claims in the application and Applicants determine that the cited documents do not constitute "prior art" under United States law, Applicants reserve the right to present to the office the relevant facts and law regarding the appropriate status of such documents.

Applicants further reserve the right to take appropriate action to establish the patentability of the disclosed invention over the listed documents, should one or more of the documents be applied against the claims of the present application.

If there is any fee due in connection with the filing of this Statement, please charge the fee to Deposit Account 06-0916.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: November 30, 2012

By: ______________________
Benjamin A. Saidman
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Use as many sheets as necessary)				*Complete if Known*	
				Application Number	12/084,134
				Filing Date	August 27, 2009
				First Named Inventor	Bruno MELIS et al.
				Parent Art Unit	2618
				Parent Examiner Name	Charles Chiang Chow
Sheet	1	of	2	*Attorney Docket Number*	09952-0468

U.S. PATENTS

Examiner Initials*	Cite No.[1]	Document Number Number-Kind Code[2] *(if known)*	Issue or Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
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Examiner Initials*	Cite No.[3]	Document Number Number-Kind Code[4] *(if known)*	Issue or Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
		US-2001/0016504	08-2001	Dam et al.	
		US-2004/0234012	11-2004	Rooyen, Pieter van	
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Note: Submission of copies of U.S. Patents and published U.S. Patent Applications is not required.

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Examiner Initials*	Cite No.[1]	Foreign Patent Document Country Code[5] Number[6] Kind Code[7] *(if known)*	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear	Translation[8]
		WO 02/03568 A1	01-2002	Sampath et al.		
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		EP-1475904 A2	11-2004	AMI SEMICONDUCTOR, INC.		

INFORMATION DISCLOSURE STATEMENT BY APPLICANT				*Complete if Known*	
				Application Number	12/084,134
				Filing Date	August 27, 2009
				First Named Inventor	Bruno MELIS et al.
				Parent Art Unit	2618
(Use as many sheets as necessary)				*Parent Examiner Name*	Charles Chiang Chow
Sheet	2	of	2	*Attorney Docket Number*	09952-0468

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NONPATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No.[1]	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation[6]
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		European International Search Report for International Application No. PCT/EP2007/011140, mailing date October 28, 2008.	

Examiner Signature		Date Considered	

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 January 2002 (10.01.2002)

PCT

(10) International Publication Number
WO 02/03568 A1

(51) International Patent Classification[7]: H04B 7/02

(21) International Application Number: PCT/US01/20470

(22) International Filing Date: 26 June 2001 (26.06.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/609,591 30 June 2000 (30.06.2000) US

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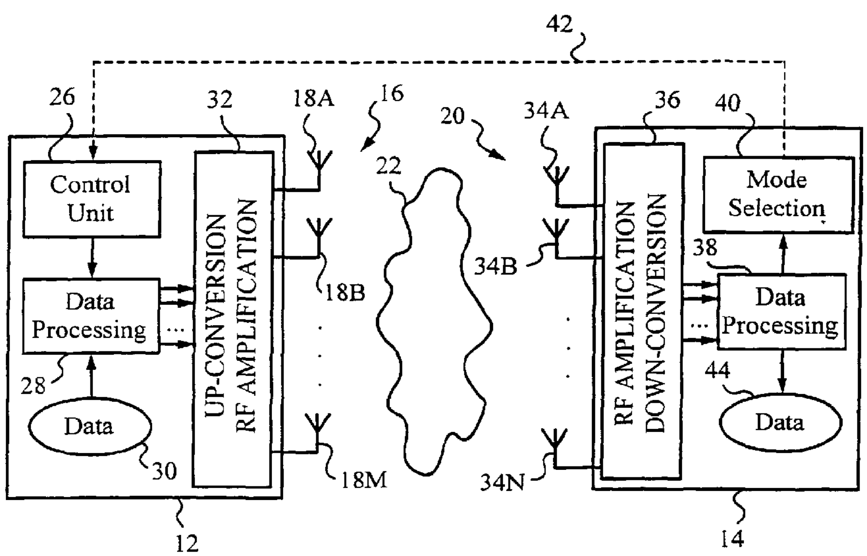
(81) Designated States *(national)*: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** METHOD AND SYSTEM FOR MODE ADAPTATION IN WIRELESS COMMUNICATION



(57) **Abstract:** A method and system for selective mode adaptation for transmitting data by spatial multiplexing applicable in communications systems with a transmit unit having multiple transmit antennas (18A-18N) or multiple transmit units and a receive unit having multiple receive antennas (34A-34N). A channel descriptor, such as channel matrix H or a channel matrix filter *H*, with has sub-descriptors correspondin g to the transmit antennas is determined and a quality parameter, such as signal-to-interference and noise ratio, signal-to-noise ratio or power level are chosen. The quality parameter is assigned a thereshold and the sub-descriptor or sub-descriptors whose quality parameters do not meet the threshold are identified and deactivated (40, 26).

WO 02/03568 A1

METHOD AND SYSTEM FOR MODE ADAPTATION IN WIRELESS COMMUNICATION

FIELD OF THE INVENTION

The present invention relates generally to wireless communication systems and methods, and more particularly to mode adaptation including selection of transmit antennas in transmit units employing multiple antennas for spatial multiplexing.

BACKGROUND OF THE INVENTION

Wireless communication systems serving stationary and mobile wireless subscribers are rapidly gaining popularity. Numerous system layouts and communications protocols have been developed to provide coverage in such wireless communication systems.

Wireless communications channels between transmit and receive devices are inherently variable and their quality fluctuates. Specifically, the quality parameters of such communications channels vary in time. Under good conditions wireless channels exhibit good communication parameters, e.g., large data capacity, high signal quality, high spectral efficiency and throughput. At these times significant amounts of data can be transmitted via the channel reliably. However, as the channel changes in time, the communication parameters also change. Under altered conditions former data rates, coding techniques and data formats may no longer be feasible. For example, when channel performance is degraded the transmitted data may experience excessive corruption yielding unacceptable communication parameters. For instance, transmitted data can exhibit excessive bit-error rates or packet error rates. The degradation of the channel can be due to a multitude of factors such as general noise in the channel, multi-path fading, loss of line-of-sight path, excessive Co-Channel Interference (CCI) and other factors.

By reducing CCI the carrier-to-interference (C/I) ratio can be improved and the spectral efficiency increased. Specifically, improved C/I ratio yields higher per link bit rates, enables more aggressive frequency re-use structures and increases the coverage of the system.

It is also known in the communication art that transmit units and receive units equipped with antenna arrays, rather than single antennas, can improve receiver performance. Antenna arrays can both reduce multipath fading of the desired signal and suppress interfering signals or CCI. Such arrays can consequently increase both the range and capacity of wireless systems. This is true for wireless cellular telephone and other mobile systems as well as Fixed Wireless Access (FWA) systems.

In mobile systems, a variety of factors cause signal degradation and corruption. These include interference from other cellular users within or near a given cell. Another source of signal degradation is multipath fading, in which the received amplitude and phase of a signal varies over time. The fading rate can reach as much as 200 Hz for a mobile user traveling at 60 mph at PCS frequencies of about 1.9 GHz. In such environments, the problem is to cleanly extract the signal of the user being tracked from the collection of received noise, CCI, and desired signal portions summed at the antennas of the array.

In FWA systems, e.g., where the receiver remains stationary, signal fading rate is less than in mobile systems. In this case, the channel coherence time or the time during which the channel estimate remains stable is longer since the receiver does not move. Still, over time, channel coherence will be lost in FWA systems as well.

Antenna arrays enable the system designer to increase the total received signal power, which makes the extraction of the desired signal easier. Signal recovery techniques using adaptive antenna arrays are described in detail, e.g., in the handbook of Theodore S. Rappaport, *Smart Antennas, Adaptive Arrays, Algorithms, & Wireless Position Location*; and Paulraj, A.J. et al., "Space-Time Processing for Wireless Communications", IEEE Signal Processing Magazine, Nov. 1997, pp. 49-83.

Prior art wireless systems have employed adaptive modulation of the transmitted signals with the use of feedback from the receiver as well as adaptive coding and receiver feedback to adapt data transmission to changing channel conditions. However, effective maximization of channel capacity with multiple transmit and receive antennas is not possible only with adaptive modulation and/or coding.

In U.S. Pat. Nos. 5,592,490 to Barratt et al., 5,828,658 to Ottersten et al., and 5,642,353 Roy III, teach about spectrally efficient high capacity wireless communication systems using multiple antennas at the transmitter; here a Base Transceiver Station (BTS) for Space Division Multiple Access (SDMA). In these systems the users or receive units have to be sufficiently separated in space and the BTS uses its transmit antennas to form a beam directed towards each receive unit. The transmitter needs to know the channel state information such as "spatial signatures" prior to transmission in order to form the beams correctly. In this case spatial multiplexing means that data streams are transmitted simultaneously to multiple users who are sufficiently spatially separated.

The disadvantage of the beam-forming method taught by Barratt et al., Ottersten et al., and Roy III is that the users have to be spatially well separated and that their spatial signatures have to be known. Also, the channel information has to be available to the transmit unit ahead of time and the varying channel conditions are not effectively taken into account. Finally, the beams formed transmit only one stream of data to each user and thus do not take full advantage of times when a particular channel may exhibit very good communication parameters and have a higher data capacity for transmitting more data or better signal-to-noise ratio enabling transmission of data formatted with a less robust coding scheme.

U.S. Pat. No. 5,687,194 to Paneth et al. describes a Time Division Multiple Access (TDMA) communication system using multiple antennas for diversity. The proposed system exploits the concept of adaptive transmit power and modulation. The power and modulation levels are selected according to a signal quality indicator fed back to the transmitter.

Addressing the same problems as Paneth et al., U.S. Pat. No. 5,914,946 to Avidor et al. teaches a system with adaptive antenna beams. The beams are adjusted dynamically as the channel changes. Specifically, the beams are adjusted as a function of a received signal indicator in order to maximize signal quality and reduce the system interference.

The prior art also teaches using multiple antennas to improve reception by transmitting the same information, i.e., the same data stream from all antennas. Alternatively, the prior art also teaches that transmission capacity can be increased by transmitting a different data stream from each antenna. For more information about capacity increases achievable by transmitting different data streams from different antennas the reader is referred to U.S. Pat. No. 5,345,599 to Paulraj, A.J. et al., and to Foschini, G.J., "Layered Space-Time Architecture for Wireless Communication in a Fading Environment when Using Multi-Element Antennas", Bell Labs Technical Journal, Autumn 1996. These two approaches are commonly referred to as antenna diversity schemes and spatial multiplexing schemes.

Adaptive modulation and/or coding in multiple antenna systems involve mapping of data converted into appropriate symbols to the antennas of the transmit antenna array for transmission. In the case of spatial multiplexing there can be no coordination between transmitters, since the transmit antennas can belong to separate base stations or mobiles rather than to a single antenna array. Prior art systems do not teach rules suitable for determining antenna mappings, or, more precisely, antenna selection for varying channel conditions in the spatial multiplexing mode. Development of rules for selecting antennas in the spatial multiplexing mode would represent a significant advance in the art.

SUMMARY

The present invention provides a method for selecting antennas for transmitting data over a channel by employing spatial multiplexing, i.e., by transmitting different data streams from different antennas. The method is applicable in communications systems with a transmit unit having multiple transmit antennas or multiple transmit units, e.g., multiple transceiver stations, and a receive unit having multiple receive antennas. The first step of the method involves determining a channel descriptor. In one embodiment the descriptor is a channel matrix H. In another embodiment, where the channel is subject to time delay spread, the descriptor is a channel matrix filter $\mathcal{H}$. The channel descriptor has sub-descriptors corresponding to the transmit antennas. Specifically, channel matrix H has sub-descriptors in the form of sub-matrices h_i corresponding to the transmit antennas. Channel matrix filter $\mathcal{H}$ has sub-

descriptors in the form of sub-matrix filters $\hbar_i$ also corresponding to the transmit antennas.

The method then calls for choosing a quality parameter and a threshold for the quality parameter. In the next steps, a sub-descriptor which does not meet the threshold is identified and the antenna from among the transmit antennas associated with the sub-descriptor is deactivated.

The quality parameter used in the method can be selected from among signal-to-interference and noise ratio, signal-to-noise ratio and power level. The threshold is typically a minimum acceptable value of the quality parameter. This threshold can be re-set or adjusted and the steps of identifying another sub-descriptor or set of sub-descriptors not meeting the threshold can be repeated. The corresponding transmit antennas are then deactivated.

In case the spatial multiplexed communication is of the type employing a number of sub-carrier tones rather than just one carrier frequency, the sub-descriptors are associated with an average value of the quality parameter. In particular, the average value is the average of the quality parameter over the sub-carrier tones. It is then this average value of the quality parameter which is compared with the threshold to determined whether the threshold is met.

In one embodiment of the method, the sub-matrix h_j is removed from the channel matrix H to obtain a subset channel matrix H'. The remaining sub-matrices h_i can be rearranged after removal of h_j. In particular, the remaining sub-matrices h can be ordered in accordance with the threshold, i.e., in descending order starting with the sub-matrix h_i which exceeds the threshold the most or has the best quality parameter.

The data transmitted is typically coded and modulated in accordance with a selected mode. The mode is characterized by a coding rate and a modulation. The setting of the threshold can be based on the selected mode and the selected mode can be based on the quality parameter.

The receive unit can employ any receiver such as a maximum likelihood receiver, a zero forcing equalizer receiver, a successive cancellation receiver, a minimum mean square error equalizer (MMSE) receiver.

In another embodiment, a set of sub-descriptors, i.e., a set of sub-matrices h_i or set of sub-matrix filters $\hbar_i$ is identified and transmit unit antennas associated with that set are all deactivated at one time, rather than one by one. This method can be applied in steps as well. A set of antennas or a single antenna not meeting the assigned threshold can be deactivated in each step.

In still another embodiment, the transmit antennas belong to separate transmit units, e.g., to different base stations. In this case the sub-matrix h_j can represent the base station transceiver which is to be deactivated to improve the quality parameter at the receive unit.

Systems of the invention can be used for spatial multiplexed communications between transmit units with multiple antennas and receive units with multiple antennas, or between separate transceivers, e.g., base stations, and receive units with multiple antennas. The receive unit has a channel estimation block for determining channel descriptor, a mode selection block for receiving the quality parameter, assigning a threshold to the quality parameter, and identifying among the sub-descriptors of the channel descriptor at least one sub-descriptor not meeting the threshold. The receive unit has a feedback unit for sending feedback related to the at least one sub-descriptor to the transmit unit or, as the case may be, to the base stations.

In case the transmit unit has an antenna array, a controller at the transmit unit receives the feedback and deactivates the corresponding transmit antennas. In case the transmit antennas belong to separate transceivers, a common controller or separate control units can be used to receive the feedback and deactivate the corresponding transceivers or their antennas.

The method of the invention can be employed in multi-tone communications using a number of sub-carrier tones for transmitting data from each transmit antenna.

A detailed description of the invention and the preferred and alternative embodiments is presented below in reference to the attached drawing figures.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 is a simplified diagram illustrating a communication system in which the method of the invention is applied.

Fig. 2 is a simplified block diagram illustrating the transmit and receive units according to the invention.

Fig. 3 is a block diagram of an exemplary transmit unit in accordance with the invention.

Fig. 4 is a block diagram of a spatial multiplexing block of the transmit unit of Fig. 3.

Fig. 5 is a block diagram of exemplary receive unit in accordance with the invention.

Fig. 6. is a schematic illustrating the operations performed on the channel matrix H.

Fig. 7 is a block diagram of a mode selection block of the receive unit of Fig. 5.

Fig. 8 is an exemplary flow chart of the method of the invention.

Fig. 9 is a diagram of another embodiment of the invention.

DETAILED DESCRIPTION

The method and wireless systems of the invention will be best understood after first considering the high-level diagrams of Figs. 1 and 2. Fig. 1 illustrates a portion of a wireless communication system **10**, e.g., a cellular wireless system. For explanation purposes, the downlink communication will be considered where a transmit unit **12** is a Base Transceiver Station (BTS) and a receive unit **14** is a mobile or stationary wireless user device. Exemplary user devices include mobile receive units **14A, 14B, 14C** which are portable telephones and car phones and a stationary receive unit **14D**, which can be a wireless modem unit used at a residence or any other fixed wireless unit. Of course, the same method can be used in uplink communication from wireless units **14** to BTS **12**.

BTS **12** has an antenna array **16** consisting of a number of transmit antennas **18A, 18B, ..., 18M.** Receive units **14** are equipped with antenna arrays **20** of N receive antennas (for details see Figs. 2, 3 and 5). BTS **12** sends transmit signals TS to all receive units **14** via channels **22A** and **22B.** For simplicity, only channels **22A, 22B** between BTS **12** and receive units **14A, 14B** are indicated, although BTS **12** transmits TS signals to all units shown. In this particular case receive units **14A, 14B** are both located within one cell **24.** However, under suitable channel conditions BTS **12** can transmit TS signals to units outside cell **24.**

The time variation of channels **22A, 22B** causes transmitted signals TS to experience fluctuating levels of attenuation, interference, multi-path fading and other deleterious effects. Therefore, communication parameters of channels **22A, 22B** such as data capacity, signal quality, spectral efficiency or throughput undergo temporal changes. Thus, channels **22A, 22B** can not at all times support efficient propagation of high data rate signals TS or signals which are not formatted with a robust coding algorithm.

In accordance with the invention, antenna array **16** at BTS **12** employs spatial multiplexing, reduces interference, increases array gain and achieves other advantageous effects. Antenna arrays **20** at receive units **14** are set up to receive the spatial multiplexed signals from BTS **12.** The method of the invention finds an optimum choice of transmit antennas **18A, 18B, ..., 18M** selected adaptively with changing conditions of channels **22A, 22B.** In other words, the method of the invention implements an adaptive and optimal selection of transmit antennas **18A, 18B, ..., 18M,** deactivating some of these antennas in accordance with the rules described below to improve performance.

Fig. 2 illustrates the fundamental blocks of transmit unit **12** and one receive unit **14** necessary to employ the method. Transmit unit **12** has a control unit **26** connected to a data processing block **28** for receiving data **30** to be converted to spatially multiplexed transmit signals TS to select transmit antennas **18A, 18B, ..., 18M** for transmission therefrom. An up-conversion and RF amplification block **32** supplies the transmit signals TS to antennas **18A, 18B, ..., 18M.**

On the other side of the link, receive unit **14** has N receive antennas **34A, 34B, ..., 34N** in its array **20** for receiving receive signals RS. An RF amplification and down-conversion block **36** processes receive signals RS and passes them to data processing block **38.** Data processing block **38** includes a channel measurement or estimation unit (see Fig. 5) which obtains a measurement of the channel coefficients matrix H characterizing channel **22.**

A mode selection block **40** uses matrix H and a chosen quality of service QoS or quality parameter QP to determine which of transmit antennas **18** should be deactivated to improve reception. The quality parameter QP used by block **40** can be any useful signal characteristics measure such as signal-to-interference and noise ratio (SINR), signal-to-noise ratio (SNR), power level. Block **40** makes the determination about which of transmit antennas **18A, 18B, ... 18M** should be transmitting in order to keep the quality parameter above a certain minimum required value or threshold. This selection is fed back as indicated by dashed line **42** to transmit unit **12.** In case channel **22** is a time-division duplexed (TDD) channel, which is reciprocal between the receive and transmit units, no separate feedback is required. In response, unit **26** switches off or deactivates the transmit antennas which block **40** has determined should be deactivated.

An exemplary embodiment of a transmit unit **50** for practicing the method of the invention is shown in Fig. 3. Data **52,** in this case in the form of a binary stream, has to be transmitted. Before transmission, data **52** may be interleaved and pre-coded by interleaver and pre-coder (not shown). The purpose of interleaving and pre-coding is to render the data more robust against errors. Both of these techniques are well-known in the art.

Data **52** is delivered to a conversion unit, more specifically a spatial multiplexing block **56.** Block **56** converts data **52** into k streams of symbols at chosen modulation rates and coding rates. For example, data **52** can be converted into symbols through modulation in a constellation selected from among PSK, QAM, GMSK, FSK, PAM, PPM, CAP, CPM or other suitable constellations. The transmission rate or throughput of data **52** will vary depending on the modulation and coding rates used in each of the k streams.

Mode	Modulation Rate (bits/symbol)	Coding Rate	Throughput (bits/s/Hz)
1	2	3/4	3/2
2	2	2/3	4/3
3	2	1/2	1
4	2	1/3	2/3
5	4	3/4	3
6	4	2/3	8/3
7	4	1/2	2
8	4	1/3	4/3
9	5	3/4	15/4
10	5	2/3	10/3
11	5	1/2	5/2
12	5	1/3	5/3
13	6	3/4	9/2
14	6	2/3	4
15	6	1/2	3
16	6	1/3	2

Table 1 illustrates some typical modulation and coding rates with the corresponding throughputs which can be used in the spatial multiplexing method of the invention. The entries are conveniently indexed by a mode number.

The mode column can be used to more conveniently identify the modulation and coding rates which are to be applied to the k streams. Tables analogous to Table 1 for other coding rates and modulation can be easily derived as these techniques are well-known in the art.

Once coded and modulated in symbols, data **52** passes to a switching unit **60.** Depending on its setting, switching unit **60** routs modulated and coded k streams of spatially multiplexed data **52** to all or a subset of its M outputs. The M outputs lead to the corresponding M transmit antennas **72** via an up-conversion and RF amplification stage **70** having individual digital-to-analog converters and up-conversion/RF amplification blocks **74.** Transmit antennas **72** transmit data **52** in the form of transmit signals TS. In this case transmit antennas T_1, T_2, ... T_M with the exception of transmit antenna T_j are transmitting coded streams. In other words, k=M-1. The determination to deactivate antenna T_j is made in accordance with the method of the invention as described below.

Transmit unit **50** also has a controller **66** connected to spatial multiplexing block **56** and to switching unit **68.** A database **78** is connected to controller **66.** Database **78** conveniently contains a table, e.g., a spatial multiplexing look-up table indexed by mode as in exemplary table 1. The convenience of indexing by mode resides in the fact that feedback to transmit unit **50** does not require much bandwidth.

Specifically, transmit unit **50** receives feedback from receive unit **90** (see Fig. 5) via a feedback extractor **80.** Feedback extractor **80** detects an antenna number or any other designation which antennas to operate and which to deactivate and forwards this information to controller **66.** In some embodiments feedback extractor detects mode number and associated antenna number, and forwards it to controller **66.** Controller **66** looks up the mode number in database **78** and thus determines the modulation, coding rate and any other parameters for the associated antenna.

Receive unit **90** can send back a channel descriptor, e.g., a channel matrix H, a channel matrix filter $\mathcal{H}$ or some other suitable descriptor identifying the action of the channel on transmitted signals TS, to transmit unit **50.** In these cases transmit unit **50** can use the channel descriptor in its operation to derive any information in addition to antenna number and mode number to adapt its transmission to channel **22.** In the event of using time-division duplexing (TDD), the feedback information, i.e., the channel parameters are obtained during the reverse transmission from receive unit **90** or remote subscriber unit, as is known in the art, and no dedicated feedback extractor **80** is required.

When channel **22** experiences delay spread, it can be modeled as a Finite Impluse Response (FIR) channel, i.e., channel **22** has a memory and any representation of channel **22** should have a time dimension. Depending on the transmission symbol rate, for a given delay spread channel **22** will have some number L of symbol delay taps. When there is no delay spread channel **22** can be represented by an NxM matrix where N is the number of receive antennas **92** (see Fig. 5) and M is the number of transmit antennas **72.** When there is delay spread, channel **22** can be represented by a matrix filter $\mathcal{H}$ which is constructed of H_1, H_2, ... H_L, where H_i is the NxM channel matrix at i-th delay tap.

When multi-carrier modulation such as OFDM is used, the symbol duration is chosen much longer than the channel delay spread. In this case, each sub-carrier frequency or tone has an individual channel represented by an NxM matrix, i.e., H_1, H_2, ... H_T where T is the number of sub-carrier tones.

In an embodiment of the invention where inter-symbol interference (ISI) is not a problem, the parameters of channel **22** are expressed by a single channel matrix H. In accordance with this descriptor, transmit signals TS propagating through channel **22** are affected by channel coefficients a_{xy} of matrix H. Matrix H is composed of sub-matrices h, here in the form of columns labeled h_1, h_2, ..., h_j, ... h_M. Each antenna T_1, T_2, ..., T_j, ..., T_M is associated with a corresponding sub-matrix h_1, h_2, ..., h_j, ... h_M. The dimension or number of entries in each sub-matrix h is dictated by the number of receive antennas **92** employed by receive unit **90** (see Fig. 5); in this case the number is N. Hence, channel coefficients matrix H is an NxM matrix with channel coefficients a_{xy} ranging from a_{11} to a_{NM}.

Fig. 4 shows a more detailed block diagram of spatial multiplexing block **56**. Data **52** received by block **56** is first parsed by parser **58**, which is in direct communication with controller **66**. Based on feedback obtained from feedback extractor **80**, controller tells parser **58** into how many streams data **52** is to be divided. Parser is connected with a multiplexing block **62** and supplies the streams to its coding and modulation blocks **64**. Having separate coding and modulation blocks **64** for each stream enables the user to employ different coding rates and modulations in each stream.

Fig. 5 illustrates receive unit **90** for receiving receive signals RS from transmit unit **50** through channel **22** with N receive antennas **92**. Receive unit **90** can be any suitable receiver capable of receiving spatial multiplexed receive signals RS via the N receive antennas **92**. Exemplary receivers include maximum likelihood receivers, zero forcing equalizer receivers, successive cancellation receivers and minimum mean square error equalizer receivers. Receive unit **90** has an RF amplification and down-conversion stage **94** having individual RF amplification/down-conversion/ and analog-to-digital converter blocks **96** associated with each of the N receive antennas **72**. The N outputs of stage **94** are connected to a block **98** which performs receive processing, signal detection and decoding and demultiplexing functions. The N outputs of stage **94** are also connected to a channel estimator **100**. Channel estimator **100** obtains a measurement of channel **22**; in particular, it determines the channel coefficients matrix H representing the action of channel **22** on transmit signals TS.

Estimator **100** is connected to block **98** to provide block **98** with the channel descriptor. The channel descriptor is typically determined by estimator **100** during training; a procedure well-known in the art. In case there is no ISI estimator **100** determines channel matrix H for the independent k streams from the k transmit antennas **72**. In case there is ISI estimator **100** determines channel matrix filter $\mathcal{H}$ with the aid of training sequences which are as long or longer than the delay spread. In multi-carrier operation each sub-carrier tone has a different channel so training is required for all sub-carrier tones. During training estimator **100** determines channel matrices H_1, H_2, ... H_T for all sub-carrier tones. A deinterleaver and decoder (not shown) can be placed in the data stream if a corresponding interleaver and coder was employed in transmitter **50**.

Channel estimator **100** is also connected to a mode selection block **102**. Mode selection block **102** is connected to a database **104**. Database **104** conveniently contains a look-up table similar to table 1 with quality parameters QP's and threshold values QP_{th} (i.e., the lowest acceptable values) of these QP's for each of the modes. In other words, for any particular QP each mode has an associated threshold QP_{th}, which is conveniently stored in database **104**. For example, when SINR is used as QP, then for a given (or required) performance criteria, e.g., a required BER, each mode has a threshold $SINR_{th}$ which depends on its modulation rate and coding rate. Mode selection block **102** can thus access in database **104** the appropriate threshold QP_{th} values for the selected modes.

Alternatively, mode selection block **102** can receive quality parameter QP and threshold value QP_{th} for each mode from an outside source. In yet another embodiment, block **102** can be pre-programmed to use a particular quality parameter QP or make its own selection of quality parameter QP. Also, threshold value QP_{th} can be provided, or pre-set by block **102** or adjusted during operation by either block **102** or some other circuit, as necessary. In the present embodiment, signal-to-interference and noise ratio (SINR) is used as quality parameter QP.

Conveniently, database **104** contains the same entries as database **78** indexed by the same mode numbers. This arrangement makes it particularly easy for selection block **102** to communicate its mode selection for each transmit antenna T_i to transmit unit **50** by sending the mode number. For example, selection block **102** provides transmit antenna number and mode to be used by that transmit antenna pairwise for feedback to transmit unit **50.** In fact, antenna number and mode can be arranged in a table for feedback. When a transmit antenna number and corresponding mode are not indicated by block **102,** then that transmit antenna T_i is deactivated by controller **66.** For active transmit antennas T_i controller **66** retrieves the corresponding coding rate and modulation from database **78.** Alternatively, selection block **102** can indicate directly which transmit antenna or antennas T_i are to be deactivated and indicate the modes to be used by active transmit antennas T_i. In some cases, the same mode can be used by all active transmit antennas T_i, e.g., at system start-up. At this time selection block **102** only sends active transmit antennas and mode for feedback to transmit unit **50**.

Mode selection block **102** is connected to a feedback block **106** for feeding back the antenna numbers and corresponding modes to receive unit **50**. Furthermore, feedback block **106** can also send channel parameters, e.g., in the form of mode number to transmit unit **50**. Receiver unit's **90** transmitter **110** is connected to feedback block **106** for transmitting this information back to transmit unit **50**.

In this embodiment, receive unit **90** is a minimum mean square error equalizer (MMSE) receiver requiring a receive processing matrix **108** based on channel matrix H to recover data **52**. Hence, mode selection block **102** has the appropriate logic to compute matrix **108** as discussed below. Block **102** communicates matrix **108** to block **98** via a link.

The operation of channel **22** on a transmit vector s of M transmit signals TS corresponding to the M transmit antennas **72** is described by the system equation:

$$x = RHs + Rv, \qquad (1)$$

where v is an Nx1 noise vector, H is the NxM channel matrix, R is the linear MMSE equalizer receiver and x is the Nx1 receive vector estimated by receive unit **90**. It is assumed that:

$$E(ss^*) = P_o;\ E(vv^*) = R_{vv};\ E(sv^*) = 0, \qquad (2)$$

where the superscript * denotes the conjugate transpose and E is the expectation value over the distributions of v and s. The error vector e can be defined as:

$$e \equiv s - RHs - Rv\,. \tag{3}$$

The linear MMSE equalizer is found by minimizing the cost function:

$$C(R) = Trace\ E\left(ee^*\right). \tag{4}$$

Using the assumptions in (2), the cost function in (4) can be simplified to:

$$C(R) = Trace\left[P_o(I - RH)(I - RH)^* + RR_{vv}R^*\right], \tag{5}$$

where I is the identity matrix. To obtain the optimum MMSE receiver, R_{opt}, the first derivative of the simplified cost function is set to zero, $\frac{\partial C(R)}{\partial R} = 0$, and solved for R_{opt} yielding:

$$R_{opt} = P_o H^*\left(P_o HH^* + R_{vv}\right)^{-1}. \tag{6}$$

The receiver R, here optimized receiver R_{opt}, determines the value of quality parameter QP for transmit signals TS transmitted via each one of transmit antennas **72**. In this embodiment, signal-to-interference and noise ratio (SINR) is chosen as the quality parameter QP. The relation between $SINR_i$ for i-th of transmit antennas **72** and R_{opt} is:

$$SINR_i = \frac{P_o}{\left|C\left(R_{opt}\right)\right|_{ii}}. \tag{7}$$

Of course, a person of average skill in the art will be able to construct analogous relationships between other quality parameters QP of transmit signals TS transmitted from each of transmit antennas **72** and the receiver.

In accordance with the method of the invention, a threshold value QP_{th} is assigned to quality parameter QP. The assignment of the threshold is based on the desired quality of receive signals RS. Conveniently, QP_{th} is the minimum threshold at which receive signals RS can be re-converted into data **52** by block **98** at an acceptable error rate given the mode (coding rate and modulation of data **52** employed by spatial multiplexing block **56** of transmit unit **50**). For example, the assignment can be based on a desired bit-error-rate (BER) of received data **52**. Alternatively, other error rates such as packet error rates or symbol error rates of data **52** can be used to characterize the quality of receive signals RS. A person of average skill in the art is familiar with these characterizations and criteria for their selection.

In this embodiment, data **52** is coded and modulated in accordance with a square QAM constellation (e.g. with four points, Z=4) and the quality parameter QP is SINR. The BER required at receive unit **90** given this mode assigns the minimum threshold $SINR_{th}$. Specifically, BER_i at receive unit **90** for data **52** transmitted in transmit signals TS from i-th antenna of transmit antennas **72** is related to $SINR_i$ for the i-th antenna as follows:

$$BER_i = \alpha_Z \times erfc\left(\sqrt{\beta_Z SINR_i}\right), \tag{8}$$

where erfc is the complementary error function, $\alpha_Z = \frac{2}{\log_2 Z}\left(1 - \frac{1}{\sqrt{Z}}\right)$, and $\beta_Z = \frac{3}{2(Z-1)}$. Selecting a minimum acceptable BER_i at receive unit **90** given the mode thus yields an $SINR_i$ value to be used as threshold value $SINR_{th}$. It should be noted that this holds for uncoded schemes, i.e., when no additional coding such as error coding is imposed on data **52**. In the event such coding is used there is generally a coding gain which will vary $SINR_{th}$, as will be appreciated by a person skilled in the art.

$SINR_{th}$ is used by mode selection block **102** to identify sub-descriptors of channel **22** which do not meet threshold $SINR_{th}$. In this embodiment the sub-descriptors of channel **22** are sub-matrices h_i of channel matrix H, as shown in Fig. 6. One sub-matrix h_i, i=1...M, is associated with each transmit antenna T_i, i=1...M, of transmit antennas **72**. The schematic of Fig. 6 illustrates a case where for all sub-matrices h_i quality parameter QP exceeds threshold QP_{th} with the exception of sub-matrix h_j. In the present embodiment QP is SINR and thus $SINR_j < SINR_{th}$.

According to the method of the invention, transmit antenna T_j corresponding to sub-matrix h_j is deactivated. In fact, transmit unit **50** is shown in Fig. 3 with antenna T_j

deactivated, i.e., no transmit signals TS are transmitted from antenna T_j. This deactivation of one or more transmitting antennas T_i will generally improve and not worsen the quality parameter QP, in this case SINR, for the remaining transmitting antennas.

Figs. 7 illustrates how mode selection block **102** implements the deactivation decision. Channel matrix H, QP and QP_{th} are received by a comparison block **110** where QP values for each sub-matrix h_i are compared with QP_{th} given the selected mode (see Fig. 6). Comparison block **110** identifies which of sub-matrices h_i has a QP_i less than QP_{th} and removes this sub-matrix, in the present embodiment sub-matrix h_j, since $QP_j<QP_{th}$, from channel matrix H. Removal of sub-matrix h_j from channel matrix H produces a subset channel matrix H'. Comparison block **110** recomputes QP_i for each sub-matrix h_i corresponding to transmit antenna T_i in subset matrix H'. Conveniently, recomputed QP_i of sub-matrices h_i of subset channel matrix H' are compared with adjusted QP_{th}. For example, recomputed QP_i are compared with QP_{th} required for particular modes to determine in which of those modes the corresponding antennas T_i should transmit. Advantageously, the mode whose required QP_{th} is closest in value to the recalculated QP_i is selected for data **52** transmitted from corresponding transmit antenna T_i.

Block **110** also passes subset channel matrix H' to a computing block **112**. Computing block **112** calculates the processing matrix **108** or optimal receiver R_{opt} and sends R_{opt} to block **98** for receive processing.

When all transmit antennas T_i meet threshold QP_{th} of a different mode then employed at the time, e.g., a mode with a higher throughput, then this higher throughput mode is selected by comparison block **110**. When a sub-matrix h_j indicates that the corresponding transmit antenna T_j no longer meets QP_{th}, then that antenna is deactivated and the mode is fed back to transmit unit **50**. In this manner, transmission of data **52** can be optimized for highest throughput at the set QP_{th}.

In fact, flow chart of Fig. 8 shows an embodiment of the method for achieving highest throughput a mode number # with corresponding threshold $QP_{th-\#}$. Initially, i is set equal to the number of transmit antennas T_i, i=M, such that k=M. Then, optimal receiver R_{opt} is computed as well as the values QP_i for all sub-matrices h_i. For convenience, antennas T_i and their corresponding sub-matrices h_i are arranged in descending order of QP_i. A mapping of this re-arranged or ordered set to the original order of sub-matrices h_i and corresponding transmit antennas T_i is maintained for administrative purposes.

In the next step, each QP_i is compared with a lowest threshold $QP_{th-\#}$. For example, lowest threshold $QP_{th-\#}$ can be equal to the threshold for the lowest throughput acceptable mode #. When a QP_i does not meet this lowest threshold $QP_{th-\#}$, the corresponding sub-matrix h_i is removed from channel matrix H to produce subset channel matrix H'. With the same action the corresponding antenna T_i is designated for deactivation. After removal of sub-matrix h_i the values of QP_i are re-computed and the comparison repeated, until subset channel matrix H' contains only sub-matrices h_i which have QP_i higher than $QP_{th-\#}$. It should be noted that more than one sub-matrix h_i can be removed at a time.

Once the final subset channel matrix H' is obtained it is sent to the second branch in the flow chart of Fig. 8 to determine the best modes to use for transmission from the remaining antennas. The number of data streams k is set to the number of remaining sub-matrices h_i, i=k. Then, in a recursive loop process, the best mode number for each antenna is determined by direct comparison of QP_k with $QP_{th-\#}$ required for that mode #. The mode # for which the comparison yields the closest match is selected for transmission from corresponding antenna #. Conveniently, the antenna # and mode # are ordered pairwise in a table for feedback to the transmit unit. Before feedback, the table is arranged to agree with the updated mapping of antenna # which was performed to arrange sub-matrices h_i in descending order of QP_i.

It should be noted, that comparison block **110** can re-set or adjust lowest $QP_{th-\#}$. For example, when data **52** is not very sensitive (e.g., voice) lowest $QP_{th-\#}$ can be lowered and when data **52** is sensitive lowest threshold $QP_{th-\#}$ can be raised. In fact, the setting of lowest $QP_{th-\#}$ depends on the type of data **52** and other parameters well-known in the art of data processing.

Comparison block **110** can repeat the steps of identifying individual or even groups or sets of sub-matrices h_i falling below lowest $QP_{th-\#}$ and deactivate the corresponding antenna or antennas among transmit antennas **72**. Of course, when channel **22** is very high quality, no transmit antennas **72** may need to be deactivated.

In general, the time period within which the above computations for antenna deactivation should be repeated should be shorter than the coherence time of channel **22**.

In another embodiment, transmit unit **50** receiving feedback of channel information, whether using TDD or simple feedback, could make the selection of antenna or antennas to deactivate on its own. This alternative approach would be convenient when receive unit **90** does not have sufficient resources or power to make the comparisons between the values of QP_i and QP_{th}. Of course, transmit unit **50** would then contain all the corresponding computation and decision-making blocks, specifically mode selection block **102**, contained in receive unit **90** as described above.

In an alternative embodiment shown in Fig. 9, the method of invention is employed in a communications system **200** using spatial-multiplexing. System **200** has several base transceiver stations (BTS), of which two **204**, **206** are shown. BTS **204**, **206** are equipped with transmit antenna arrays **208**, **210** respectively for sending transmit signals to receive unit **212**. It should be noted, however, that a combination of BTS with single transmit antennas can be used as long as spatial multiplexing is employed.

Receive unit **212** sets a threshold QP_{th} and identifies among the sub-descriptors of a descriptor of channel **22**, e.g., h_i

matrices of channel matrix H, one or more sub-descriptors which do not meet threshold QP_{th} in the selected mode. As described above, receive unit **212** can adjust threshold QP_{th}, in particular, it can adjust threshold QP_{th} based on the desired mode. Receive unit **212** then determines a final selection which transmit antennas of transmit antenna arrays **208, 210** should be deactivated. Additionally, receive unit **212** determines which modes should be used by the remaining active transmit antennas of arrays **208, 210**. It should be noted that under certain circumstances receive unit **212** may determine that one of base stations **204, 206** should not be transmitting any transmit signals to receive unit **212** at all.

The selection of antennas and modes is fed back from receive unit **212** to BTS **204, 206**. In particular, a control logic, in this embodiment a controller **202** receives the feedback from receive unit **212**. Controller **202** can be a central control unit supervising the operation of BTS **204, 206** and any other BTS of communication system **200**. Alternatively, control logic can consist of separate control units as indicated in dashed lines.

In another embodiment of the invention, the descriptor of channel **22** is a channel matrix filter $\mathcal{H}$ and sub-descriptors are sub-matrix filters $\mathcal{h}_i$. Conveniently, channel matrix filter $\mathcal{H}$ is used as descriptor when inter-symbol interference (ISI) is present due to broadly varying times of arrival or under other adverse conditions associated with delay spread. A person of average skill in the art is familiar with channel matrix filters $\mathcal{H}$, their construction and their use in reconstructing transmitted data under such channel conditions.

In particular, for a channel with delay spread the system equation is:

$$X = \mathcal{H}S + N. \qquad (9)$$

This equation can be rewritten in matrix form as:

$$\begin{pmatrix} \underline{x}_k \\ \underline{x}_{k-1} \\ \cdot \\ \cdot \\ \cdot \\ \underline{x}_{k-q+1} \end{pmatrix} = \begin{array}{c} 1 \\ 2 \\ \cdot \\ \cdot \\ \cdot \\ q \\ \end{array} \begin{array}{c} \begin{pmatrix} H_o & H_1 \ldots H_L & 0 \ldots & 0 \\ 0 & H_o & H_1 \ldots H_L & 0 \\ \cdot & & & \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & & & \\ 0 & 0 & .. & H_o \ldots H_L \end{pmatrix} \\ \begin{array}{cccc} 1 & 2 & \ldots. & p \end{array} \end{array} \begin{pmatrix} \underline{s}_k \\ \underline{s}_{k-1} \\ \cdot \\ \cdot \\ \cdot \\ \underline{s}_{k-p+1} \end{pmatrix} + \begin{pmatrix} \underline{n}_k \\ \underline{n}_{k-1} \\ \cdot \\ \cdot \\ \cdot \\ \underline{n}_{k-p+1} \end{pmatrix},$$

where $\underline{s}_k$ is the signal vector at time $\underline{k}$, $\underline{n}_k$ is the noise vector at time $\underline{k}$, $\underline{x}_k$ is the received signal vector at time $\underline{k}$, q is the number of received signal snap shots used for processing (also referred to as the number of equalizer taps), L is the number of delay elements in the channel and $p \geq q+L$. As is clear from the explicit system equation, channel matrix filter $\mathcal{H}$ actually consists of a number of channel matrices H, each of which is an NxM matrix, where N is the number of receive antennas at the receive unit and M is the number of transmit antennas. Therefore, channel matrix filter H is actually qNxpM. In fact, M is the total number of antennas from which receive unit is meant to receive spatially multiplexed signals. As discussed above, these transmit antennas can belong to separate BTS, include single transmit antennas or transmit antennas which are part of any suitable transmit antenna array.

The receiver equalizer R(z) for processing the q time snap shots of the received vector $\underline{x}_k$ to obtain a good MMSE estimator of the transmitted signal vector $\underline{s}_k$ can be represented as follows:

$$R(z) = \sum_{i=0}^{q-1} R_i z^{-i} \quad , \tag{10}$$

where z is the delay element, R_i is the equalizer tap at the i-th instant. Using system equation (9) and equation (10) the recovered signal vector, $\hat{\underline{s}}_k$, where the hat indicates recovered signal, can be written as:

$$\hat{\underline{s}}_k = \left[R_o,\ \mathrm{R}_1 \ldots R_{q-1}\right]\mathcal{H}S + \left[R_o,\ \mathrm{R}_1 \ldots R_{q-1}\right]N\,. \tag{11}$$

By defining the following correlation matrices:

$$E\left[NN^*\right] = \sigma^2 I \tag{12}$$

$$E\left[SS^*\right] = I\,, \tag{13}$$

where σ^2 is the noise variance and I is the identity matrix, the MMSE estimator R for estimating $\hat{\underline{s}}_k$ from S can be written as:

$$R = \left[H_o^*\, 0\, 0\, \ldots\ \right]\left(\mathcal{H}\mathcal{H}^* + \sigma^2\right)^{-1}. \tag{14}$$

In this embodiment the quality parameter QP is chosen to be signal-to-noise ratio (SNR). Now, for the i-th transmit antenna the SNR is given by:

$$SNR_i = \frac{1}{\sigma^2}\left[R\mathcal{H}\mathcal{H}^* R^*\right]_{ii}, \qquad (15)$$

where i=1, 2, ... M. At this point the SNR values for each transmit antenna can be compared with a threshold SNR_{th}. The remaining steps leading to the selection of which transmit antenna should be deactivated are analogous to those described above.

The method of invention can also be used in multi-carrier systems using spatial multiplexing. In these types of communication systems several sub-carrier frequencies or sub-carrier tones are transmitted from each transmit antenna. Each of these sub-carrier tones experiences a different channel in propagating from the transmit unit to the receive unit. Hence, each transmit antenna has associated with it a group of sub-descriptors; one for each sub-carrier tone.

In this case each transmit antenna and its associated sub-descriptor will yield a different quality parameter QP at the different sub-carrier frequencies. In other words, data transmitted from a transmit antenna T_j on a first sub-carrier tone ST_1 will exhibit a quality parameter QP_{j1} different from a quality parameter QP_{j2} for data transmitted from the same transmit antenna T_j on a second sub-carrier tone ST_2. Hence, the selection of which transmit antenna to deactivate in this case is made based on the average quality parameter $\underline{QP}_j$ for the group of sub-descriptors associated with that antenna. With this change, the method of invention can be employed in multi-carrier systems as described for non multi-carrier communication systems.

The method of the invention can be used in soft hand-off between base stations in cellular systems. Alternatively, partial hand-offs or gradual hand-offs between base stations can be implemented, depending on antenna selection. In fixed wireless systems the user device can operate by receiving signals from a selection of antennas belonging to different base stations at all times. Also, in the case of fixed wireless devices there may be cases where the channel does not change appreciably over time. In this case, once the antenna selection is made, no feedback may be required.

It will be clear to one skilled in the art that the above embodiments may be altered in many ways without departing from the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.

CLAIMS

What is claimed is:

1. A method for selecting antennas for spatial multiplexed communication in a channel for transmitting data between a transmit unit having transmit antennas and a receive unit having receive antennas, said method comprising:
   a) determining a channel descriptor having sub-descriptors corresponding to said transmit antennas;
   b) choosing a quality parameter;
   c) assigning a threshold to said quality parameter;
   d) identifying among said sub-descriptors a sub-descriptor not meeting said threshold; and
   e) deactivating among said transmit antennas an antenna associated with said sub-descriptor.

2. The method of claim 1, wherein said quality parameter is selected from the group consisting of signal-to-interference and noise ratio, signal-to-noise ratio, power level.

3. The method of claim 1, wherein said channel descriptor is a channel matrix filter $\mathcal{H}$, said sub-descriptors are sub-matrix filters h_i of said channel matrix filter $\mathcal{H}$, and said sub-descriptor is a sub-matrix filter h_j.

4. The method of claim 3, further comprising removing said sub-matrix filter h_j from said

channel matrix filter $\mathcal{H}$ to obtain a subset channel matrix filter $\mathcal{H}'$.

5. The method of claim 4, further comprising repeating said identifying and said deactivating.

6. The method of claim 1, wherein said spatial multiplexed communication employs a number of sub-carrier tones associating groups of said sub-descriptors with said transmit antennas.

7. The method of claim 6, wherein said identifying comprises computing an average quality parameter for said groups of sub-descriptors and identifying among said groups of sub-descriptors a group of sub-descriptors not meeting said threshold, and said deactivating comprises deactivating among said transmit antennas an antenna associated with said group of sub-descriptors.

8. The method of claim 1, wherein said channel descriptor is a channel matrix H, said sub-descriptors are sub-matrices h_i of said channel matrix H, and said sub-descriptor is a sub-matrix h_j.

9. The method of claim 8, further comprising removing said sub-matrix h_j from said

channel matrix H to obtain a subset channel matrix H'.

10. The method of claim 9, further comprising repeating said identifying and said deactivating.

11. The method of claim 1, further comprising adjusting said threshold.

12. The method of claim 1, wherein said data is coded and modulated in accordance with a selected mode.

13. The method of claim 12, wherein said mode comprises a predetermined coding rate and modulation.

14. The method of claim 12, wherein said threshold is assigned based on said selected mode.

15. The method of claim 12, wherein said selected mode is based on said quality parameter.

16. The method of claim 12, wherein said selected mode is fed back to said transmit unit.

17. The method of claim 1, wherein said receive unit is selected from the group consisting of maximum

likelihood receivers, zero forcing equalizer receivers, successive cancellation receivers and minimum mean square error equalizer receivers.

18. A method for selecting antennas for spatial multiplexed communication in a channel for transmitting data between a transmit unit having transmit antennas and a receive unit having receive antennas, said method comprising:

a) determining a channel descriptor having sub-descriptors corresponding to said transmit antennas;
b) choosing a quality parameter;
c) assigning a threshold to said quality parameter;
d) identifying among said sub-descriptors a set of sub-descriptors not meeting said threshold; and
e) deactivating among said transmit antennas, antennas associated with said set of sub-descriptors.

19. The method of claim 18, wherein said quality parameter is selected from the group consisting of signal-to-interference and noise ratio, signal-to-noise ratio, power level.

20. The method of claim 18, wherein said channel descriptor is a channel matrix filter $\mathcal{H}$, said sub-descriptors are sub-matrix filters h_i of said channel matrix filter $\mathcal{H}$, and said set of sub-descriptors is a set of said sub-matrix filters h_i.

21. The method of claim 20, further comprising removing said set of sub-matrix filters $\mathcal{h}_i$ from said channel matrix filter $\mathcal{H}$ to obtain a subset channel matrix filter $\mathcal{H}'$.

22. The method of claim 21, further comprising repeating said identifying and said deactivating.

23. The method of claim 18, wherein said spatial multiplexed communication employs a number of sub-carrier tones associating groups of said sub-descriptors with said transmit antennas.

24. The method of claim 23, wherein said identifying comprises computing an average quality parameter for said groups of sub-descriptors and identifying among said groups of sub-descriptors a set of groups of sub-descriptors not meeting said threshold, and said deactivating comprises deactivating among said transmit antennas a set of antennas associated with said set of groups of sub-descriptors.

25. The method of claim 18, wherein said channel descriptor is a channel matrix H, said sub-descriptors are sub-matrices h_i of said channel matrix H, and said set of sub-descriptors is a set of said sub-matrices h_i.

26. The method of claim 25, further comprising removing said set of sub-matrices h_i from said channel matrix H to obtain a subset channel matrix H'.

27. The method of claim 26, further comprising repeating said identifying and said deactivating.

28. The method of claim 18, further comprising adjusting said threshold.

29. The method of claim 18, wherein said data is coded and modulated in accordance with a selected mode.

30. The method of claim 29, wherein said mode comprises a predetermined coding rate and modulation.

31. The method of claim 29, wherein said threshold is assigned based on said selected mode.

32. The method of claim 29, wherein said selected mode is based on said quality parameter.

33. The method of claim 29, wherein said selected mode is fed back to said transmit unit.

34. The method of claim 18, wherein said receive unit is selected from the group consisting of maximum likelihood receivers, zero forcing equalizer receivers, successive cancellation receivers and minimum mean square error equalizer receivers.

35. A method for selecting antennas for spatial multiplexed communication in a channel for transmitting data between transmit antennas and a receive unit having an array of receive antennas, said method comprising:

a) determining a channel descriptor having sub-descriptors corresponding to said transmit antennas;

b) choosing a quality parameter;

c) assigning a threshold to said quality parameter;

d) identifying among said sub-descriptors a sub-descriptor not meeting said threshold; and

e) deactivating among said transmit antennas an antenna associated with said sub-descriptor.

36. The method of claim 35, wherein said quality parameter is selected from the group consisting of signal-to-interference and noise ratio, signal-to-noise ratio, power level.

37. The method of claim 35, wherein said channel descriptor is a channel matrix filter $\mathcal{H}$, said sub-descriptors are sub-matrix filters h_i of said channel matrix filter $\mathcal{H}$, and said sub-descriptor is a sub-matrix filter h_j.

38. The method of claim 37, further comprising removing said sub-matrix filter h_j from said channel matrix filter $\mathcal{H}$ to obtain a subset channel matrix filter $\mathcal{H}'$.

39. The method of claim 38, further comprising repeating said identifying and said deactivating.

40. The method of claim 35, wherein said spatial multiplexed communication employs a number of sub-carrier tones associating groups of said sub-descriptors with said transmit antennas.

41. The method of claim 40, wherein said identifying comprises computing an average quality parameter for said groups of sub-descriptors and identifying among said groups of sub-descriptors a group of sub-descriptors not meeting said threshold, and said deactivating comprises deactivating among said transmit antennas an antenna associated with said group of sub-descriptors.

42. The method of claim 35, wherein said channel descriptor is a channel matrix H, said sub-descriptors are sub-matrices h_i of said channel matrix H, and said sub-descriptor is a sub-matrix h_j.

43. The method of claim 42, further comprising removing said sub-matrix h_j from said channel matrix H to obtain a subset channel matrix H'.

44. The method of claim 43, further comprising repeating said identifying and said deactivating.

45. The method of claim 35, further comprising adjusting said threshold.

46. The method of claim 35, wherein said selected mode is based on said quality parameter.

47. The method of claim 35, wherein said receive unit is selected from the group consisting of maximum likelihood receivers, zero forcing equalizer receivers, successive cancellation receivers and minimum mean square error equalizer receivers.

48. A system for spatial multiplexed communication in a channel for transmitting data between a transmit unit having transmit antennas and a receive unit having receive antennas, said receive unit comprising:

a) a channel estimation block for determining a channel descriptor having sub-descriptors corresponding to said transmit antennas;

b) a mode selection block for receiving a quality parameter, assigning a threshold to said quality parameter, and identifying among said sub-descriptors at least one sub-descriptor not meeting said threshold;

c) a feedback unit for sending feedback related to said at least one sub-descriptor to said transmit unit;

and said transmit unit comprising a control logic for receiving said feedback and deactivating among said transmit antennas, antennas associated with said at least one sub-descriptor.

49. The system of claim 48, wherein said transmit unit further comprises a spatial multiplexing block connected to said controller for coding and multiplexing said data.

50. The system of claim 48, wherein said transmit unit further comprises a switching unit for deactivating said antennas.

51. The system of claim 48, wherein said receive unit is selected from the group consisting of maximum likelihood receivers, zero forcing equalizer receivers, successive cancellation receivers and minimum mean square error equalizer receivers.

52. A system for spatial multiplexed communication in a channel for transmitting data between a number of transceivers having transmit antennas and a receive unit having receive antennas, said receive unit comprising:

a) a channel estimation block for determining a channel descriptor having sub-descriptors corresponding to said transmit antennas;

b) a mode selection block for receiving a quality parameter, assigning a threshold to said quality parameter, and identifying among said sub-descriptors at least one sub-descriptor not meeting said threshold;

c) a feedback unit for sending feedback related to said at least one sub-descriptor to said transmit unit;

and said number of transceivers comprising a control logic for receiving said feedback and deactivating among said transmit antennas, antennas associated with said at least one sub-descriptor.

53. The system of claim 52, wherein said transceivers further comprise spatial multiplexing blocks for coding and multiplexing said data.

54. The system of claim 52, wherein said transceivers further comprise switching units for deactivating said antennas.

55. The system of claim 52, wherein said receive unit is selected from the group consisting of maximum

likelihood receivers, zero forcing equalizer receivers, successive cancellation receivers and minimum mean square error equalizer receivers.

56. The system of claim 52, wherein said control logic comprises a number of control units.

57. The system of claim 56, wherein each of said transceivers has one of said control units.

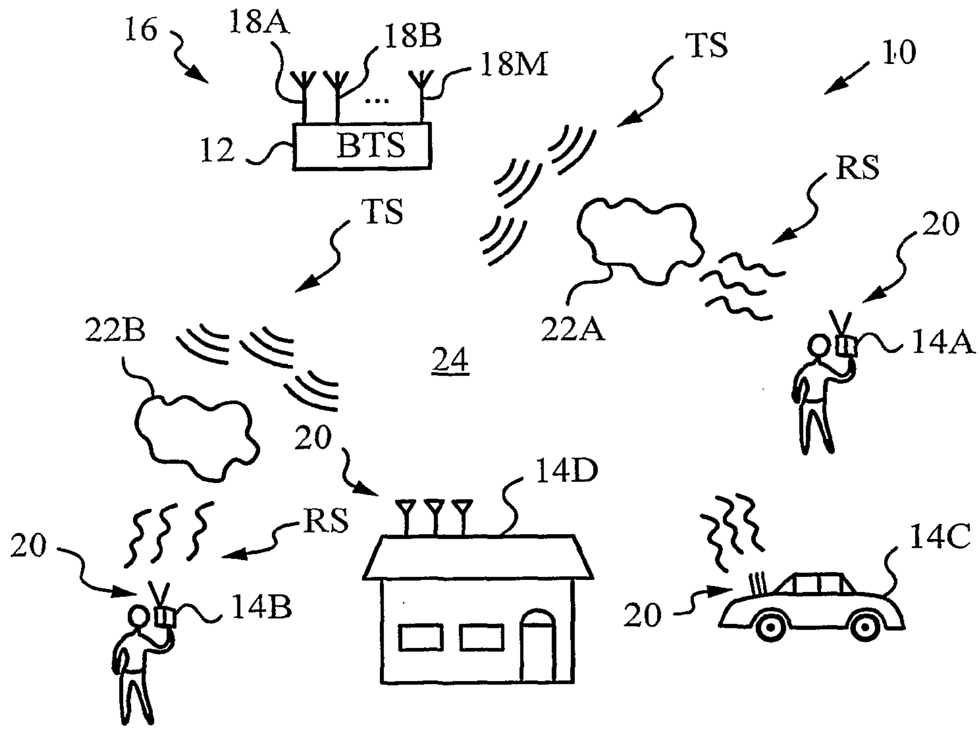

16
18A
18B
18M
12
BTS
TS
10
RS
20
TS
22B
24
22A
14A
20
14D
RS
20
14C
14B
20

FIG. 1

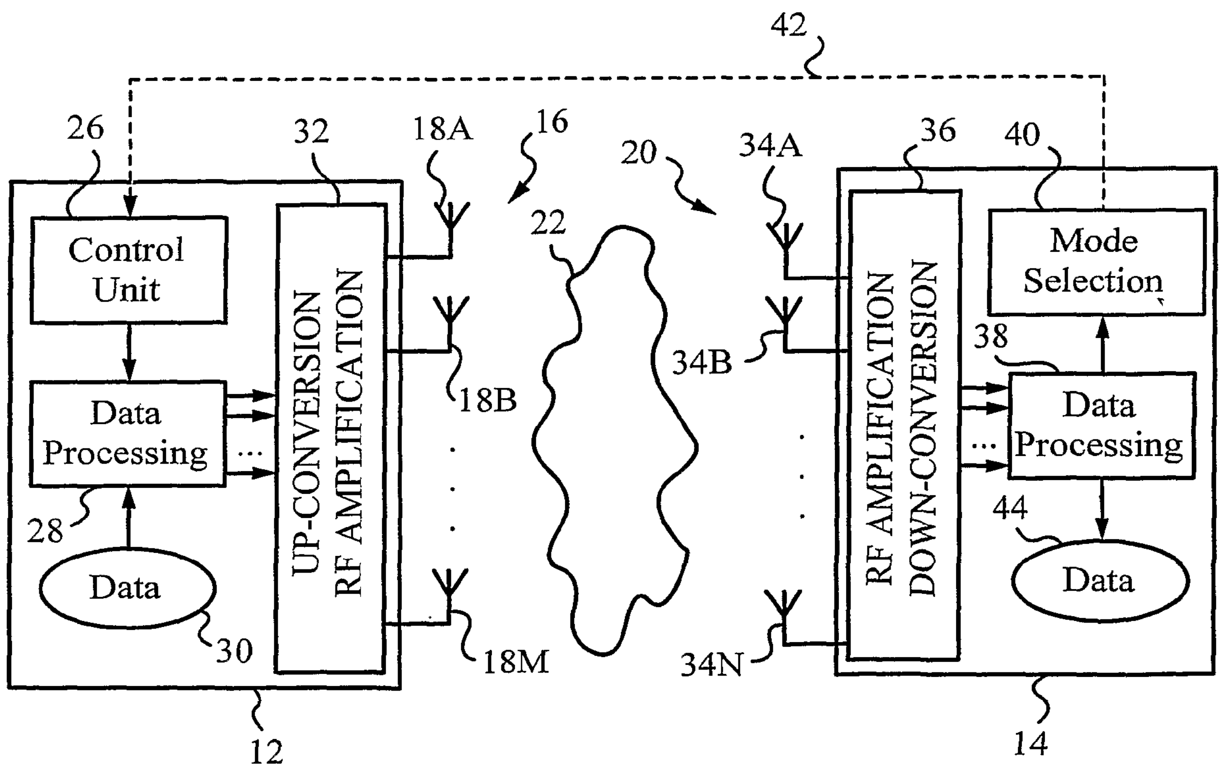

42
26
32
18A
16
20
34A
36
40
22
Control Unit
Mode Selection
UP-CONVERSION RF AMPLIFICATION
RF AMPLIFICATION DOWN-CONVERSION
34B
38
Data Processing
18B
Data Processing
28
44
Data
Data
30
18M
34N
12
14

FIG. 2

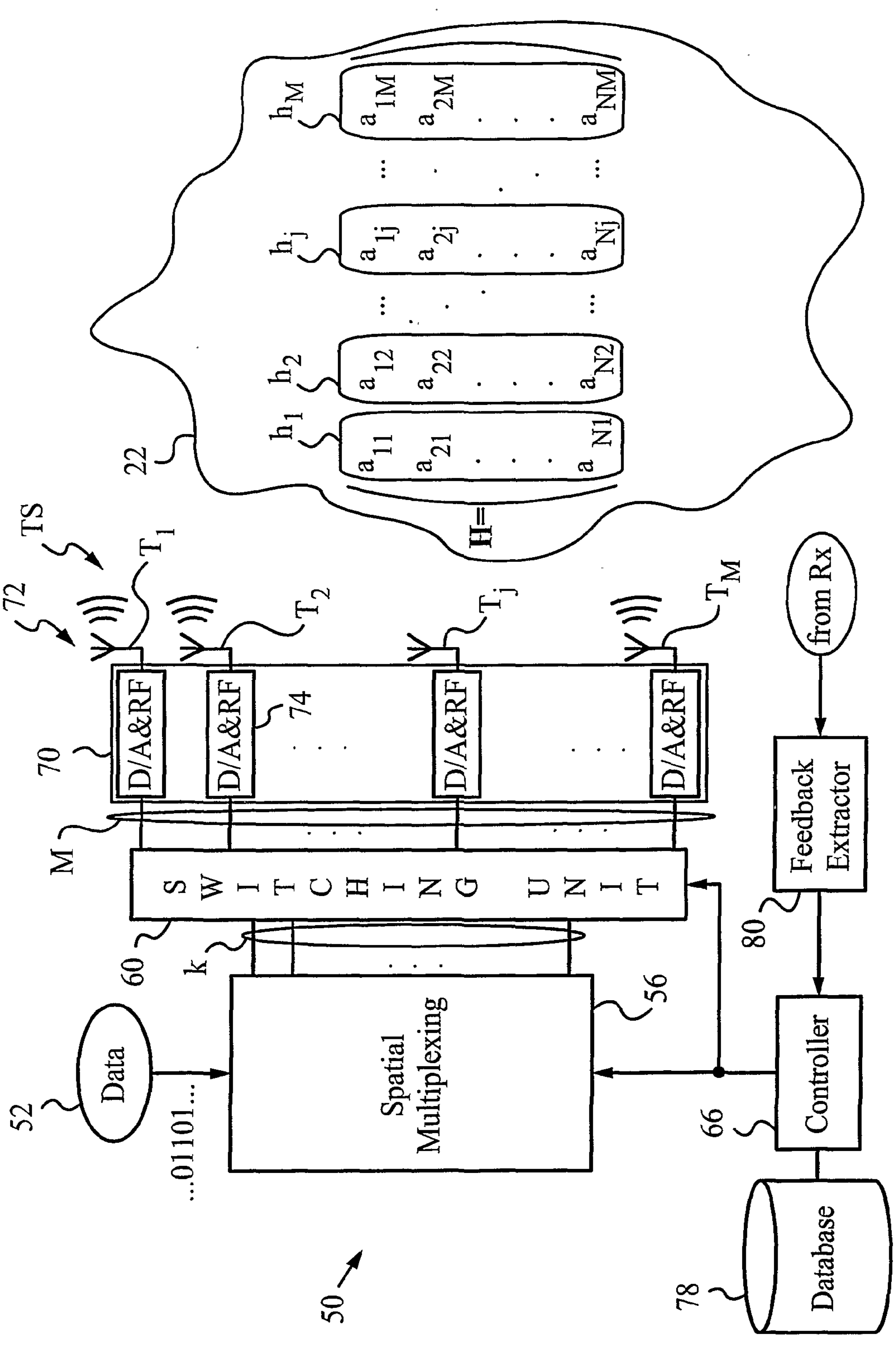

50
52
Data
...01101...
Spatial Multiplexing
56
60
k
SWITCHING UNIT
M
70
D/A&RF
74
72
TS
T_1
T_2
T_j
T_M
22
H=
h_1
h_2
h_j
h_M
a_{11} a_{21} . . . a_{N1}
a_{12} a_{22} . . . a_{N2}
a_{1j} a_{2j} . . . a_{Nj}
a_{1M} a_{2M} . . . a_{NM}
from Rx
Feedback Extractor
80
Controller
66
Database
78

FIG. 3

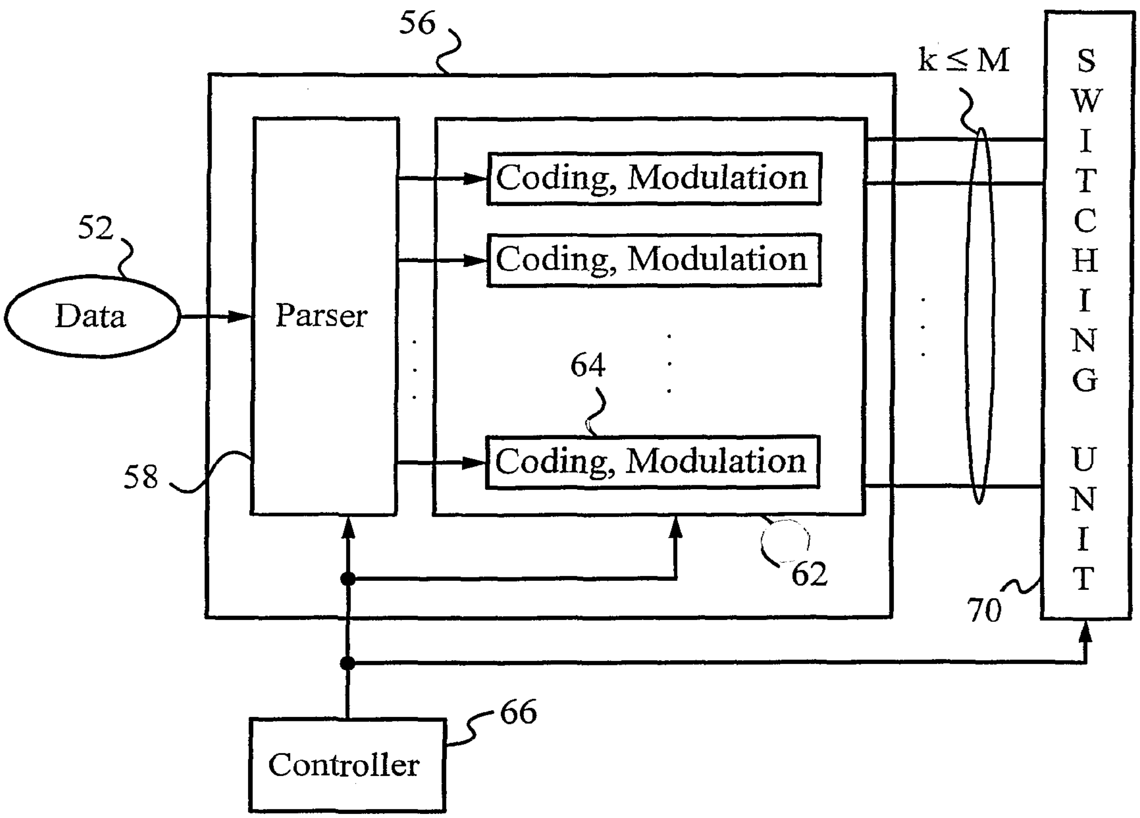

56
k ≤ M
S W I T C H I N G U N I T
Coding, Modulation
Coding, Modulation
52
Data
Parser
64
58
Coding, Modulation
62
70
66
Controller

FIG. 4

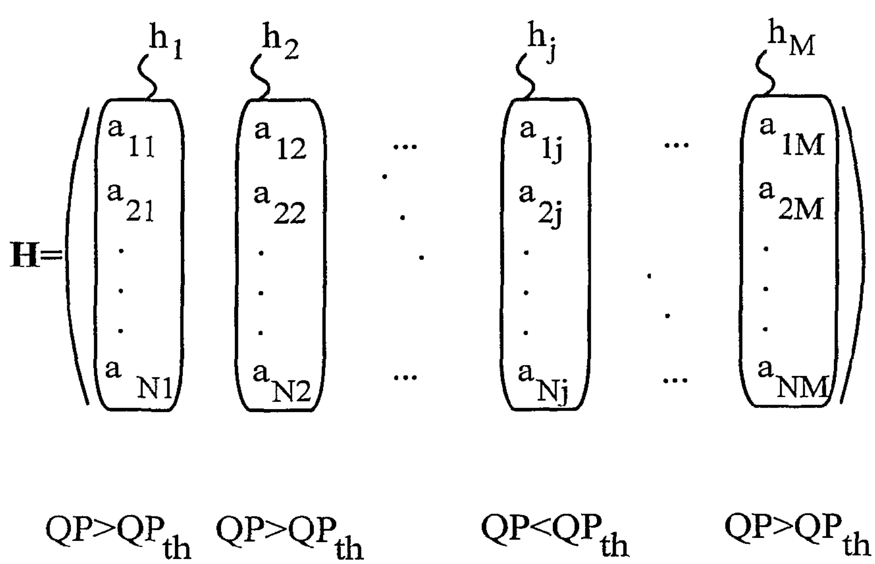

h_1
h_2
h_j
h_M
H=
a_{11}
a_{21}
a_{N1}
a_{12}
a_{22}
a_{N2}
a_{1j}
a_{2j}
a_{Nj}
a_{1M}
a_{2M}
a_{NM}
$QP>QP_{th}$ $QP>QP_{th}$ $QP<QP_{th}$ $QP>QP_{th}$

FIG. 6

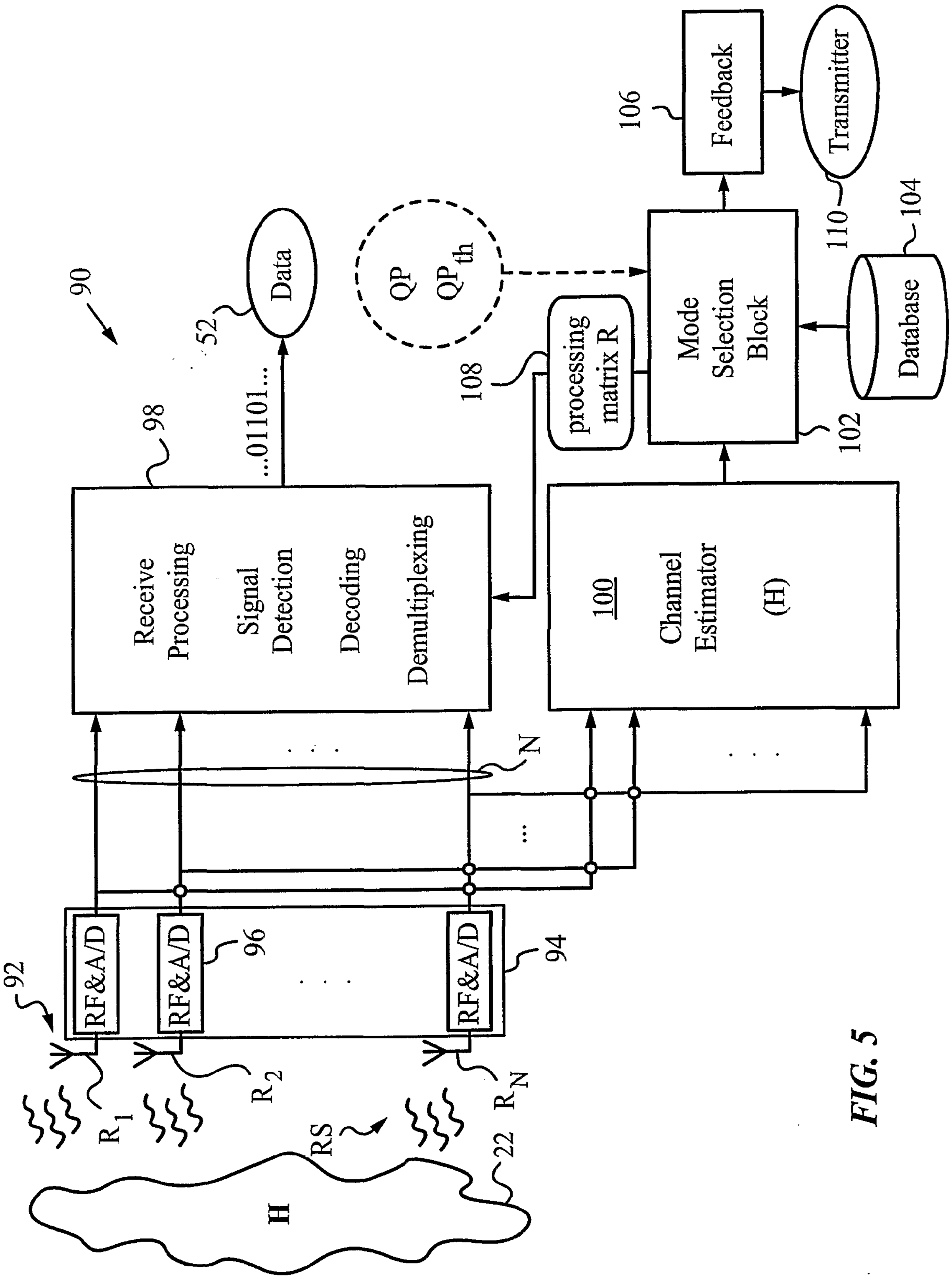

90
52
Data
98
...01101...
Receive
Processing
Signal
Detection
Decoding
Demultiplexing
QP
QP$_{th}$
108
processing
matrix R
106
Feedback
Transmitter
110
104
Mode
Selection
Block
Database
102
100
Channel
Estimator
(H)
N
92
RF&A/D
96
94
R_1
R_2
R_N
RS
22
H

FIG. 5

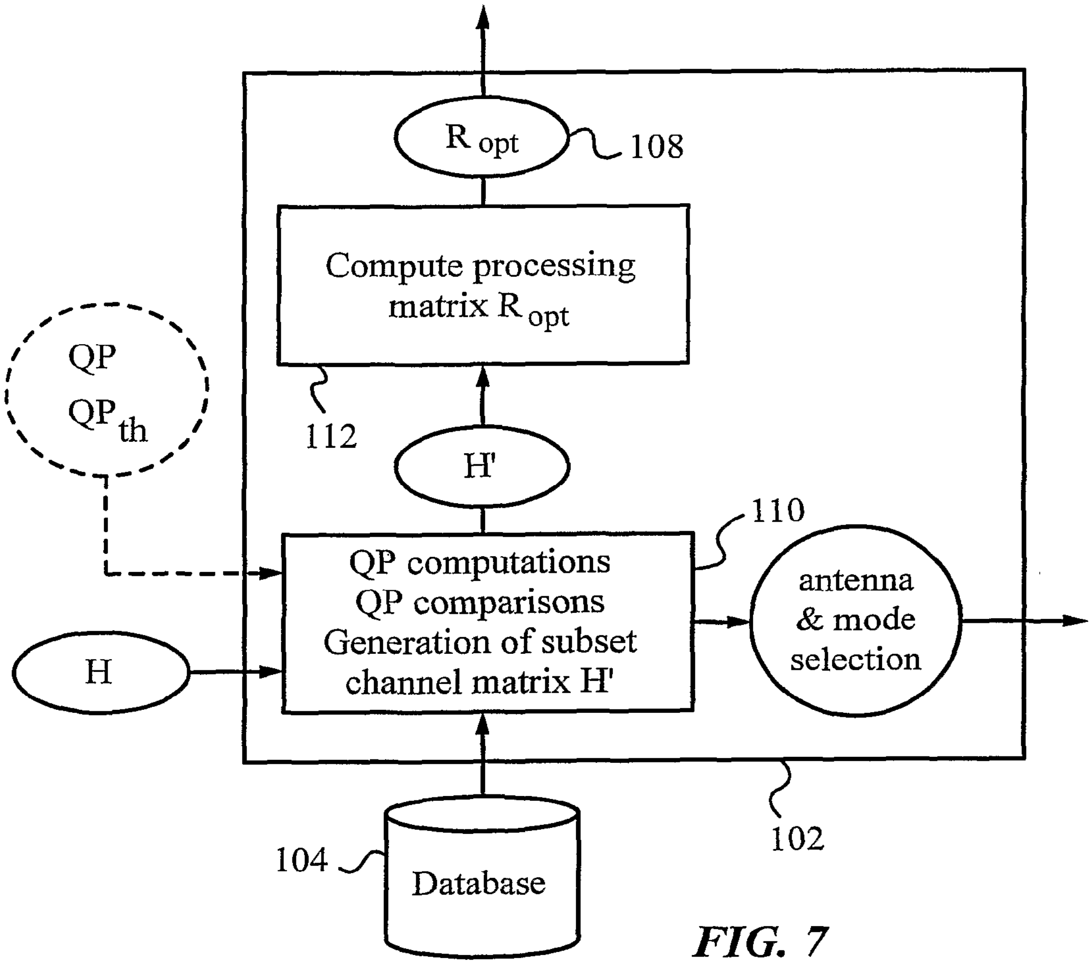

R opt
108
Compute processing
matrix R_{opt}
QP
QP_{th}
112
H'
110
QP computations
QP comparisons
Generation of subset
channel matrix H'
antenna
& mode
selection
H
102
104
Database

FIG. 7

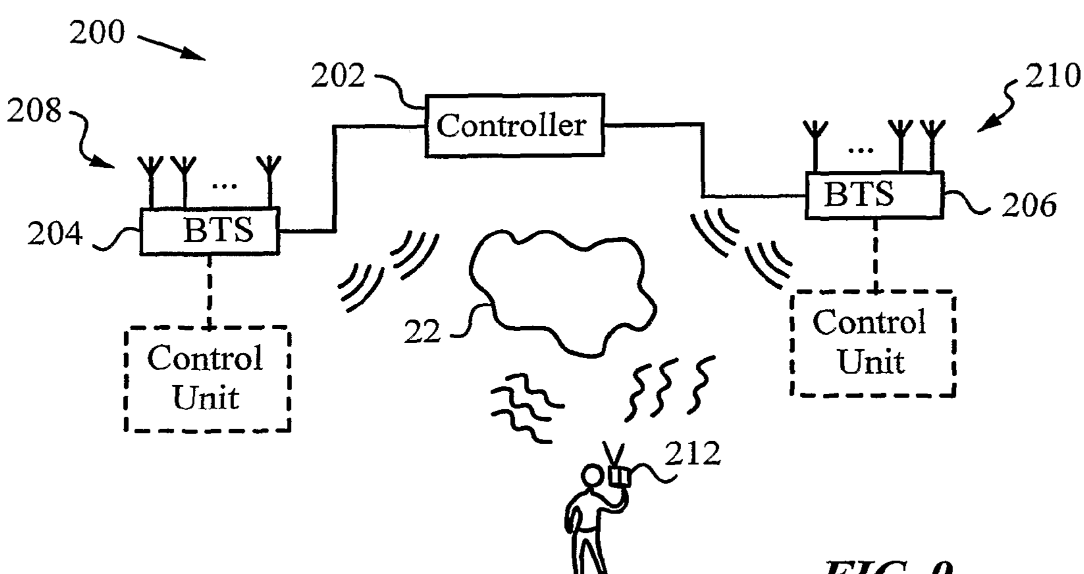

200
202
Controller
210
208
BTS
206
204
BTS
22
Control
Unit
Control
Unit
212

FIG. 9

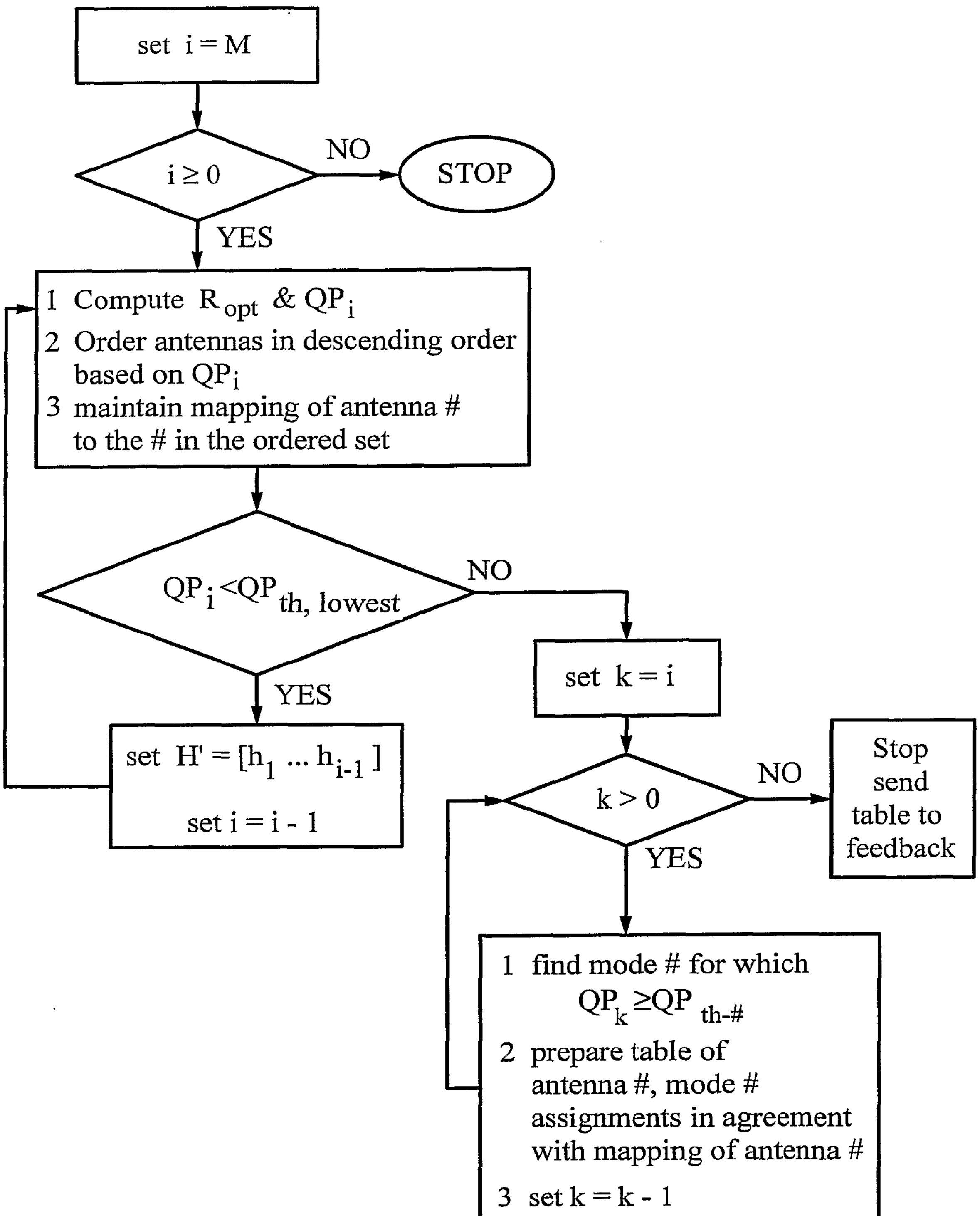

set i = M
i ≥ 0
NO
STOP
YES
1 Compute R_{opt} & QP_i
2 Order antennas in descending order based on QP_i
3 maintain mapping of antenna # to the # in the ordered set
$QP_i < QP_{th, lowest}$
NO
YES
set $H' = [h_1 \ldots h_{i-1}]$
set i = i - 1
set k = i
k > 0
NO
Stop send table to feedback
YES
1 find mode # for which $QP_k \geq QP_{th\text{-}\#}$
2 prepare table of antenna #, mode # assignments in agreement with mapping of antenna #
3 set k = k - 1

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/20470

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :Please See Extra Sheet.
US CL : 375/267,299, 347; 455/69, 101, 136, 269
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 375/26, 299, 347; 455/69, 101, 136, 269

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST search terms: antennas, feedback, diversity

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, P	US 6,128,476 A (FUJITA) 03 OCTOBER 2000, SEE ABSTRACT, FIG. 2, 4	1, 2, 11-19, 28-36, 45-57
Y	US RE.36,591 E (HAYASHI ET AL) 29 FEBRUARY 2000, SEE ABSTRACT, FIG. 4, COL. 3, LINE 34-COL. 4, LINE 7.	1, 2, 11-19, 28-36, 45-57
Y	US 5,886,987 A (YOSHIDA ET AL) 23 MARCH 1999, SEE ABSTRACT, COL. 2, LINE 57-COL. 3	1, 2, 11-19, 28-36, 45-57

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 AUGUST 2001	16 NOV 2001

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	AMANDA T. LE
Facsimile No. (703) 305-3230	Telephone No. (703)305-4769

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/20470

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (7):

H04B 7/02

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 267 501 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
18.12.2002 Bulletin 2002/51

(51) Int Cl.[7]: **H04B 7/06**

(21) Application number: **02076862.8**

(22) Date of filing: **10.05.2002**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **12.06.2001 GB 0114267**

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(54) **Smart antenna array**

(57) The present invention relates to a beamforming method for smart antenna arrays. Smart antennas employ arrays of low gain antennas connected to a combining/beamforming network. Smart antennas can provide enhanced coverage through range extension, hole filling and improved building penetration. By improving transmission and reception at the base station, the tolerable path losses can be increased whereby the range of the base station can be improved. A first aspect of the invention addresses the feedback signalling technique presently being considered by standards bodies for four antennas in large arrays. The invention is suitable for CDMA wireless cellular systems, as presently determined for third generation cellular wireless networks, and other wireless systems such as TDMA systems and wireless LANs.

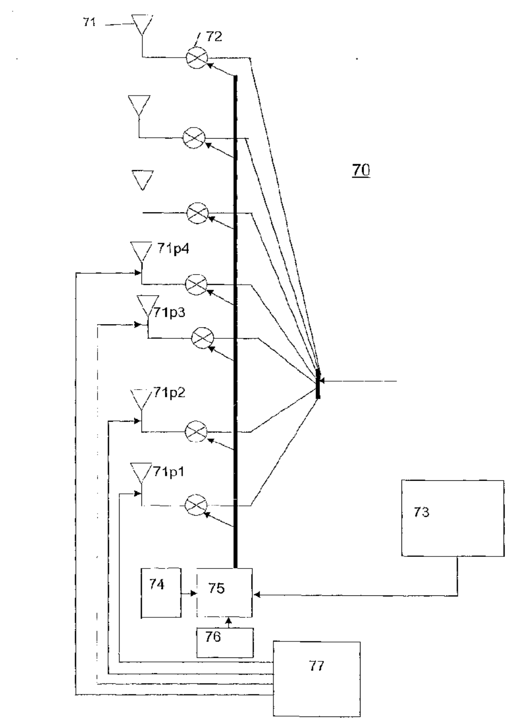

FIGURE 10

EP 1 267 501 A2

Description

Field of the Invention

[0001] This invention relates to a beamforming method for smart antenna arrays.

Background to the Invention

[0002] Smart antenna arrays, otherwise known as adaptive antenna arrays, comprise of low gain antennas connected to a combining/beamforming network. Smart antennas can provide enhanced coverage through range extension, hole filling and improved building penetration. By improving transmission and reception at the base station, the tolerable path losses can be increased whereby the range of the base station can be improved. By using smart antennas at the base station, initial deployment costs of a wireless network can be reduced: with the development in system usage, system capacity can be increased by adding additional cell sites and decreasing the range of existing base stations.

[0003] Digital beamforming, whereby smart antenna arrays are conveniently implemented, is considered as one of the most promising techniques for UMTS networks. Linear and planar antenna arrays are normally considered as candidate antenna types, since they produce low sidelobe levels with respect to other types of antenna such as the circular array. If a communications antenna array produces high sidelobes in the beampattern, it will cause strong interfering signals to mobile terminals in some directions, which can be a severe problem for downlink transmission.

[0004] In the R'99 UTRAN specification, a feedback mechanism was introduced to assist the transmit diversity technique employing two antennas. The concept is to transmit downlink signals of constant power from two different antennas using different scrambling codes to all the mobiles in the common channels and then to adapt the antenna weights for dedicated channels according to the feedback received from the intended mobile. Currently, there is great commercial interest in proposals to introduce feedback signalling to four antennas. Such feedback information enables adaptive beamforming for arrays with four elements. On the one hand, owing to the limited bandwidth for signalling, it is unlikely that any signalling mechanism for more than four antennas will be ever introduced. On the other hand, certain arrays such as circular arrays for cellular networks need at least eight antennas to achieve significant array gain. Also, it is conceivable that linear antenna arrays consisting of more than four elements will be used in future UTRAN products.

Object of the invention

[0005] The present invention seeks to provide an improved antenna arrangement suitable for use in a cellular base station. The present invention further seeks to provide an antenna arrangement operable to increase the capacity of a cellular communications base station. The present invention also seeks to provide a beamforming technique which enables the exploitation of the current feedback signalling scheme in large arrays, for antennas which are either directional or omni-directional.

Statement of the Invention

[0006] In accordance with a first aspect of the invention, there is provided a smart antenna basestation arrangement comprising an array of antenna elements, subdivided into a number of sub-arrays wherein:

an element or selected elements from each sub-array is operable to broadcast common control channel signals, which are, in operation, returned by mobile terminals in the area of coverage of the basestation;
the arrangement being operable to apply stored weight data and direction of arrival data together with feedback data to enable the array to generate directional downlink beams in the direction of said mobile.

[0007] The feedback signal can assist in the optimisation of phase and amplitude components for the beamforming weights to be assigned for dedicated channels.

[0008] The feedback signal can assist in the optimisation of a phase component for the beamforming weights to be assigned for dedicated channels.

[0009] The feedback signal can assist in the optimisation of an amplitude component for the beamforming weights to be assigned for dedicated channels.

[0010] The phase information of the feedback signal can be used to determine a phase component of the pilot antenna weights.

[0011] The magnitude of the feedback signal can be used to determine a magnitude component of the pilot antenna weights.

[0012] The array can comprise directional antennas or an array of omni-directional antennas.

[0013] In accordance with a second aspect of the invention, there is provided a method of operating a smart antenna basestation arrangement comprising an array of antenna elements, subdivided into a number of sub-arrays, the method comprising the steps of:

transmitting from an element or selected elements of each sub-array pilot signals,
receiving feedback signals returned by mobile terminals in the area of coverage of the basestation;
the arrangement being operable to apply stored weight data and direction of arrival data together with feedback data to enable the array to generate

directional downlink beams in the direction of said mobile.

[0014] A first aspect of the invention thus addresses the feedback signalling technique presently being considered by 3GPP for four antennas, either directional or omni-directional in large arrays. The invention is suitable for CDMA wireless cellular systems, as presently determined for third generation cellular wireless networks, and other wireless systems such as TDMA systems and wireless LANs. The present invention therefore can assist in the realisation of further advantages in smart antennas.

Brief description of the figures

[0015] The invention may be understood more readily, and various other aspects and features of the invention may become apparent from consideration of the following description and the figures as shown in the accompanying drawing sheets, wherein:

Figure 1 shows beampattern examples of a circular array;
Figure 2 shows a 2-dimendional arrangement of omni-directional antennas arranged in a circle;
Figure 3 shows a 2-dimensional arrangement of omni-directional antennas arranged in a square;
Figure 4 shows a basic adaptive beamformer configuration;
Figure 5 shows a main beam array pattern interpolation/rotation scale;
Figure 6 shows a flow chart relating to beamforming;
Figure 7 shows a second flow chart relating beamforming;
Figures 8 a and b show some low sidelobe patterns in the horizontal plane from an omni-directional antenna array, at a frequency of 2 GHz;
Figure 9 illustrates sub-arrays of a circular array;
Figure 10 illustrates a beamformer made in accordance with a first aspect of the present invention.
Figures 11-13 are flow charts relating to the operation of a beamformer in accordance with the invention.

Detailed description of the invention

[0016] There will now be described, by way of example, the best mode contemplated by the inventors for carrying out the invention. In the following description, numerous specific details are set out in order to provide a complete understanding of the present invention. It will be apparent, however, to those skilled in the art, that the present invention may be put into practise with variations of this specific. For example, the specific description relates to antennas which are omni-directional, but it will be apparent that directional antennas could be used instead.

[0017] Hitherto, the use of circular arrays has been limited since most beamforming algorithms tend to generate high sidelobes when used for circular arrays, thus causing strong interference to other mobiles and limiting the use of spatial domain multiple access (SDMA). The use of other types of 2-dimensional arrays, not being circular, certainly has not been publicised, but would also suffer from similar problems. Referring to Figure 1, there is shown some beampatterns of Siemens' TD-SCDMA circular antenna array. It can be seen that the sidelobe level (of the directional beams) can be as high as -4dB, whereas it is not difficult to achieve -12dB sidelobe level for a linear array. The problem is especially severe for W-CDMA networks as code shortage in the downlink effectively limits the data rate. A reference pattern, substantially uniform in all directions is shown, provided by a single omni-directional antenna.

[0018] The beampattern of an antenna array is determined to a large extent by the beamforming weights. For linear arrays, there are a number of well-known weight distribution functions which produce low sidelobes, such as Taylor and Chebyshev distributions. For non-linear arrays, unfortunately, there is no easy solution. In theory, given the constraint conditions and objective function, the weights of an array can be optimised in real time by the use of optimisation methods. In practice, however, such a technique is difficult to implement due to the excessive demand on the signal processing power.

[0019] Referring now to Figure 2, there is shown a periodic circular array of omnidirectional antennas, as described in Applicant's concurrently filed co-pending application (attorney no. 2001P09403, serial no to be assigned); a beamforming means is operable to generate, in the radial direction of each element in the elevation plane, a group of optimised patterns with low sidelobes in the angular directions between any two adjacent elements, to cover an angular range. In order to cover a range of 360°, only a small weight set operable to cover an angular period is required: each angular period of arc between adjacent antennas is a repetition in terms of the weight applied to other arcs about a central axis of the antenna arrangement. For example a weight set comprising a weight for a beam to be formed in a radial direction from one antenna element together with weights for a number of angles between that antenna element and one of its adjacent antenna elements can be stored to cover one twelfth of the area about the base station: rotation of the weight set twelve times over 360° provides coverage for the whole space surrounding the antenna arrangement. Such an optimum group of beamforming weight sets can be stored in a buffer or other ROM device. The optimum weight set can be used in any other direction by interpolation and rotation of the weight assignment. Figure 3 shows an antenna arrangement with the antenna elements, being omni-directional in the horizontal plane, arranged in a square.

There are four 90° angular periods of rotational symmetry: rotation of the weight set four times over 360° provides coverage for the whole space surrounding the antenna arrangement.

[0020] The direction of the downlink beam needs to be determined. This information can be obtained in a number of ways: for example feedback signal may disclose the position by virtue of the Global Positioning System (GPS), by triangulation through the network or the base station itself, as is known. When the downlink beamforming is needed and the direction of the beam is given, a weight set is assigned based on the stored optimum weight set group, and a beampattern with guaranteed low sidelobe level is produced.

[0021] Figure 4 shows a schematic configuration of the downlink beamformer; only four antenna elements 40 are shown here, but the beamformer 42 takes into account the direction of arrival of signals 44 which are obtained from a mobile with which it is desired to communicate; weight information is obtained from a ROM 46 or similar. The signals from the beamformer are applied to the antenna input feed by way of multipliers 48. When communication is desired, stored weights corresponding to the directions are obtained; rotation or rotation and interpolation data is factored in and the signals to the antennas are appropriately weighted.

[0022] Figure 5 shows how a 360° angular range, being part of an omni-directional beam is divided into 12 'nl' main beams: for example corresponding to the twelve antenna directions of the circular arrangement of Figure 2. In a simple case, it may be that the rotation of the main beam into any one of twelve antenna directions may be sufficient, then reference need not be made to the n2 weights to provide intermediate beams. Nevertheless n2 intermediate beams would need to be relied upon if the 3dB beamwidth was less than 30°, for a twelve beam arrangement. The example of Figure 5 shows four intermediate beams.

[0023] Figure 6 shows a first flowchart: also with reference to Figure 4, where direction of arrival (DoA) of feed back data from a mobile of a mobile user with whom communication is desired is received by processor 44: the nearest discrete angles relative to a reference are determined. Beamformer 42 refers to stored weight data in ROM 46. In this figure the direction of arrival information corresponds with a main beam direction, the 3dB beamwidth being such that only rotation of the main beam is required to enable all areas of the cell to be covered. Note, however, that it is possible to determine main beam directions which are independent of any periodicity of the two dimensional array. It will be appreciated that, if the beamwidth is sufficiently broad or there are sufficient stored weights, it is advantageous not to have interpolation between main beam directions since non-regular interpolation can make calculations more difficult or require more processing power/more memory.

[0024] Figure 7 shows a second flow chart. As in the case of Figure 6 DoA information is processed to determine the nearest discrete angle relative to a reference (step 2). An interpolation weight set index must be relied upon to determine, together with the rotation weights, an interpolated and rotated main beam (steps 3 - 5). As with Figure 6, the signals drive beamformer multipliers 42. Figures 8a & b show two optimised low-sidelobe beampatterns. It will be appreciated that the sidelobes are low, being less than -12 dB.

[0025] In the R'99 UTRAN specification, a feedback mechanism was introduced to assist the transmit diversity technique employing two antennas. The concept is to transmit downlink signals of constant power from two different antennas using different scrambling codes to all the mobiles in the common channels and then to adapt the antenna weights for dedicated channels according to the feedback received from the intended mobile. Currently, there is great commercial interest in proposals to introduce feedback signalling to four antennas. Such feedback information enables adaptive beamforming for arrays with four elements. On the one hand, owing to the limited bandwidth for signalling, it is unlikely that any signalling mechanism for more than four antennas will be ever introduced. On the other hand, circular arrays for cellular networks need at least eight antennas to achieve significant array gain. Also, it is conceivable that linear antenna arrays consisting of more than four elements will be used in future UTRAN products. Therefore, new beamforming techniques which enable the exploitation of the current feedback signalling scheme, which are limited to two and four antennas, for large arrays are needed.

[0026] Referring now to Figure 9, there is shown further embodiment of the present invention. A large antenna array is divided into a small number of groups called sub-arrays, in this case four groups, comprising, for example, two to ten elements, in this case three antenna elements each. Because antenna elements in each sub-array are closely spaced, an antenna element from each array can be chosen as a pilot antenna to transmit different signals as with the transmit diversity scheme. The feedback signal from the intended mobile is then used to place the constraint on the weights of each sub-array for the transmission of dedicated signals.

[0027] The magnitude information can be used to set the range for the magnitudes of sub-array weights and then to optimise all the antenna weights subject to such constraints. Alternatively, such magnitude information could be used to fix the magnitudes of each sub-array weights and the phases of all the antenna weights are subsequently determined to optimise the beams. As discussed above, a direction finding function is required to perform such optimisation.

[0028] The optimum beam can either be generated in real time, provided that adequate signal processing power is available, or chosen from a prestored optimum set as described above. Figure 10 shows the configuration of such a downlink beamformer, 70, where four pilot antennas, 71 p1...71p4 are used. The signalling for the downlink beams is controlled by unit 77: feedback from the mobiles is interpreted in unit 73 and data is used from unit 73 together with data from stored weight memory 76 and direction of arrival data from unit 74 in a weight assignment unit 75. Signals from the weight assignment unit are fed to the multiplier units in the input transmission line to the antennas. The beamformer corresponds to one suitable for the arrangement of antennas shown in Figure 9, but only seven antennas are shown in the figure with the pilot antennas 71 p1 - 71 p4 of Figure 10 corresponding to pilot antennas 1, 2, 3 and 4 of Figure 2, the total number of antennas will vary, depending upon the type of antenna employed, be it a circular array, for example, where the number is likely to be eight, twelve or sixteen in practice.

[0029] Referring now to Figure 11, there is shown a flowchart which depicts the operation of the invention. Essentially, the antenna array is grouped into a number of sub-arrays, for example each sub-array associated with a 90° period about an omni-directional cell-site, with one or more pilot antennas from each sub-group being operable to broadcast pilot signals. The use of only one or only a small number of the antenna elements of a sub-array reduces the bandwidth required for signalling. Feedback received from a mobile in the area of coverage is used as constrain conditions for the optimisation of beamforming weights; no assumption on the antenna elements or array arrangement is made.

[0030] A detailed description will now follow: Each pilot antenna from each group of sub-arrays broadcasts pilot signals (step i). Mobile telephones active within the area of coverage measure the pilot signals in terms of signal phase and magnitude (step ii), which information is returned to the base transceiver station (BTS) (step iii). The beam forming weights are then optimised taking into account the constraint of the feedback and direction of arrival information (step iv), which weights are passed to the beamforming means, which can conveniently take the form of multipliers.

[0031] Figure 12 shows a preferred means of implementing the general concept shown in Figure 11. For each discrete angle, which is represented by index m_1, there is a number of pre-optimised weights corresponding to different feedback combinations which is denoted by index m_2. The number of pre-optimised weights could conveniently correspond with the main beams described above, with further pre-optimised weights for the interpolation beam directions, as appropriate.

[0032] In Figure 13, a third index m_3 is introduced to reflect the fact that there may be a certain symmetry/periodicity associated with the arrangement which can usefully be exploited, so that the number of stored weights can be reduced and, subsequently, an operation of rotation or reflection can be implemented.

Claims

1. A smart antenna basestation arrangement comprising an array of antenna elements, subdivided into a number of sub-arrays wherein:

    an element or selected elements from each sub-array is operable to transmit pilot signals, which are, in operation, returned by mobile terminals in the area of coverage of the basestation;
    the arrangement being operable to apply stored weight data and direction of arrival data together with feedback data to enable the array to generate directional downlink beams in the direction of said mobile.

2. An arrangement according to claim 1 wherein the feedback signal assists in the optimisation of phase and amplitude components for the beamforming weights to be assigned for dedicated channels.

3. An arrangement according to claim 1 wherein the feedback signal assists in the optimisation of a phase component for the beamforming weights to be assigned for dedicated channels.

4. An arrangement according to claim 1 wherein the feedback signal assists in the optimisation of an amplitude component for the beamforming weights to be assigned for dedicated channels.

5. An arrangement according to claim 3 wherein the phase information of the feedback signal is used to determine a phase component of the pilot antenna weights.

6. An arrangement according to claim 8 wherein the magnitude of the feedback signal is used to determine a magnitude component of the pilot antenna weights.

7. An arrangement according to claim 1 wherein the array has a physical periodicity whereby to reduce the number of principle optimum weight sets.

8. An arrangement according to anyone of claims 1 - 7 wherein the array comprises a circular array with a regular space between adjacent elements.

9. An arrangement according to anyone of claims 1 - 7 wherein the array comprises a square array.

10. An arrangement according to anyone of claims 1 - 7 wherein the antennas comprise directional antennas.

11. An arrangement according to anyone of claims 1 -

7 wherein the antennas comprise omni-directional antennas.

12. An arrangement according to any one of claims 1 to 3 wherein a number of angular directions are selected within an angle formed by two adjacent elements whereby to obtain the basic optimum weight set group.

13. A method of operating a smart antenna basestation arrangement comprising an array of antenna elements, subdivided into a number of sub-arrays, the method comprising the steps of:

transmitting. from an element or selected elements of each sub-array pilot signals,
receiving feedback signals returned by mobile terminals in the area of coverage of the basestation;
the arrangement being operable to apply stored weight data and direction of arrival data together with feedback data to enable the array to generate directional downlink beams in the direction of said mobile.

14. A method according to claim 13 wherein the feedback signal assists in the optimisation of phase and amplitude components for the beamforming weights to be assigned for dedicated channels.

15. A method according to claim 13 wherein the feedback signal assists in the optimisation of a phase component or the beamforming weights to be assigned for dedicated channels.

16. An arrangement according to claim 13 wherein the feedback signal assists in the optimisation of a amplitude component for the beamforming weights to be assigned for dedicated channels.

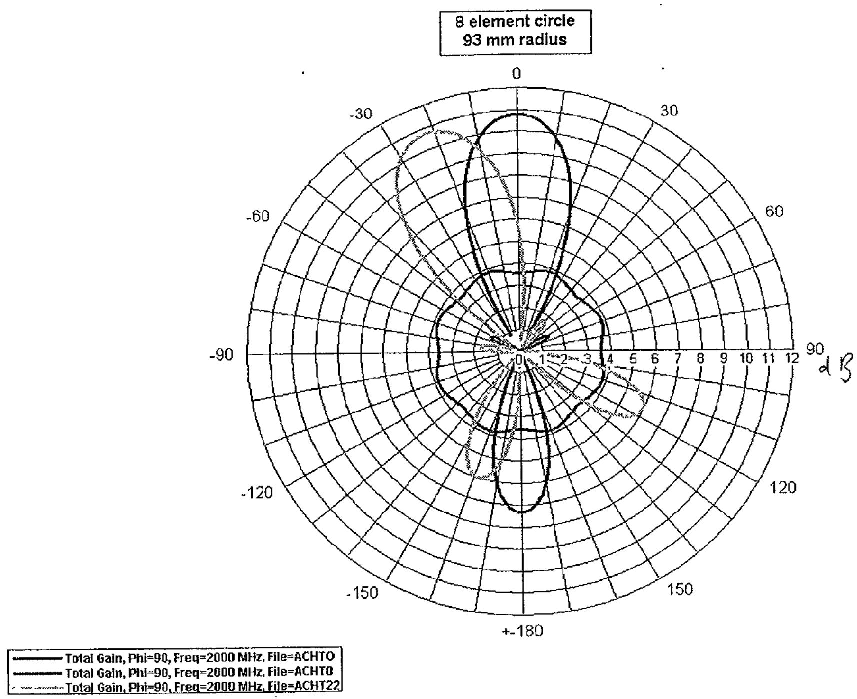

FIGURE 1

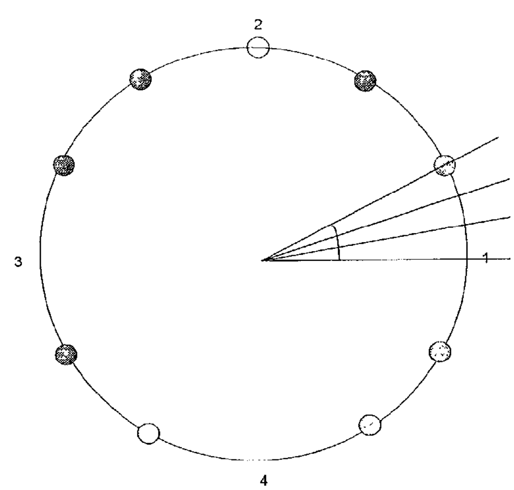

FIGURE 2

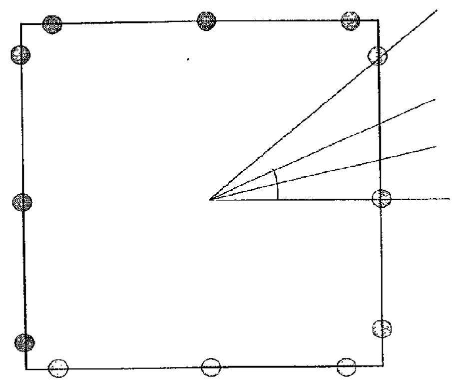

FIGURE 3

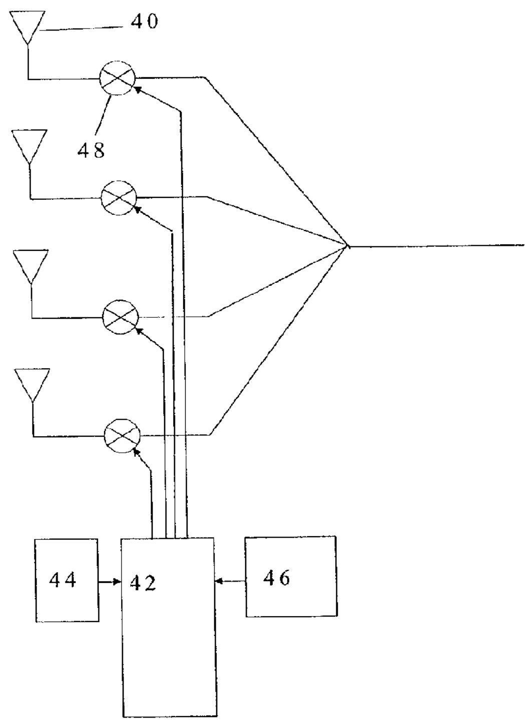

FIGURE 4

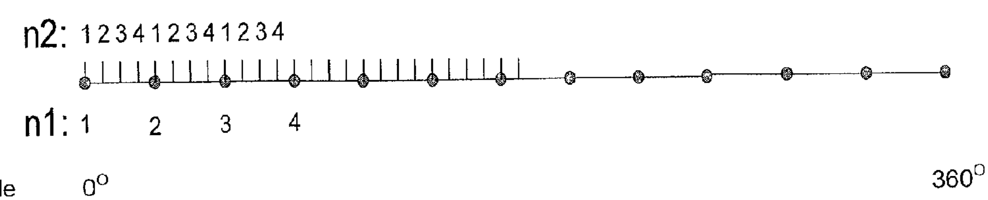

FIGURE 5

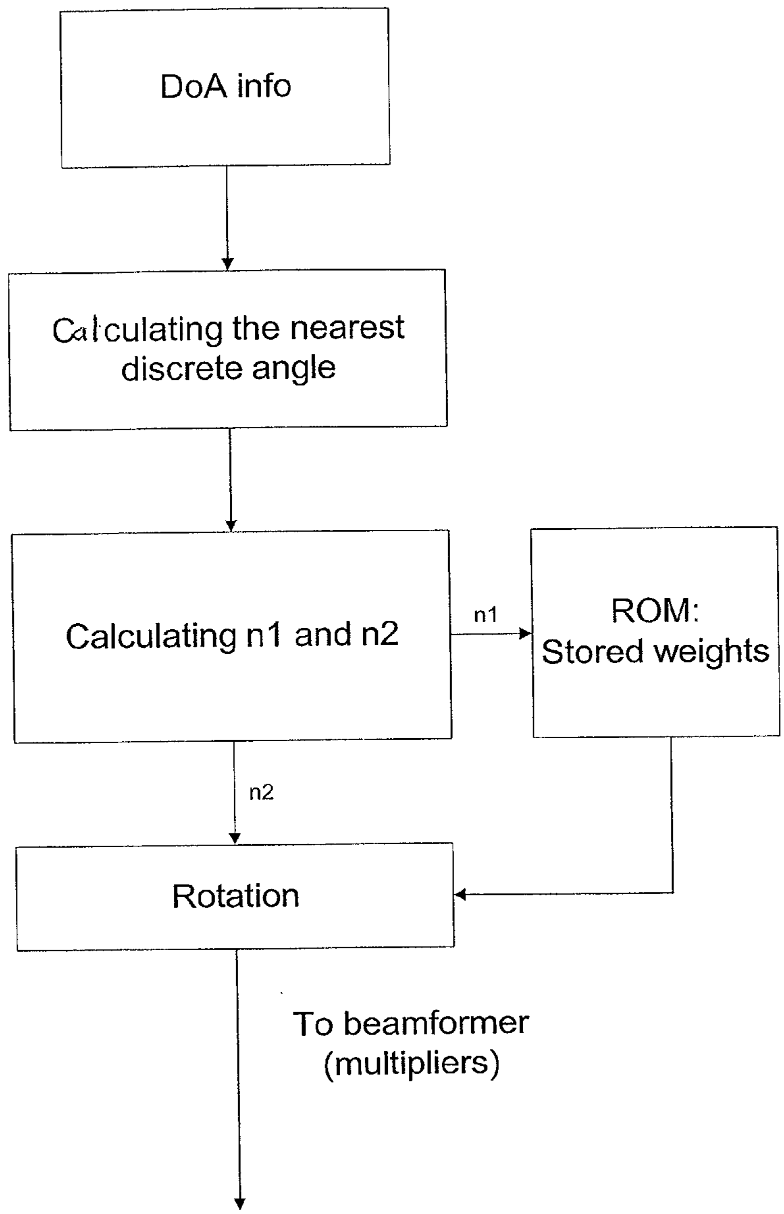
DoA info
Calculating the nearest discrete angle
Calculating n1 and n2
n1
ROM:
Stored weights
n2
Rotation
To beamformer (multipliers)

FIGURE 6

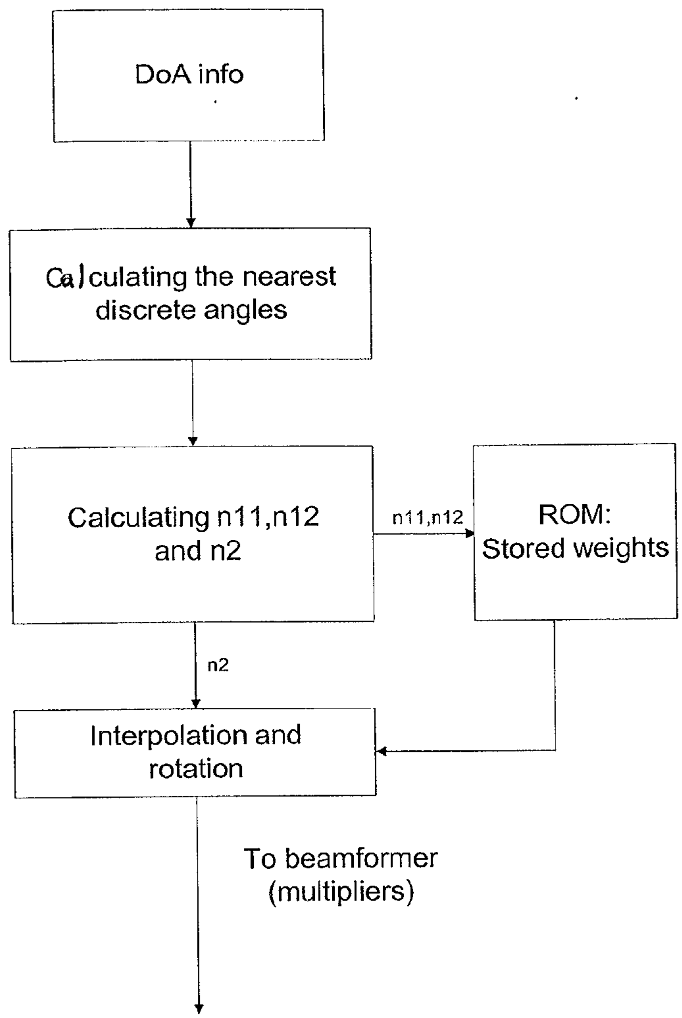

FIGURE 7

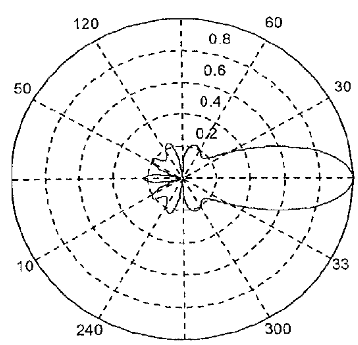

FIGURE 8 a

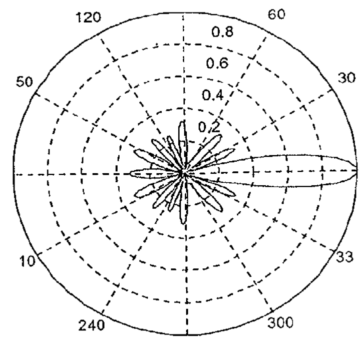

FIGURE 8 b

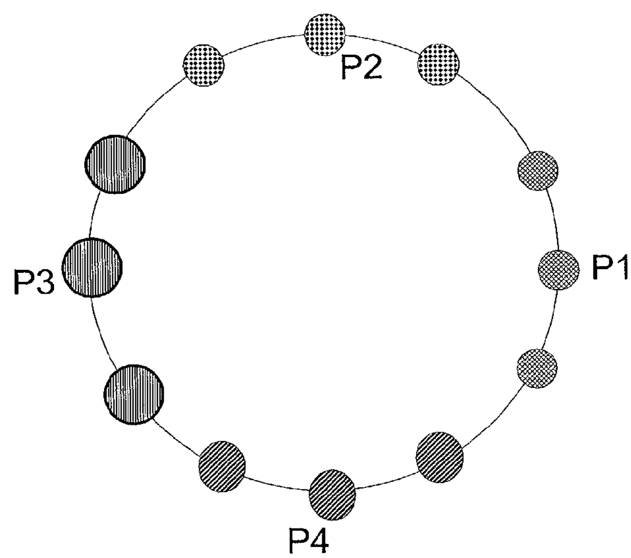

FIGURE 9

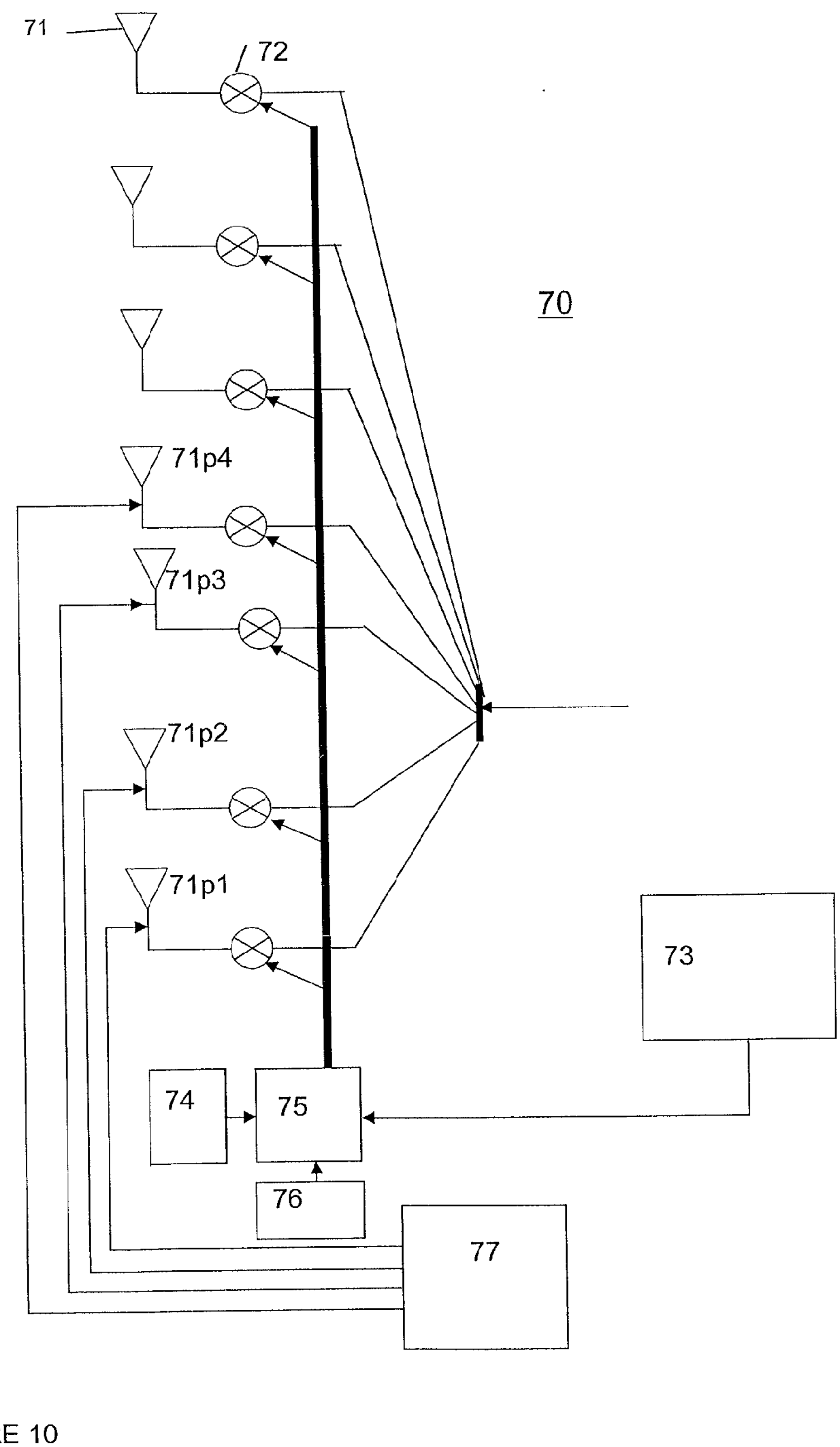

FIGURE 10

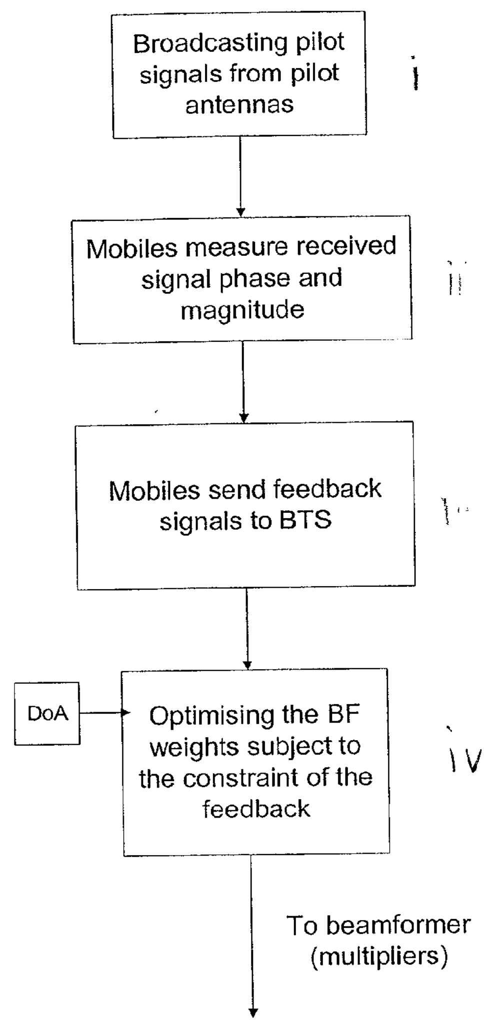
Broadcasting pilot signals from pilot antennas
i
Mobiles measure received signal phase and magnitude
ii
Mobiles send feedback signals to BTS
iii
DoA
Optimising the BF weights subject to the constraint of the feedback
iv
To beamformer (multipliers)

FIGURE 11

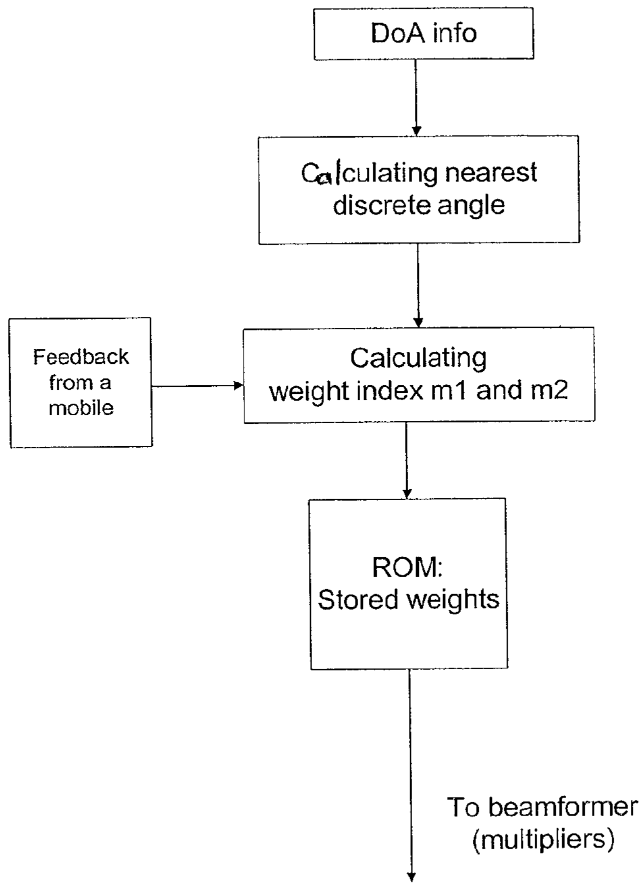
DoA info
Calculating nearest discrete angle
Feedback from a mobile
Calculating weight index m1 and m2
ROM: Stored weights
To beamformer (multipliers)

FIGURE 12

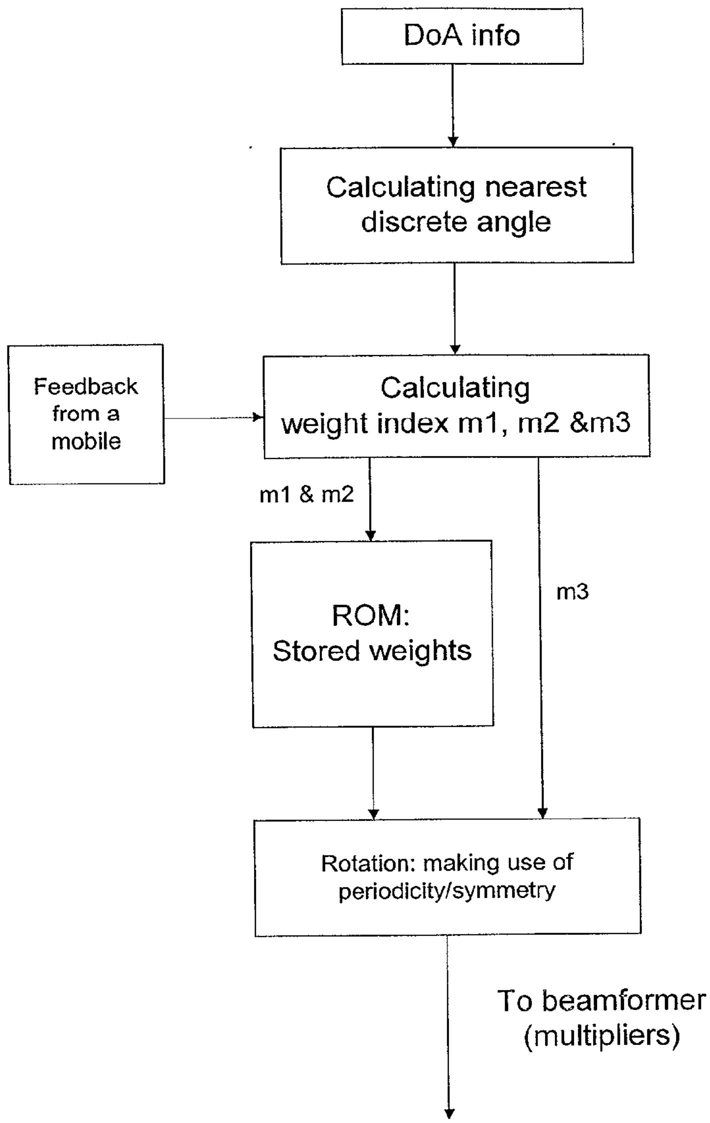
DoA info
Calculating nearest discrete angle
Feedback from a mobile
Calculating weight index m1, m2 &m3
m1 & m2
ROM: Stored weights
m3
Rotation: making use of periodicity/symmetry
To beamformer (multipliers)

FIGURE 13

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 475 904 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
10.11.2004 Bulletin 2004/46

(51) Int Cl.7: **H04B 7/08**

(21) Application number: **04010222.0**

(22) Date of filing: **29.04.2004**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL HR LT LV MK

(30) Priority: **06.05.2003 US 430455**

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(54) **An adaptive diversity receiver architecture**

(57) A diversity receiver circuit that adaptively selects a variable number of one or more antennas for use in improving signal quality. Each antenna is provided its own receiver that each generates a representation of a received signal. The first and second representations of the signal are adaptively phase shifted only if both have sufficient strength. Otherwise only one of the processed first and second representations are selected for further processing. This adaptive selection offers high dynamic adaptability in using the appropriate antennas and receivers at the appropriate time to thereby improving signal-to-noise ratio. The receivers may be direct conversion receivers that implement up-conversion of the baseband signal to reduce DC offset and 1/f noise characteristic of direct conversion architectures.

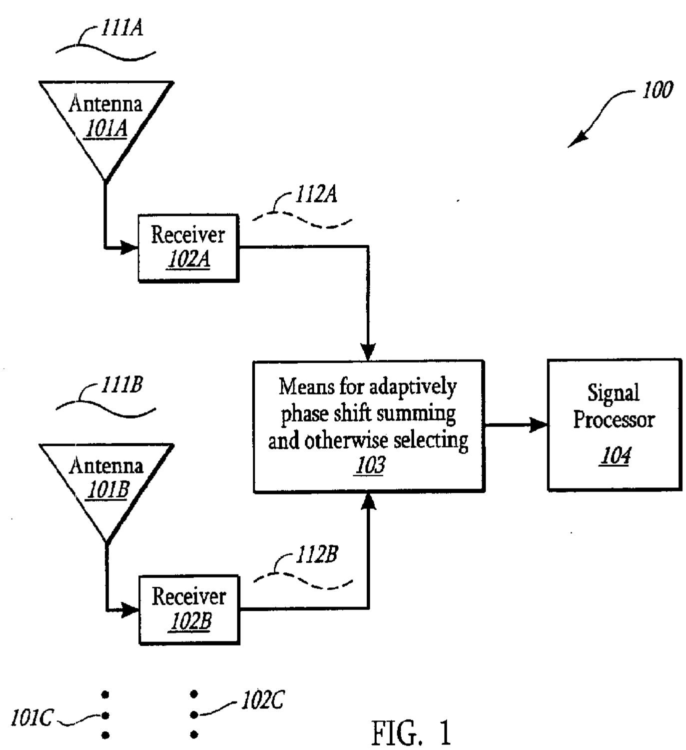

FIG. 1

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Description

BACKGROUND OF THE INVENTION

1. The Field of the Invention

[0001] The present invention relates to analog integrated circuit design, and more particularly, to a direct conversion receiver that processes constant envelope phase and frequency modulated signals.

2. Background and Related Art

[0002] Electrical signals have proven to be an effective means of conveying data from one location to another. The further a signal is transmitted, however, the greater the decay in the signal and the greater the chance for irreversible loss in the data represented by the signal. In order to guard against this signal decay, the core electrical signal that represents the data (i.e., the baseband signal) may be modulated or superimposed on a carrier wave in the Radio Frequency (RF) frequency spectrum.

[0003] In order to properly interpret the signal, conventional RF receivers extract the baseband signal from the received signal. The data represented by the extracted baseband signal may then be interpreted by other downstream circuitry. In order to perform this extraction, typical receivers include circuitry which first converts the received radio frequency modulated signal into an intermediate frequency ("IF") signal. This intermediate frequency signal is then converted into the baseband signal for further data processing. Receiver architectures that convert through the intermediate frequency are often called "heterodyne" receiver architectures. Naturally, circuit elements (called "IF components") are required in order to deal with the intermediate conversion to and from the intermediate frequency.

[0004] It is desirable to reduce the cost, size, and power consumption of a particular receiver architecture design for strategic marketing of the receiver. This is particularly true of wireless RF receivers since those receivers are often portable and run on battery power.

[0005] One technology developed in order to reduce RF receiver cost, size, and power consumption is called "direct conversion." Direct conversion refers to the direct conversion of RF modulated signals into corresponding baseband signals without requiring conversion through the intermediate frequency. Such direct conversion receiver architectures are often also called "zero-IF," "synchrodyne," or "homodyne" receiver architectures.

[0006] Figure 7 illustrates a conventional direct conversion circuit 700 in accordance with the prior art. The circuit 700 includes an antenna 701 which receives the RF modulated signal. The antenna 701 then provides the received signal to an amplifier 702 which amplifies the signal for further processing. The amplifier 702 may be, for example, an RF low noise amplifier.

[0007] The amplified signal is then split into two branches, an "in-phase" branch 710, and a "quadrature-phase" branch 720. Each branch includes a mixer that initially receives the amplified signal. For instance, the in-phase branch 710 includes an in-phase mixer 711, and the quadrature-phase branch 720 includes a quadrature-phase mixer 721. A local oscillator 730 provides a sine or square wave signal as a control signal to each of the mixers. Each mixer is configured to nonlinearly process the amplified signal and control signal, resulting in output signal components at frequencies equal to the sum and difference of amplified signal and control signal frequencies, plus higher-order components at other frequencies. The circuit includes a 90-degree phase shifter 731 which causes the control signal for the quadrature-phase mixer 721 to be 90 degrees out of phase with the control signal for the in-phase mixer 711.

[0008] The signal from the in-phase mixer 711 is then passed through a low pass filter 712 to a baseband amplifier 713 to complete the extraction of the baseband (difference frequency) signal from the received signal as far as the in-phase branch 710 is concerned. Likewise, the signal from the quadrature-phase mixer 721 is passed through a low pass filter 722 to a baseband amplifier 723 to complete the extraction of the baseband (difference frequency) signal as far as the quadrature-phase branch is concerned. The in-phase and quadrature-phase baseband signals are then processed by signal processing circuitry 750.

[0009] The direct conversion circuit of Figure 7 does not convert through an intermediate frequency and thus there are no IF components needed to deal with an intermediate conversion. Consequently, the direct conversion circuit of Figure 7 is smaller, and requires less power than conventional heterodyne receiver architectures. Furthermore, the direct conversion circuit does not have to deal with image suppression as much as do heterodyne receivers. Accordingly, direct conversion receivers have many advantages over heterodyne receiver architectures. Unfortunately, direct conversion architectures characteristically introduce more DC offset and 1/f noise than do heterodyne receiver architectures thereby limiting dynamic range.

[0010] In a direct conversion receiver architecture, as in heterodyne receiver architectures, it is often desirable to implement antenna diversity. Antenna diversity involves the use of more than one antenna to receive a signal to improve the ability to properly receive the signal. When using one antenna to receive a signal, the signal may have actually taken several paths from the transmitter to the receiver, each having a different length. This causes an echo effect that might actually lead to destructive interference between the signals receive from different paths. The use of two or more antennas that are appropriately spaced reduces the degradation due to the echo effect since the echo at one antenna will typically be different than the echo at another, thereby reducing the likelihood that the echo would degrade the signal.

[0011] The use of multiple antennas is also helpful to improve signal-to-noise ratio even if there is no echo effect. By coherently adding the two versions of signal together, the signal-to-noise ratio may improve by a factor of the square root of the number of antennas in the diversity receiver system. Conventional antenna diversity systems that perform such coherent adding of the signal consistently add the two signals together without reverting back to a single antenna system when one of the antennas is not picking up a good signal.

[0012] Accordingly, a diversity receiver would be advantageous in which the antenna selection is adaptively determined based on the ability of an antenna at any given point in time to properly receive the signal. It would further be advantageous if such a diversity receiver could implement direct conversion receivers, especially if such direct conversion receivers had reduced DC offset and 1/f noise as compared to conventional direct conversion receivers.

BRIEF SUMMARY OF THE INVENTION

[0013] The foregoing problems with the prior state of the art are overcome by the principles of the present invention, which are directed towards a diversity receiver circuit that adaptively selects which one or more antennas to use to improve signal processing. Each antenna is provided its own receiver, each receiver generating a representation of the received signal. The receivers may be direct conversion receivers that implement up-conversion of the baseband signal to reduce DC offset and 1/f noise characteristic of direct conversion architectures.

[0014] The diversity receiver may phase shift sum all of the respective representations of the signals received via all the antennas if the signal strength is sufficient from each of the antennas. Alternatively, one or more receivers may be adaptively disconnected from the summing operations if they have too weak of a signal to contribute positively to the summed signal. If one representation of the signal is all that has sufficient strength, then that may be the only representation of the signal provided to the signal processor.

[0015] The signals are summed in a manner that the phase of one representation is relatively fixed with respect to another representation of the phase, thereby improving the predictability in improving the signal-to-noise ratio. Furthermore, the adaptive antenna and receiver selection is not limited to all or just one of the antennas being selected, and may change the number of receivers whose resulting signals are summed depending on the then existing circumstances. Accordingly, more appropriate antenna selection may be accomplished thereby often improving signal-to-noise ratio.

[0016] The components of the diversity receiver architecture may all be fabricated using conventional CMOS processes thereby allowing the diversity receiver to be implemented all on a single die or chip.

[0017] Additional features and advantages of the invention will be set forth in the description that follows, and in part will be obvious from the description, or may be learned by the practice of the invention. The features and advantages of the invention may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features of the present invention will become more fully apparent from the following description and appended claims, or may be learned by the practice of the invention as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] In order to describe the manner in which the above-recited and other advantages and features of the invention can be obtained, a more particular description of the invention briefly described above will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the invention and are not therefore to be considered to be limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

[0019] Figure 1 illustrates a schematic diagram of a diversity receiver circuit that adaptively selects one or more antennas and receivers for further processing in accordance with the principles of the present invention;

[0020] Figure 2A illustrates one example of a means for phase shift summing and otherwise selecting less than all representations of a received signal;

[0021] Figure 2B illustrates a second example of a means for phase shift summing and otherwise selecting less than all representations of a received signal;

[0022] Figure 2C illustrates a third example of a means for phase shift summing and otherwise selecting less than all representations of a received signal;

[0023] Figure 3 illustrates a fourth and more specific example of a means for phase shift summing and otherwise selecting less than all representations of a received signal;

[0024] Figure 4 illustrates a circuit diagram of a direct conversion receiver that implements up-conversion on the baseband signal and that may be used as one or both of the receivers of Figure 1 in accordance with the principles of the present invention;

[0025] Figure 5A illustrates a component-level circuit diagram showing further details of an embodiment of the down-converting mixer, a low pass filter, and an up-converting mixer that may be used in the circuit of Figure 4 as passive elements;

[0026] Figure 5B illustrates a component-level circuit diagram showing an alternative structure for the down-converting mixer;

[0027] Figure 5C illustrates a component-level circuit diagram showing a second alternative structure for the down-converting mixer;

[0028] Figure 6 illustrates a component-level circuit diagram showing further details of another embodiment of an up-converting mixer that may be used in the circuit of Figure 4 as a passive element; and

[0029] Figure 7 illustrates a high-level circuit schematic of a direct conversion circuit in accordance with the prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0030] The principles of the present invention are directed towards a diversity receiver circuit that adaptively selects a variable number of one or more antennas to use to improve signal processing. Each antenna is provided its own receiver that each generates a representation of a received signal. This adaptive selection offers high dynamic adaptability in using the appropriate antennas and receivers at the appropriate time thereby improving signal-to-noise ratio. The receivers may be direct conversion receivers that implement up-conversion of the baseband signal to reduce DC offset and 1/f noise characteristic of direct conversion architectures.

[0031] In this description and in the claims, one node in a circuit is "coupled" to another node in the circuit if charge carriers freely flow (even through some devices and/or with some resistance) between the two nodes during normal operation of the circuit. One node in a circuit is "capacitively coupled" to another node in the circuit if there are one or more capacitors that intervene between the two nodes. One node in a circuit is "at least capacitively coupled" to another node if the two nodes are either coupled together as just defined, or are capacitive coupled together as just defined.

[0032] In this description and in the claims, a signal being "down-converted" means that the signal is operated upon such that its frequency spectrum tends more towards lower frequencies as compared to before the operation, the operation occurring without any loss in the core data represented by the signal. A signal being "up-converted" means that the signal is operated upon such that its frequency spectrum tends more towards higher frequencies as compared to before the operation, the operation also occurring without any loss in the core data represented by the signal.

[0033] In this description and in the claims, two signals being "phase shift" summed means that the two signals are summed while maintaining a relatively fixed phase shift between the signals within the tolerances allowable by a phase detector. The relatively fixed phase shift should be at least ten degrees, but is preferably a ninety degree phase shift to maximize signal to noise obtainable from the two signals.

[0034] Figure 1 illustrates a diversity receiver circuit 100 in accordance with the principles of the present invention. The diversity receiver circuit 100 includes a first antenna 101A that receives a first representation of a signal 111A over-the-air and converts that signal into a first representation of the signal on the wire. A first receiver 102A receives and processes the first representation of the signal to generate a processed first representation 112A of the signal (also hereinafter referred to as "received signal 112A").

[0035] The diversity receiver circuit 100 also includes a second antenna 101B that receives a second representation of a signal 111B over-the-air and converts that signal into a second representation of the signal on the wire. A second receiver 102B receives and processes the second representation of the signal to generate a processed second representation 112B of the signal (also hereinafter referred to as "received signal 112B").

[0036] The diversity receiver circuit 100 may even include more antennas and corresponding receivers as represented by vertical ellipses 101C and 102C that each generate their own received signals.

[0037] The received signals from each receiver are provided to a means for (element 103) adaptively phase shift summing the received signals only if the received signals all have sufficient strength, and otherwise selecting less than all of the received signals for further processing. The summed signal(s) or selected received signal is then provided to a signal processor 104 for further processing. Accordingly, the diversity receiver circuit 100 sums all received signals, or selects less than all or even one of the received signals for further processing should circumstances warrant. The ability to adapt in this manner typically improves signal-to-noise ratio of the signal processed by the signal processor 104.

[0038] The means 103 may include any corresponding structure and materials for accomplishing this result. All such structures are intended to be encompassed within the scope of the present invention. It would be impossible to outline all structures that fall within the scope of the present invention. However, Figures 2A, 2B, 2C and 3 illustrated specific examples of the means 103 for adaptively phase shift summing the received signals only if the received signals all have sufficient strength, and otherwise selecting less than all of the received signals for further processing.

[0039] Each of the means of Figure 2A, 2B, 2C and 3 include a phase shifter (e.g., phase shifter 213 in Figures 2A and 2B, phase shifter 213A of Figure 2C, and phase shifter 313 of Figure 3). The phase shifter is configured to receive the processed first received signal 112A at least when the first received signal exceeds a first threshold value. The phase shifter further generates a phase shifted version of the first received signal at least when the first received signal exceeds the first threshold value.

[0040] A summer (e.g., summer 214 of Figures 2A, 2B and 2C; and summer 314 of Figure 3) sums the phase shifted version of the first received signal with the second received signal when both of the following conditions are true: 1) the processed first received signal exceeds the first threshold value, and the processed second received signal exceeds a second threshold value. Note that the first and second threshold values may be different or the same. In Figure 3, the first and second threshold voltages used for comparison are provided by the threshold voltage source 315 on a common wire and thus are the same, although that need not be the case.

[0041] In the circuit 203A of Figure 2A, the phase shifter 213 may be selectively coupled to the first received signal 112A, or may alternatively be selectively coupled to the summer 214. Although both switches 211 and 212 are shown, only one or the other is present. If the switch 211 is present, the switch 211 is closed when the first received signal exceeds the first threshold value, and otherwise is open. Accordingly, the phase shifter 213 would phase shift the first received signal only when the first received signal exceeds the first threshold value. If the switch 212 is present, the phase shifter 213 always receives and phase shifts the first received signal. However, the summer 214 would only receive the phase-shifted version of the first received signal if the first received signal exceeds the first threshold value. Alternatively, both switches 211 and 212 could be present.

[0042] The switch 215 is closed when the second received signal exceeds the second threshold value. The phase shifter 213 is configured such that both representations of the first and second received signals are either synchronized or have a relatively fixed phase offset with respect to each other. Accordingly, the summer 214 of Figure 2A provides the summed version of the first and second representations if both received signal have sufficient strength. Alternatively, if one of the received signals is too weak, the summer 214 provides only the stronger of the two signals to the signal processor 104.

[0043] The circuit 203B of Figure 2B illustrates an alternative structure in which the phase shifter 213 always receives and phase shifts the first received signal, and in which the summer always sums the phase-shifted version of the first received signal with the second received signal. However, switch 217 may only be closed when both received signals are of sufficient strength, switch 216 may only be closed when just the first received signal is of sufficient strength, and switch 218 may only be closed when just the second received signal is of sufficient strength.

[0044] The circuit 203C of Figure 2C illustrates an alternative structure in which the phase shifter 213A is configured very similar to the structure described above with respect to the circuit 203A of Figure 2A. In this case, however, a second phase shifter 213B is added. Although both switches 219 and 220 are shown, only one or the other is present. If the switch 220 is present, the switch 220 is closed when the second received signal exceeds the second threshold value, and otherwise is open. Accordingly, the phase shifter 213B would phase shift the second received signal only when the second received signal exceeds the second threshold value. If the switch 219 is present, the phase shifter 213B always receives and phase shifts the second received signal. However, the summer 214 would only receive the phase-shifted version of the second received signal if the second received signal exceeds the second threshold value. Alternatively, both switches 219 and 220 could be present.

[0045] Figure 3 illustrates a more specific example of the means 103. A first comparator 312 receives and compares the first received signal 112A and a threshold value generated by threshold voltage source 315, and closes the switch 311 if the first received signal 112A exceeds the threshold value. A second comparator 316 receives and compares the second received signal 112B and the threshold value, and closes the switch 319 if the second received signal 112B exceeds the threshold value.

[0046] If only me first received signal 112A has sufficient magnitude, then the first received signal 112A passes through a controllable phase shifter 313, and the phase-shifted version of the first received signal passes through the summer 314 unchanged since the switch 319 is open. If only the second received signal 112B has sufficient magnitude, then the second receive signal 112B passes through the summer 314 unchanged since the switch 311 is open.

[0047] If both the received signals have sufficient strength, then the second received signal 112B is provided not only to the summer 114, but also to a fixed phase shifter 317 that imposes a fixed phase shift on the second received signal 112A. In one embodiment, the fixed phase shifter 317 imposes a phase shift of ninety degrees. A phase detector 318 compares the phase-shifted version of the first received signal with the phase-shifted version of the second signal, and controls the controllable phase shifter 313 so that the phase-shifted version of the first and second signals are approximately synchronized. Or gate 320 ensures that phase detector 318 will be controlling the controllable phase shifter so long as both the first or second received signals are of sufficient strength. Accordingly, the summer 314 receives a phase-shifted version of the first received signal that is approximately ninety-degrees out of phase with the second received signal received at the summer. Such a phase shift improves signal-to-noise of the summed signal by approximate a factor of the square root of two as compared to the received signals individually.

[0048] Figure 4 illustrates a specific example of receiver 102A and/or 102B of Figure 1. In particular, the receiver 400 includes an in-phase amplifier 415 that receives and amplifies an in-phase differential signal that represents an in-phase portion of the received signal. A quadrature-phase amplifier 425 receives and amplifies the quadrature-phase differential signal that represents a quadrature-phase portion of the received signal. The summer 417 has two differential inputs and one differential output for summing each of the in-phase and quadrature-phase signals. A band pass filter 442 receives the amplified in-phase and quadrature-phase summed signals. A limiting amplifier 440 receives and amplifies the differential summed and filtered in-phase and quadrature-phase signals.

[0049] The output of the limiting amplifier 440 may be the received signal 112A of Figure 1 if the receiver 400 obtains the signal from the antenna 101A. Otherwise, the output of the limiting amplifier 440 may be the received signal 112B of Figure 1 if the receiver 400 obtains the signal from the antenna 101B.

[0050] An amplifier 402 amplifies the signal received from the antenna so as to generate a signal of sufficient magnitude upon which to perform subsequent operations. An impedance matching circuit 401 operates to match the impedance of the antenna and the input impedance of the amplifier 402 so as to improve admittance of the signal from the antenna to the remaining circuitry. The impedance matching circuit 401 receives the signal from antenna 101A if the receiver 400 is an example of receiver 102A, and otherwise receives the signal from antenna 101B if the receiver 400 is an example of receiver 102B.

[0051] Such impedance matching reduces reflectance of the signal and improves power transfer as is known to those or ordinary skill in the art. The frequency response of the impedance matching circuit 401 also acts as a band pass filter, which is useful to filter out harmonics of the down-converting oscillator 430. The amplifier 402 may be a low noise amplifier of the type commonly used to amplify a received signal in direct conversion receiver circuits.

[0052] The amplified signal from the amplifier 402 is then provided to an in-phase branch 410, and to a quadrature phase branch 420. For example, signals that are passed through the in-phase branch 410 are first provided to a down-converting single input to differential output mixer 411, which down-converts the signal to thereby extract the baseband signal. A down-converting oscillator 430 provides control signals A, B, !A and !B. Control signals A and B each having a duty cycle of approximately twenty-five percent and are approximately 180 degrees out of phase with each other. Control signals !A and !B are the binary complement of control signals A and B, respectively.

[0053] These control signals may be cycled at approximately the frequency of the carrier frequency of the received signal. However, to achieve a substantial reduction in DC offset resulting from the self-mixing product of the mixer 411 at its output terminals, the mixer control signals A, B, !A and !B are operated at a twenty-five percent duty cycle at the frequency of the received signal. Furthermore, control signals A and B (and !A and !B) shift 180 degrees relative to each other. Thus results in the leakage combination being a square wave at twice the frequency of the received signal. This reduction in DC offset stems from the fact that even if the control signals were to irradiate back to the antenna (and thus introduce feedback into the mixer), the leakage component would be twice the frequency of the carrier frequency of the signal, thereby resulting in very little DC component in the self-mixing product.

[0054] Additionally, the mixer 411 has a differential output results in a reduction of second-order intermodulation product (also often referred to as "IP2"). The second-order intermodulation product is a product of a squaring function. Accordingly, the polarity of the second-order intermodulation product will be the same for each of the differential outputs of the mixer 411. Accordingly, the second-order intermodulation product manifests itself as a common mode signal at the differential output terminals of the mixer 411. The common mode rejection capability of subsequent circuitry that operates on the signal will thus reduce the effect of the second-order intermodulation product.

[0055] The signal output from the mixer 411 will not only include the baseband signal having the data of interest, but will also include higher frequency components that do not contain the desired data. Accordingly, the output signals from the mixer 411 are passed through a low pass filter 412 to remove the higher frequency components including all out of band signals and noise as well as the potential secondary image created by the up-converting mixer 413. The output from the low pass filter 412 will thus include only the baseband signal having the data of interest. This low pass filter 412 may be a passive element such as a Resistor-Capacitor (RC) filtering circuit. The low pass filter 412 should have a cutoff frequency that provides sufficient channel selectivity of the baseband signal. This may be accomplished using a four pole low pass filter composed of four RC low pass filters cascaded in series. By so doing, a roll-off of 80 decibels per decade may be accomplished. The use of a passive low pass filter allows for reduced or even eliminated DC offset since such passive elements do not generate the same 1/f noise that active elements do. Also, the use of the passive filter does not significantly reduce dynamic range in the way that an active filter would. The passive components of low pass filter 412 assures that there will not be any consequential degradation of the desired signal by flicker noise and that only a small amount of white noise is added.

[0056] Typically, in conventional direct conversion receiver circuits, the baseband signal itself is processed by active elements (such as high sensitivity amplifiers) in downstream circuitry. However, such active elements introduce significant 1/f noise since the baseband signal has a frequency spectrum tending towards lower frequencies. "1/f noise" refers to an effect whereby active elements introduce more noise when operating on lower frequencies, than they do on higher frequencies. Such an effect is common in any active elements. In accordance with the principles of the present invention, active elements do not operate upon the baseband signal itself, but on an up-converted version of the baseband signal. Accordingly, the noise introduced by the active element on the up-converted version of the baseband signal is much lower thereby preserving the dynamic range of the direct conversion receiver as a whole.

[0057] Specifically, the filtered baseband signal output by the low pass filter 412, is passed to an up-converting mixer 413 controlled by control signals E and !E provided by an up-converting oscillator 432. The control signals E and !E have a duty cycle of approximately 50% (or 25%) and are 180 degrees out of phase with each other. Additionally, the cycle frequency of the control signals E and !E is equal to the cycle frequency of the control signals A, B, !A and !B divided by some positive integer greater than one. In order to accomplish this, the down-converting oscillator 430 and the up-converting oscillator 432 may be interconnected as illustrated by arrow 431 so to enforce this frequency division relationship. This may be accomplished using conventional frequency division circuitry. Accordingly, the mixer 413 outputs an up-converted version of the baseband signal, which has a frequency spectrum tending towards higher frequencies than does the baseband signal itself. The frequency of the mixer 413 may be chosen in conjunction with the low pass filter 412 cutoff frequency to provide a desired level of image suppression from input signals spaced at integer multiples of the lower frequency of the mixer 413 from the baseband output of the mixer 411. Thus, the modifications of the direct conversion architecture not only provide reduction in DC offset and 1/f noise, but also retain the benefit of image suppression characteristic of direct convention receiver circuits. Amplification may be performed on the intermediate frequency signal output by the up-converted mixer 413 without the flicker noise of the amplifier introducing consequential degradation into the signal.

[0058] The downstream circuitry that includes active elements then operates directly on this higher frequency version of the baseband signal. Accordingly, the active components, such as amplifier 415 do not introduce as much 1/f noise. Furthermore, the subsequent circuitry may be interconnected via intervening capacitors since a higher frequency signal is being processed. This reduces and potentially even eliminates the impact of any DC offset or drift introduced by the active components as well. For instance, the differential outputs of the up-converting mixer 413 are passed to the amplifier 415 via capacitors 414A and 414B. The differential outputs of the amplifier 415 may be provided to the summer 417 via capacitors 416A and 416B. The output of the summer 417 may be provided to the limiting amplifier via capacitor 418.

[0059] The quadrature-phase branch 420 is similar to the in-phase branch 410 in that the down-converting mixer 423, control signal C, control signal D, control signal !C, control signal !D, low pass filter 422, up-converting mixer 423, control signal F, control signal !F, capacitors 424A and 424B, amplifier 425, capacitors 426A and 426B, summer 427 and capacitors 428 may have the same structure and interconnections as described above for their respective elements in the in-phase branch. However, the control signals C, D, !C, !D, F and !F will be 90 degrees out of phase with respective signals A, B, !A, !B, E and !E.

[0060] The use of a quadrature-phase branch 420 is helpful in that it allows the receiving cycle to be asynchronous with the modulation cycle. However, in the event that the in-phase branch 410 is synchronized with the modulation cycle of the received signal without the use of the quadrature-phase branch 420, the quadrature-phase branch 420 would not strictly be necessary.

[0061] Figure 5A illustrates a specific embodiment 500 of an interconnected down-converting mixer 511, low pass filter 512, and up-converting mixer 513, which may be examples of down-converting mixer 411, low pass filter 412, and up-converting mixer 413, respectively, of Figure 4.

[0062] The down-converting mixer 511 has one input terminal and two output terminals. Field-effect transistors 561 through 563 are coupled with their channel regions in series between the input terminal and the upper output terminal of the down-converting mixer 511. Field-effect transistors 564 through 566 are coupled with their channel regions in series between the input terminal and the lower output terminal of the down-converting mixer 511. Field effect transistors 561, 563, 564 and 566 have their source and drain connections shorted. To minimize charge injection while accomplishing down-conversion, down-converting control signal A is applied at the gate terminal of field-effect transistor 565, while down-converting control signal !A is applied at the gate terminal of field-effect transistors 564 and 566. Similarly, down-converting control signal B is applied at the gate terminal of field-effect transistor 562 while down-converting control signal !B is applied at the gate terminal of field-effect transistors 561 and 563.

[0063] As previously mentioned, the down-converting control signals A, B, !A, and !B may be cycled at about twice the carrier frequency of the received signal thereby reducing (or eliminating) DC offset introduced by the down-converting mixer 511. Additionally, second-order intermodulation product introduced by the down-converting mixer 511 may be reduced by the common mode rejection properties of downstream circuitry.

[0064] The low pass filter may be any passive low pass filter that includes one or more poles. However, in the illustrated embodiment, filter 512 is a resistor-capacitor circuit that has a low pass frequency response for each of the differential input signals. As will be apparent to those or ordinary skill in the an, the resistor-capacitor circuit has a frequency response that includes four poles. The low pass filter 512 may include resistors 571 through 576 and capacitors 577 through 587 configured as shown in Figure 5A. By designing these resistor and capacitors with appropriate values, the position of those poles may be adjusted. In one embodiment, in order to obtain a high roll-off for better selectivity of the passed signal, the four poles are adjusted to be coincident so as to have an 80dB per decade roll-off. The low pass filter 512 is a passive element and thus does not introduce new DC offset or 1/f noise into the signal, thereby preserving dynamic range.

[0065] The up-converting mixer 513 includes two input terminals, two output terminals, and four field-effect transistors 591 through 594. The field-effect transistor 591 has its channel region coupled between the upper input terminal and the lower output terminal of the up-converting mixer 513 and is controlled at its gate terminal by up-converting control signal E. The field-effect transistor 592 has its channel region coupled between the upper input terminal and the upper output terminal of the up-converting mixer 513 and is controlled at its gate terminal by up-converting control signal !E. The field-effect transistor 593 has its channel region coupled between the lower input terminal and the upper output terminal of the up-converting control signal E. The field-effect transistor 594 has its channel region coupled between the lower input terminal and the lower output terminal of the up-converting control signal !E.

[0066] Figure 5B illustrates an alternative embodiment of the down-converting mixer 511 in the form of down-converting mixer 511B. The down-converting mixer 511B is similar to the down-converting mixer 511, except that the field effect transistors 561, 563, 564 and 566 are not present, and field effect transistors 562' and 565' replace transistors 562 and 565.

[0067] Figure 5C illustrates a second alternative embodiment of the down-converting mixer 511 in the form of down-converting mixer 511 C. The down-converting mixer 511 C is similar to the down-converting mixer 511, except that the field effect transistors 562" and 565" replace transistors 562 and 565.

[0068] Figure 6 illustrates an alternative structure 613 for the up-converting mixer 413. The up-converting mixer 613 includes field-effect transistors 691 through 694 which are configured the same as described above for respective transistors 591 through 594 in up-converting mixer 513. Additionally, the up-converting mixer 613 includes field-effect transistors 695 through 698 that have an opposite polarity as compared to respective field-effect transistors 691 through 694. For example, if field-effect transistors 691 through 694 are n-type field effect transistors as in the illustrated example, the field-effect transistors 695 through 698 would be p-type field effect transistors, and vice versa. Each of the field-effect transistors 695 through 698 are coupled between respective input terminal and respective output terminals as described above for corresponding field-effect transistors 591 through 594. In order to maximize dynamic range, the dc offsets at the input and output terminals of the up-converting mixer 613 should all be midway between the supply voltages Vdd and Vss.

[0069] Accordingly, the principles of the present invention allow for more adaptive control over antenna and receiver selection that takes into account current circumstances. All receivers, less than all, or even just one received signal may be used. Furthermore, the receivers may implement direct receiver architectures in which up-conversion of the baseband signal occurs after down-conversion thereby reducing DC offset and 1/f noise. Furthermore, all of the components described above may be implemented using standard CMOS technology and thus may be integrated on the same chip even though multiple receivers are involved.

[0070] The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes, which come within the meaning and range of equivalency of the claims, are to be embraced within their scope.

[0071] What is claimed and desired secured by United States Letters Patent is:

Claims

1. A diversity receiver circuit comprising the following:

    a first receiver configured to receive a first representation of a signal on a first antenna and process the first representation of the signal;
    a second receiver configured to receive a second representation of the signal on a second antenna and process the second represent of the signal; and
    means for adaptively phase shift summing the processed first and second representations of the signal only if the processed first and second representations have sufficient strength, and otherwise selecting only one of the processed first and second representations of the signal for further processing.

2. A diversity receiver circuit in accordance with Claim 1, wherein the means for adaptively phase shift summing the processed first and second representations of the signal only if the processed first and second representations have sufficient strength, and otherwise selecting only one of the processed first and second representations of the signal for further processing comprise the following:

    a phase shifter configured to receive the processed first representation of the signal at least when the processed first representation of the signal exceeds a first threshold value, the phase shifter further configured to generate a phase shifted version of the processed first representation of the signal at least when the processed first representation of the signal exceeds the first threshold value; and a summer configured to sum the phase shifted version of the processed first representation of the signal with the processed second representation of the signal at least when both of the following conditions are true:

the processed first representation of the signal exceeds the first threshold value, and
the processed second representation of the signal exceeds a second threshold value.

3. A diversity receiver circuit in accordance with Claim 2, wherein the first and second threshold values are the same threshold value.

4. A diversity receiver circuit in accordance with Claim 2, wherein the first and second threshold values are different threshold values.

5. A diversity receiver circuit comprising the following:

a first receiver configured to receive a first representation of a signal on a first antenna and process the first representation of the signal;
a second receiver configured to receive a second representation of the signal on a second antenna and process the second represent of the signal;
a phase shifter configured to receive the processed first representation of the signal at least when the processed first representation of the signal exceeds a first threshold value, the phase shifter further configured to generate a phase shifted version of the processed first representation of the signal at least when the processed first representation of the signal exceeds the first threshold value; and
a summer configured to sum the phase shifted version of the processed first representation of the signal with the processed second representation of the signal at least when both of the following conditions are true:

the processed first representation of the signal exceeds the first threshold value, and
the processed second representation of the signal exceeds a second threshold value.

6. A diversity receiver circuit in accordance with one of claims 1 to 5, wherein each element of the diversity receiver circuit is fabricated on a single integrated die.

7. A diversity receiver circuit in accordance with one of claims 2 to 5, further comprising the following:

a first comparator configured to receive and compare the processed first representation of the signal and the first threshold value, the first comparator configured to couple the processed first representation of the signal with the phase shifter if the processed first representation of the signal exceeds the first threshold value.

8. A diversity receiver circuit in accordance with Claim 7, further comprising the following:

a second comparator configured to receive and compare the processed second representation of the signal and the second threshold value, the second comparator configured to couple the processed second representation of the signal with the summer when the processed second representation of the signal exceeds the second threshold value.

9. A diversity receiver circuit in accordance with Claim 8, wherein the phase shifter is a first phase shifter, the diversity receiver circuit further comprising the following:

a second phase shifter configured to receive the processed second representation of the signal at least when the processed second representation of the signal exceeds the second threshold value, the second phase shifter further configured to generate a phase shifted version of the processed second representation of the signal at least when the processed second representation of the signal exceeds the second threshold value.

10. A diversity receiver circuit in accordance with Claim 9, wherein the summer is configured to sum the phase shifted version of the processed first representation of the signal and the phase shifted version of the processed second representation of the signal at least when both of the following conditions are true:

the processed first representation of the signal exceeds the first threshold value, and
the processed second representation of the signal exceeds a second threshold value.

11. A diversity receiver circuit in accordance with Claim 9, further comprising the following:

a phase detector configured to detect when the phase shifted version of the processed first representation of the signal is out of phase with the phase shifted version of the processed second representation of the signal, and is configured to control either or both of the first phase shifter and the second phase shifter so that the processed first and second representations of the signal received by the summer tend to be towards a relatively fixed phase shift with each other.

12. A diversity receiver circuit in accordance with Claim 9, wherein the relatively fixed phase shift is approximately ninety degrees.

13. A diversity receiver circuit in accordance with one of claims 1 to 12, further comprising the following:

a third receiver configured to receive a third representation of a signal on a third antenna and process the third representation of the signal,

wherein the diversity receiver circuit is configured for phase shift summing the processed first, second, and third representations of the signal only if the processed first, second, and third representations have sufficient strength, and otherwise selecting less than all of the processed first, second and third representations of the signal for further processing.

14. A diversity receiver circuit in accordance with one of claims 1 to 13, wherein the first receiver is a direct conversion receiver having an in-phase branch and a quadrature-phase branch.

15. A diversity receiver circuit in accordance with Claim 14, wherein the direct conversion receiver comprises the following:

an in-phase amplifier configured to receive and amplify an in-phase differential signal that represents an in-phase portion of the processed first representation of the signal;
an in-phase summer configured to receive and sum the amplified in-phase differential signal;
a quadrature-phase amplifier configured to receive and amplify the quadrature-phase differential signal that represents a quadrature-phase portion of the processed first representation of the signal;
a quadrature-phase summer configured to receive and sum the amplified quadrature-phase differential signal, and
a limiting amplifier configured to receive and amplify in a limited fashion the difference between the summed in-phase signal and the summed quadrature-phase signal.

16. A diversity receiver circuit in accordance with Claim 15, wherein the direct conversion receiver further comprising the following:

a band pass filter configured to receive and filter the limit amplified signal.

17. A diversity receiver circuit in accordance with Claim 16, wherein the direct conversion receiver further comprises the following:

an in-phase down-converting mixer that is configured to down-convert a received modulated signal to thereby generate an in-phase portion of a baseband signal;
an in-phase low pass filter that is coupled to the in-phase down-converting mixer so as to filter high frequency components of the in-phase down-converted signal to thereby generate an in-phase filtered down-converted signal;
an in-phase up-converting mixer that is coupled to the in-phase low pass filter so as to receive and up-convert the in-phase filtered down-converted signal to generate the in-phase differential signal, wherein there are no active components that operate on the in-phase down-converted signal prior to being up-converted;
a quadrature-phase down-converting mixer that is configured to down-convert the received modulated signal to thereby generate a quadrature-phase portion of the baseband signal;
a quadrature-phase low pass filter that is coupled to the quadrature-phase down-converting mixer so as to filter high frequency components of the quadrature-phase down-converted signal to thereby generate a quadrature-phase down-converted signal; and
a quadrature-phase up-converting mixer that is coupled to the quadrature-phase low pass filter so as to receive and up-convert the quadrature-phase filtered down-converted signal to generate the quadrature-phase differential signal, wherein there are no active components that operate on the quadrature-phase down-converted signal prior to being up-converted.

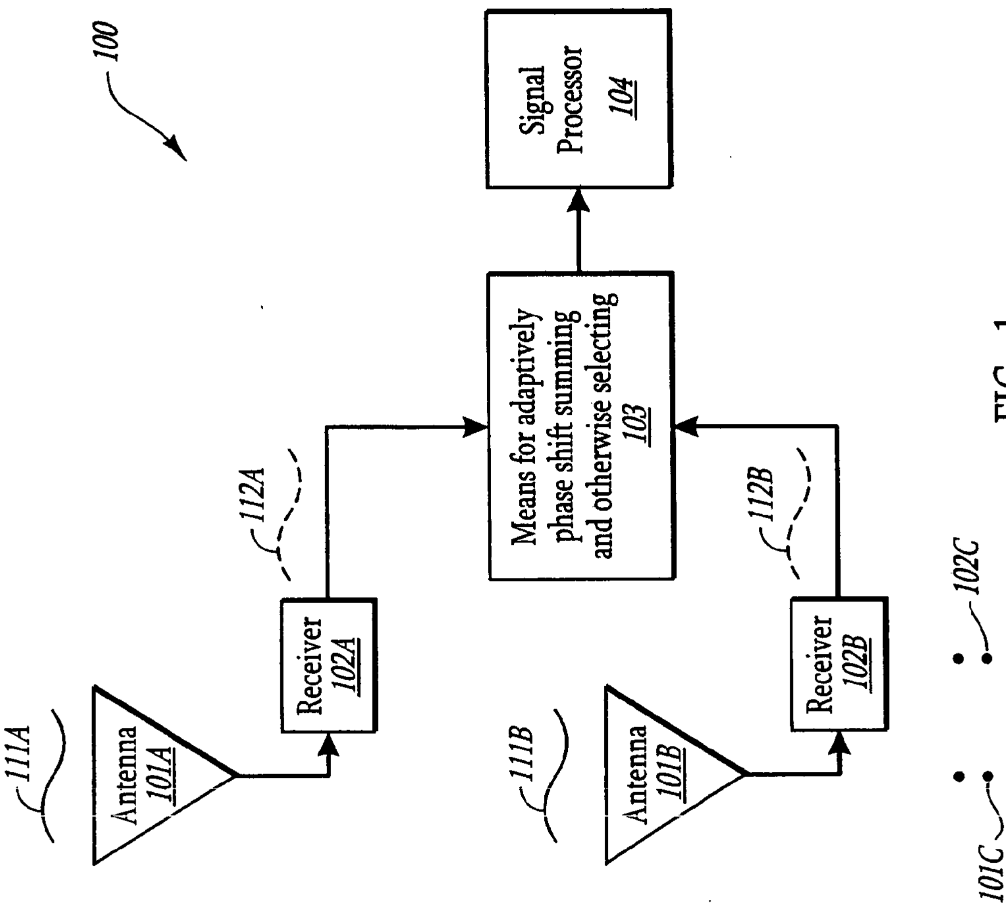
100
Antenna
101A
111A
Receiver
102A
112A
Means for adaptively phase shift summing and otherwise selecting
103
Signal Processor
104
Antenna
101B
111B
Receiver
102B
112B
101C
102C

FIG. 1

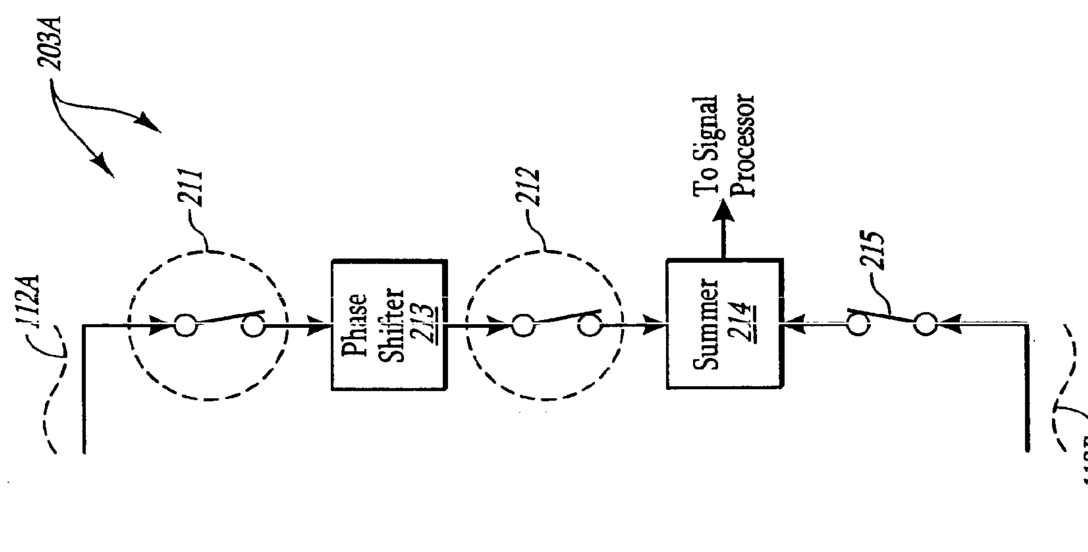
203A
112A
211
Phase Shifter 213
212
Summer 214
To Signal Processor
215
112B

FIG. 2A

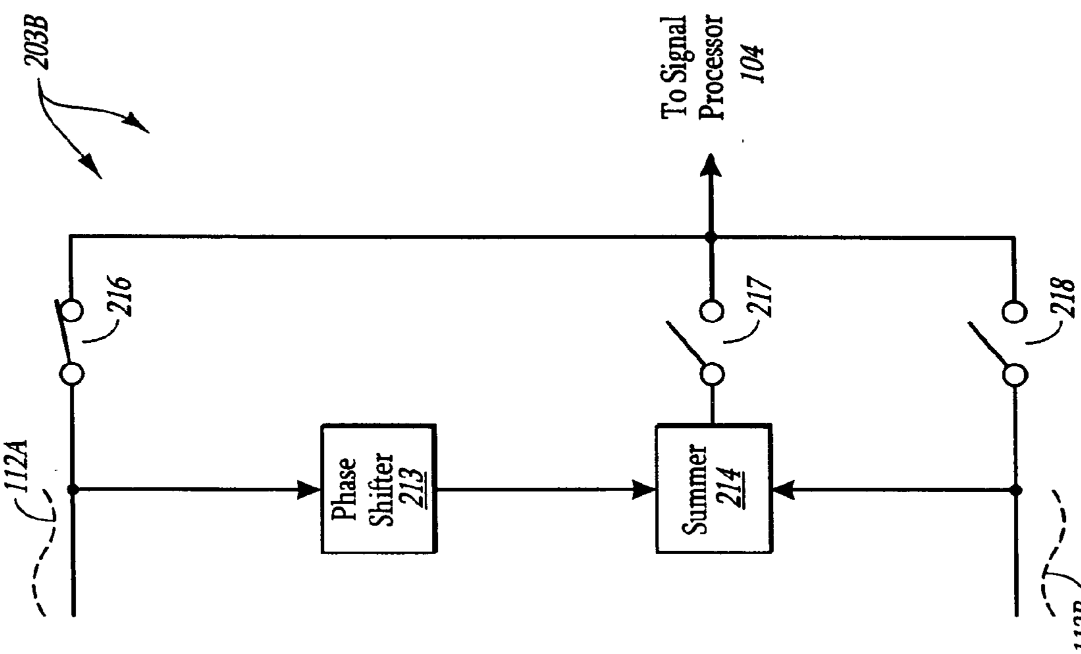
203B
112A
216
Phase Shifter 213
Summer 214
217
218
To Signal Processor 104
112B

FIG. 2B

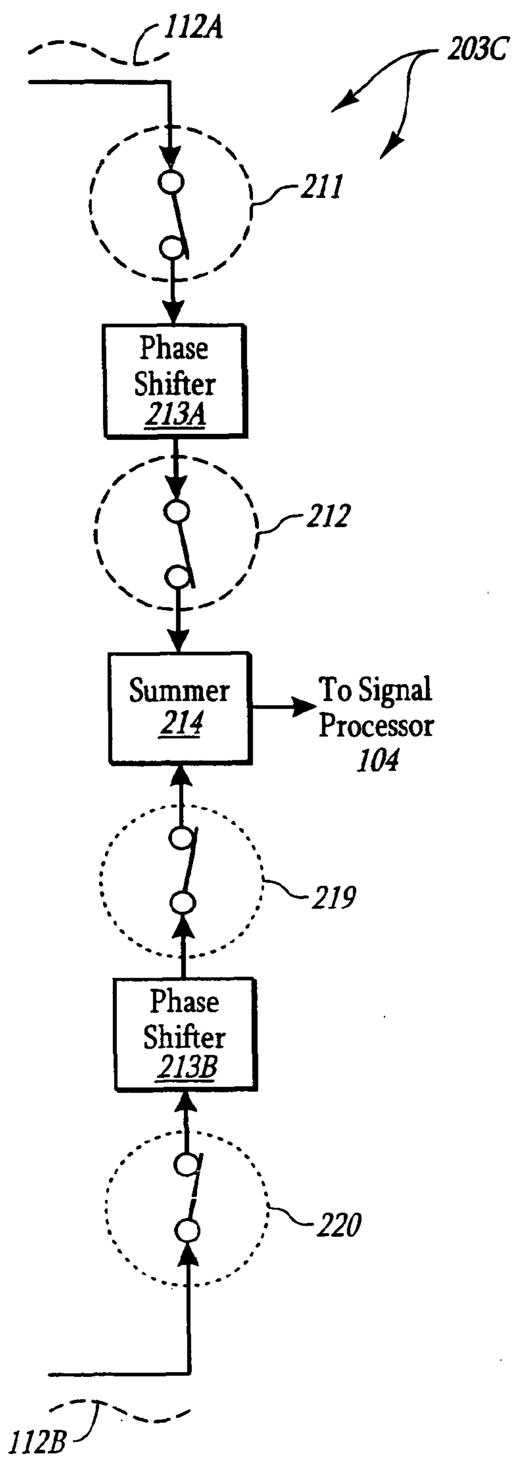
112A
203C
211
Phase
Shifter
213A
212
Summer
214
To Signal
Processor
104
219
Phase
Shifter
213B
220
112B

FIG. 2C

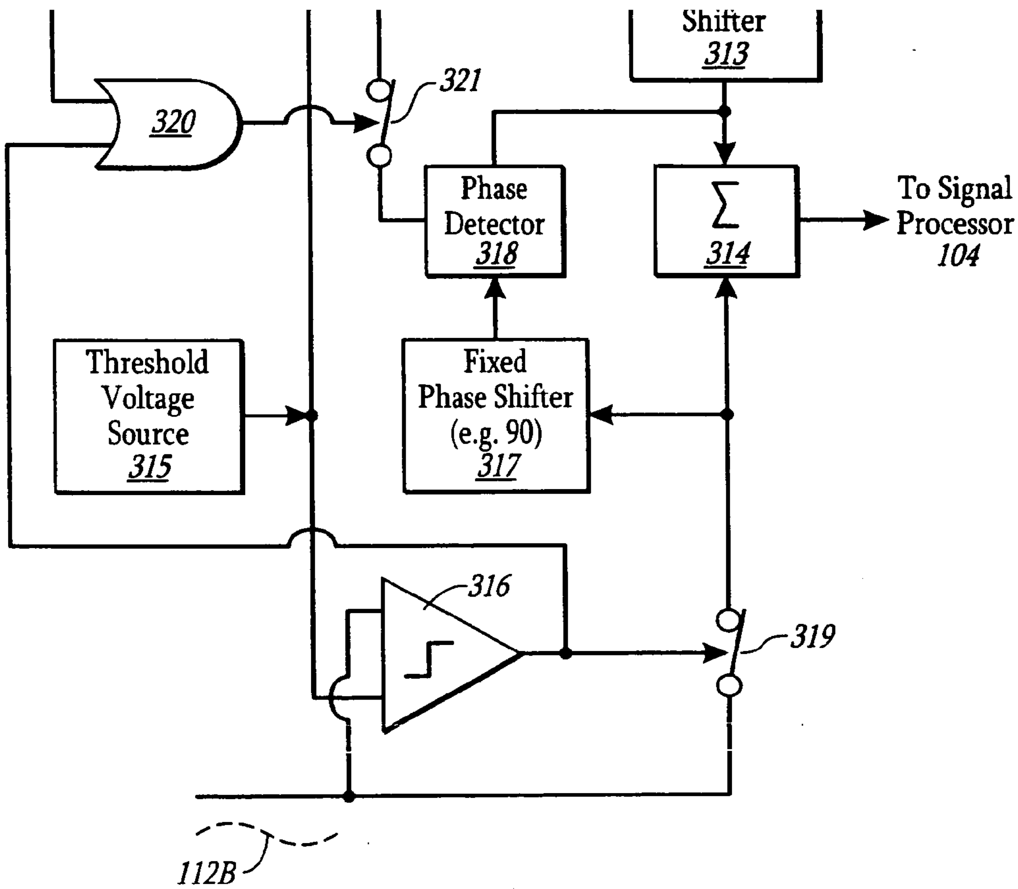
Shifter
313
320
321
Phase
Detector
318
∑
314
To Signal
Processor
104
Threshold
Voltage
Source
315
Fixed
Phase Shifter
(e.g. 90)
317
316
319
112B

FIG. 3

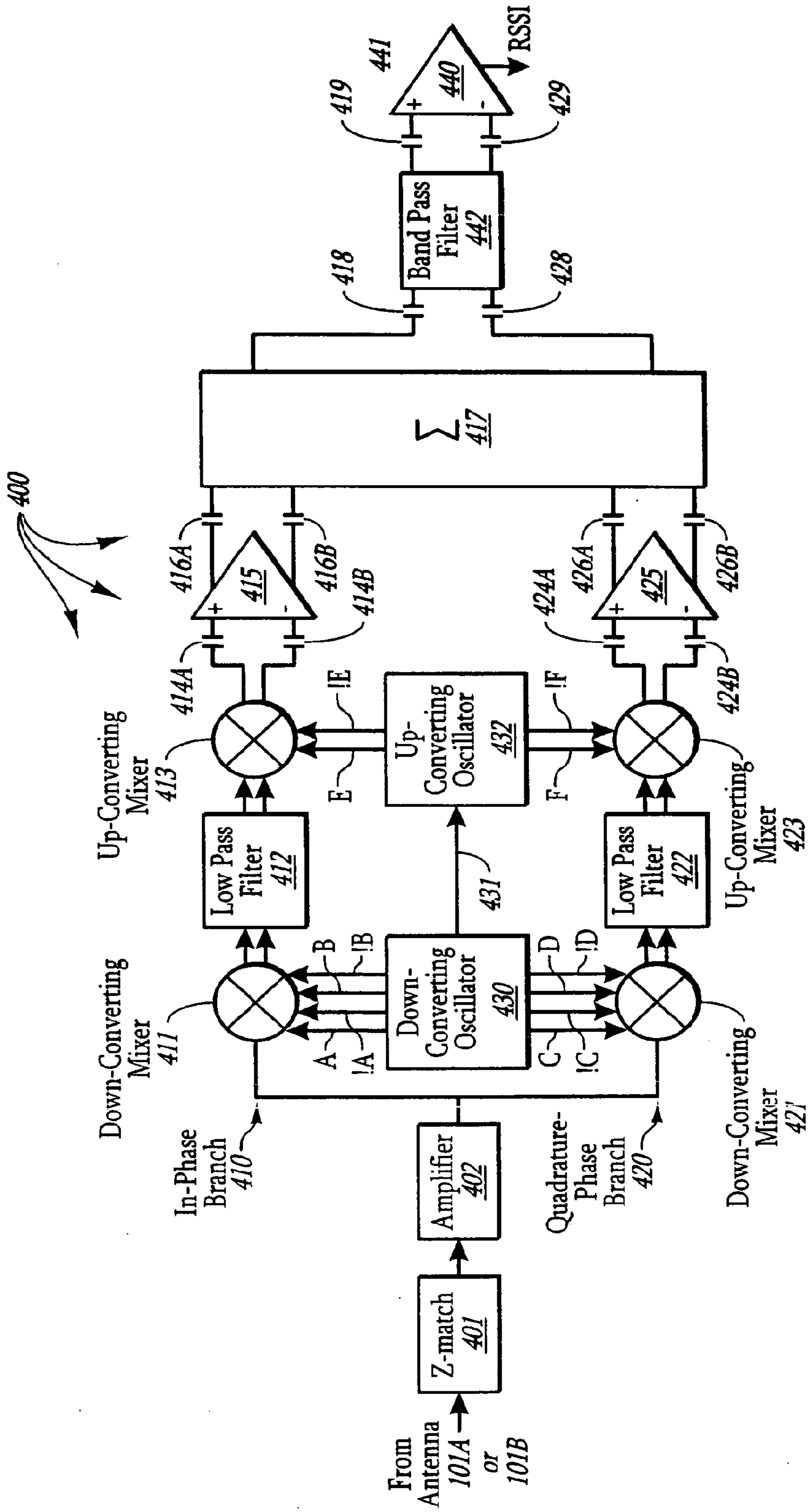
400
From Antenna 101A or 101B
Z-match 401
Amplifier 402
In-Phase Branch 410
Quadrature-Phase Branch 420
Down-Converting Mixer 411
Down-Converting Mixer 421
Down-Converting Oscillator 430
A
!A
B
!B
C
!C
D
!D
Low Pass Filter 412
Low Pass Filter 422
431
Up-Converting Oscillator 432
E
!E
F
!F
Up-Converting Mixer 413
Up-Converting Mixer 423
414A
414B
424A
424B
415
425
416A
416B
426A
426B
417
418
428
Band Pass Filter 442
419
429
440
441
RSSI

FIG. 4

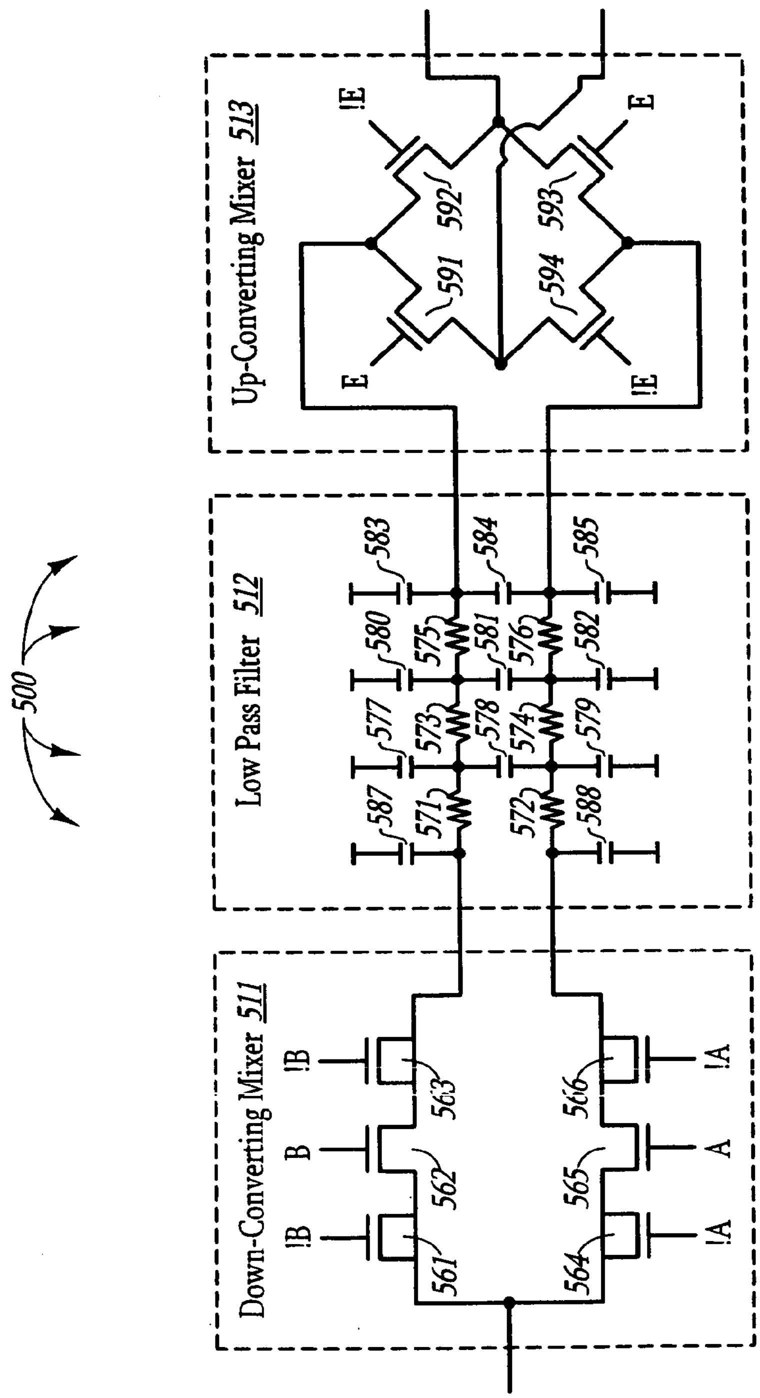
500
Down-Converting Mixer 511
!B
B
!B
!A
A
!A
561
562
563
564
565
566
Low Pass Filter 512
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
587
588
Up-Converting Mixer 513
E
!E
!E
E
591
592
593
594

FIG. 5A

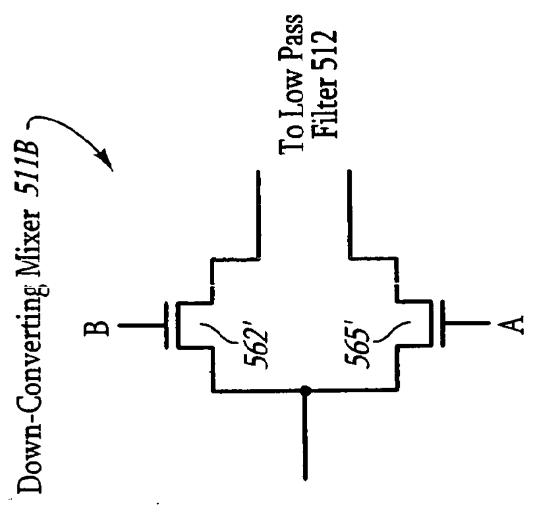
Down-Converting Mixer 511B
To Low Pass Filter 512
B
562'
565'
A

FIG. 5B

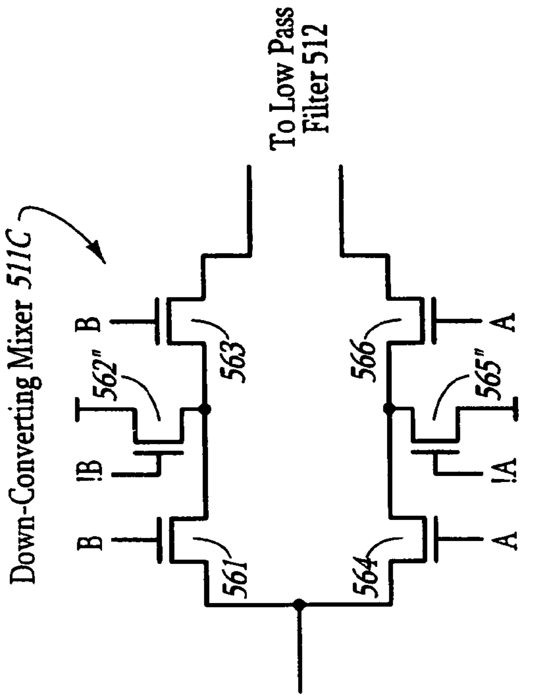
Down-Converting Mixer 511C
To Low Pass Filter 512
B
!B
562"
B
561
563
564
566
565"
A
!A
A

FIG. 5C

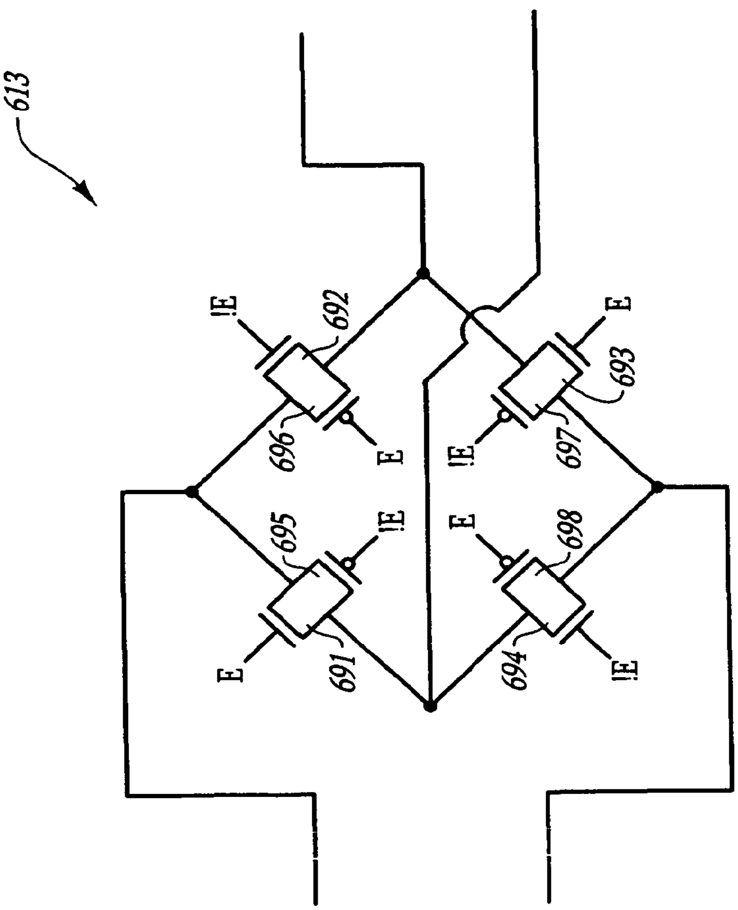

FIG. 6

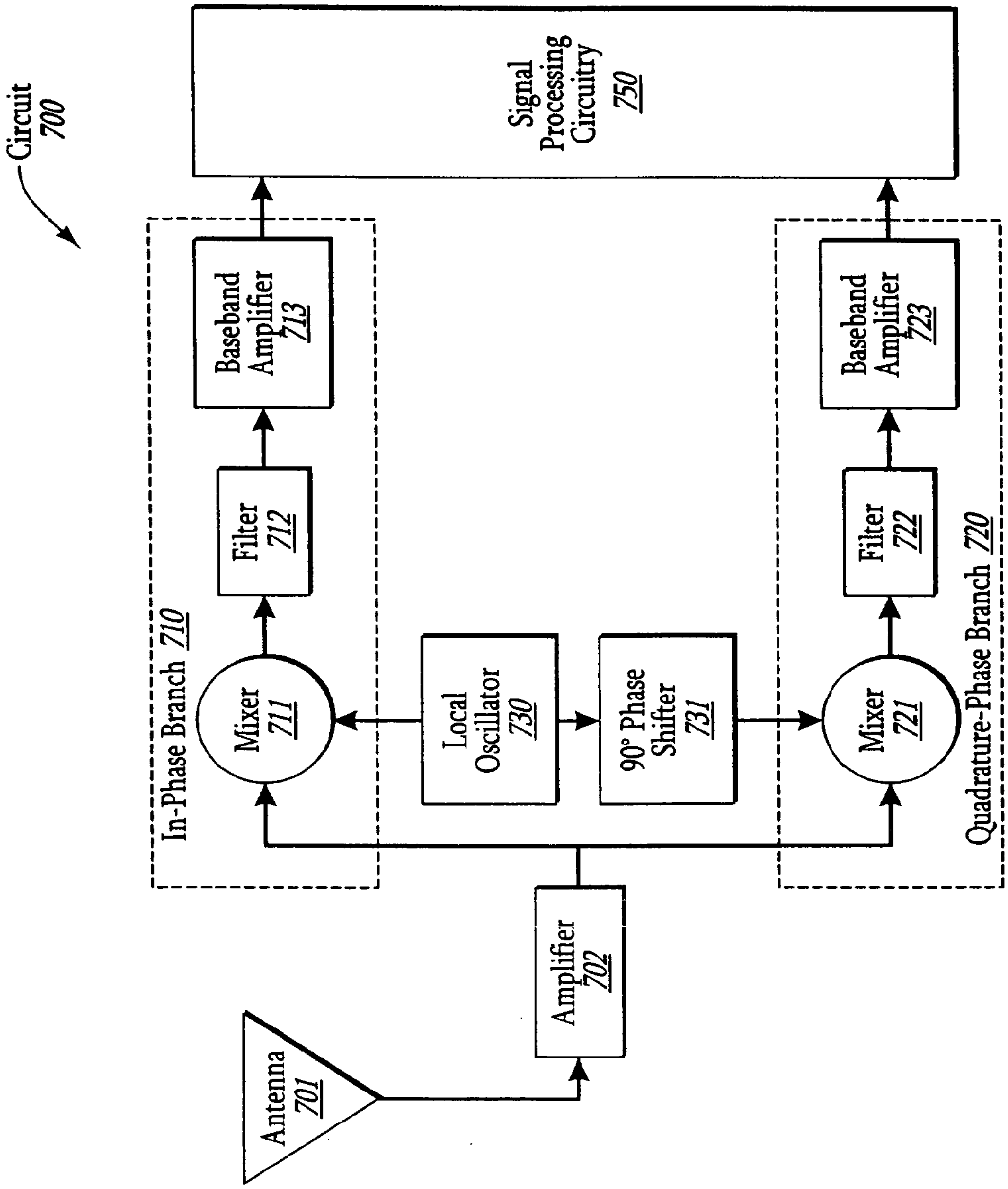

FIG. 7
(Prior Art)

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 489 758 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
22.12.2004 Bulletin 2004/52

(21) Application number: **03744992.3**

(22) Date of filing: **11.03.2003**

(51) Int Cl.7: **H04B 7/10**, H04B 7/26, H01Q 3/26

(86) International application number:
PCT/JP2003/002883

(87) International publication number:
WO 2003/081806 (02.10.2003 Gazette 2003/40)

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR

(30) Priority: **22.03.2002 JP 2002081375**

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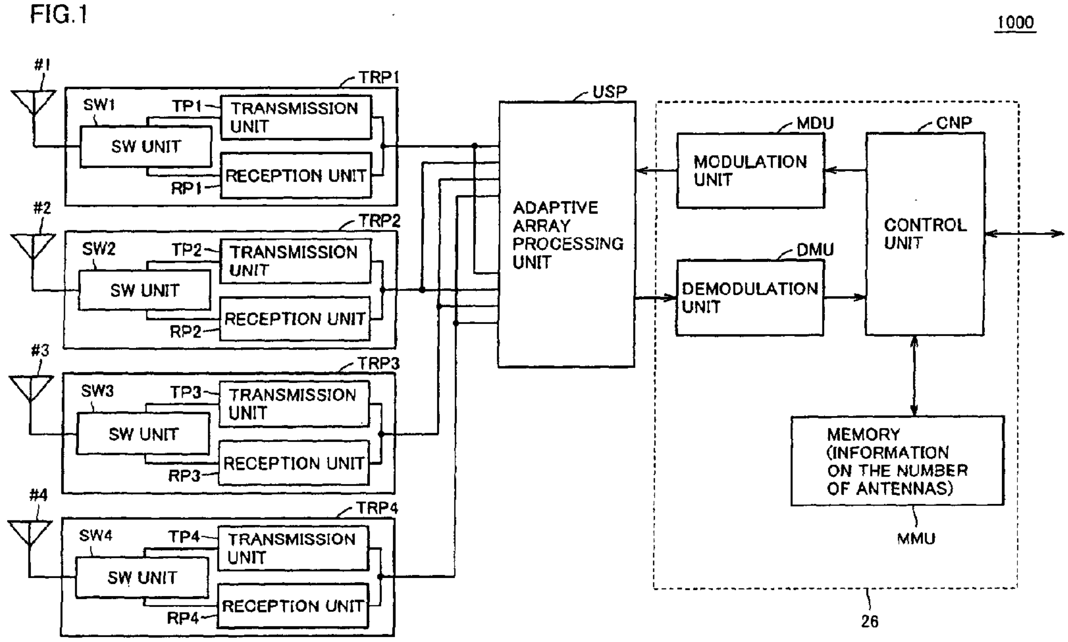
(54) RADIO DEVICE, SPATIAL PATH CONTROL METHOD, AND SPATIAL PATH CONTROL PROGRAM

(57) A PDMA terminal (1000) establishes communication by forming a plurality of spatial paths to another single radio apparatus. A plurality of antennas constituting an array antenna are divided into a plurality of subarrays corresponding to the plurality of spatial paths respectively. An adaptive array processing unit (USP) can perform an adaptive array processing for each of the plurality of subarrays. A memory (MMU) stores in advance information on the number of antennas associated with the number of spatial paths that can be formed by the array antenna. A control unit (CNP) controls a processing to transmit possible multiplicity information to another radio apparatus at a prescribed timing.

FIG.1



Printed by Jouve, 75001 PARIS (FR)

Description

Technical Field

[0001] The present invention relates to a radio apparatus, and a method and a program for controlling a spatial path, and more particularly to a radio apparatus capable of establishing multiplex communication between one radio terminal and a radio base station via a plurality of paths formed by space division, as well as to a method and a program for controlling a spatial path.

Background Art

[0002] Recently, as a communication scheme for a rapidly developing mobile communication system, for example, PHS (Personal Handy phone System), a TDMA scheme in which 1 frame (5ms) consisting of respective 4 slots (1 slot: 625μs) for transmission and reception is regarded as a base unit has been adopted. Such a communication scheme for PHS is standardized as the "second generation cordless communication system," for example.

[0003] A signal of 1 frame is divided into 8 slots, that is, first 4 slots serve for reception, while following 4 slots serve for transmission, for example.

[0004] Each slot consists of 120 symbols. For example, in a signal of 1 frame, , assuming that one reception slot and one transmission slot form one pair, three pairs of slots are allocated as traffic channels for three users, and remaining one pair of slots is allocated as a control channel, respectively.

[0005] In the PHS system, in a control procedure for establishing synchronization, a link channel is initially established by the control channel, followed by a processing for measuring an interference wave (an undesired wave: U wave). In addition, after a processing for setting communication condition by the allocated channel, speech communication is started. Such a procedure is disclosed in detail in Personal Handy Phone System RCR Standard RCR STD-28 (published by Association of Radio Industries and Businesses), which is a standard of PHS.

[0006] Fig. 19 shows a flow in such a communication sequence in PHS. In the following, brief description thereof will be provided with reference to Fig. 19.

[0007] First, a C channel (control channel: CCH) is used to transmit a link channel establishment request signal (LCH establishment request signal) from a PHS terminal to a base station. A PHS base station detects an empty channel (empty traffic channel: empty T channel) (carrier sensing), and uses the C channel to transmit a link channel allocation signal (LCH allocation signal) designating an empty T channel to the PHS terminal.

[0008] In the PHS terminal, whether or not an interference wave signal having a power larger than a prescribed level is received is measured in the designated T channel (U wave measurement) based on link channel information received from the PHS base station. When the interference wave signal with a power larger than a prescribed level is not detected, that is, when other PHS base station does not use the designated T channel, the PHS terminal uses the designated T channel to transmit a synchronous burst signal to the base station. Meanwhile, the base station sends back a synchronous burst signal to the terminal. Synchronization is thus established.

[0009] On the other hand, when an interference wave signal having a power larger than a prescribed level is detected in the designated T channel, that is, when the T channel is being used by other PHS base station, the PHS terminal repeats the control procedure from the link channel establishment request signal.

[0010] In this manner, in the PHS system, a traffic channel between a terminal and a base station is connected, using a channel where the interference wave is weak and excellent communication performance is attained.

[0011] In the PHS, a PDMA (Path Division Multiple Access) scheme has been implemented, in which, in order to enhance an efficiency in utilizing a frequency of a radio wave, mobile radio terminal units (terminals) of a plurality of users establish spatial multiple connection to a radio base station (base station) through a plurality of paths formed by spatially dividing an identical time slot of an identical frequency.

[0012] The PDMA scheme adopts an adaptive array technique, for example. In an adaptive array processing, based on a reception signal from a terminal, a weight vector consisting of reception coefficients (weights) for respective antennas in the base station is calculated for adaptive control, and a signal from a desired terminal is accurately extracted.

[0013] With such an adaptive array processing, an uplink signal from the antenna of each user terminal is received by the array antenna of the base station, and then separated and extracted with reception directivity. A downlink signal from the base station to the terminal is transmitted from the array antenna with transmission directivity to the antenna of the terminal.

[0014] Such an adaptive array processing is a well-known technique, and described in detail, for example, in Nobuyoshi Kikuma, "Adaptive Signal Processing by Array Antenna", Kagaku Gijutsu Shuppan, pp.35-49, "Chapter 3: MMSE Adaptive Array" published on November 25, 1998. Therefore, description of its operation principle will not be provided.

[0015] Fig. 20A is a conceptual view schematically illustrating an example in which one terminal 2 with a single antenna is connected to a PDMA base station 1 via one of a plurality of paths formed by space division in a mobile communication system (PHS) adopting the PDMA scheme.

[0016] More specifically, PDMA base station 1 receives an uplink signal from one antenna 2a of terminal

2 with an array antenna 1 a, and the signal is separated and extracted with reception directivity through the above-described adaptive array processing. On the other hand, array antenna 1a of PDMA base station 1 transmits a downlink signal with transmission directivity to one antenna 2a of terminal 2. Terminal 2 receives the downlink signal with its antenna 2a without adaptive array processing.

[0017] Fig. 20B is a timing chart schematically showing a manner of channel allocation in this example. In the example of Fig. 20B, users 1 to 4 establish time-division multiplexed to respective time slots obtained by division in a direction of time axis at an identical frequency. Here, one user is allocated to each slot via one path in a spatial direction.

[0018] Identification of a desired signal out of signals received in the PDMA scheme is performed in the following manner. A radio wave signal transmitted/received between a terminal such as a mobile phone and a base station is transmitted in what is called a frame configuration including a plurality of frames. For example, each frame includes a total of 8 slots, that is, 4 slots for uplink communication and 4 slots for downlink communication. Broadly speaking, the slot signal is constituted of a preamble consisting of a signal sequence already known to a reception side, and data (such as voice) consisting of a signal sequence unknown to the reception side.

[0019] The signal sequence in the preamble includes a signal train (reference signal: unique word signal, for example) of information for discerning whether or not a sender is a desired party for the reception side to establish communication. For example, an adaptive array radio base station performs weight vector control (determines weight coefficient) so as to extract a signal that seems to include a signal sequence corresponding to a desired party, based on comparison of the received signal sequence with the unique word signal taken out from a memory.

[0020] In addition, each frame is assumed to have a configuration in which a unique word signal (reference signal) section described above is included and cyclic redundancy check (CRC) is enabled.

[0021] In contrast, an MIMO (Multi Input Multi Output) scheme has been proposed, in which multiplex communication is established between one terminal having a plurality of antennas and a PDMA base station via a plurality of spatial paths of an identical frequency and an identical time slot.

[0022] Communication technologies for such MIMO scheme are described in detail, for example, in Nishimura et al., "SDMA Downlink Beamforming for a MIMO Channel," Technical Report of IEICE, A-P2001-116, RCS2001-155, pp.23-30, October 2001, and in Tomisato et al., "Radio Signal Processing for Mobile MIMO Signal Transmission," Technical Report of IEICE, A-P2001-97, RCS2001-136, pp.43-48, October 2001.

[0023] Fig. 21 is a conceptual view schematically illustrating an example in which one terminal PS1 with two antennas establishes spatial multiple connection to a PDMA base station CS1 via a plurality of paths (e.g. two paths) PTH1, PTH2 formed by space division in the mobile communication system (PHS) adapted to such MIMO scheme.

[0024] More specifically, PDMA base station CS 1 receives uplink signals from respective two antennas 12a, 12b of terminal CS1 with an array antenna 11a, and the signals are separated and extracted with reception directivity through the above-described adaptive array processing.

[0025] On the other hand, array antenna 11a of PDMA base station CS1 transmits downlink signals with transmission directivity to respective two antennas 12a, 12b of terminal PS1. Terminal PS 1 receives corresponding downlink signals with its respective antennas without adaptive array processing.

[0026] Fig. 22 is a timing chart schematically showing a manner of channel allocation in this example. In the example of Fig. 22, users 1 to 4 are time-division multiplexed to respective time slots divided in a direction of time axis at an identical frequency. An identical user is allocated in a manner of multiple connection to each slot via two paths in a spatial direction.

[0027] For example, noting a first time slot in Fig. 22, user 1 is allocated to all channels via two spatial paths. Then, a signal of user 1 is divided and transmitted between the terminal and the base station via two paths in the identical slot, and the divided signals are reconfigured on the reception side. Two-paths-for-one-user scheme as shown in Fig. 22 can double a communication speed, as compared with one-path-for-one-user scheme in Fig. 20B.

[0028] Here, some of the plurality of spatial paths in the identical slot in the PDMA scheme may be used to establish communication in multiple-paths-for-one-user scheme as shown in Fig. 21. Concurrently, remaining paths may be used to establish communication in one-path-for-one-user scheme as shown in Figs. 20A and 20B.

[0029] A specific method of transmission/reception of a signal in the MIMO scheme as shown in Fig. 21 is disclosed in detail in Japanese Patent Laying-Open No. 11-32030, for example.

[0030] In the MIMO scheme as shown in Fig. 21, the terminal side prepares antennas in the number corresponding to the number of paths to be set, so as to establish communication.

[0031] If a failure occurs on a propagation path, however, there is no degree of freedom in that path allowing for avoiding such a failure. Eventually, disconnection of the path has been likely.

[0032] In this manner, though improvement in the communication speed can be expected with the conventional MIMO scheme in an environment where a condition for communication is excellent, it is difficult in some cases to achieve a stable communication speed.

[0033] Accordingly, an object of the present invention is to provide a radio apparatus capable of adaptive modification in connection of a plurality of paths between a terminal and a base station in accordance with a communication condition in a mobile communication system where communication is established with a multiple-paths-for-one-user scheme such as the MIMO scheme, as well as a method and a program for controlling a spatial path.

Disclosure of the Invention

[0034] According to one aspect of the present invention, a radio apparatus can establish communication by forming a plurality of spatial paths to another single radio apparatus. The radio apparatus includes a plurality of antennas constituting an array antenna, and the plurality of antennas are divided into a plurality of subarrays corresponding to the plurality of spatial paths respectively. The radio apparatus further includes adaptive array means capable of adaptive array processing for each of the plurality of subarrays; storage means for storing in advance information on possible multiplicity associated with a number of spatial paths that can be formed by the array antenna; and control means for controlling a processing to transmit the information on possible multiplicity to another radio apparatus at a prescribed timing.

[0035] Preferably, the information on possible multiplicity is information on a total number of the plurality of antennas.

[0036] Preferably, the radio apparatus further includes monitor means for detecting a communication status for each of the plurality of antennas. The information on possible multiplicity is information associated with a maximum number of spatial paths that can be used for multiplex communication, determined based on a detection result by the monitor means.

[0037] Preferably, the monitor means detects a number of antennas that can attain normal reception, and the information on possible multiplicity is information on a maximum number of antennas that can attain normal reception.

[0038] Preferably, a signal transmitted/received by the radio apparatus is divided into a plurality of frames. The monitor means detects an error rate for each frame in each spatial path. The information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

[0039] Preferably, the monitor means detects an amount of interference between the spatial paths, and the information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

[0040] Preferably, the adaptive array processing means can change a combination of the antennas allocated to each subarray to perform the adaptive array processing. The control means divides the plurality of antennas into a set or sets in a number corresponding to a number of paths, in accordance with the number of paths notified from another radio apparatus, to implement the set or sets of the antennas as each subarray.

[0041] Preferably, the adaptive array processing means can change a combination of the antennas allocated to each subarray to perform the adaptive array processing. The control means allocates one antenna out of the plurality of antennas to respective subarray or subarrays in a number corresponding to the number of paths notified from another radio apparatus, and subsequently allocates remaining antennas out of the plurality of antennas to each of the subarrays in a prescribed order.

[0042] Preferably, the control means preferentially allocates the antennas having an identical plane of polarization to an identical subarray.

[0043] Preferably, the radio apparatus further includes means for detecting a reception level for each antenna. The control means preferentially allocates the antennas having planes of polarization different from each other to an identical subarray.

[0044] Preferably, the adaptive array processing means can change a combination of the antennas allocated to each subarray to perform the adaptive array processing. The radio apparatus further includes monitor means for monitoring communication quality for each spatial path during communication. The control means changes the number of the antennas allocated to each subarray in accordance with a detection result of the monitor means.

[0045] According to another aspect of the present invention, a method of controlling a spatial path in a radio apparatus capable of communication by forming a plurality of spatial paths to another single radio apparatus is provided. The radio apparatus includes an array antenna constituted of a plurality of antennas that can be divided into a plurality of subarrays corresponding to the plurality of spatial paths respectively, and adaptive array means capable of adaptive array processing for each of the plurality of subarrays. The method includes the steps of: storing in advance information on possible multiplicity associated with a number of spatial paths that can be formed by the array antenna; transmitting the information on possible multiplicity to another radio apparatus from the radio apparatus at a prescribed timing; and determining the antenna to be allocated to the subarray based on information specifying the number of the spatial paths provided from another radio apparatus.

[0046] Preferably, the method of controlling a spatial path further includes the step of detecting a number of antennas capable of normal reception in the radio apparatus. The information on possible multiplicity is information on a maximum number of antennas that can attain normal reception.

[0047] Preferably, a signal transmitted/received by the radio apparatus is divided into a plurality of frames. The method further includes the step of detecting an error rate for each frame for each of the spatial paths in the radio apparatus. The information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

[0048] Preferably, the method of controlling a spatial path further includes the step of detecting an amount of interference between the spatial paths in the radio apparatus. The information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

[0049] Preferably, the step of determining the antenna includes the step of dividing the plurality of antennas into a set or sets in the number corresponding to a number of paths, in accordance with the number of paths notified from another radio apparatus, to allocate the set or sets of the antennas to each subarray.

[0050] Preferably, the step of determining the antenna includes the step of allocating one antenna out of the plurality of antennas to respective subarray or subarrays in a number corresponding to the number of paths notified from another radio apparatus, followed by allocating remaining antennas out of the plurality of antennas to each subarray in a prescribed order.

[0051] Preferably, in the step of allocating antennas to the subarray, the antennas having an identical plane of polarization are preferentially allocated to an identical subarray.

[0052] Preferably, in the step of allocating antennas to the subarray, the antennas having planes of polarization different from each other are preferentially allocated to an identical subarray.

[0053] According to yet another aspect of the present invention, a program for controlling a spatial path in a radio apparatus capable of communication by forming a plurality of spatial paths to another single radio apparatus is provided. The radio apparatus includes an array antenna constituted of a plurality of antennas that can be divided into a plurality of subarrays corresponding to the plurality of spatial paths respectively, and adaptive array means capable of adaptive array processing for each of the plurality of subarrays. The program causes a computer to execute the steps of: storing in advance information on possible multiplicity associated with a number of spatial paths that can be formed by the array antenna; transmitting the information on possible multiplicity to another radio apparatus from the radio apparatus at a prescribed timing; and determining the antenna to be allocated to the subarray based on information specifying the number of the spatial paths provided from another radio apparatus.

[0054] Preferably, the method of controlling a spatial path further includes the step of detecting a number of antennas capable of normal reception in the radio apparatus. The information on possible multiplicity is information on a maximum number of antennas that can attain normal reception.

[0055] Preferably, a signal transmitted/received by the radio apparatus is divided into a plurality of frames. The method further includes the step of detecting an error rate for each frame for each of the spatial paths in the radio apparatus. The information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

[0056] Preferably, the method of controlling a spatial path further includes the step of detecting an amount of interference between the spatial paths in the radio apparatus. The information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

[0057] Preferably, the step of determining the antenna includes the step of dividing the plurality of antennas into a set or sets in a number corresponding to a number of paths, in accordance with the number of paths notified from another radio apparatus, to allocate the set or sets of the antennas to each subarray.

[0058] Preferably, the step of determining the antenna includes the step of allocating one antenna out of the plurality of antennas to respective subarray or subarrays in a number corresponding to the number of paths notified from another radio apparatus, followed by allocating remaining antennas out of the plurality of antennas to each subarray in a prescribed order.

[0059] Preferably, in the step of allocating antennas to the subarray, the antennas having an identical plane of polarization are preferentially allocated to an identical subarray.

[0060] Preferably, in the step of allocating antennas to the subarray, the antennas having planes of polarization different from each other are preferentially allocated to an identical subarray.

[0061] Therefore, according to the present invention, in a terminal or a base station in the mobile communication system adapted to the MIMO scheme, communication in each spatial path is established by antennas divided into subarrays. As the antennas adapted to each path or the number of paths are adaptively controlled in accordance with a communication status, stable communication in the MIMO scheme can be achieved.

[0062] The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

Brief Description of the Drawings

[0063]

Fig. 1 is a functional block diagram showing a configuration of a PDMA terminal 1000 adapted to an MIMO scheme in a first embodiment of the present invention.

Fig. 2 is a conceptual view illustrating a state in which PDMA terminal 1000 according to the present invention and a PDMA base station CS1 are communicating with each other.

Fig. 3 is a flowchart illustrating an operation for notifying base station CS 1 of information on the number of antennas from terminal 1000.
Fig. 4 is a schematic block diagram illustrating a configuration of a PDMA terminal 1200 in a variation of the first embodiment of the present invention.
Fig. 5 is a schematic block diagram illustrating a configuration of a PDMA terminal 2000 in a second embodiment of the present invention.
Fig. 6 is a schematic block diagram illustrating a configuration of a PDMA terminal 2200 in a first variation of the second embodiment of the present invention.
Fig. 7 is a flowchart showing a flow in adaptive control of the number of paths to be set in PDMA terminal 2000 or PDMA terminal 2200.
Fig. 8 is a flowchart showing a method of adaptive control of the number of paths to be set with regard to terminal 2000 in a second variation of the second embodiment.
Fig. 9 shows a configuration in which four antennas #1 to #4 are arranged in a notebook personal computer 3000.
Fig. 10 is a conceptual view illustrating an arrangement of four antennas attached to a mobile phone terminal 4000.
Fig. 11 is a flowchart illustrating an operation when antennas having an identical plane of polarization are selected for a subarray.
Fig. 12 is a flowchart illustrating another method of allocating a plurality of antennas of a terminal to each path.
Fig. 13 is a schematic block diagram illustrating a configuration of a PDMA terminal 5000.
Fig. 14 is a flowchart illustrating an operation of a control circuit CNP and a subarray selector 32.
Fig. 15 is a flowchart illustrating a processing for allocating antennas in terminal 5000 to respective paths based on a reception level.
Fig. 16 is a flowchart illustrating another method of allocating each antenna to each path based on the reception level.
Fig. 17 is a conceptual view illustrating a configuration before and after a combination of antennas constituting a path is changed.
Fig. 18 is a conceptual view illustrating a state after a combination in a subarray is changed as a result of detection of deterioration in communication quality as shown in Fig. 17.
Fig. 19 shows a flow of a communication sequence in PHS.
Figs. 20A and 20B are conceptual views illustrating an example in which one terminal 2 with a single antenna is connected to a PDMA base station 1 via one of a plurality of paths formed by space division.
Fig. 21 is a conceptual view illustrating an example in which one terminal PS 1 with two antennas establishes spatial multiple access to PDMA base station CS1 via paths PTH1, PTH2 formed by space division.
Fig. 22 is a timing chart schematically showing a manner of channel allocation.

Best Modes for Carrying Out the Invention

[0064] In the following, embodiments of the present invention will be described in detail with reference to the figures. It is noted that the same reference characters refer to the same or corresponding components in the figures.

(First Embodiment)

[0065] Fig. 1 is a functional block diagram showing a configuration of a PDMA terminal 1000 adapted to the MIMO scheme in a first embodiment of the present invention.

[0066] Referring to Fig. 1, PDMA terminal 1000 includes: transmission/reception units TRP 1 to TRP4 providing transmission signals to an array antenna constituted of a plurality of antennas #1 to #4 or receiving reception signals; a signal processing unit USP subjecting signals from transmission/reception units TRP 1 to TRP4 to adaptive array processing for separating and extracting a signal from a base station during communication, and adjusting an amplitude and a phase of the transmission signal so as to form transmission directivity to the base station during communication; a modulation unit MDU for modulating a signal provided to signal processing unit USP; a demodulation unit DMU for demodulating a signal from signal processing unit USP; a control unit CNP controlling a baseband signal provided to modulation unit MDU and a baseband signal provided from demodulation unit DMU, and controlling an operation of PDMA terminal 1000; and a memory MMU for holding information of the number of antennas for PDMA terminal 1000 (hereinafter, referred to as "antenna number information").

[0067] Here, a processing such as an adaptive array processing, a modulation processing, a demodulation processing, or a control processing performed by PDMA terminal 1000 can be performed, individually or as an integrated processing, with software by means of a digital signal processor.

[0068] Transmission/reception unit TRP 1 includes a transmission unit TP 1 for processing a high-frequency signal in transmission, a reception unit RP 1 for processing a high-frequency signal in reception, and a switch unit SW1 for switching connection between antenna #1 and transmission unit TP1 or reception unit RP1 in accordance with a transmission mode or a reception mode. Other transmission/reception units TRP2 to TRP4 are configured in a similar manner.

[0069] When terminal 1000 is a PC card mounted to a personal computer, a signal from control circuit CNP may be output to the personal computer mounted with terminal 1000 via a not-shown interface. Alternatively, when terminal 1000 is an independent communication terminal, for example, a mobile phone, the signal from control circuit CNP may be provided to a processor for voice signal processing or the like within terminal 1000.

[0070] In the description above, though the number of antennas has been set to 4, more generally, it may be set to N (N: natural number). As described below, though the number of spatial paths for communication with the base station (hereinafter, simply referred to as "path") with respect to the number of antennas is set to 2, communication can be established with the possible number of paths in accordance with the number of antennas.

[0071] For example, it is assumed that the number of antennas is set to 4, and the number of paths is set to 2. Then, two series of adaptive array processing units corresponding to the two paths respectively should only be provided in advance in signal processing unit USP. When there are larger number of antennas or paths, similarly, adaptive array processing units in the number corresponding to respective paths should only be provided. In addition, if a combination of the antennas processed by each series should be changed, each series of adaptive array processing units and the antennas connected thereto should only be switched under control of control unit CNP.

[0072] Fig. 2 is a conceptual view illustrating a state in which PDMA terminal 1000 according to the present invention and PDMA base station CS 1 are communicating with each other.

[0073] As shown in Fig. 2, PDMA terminal 1000 has four antennas #1 to #4. PDMA terminal 1000 forms one path to base station CS1 with directivity by means of antennas #1 and #3, and forms another path to base station CS1 with transmission/reception directivity by means of antennas #2 and #4. For example, though not limited to such an example, a plurality of spatial paths for communication can be formed by forming transmission/reception directivity described above by utilizing the fact that an identical signal reaches PDMA terminal 1000 via different propagation paths due to an influence of buildings in a communication path.

[0074] For example, in terminal 1000 having four antennas, two subarrays serving as two-element adaptive array respectively are implemented in setting two paths with the array antenna. Here, two-element adaptive array reception and transmission is performed in one subarray.

[0075] As described above, memory MMU within terminal 1000 stores the "antenna number information". Therefore, terminal 1000 transmits the antenna number information to base station CS 1 at a prescribed timing. Base station CS1 issues an instruction for the number of paths to be set to base station 1000 based on the antenna number information from terminal 1000. Terminal 1000 sets the number of paths to be formed in accordance with the instruction from base station CS 1.

[0076] Fig. 3 shows a flow illustrating an operation for notifying base station CS 1 of the antenna number information from terminal 1000 in such a manner.

[0077] In Fig. 3, solely a portion required for transmitting/receiving information between terminal 1000 and base station CS 1 in a control procedure for establishing synchronization in a common PHS system described in connection with Fig. 19 is extracted for representation.

[0078] First, the antenna number information is transmitted to the base station from terminal 1000 as control information in requesting establishment of a link channel (LCH allocation request).

[0079] Base station CS1 gives an instruction for the number of paths stating that the number of paths to be set should be equal to or smaller than the number of antennas, as the control information for link channel allocation instruction, for example, based on the antenna number information from the terminal.

[0080] In succession, terminal 1000 transmits a synchronous burst signal to base station CS 1 using a designated traffic channel (T channel), and the base station also sends back a synchronous burst signal to the terminal. Synchronization is thus established. Thereafter, the traffic channel (T channel) is activated based on the established synchronization, and communication is started.

[0081] Here, the base station adaptively modifies the number of paths set by terminal 1000 in accordance with the status during communication, and terminal 1000 is notified of a resultant value as the control information during communication.

[0082] Though the timing of notification of the antenna number information from terminal 1000 to base station CS 1 has been set at the time of request of establishing the link channel in the description above, it may be at a control information stage during establishing the traffic channel (TCH), or alternatively, the antenna number information may be notified from terminal 1000 to base station CS1 as the control information after the traffic channel is established.

[0083] With the above-described configuration, in terminal 1000, a plurality of subarrays formed by dividing a plurality of antennas constituting an array antenna can control communication in one path establishing communication with base station CS 1. Accordingly, the path can be formed in a flexible manner in accordance with a change in communication status between base station CS 1 and terminal 1000. Therefore, even if the communication status is varied, stable multiplex communication can be achieved via a plurality of spatial paths of an identical frequency and an identical time slot.

(Variation of First Embodiment)

[0084] Fig. 4 is a schematic block diagram illustrating a configuration of a PDMA terminal 1200 in a variation of the first embodiment of the present invention.

[0085] PDMA terminal 1200 in a second embodiment is different from PDMA terminal 1000 in the first embodiment shown in Fig. 1 in that terminal 1200 includes an antenna abnormal state detector ADP capable of detecting abnormality in a communication status for each antenna upon receiving communication information from each antenna #1 to #4.

[0086] As PDMA terminal 1200 is otherwise configured in a manner similar to PDMA terminal 1000, the same reference characters are given to the same or corresponding components and description thereof will not be repeated.

[0087] In terminal 1200, memory MMU stores not only the antenna number information, but also information on an antenna in an abnormal state (the number of antennas in an abnormal state and an abnormal antenna identifier) from antenna abnormal state detector ADP. Based on such information, terminal 1200 transmits the information on the number of antennas capable of normal transmission/reception to the base station at a prescribed timing similar to that in the first embodiment.

[0088] Base station CS 1 determines the number of paths to be set based on the antenna number information from terminal 1200 indicating the maximum number of antennas capable of normal transmission/reception, and notifies terminal 1200 of the number of paths at a timing similar to that in the first embodiment.

[0089] With the above-described configuration, a plurality of spatial paths can be established without using antennas incapable of normal transmission/reception due to a status of hardware, communication status, or the like among the plurality of antennas, and stable multi-input multi-output multiplex communication can be achieved.

(Second Embodiment)

[0090] Fig. 5 is a schematic block diagram illustrating a configuration of a PDMA terminal 2000 in a second embodiment of the present invention.

[0091] PDMA terminal 2000 is different from PDMA terminal 1000 shown in the first embodiment in that a signal from demodulation unit DMU is provided to an FER counter 22 detecting a frame error rate.

[0092] FER counter 22 counts the number of errors in a signal frame for each path. A resultant frame error rate (FER), which is an error rate per frame, is stored in memory MMU as one of elements in communication quality information for evaluating communication quality.

[0093] The demodulated signal of which errors are counted in FER counter 22 is provided to control unit CNP, which communicates with memory MMU, refers to the communication quality information of the downlink signal such as an FER held in memory MMU, and performs control of an uplink spatial path with a method of controlling a spatial path according to the present invention described later.

[0094] Here, a processing such as an adaptive array processing, a modulation processing, a demodulation processing, or a control processing, performed by PDMA terminal 2000 can be performed, individually or as an integrated processing, with software by means of a digital signal processor.

[0095] Terminal 2000 notifies base station CS 1 of quality information for each spatial path acquired in a manner described above and held in MMU, or information on the antenna currently allocated to each path at a prescribed timing similar to that in the first embodiment.

[0096] Though the information held in memory MMU has been assumed as the antenna number information or FER data in the description above, not the number of antennas themselves but the FER data and the maximum number of paths P_MAX that can be formed in terminal 2000 determined from the FER data described above may be stored in MMU, for example.

(First Variation of Second Embodiment)

[0097] Fig. 6 is a schematic block diagram illustrating a configuration of a PDMA terminal 2200 in a first variation of the second embodiment of the present invention.

[0098] PDMA terminal 2200 is different from PDMA terminal 2000 in the second embodiment shown in Fig. 5 in that an interference measurement device 24 for measuring an amount of interference from another path with respect to a signal input to demodulation unit DMU is provided instead of FER counter 22, and memory MMU stores the information on communication quality in a path based on the amount of interference and information on antenna allocation, that is, how antennas are currently allocated to each path.

[0099] In this manner, based on the information on communication quality in the path and the information on antenna allocation stored in memory MMU, terminal 2200 notifies base station CS 1 of the number of paths available for communication at a prescribed timing similar to that in the first embodiment.

[0100] Interference measurement device 24 measures an interference component contained in a complex reception signal input to the demodulation circuit.

[0101] In a method of measurement, an error component e(t) between a complex reception signal y(t) and a reference signal d(t) stored in memory MMU is calculated, and a power of that error signal component is regarded as a power of the interference signal.

[0102] Here, e(t) and the interference power are expressed in the following equations:

$$e(t) = y(t) - d(t)$$

$$(\text{interference power}) = \Sigma\, |e(t)| / T$$

where T represents an observation time (or reference signal length).

[0103] With the above-described configuration as well, the communication quality for each path can be ascertained in terms of an amount of interference, and an effect as in the second embodiment can be obtained.

(Operation in Second Embodiment or First Variation of Second Embodiment)

[0104] Fig. 7 is a flowchart showing a flow in adaptive control of the number of paths set in PDMA terminal 2000 in the second embodiment described in connection with Fig. 5 or PDMA terminal 2200 in the first variation of the second embodiment described in connection with Fig. 6.

[0105] In the following, an operation of PDMA terminal 2000 in the second embodiment will basically be described, and subsequently, difference from the operation of PDMA terminal 2000 will be described with respect to an operation of PDMA terminal 2200 in the first variation of the second embodiment.

[0106] Referring to Fig. 7, first, terminal 2000 notifies base station CS 1 of the number of antenna elements N in the terminal or the maximum number of paths P_MAX (step S100).

[0107] In terminal 2000, the total N antennas are used to form one subarray, and one path is set for communication (step S 102).

[0108] In succession, in terminal 2000, communication quality is evaluated by the FER for each path. It is determined whether FERs of all paths are equal to or smaller than a prescribed threshold value, whether the number of paths that can be set has not yet been attained, and whether or not the communication speed is insufficient (step S104).

[0109] Here, the expression that "communication speed is insufficient" means that, when an amount of data to be transferred is compared with the current communication speed, transfer is not completed in a sufficiently short period of time in terminal 2000 with respect to a processing of an application during execution, for example.

[0110] When it is determined in step S104 that, with regard to the communication quality for each path and the number of paths that can be set, the number of paths can further be increased and the communication speed is insufficient, notification that an increase in the number of paths P by 1 is desired is transmitted from terminal 2000 to base station CS 1 (step 106).

[0111] Then, when terminal 2000 receives permission for setting from base station CS 1 (step S108), terminal 2000 increases the number of paths to be set by 1. In response, terminal 2000 selects P (P=P+1) subarrays for communication (step S 110), and the processing returns to step S104.

[0112] On the other hand, when it is determined in step S104 that the communication status is poor or the communication speed is sufficient, or when permission for setting from the base station is not received in step S108, communication is performed with the current number of paths for a prescribed time period (step S 112), and the processing returns to step S104.

[0113] With the above-described processing, while the number of paths to be set for multi-input multi-output communication is adaptively modified, communication between base station CS1 and terminal 2000 can be established. While maintaining excellent communication quality and excellent communication speed, communication in the MIMO scheme can be attained.

[0114] It is to be noted in Fig. 7 that the number of antennas is in principle divisible by the number of paths designated by the base station.

[0115] In other words, the number of antennas in the antenna set (subarray) transmitting/receiving an identical signal to be set is obtained by dividing the total number of antennas by the number of paths to be set.

[0116] For example, when a terminal has a total of 4 antennas and two paths are set, two pairs (subarrays) each formed with two antennas are prepared.

[0117] Then, each subarray performs transmission/ reception in each path.

[0118] In an operation of terminal 2200 in the first variation of the second embodiment, in step S104, the communication quality of the path is evaluated not based on the FER value for each path but based on the amount of interference for each path.

(Second Variation of Second Embodiment)

[0119] In a second variation of the second embodiment described below, unlike Fig. 7, a method of adaptive control of the number of paths to be set, which is applicable even when the number of paths designated by the base station cannot divide the number of antennas, will be described.

[0120] Such an operation can also be processed in terminal 2000 and terminal 2200.

[0121] Fig. 8 is a flowchart showing a method of adaptive control of the number of paths to be set with regard to terminal 2000 in the second variation of the second embodiment.

[0122] Referring to Fig. 7, terminal 2000 notifies base station CS 1 of the number of antenna elements N in the terminal. Alternatively, the maximum number of paths P_MAX may be notified (step S200).

[0123] In terminal 2000, one antenna is used to set one path (the number of paths P is set to 1) for communication (step S202).

[0124] In succession, in terminal 2000, it is determined whether FERs of all paths on terminal side are equal to or smaller than a prescribed threshold value, that is, the communication status is determined to be so excellent as to allow increase in the number of paths, whether the current number of paths has not yet reached the number of paths that can be set, whether or not the communication speed is insufficient, and whether or not an antenna element which is not yet allocated to the path is present (step S204).

[0125] When the conditions in step S204 are satisfied, notification that increase in the number of paths P by 1 is desired is transmitted from terminal 2000 to base station CS 1 (step S206).

[0126] When terminal 2000 receives permission for setting from base station CS1 (step S208), terminal 2000 increases the number of paths to be set by 1 (P←P+1), and P antennas are selected to start communication (step S210), and the processing returns to step S204.

[0127] When the conditions in step S204 are not satisfied, or when permission for setting from base stationCS1 is not received in step S208, whether or not an antenna which is not set for a path is present is determined (step S212). When an antenna which has not been set is remaining, one antenna element is further allocated to a path which is determined to have attained a quality lower than a prescribed level, so as to form a subarray (step S214).

[0128] In succession, communication is performed with the current number of paths P for a prescribed time period (step S216), and the processing returns to step S204.

[0129] On the other hand, when there is no remaining antenna which has not been set for a path in step S212, the processing moves to step S216.

[0130] In other words, in the second variation of the second embodiment, the number of antennas for each subarray is determined in the following manner. One antenna is first allocated to each set path. Then, among remaining antennas, an additional antenna is sequentially allocated to each path in accordance with the path identifier or the antenna identifier while determining necessity for the increase in the number of antennas. For example, when all subarrays are provided with two antennas each, remaining antennas are again allocated. With such a process, each subarray performs transmission/reception in each path.

[0131] With above-described allocation of antennas to each path, the optimal number of antennas can be arranged for each path even when the number of antennas is not necessarily divisible by the number of paths which perform transmission/reception between base station CS 1 and terminal 2000. Communication in the MIMO scheme is thus enabled.

[0132] In an operation of terminal 2200 in the first variation of the second embodiment, in step S104, the communication quality of the path is evaluated not based on the FER value for each path but based on the amount of interference for each path.

(Third Embodiment)

[0133] In the first and second embodiments, an arrangement of antennas used in the MIMO scheme has not been limited in particular.

[0134] In a third embodiment, a configuration in which further improvement in the communication quality is attained by employing a specific arrangement of a plurality of antennas will be described.

[0135] Fig. 9 shows a configuration in which four antennas #1 to #4 are arranged for a notebook personal computer 3000.

[0136] Antennas #1 and #3 are arranged on opposing ends of a display 3010 of notebook personal computer 3000, and antennas #2 and #4 are arranged on opposing ends of a keyboard. Here, in such a spatial arrangement of the antennas, antennas #1 and #3 operate as antennas in an identical plane of polarization (vertical polarization), while antennas #2 and #4 operate as antennas in an identical plane of polarization (horizontal polarization).

[0137] Fig. 10 is a conceptual view illustrating an arrangement of four antennas attached to a mobile phone terminal 4000.

[0138] When a plurality of types of antenna elements are incorporated in mobile phone terminal 4000, as shown in Fig. 10, antennas #1 and #3 are arranged longitudinally and in parallel on opposing ends of a display 4010 so as to have an identical plane of polarization (vertical polarization), while antennas #2 and #4 are arranged so as to have an identical plane of polarization (horizontal polarization) with display 4010 and operation buttons 4020 interposed.

[0139] Though not specifically limited, antennas #1 and #3 arranged longitudinally may be whip antennas, while antennas #2 and #4 may be inverted-F shaped antennas.

[0140] In addition, antennas of the same type such as a chip antenna or a patch antenna may be arranged so as to form a set with respect to the identical plane of polarization.

[0141] In the above-described configuration, selection of antennas for forming a subarray may be made such that antennas with the identical plane of polarization form an identical subarray. Here, when a set of antennas constituting a subarray is selected in the second embodiment or the first variation of the second embodiment, or when a subarray is formed by sequentially allocating remaining antennas as described in the second variation of the second embodiment, antennas with the identical plane of polarization are allocated to an identical subarray.

[0142] By constituting one subarray with antennas having the identical plane of polarization in such a manner, the following effect can be obtained.

[0143] Under a condition of normal radio wave propagation, a path of an incoming radio wave tends to be spatially different if the plane of polarization is different. On the other hand, in order to obtain array gain with an adaptive array, sufficient array gain cannot be obtained if there is a great level difference between reception signals.

[0144] Therefore, in selecting a subarray when two subarrays are both available for communication, antennas which have the identical plane of polarization, that is, antennas which are expected to have approximately the same reception levels are selected, whereby sufficient array gain can be obtained.

[0145] In other words, constituting a subarray with antennas with the identical plane of polarization is particularly effective in an example in which variation in the reception levels of four antennas is observed due to different planes of polarization, though the reception levels thereof are all higher than the minimum reception level.

[0146] Fig. 11 is a flowchart illustrating an operation when antennas having an identical plane of polarization are selected for a subarray.

[0147] Referring to Fig. 11, terminal 3000 (or terminal 4000) notifies base station CS 1 of the number of antenna elements N (step S300).

[0148] In succession, the number of paths M set by base station CS 1 is sent back, which is received by mobile terminal 3000 (or terminal 4000) (step S302).

[0149] In mobile terminal 3000 (or terminal 4000), the number of antennas N is divided by the number of paths M, and the resultant value n is set as the number of antenna elements in a subarray. Here, antennas having the identical plane of polarization are selected as antenna elements constituting an identical subarray (step S504).

[0150] If the number of antennas with the identical plane of polarization is not an integer multiple of the number of antennas n in a subarray, remaining antennas may be allocated to other subarrays.

[0151] Then, a channel adapted to the multi-input multi-output scheme (MIMO channel) is set for each subarray between mobile terminal 3000 (or terminal 4000) and base station CS 1 for communication (step S306).

[0152] With the above-described allocation process of the antennas, communication is achieved by a subarray constituted of a set of antennas implemented by preferentially selecting antennas with the identical plane of polarization for each spatial path.

[0153] Fig. 12 is a flowchart illustrating another method of allocating a plurality of antennas in a terminal to each path.

[0154] Referring to Fig. 12, first, terminal 3000 (or terminal 4000) notifies base station CS1 of the number of antenna elements N (step S400).

[0155] In succession, the number of paths M set by the base station is sent back, which is received by mobile terminal 3000 (or terminal 4000) (step S402).

[0156] Mobile terminal 3000 (or terminal 4000) includes an antenna group having x types ($x \geq M$) of planes of polarization. Here, M antennas are selected and allocated to subarrays respectively such that corresponding planes of polarization are not overlapped with one another (step S404).

[0157] In succession, a value of a variable na is set to 1 (step S406).

[0158] In addition, whether an unallocated antenna is present or not is determined. When an unallocated antenna is present (step S408), the unallocated antenna is allocated to a subarray having na antennas. Here, the unallocated antenna is allocated such that the plane of polarization thereof is identical to that of the antenna already contained in the subarray (step S410).

[0159] Next, it is determined whether there is no longer an antenna that can be allocated on the basis of the identical plane of polarization. If an antenna to be allocated on that basis is still present (step S412), the value of variable na is incremented by 1 (step S414), and the processing returns to step S408.

[0160] On the other hand, when there is no antenna that can be allocated on the basis of the identical plane of polarization (step S412), an unallocated antenna is allocated to a subarray having na antennas (step S416). Then, the value of variable na is incremented by 1 (step S414), and the processing returns to step S408.

[0161] When there is no longer an unallocated antenna in step S408, an MIMO channel is set for each subarray for communication (step S420).

[0162] With the above-described allocation process of the antennas as well, communication is achieved by a subarray constituted of a set of antennas implemented by preferentially selecting antennas with the identical plane of polarization for each spatial path.

(Fourth Embodiment)

[0163] The third embodiment has described an example in which antennas having the identical plane of polarization constitute a subarray.

[0164] Depending on a communication status, however, enhanced transmission/reception performance can be obtained when the subarray is constituted of antennas having different planes of polarization.

[0165] Such an example will be described in the following.

[0166] In the third embodiment, in selecting antennas for forming a subarray, for example, a set of antennas can be selected so that antennas having reception levels or antenna gains proximate to one another are located in an identical subarray. Alternatively, the reception level is measured for each antenna in advance and antennas are ranked in terms of the reception level. The antennas can be allocated to a subarray so that antennas in a high rank in terms of the reception level are not unevenly distributed in a specific subarray.

[0167] Here, when a set of antennas constituting a subarray is selected in the second embodiment or the first variation of the second embodiment, or when a subarray is formed by sequentially allocating remaining antennas as described in the second variation of the second embodiment, antennas having reception levels or antenna gains proximate to one another are allocated to an identical subarray.

[0168] Under a condition of normal radio wave propagation, a path of an incoming radio wave will spatially be different if the plane of polarization is different. Accordingly, if something crosses the propagation path of the radio wave between the terminal and the base station, a phenomenon called "shadowing" in which reception power in a communication path abruptly falls may occur, when the communication path is formed solely by antennas with the identical plane of polarization.

[0169] If shadowing occurs, in some cases, the reception power in the path may abruptly fall as low as a level at which communication is difficult. In such a case, communication in that path may be disconnected. Therefore, in a communication environment in which shadowing often takes place, it is desirable to locate antennas with different planes of polarization in the identical subarray. With such a configuration of a subarray, even if the reception level of an antenna with a specific plane of polarization falls to a level disabling communication, an antenna with a different plane of polarization can maintain a level allowing reception. Accordingly, communication in all communication paths can be maintained.

[0170] As such, in control unit CNP, it is possible to selectively employ a method of constituting a subarray as described in the third embodiment and a method of constituting a subarray described below, in accordance with a degree of stability in path multiplicity and by comparing a current communication status and an allocation state of antennas to a subarray.

[0171] Fig. 13 is a schematic block diagram illustrating a configuration of a PDMA terminal 5000 capable of selecting antennas constituting a subarray based on information on the reception level or the plane of polarization as described above.

[0172] PDMA terminal 5000 is different from PDMA terminal 1000 in the first embodiment shown in Fig. 1 in that a reception level measurement device 30 capable of measuring a reception level for each antenna with respect to reception signals from respective antennas #1 to #4 is provided, a measurement result of the reception level measurement device is provided to control unit CNP, and control unit CNP causes memory MMU to store information on the reception level.

[0173] In addition, memory MMU stores not only the measurement result of the reception level, but also information on the plane of polarization of the antenna and information on occurrence of communication disruption seemingly caused by shadowing. In response, a subarray selector 32 notifies control circuit CNP of a set of antennas to be selected as a subarray, from the information on the plane of polarization of the antenna, the information on shadowing or the like stored in the memory.

[0174] In other words, reception level measurement device 30 measures the reception level for each antenna. Control circuit CNP measures reception level data for each antenna for a prescribed period of time, and measures "shadowing information" such as duration or frequency of a case in which reception is disabled for each antenna. Such results are stored in memory MMU. Subarray selector 32 selects a pair (or a set) of antennas to be selected as a subarray, from the shadowing information and the information on the plane of polarization in each antenna in memory MMU.

[0175] Fig. 14 is a flowchart illustrating an operation of control circuit CNP and subarray selector 32 among the operations described above.

[0176] First, control circuit CNP measures the reception level for each antenna in reception level measurement device 30, and measures duration or frequency of a case in which reception is disabled (shadowing information) for each antenna. Such results are stored in memory MMU (step S500).

[0177] Then, control unit CNP determines whether or not shadowing exceeds a prescribed reference (step S502).

[0178] Here, though not limited in particular, "a prescribed reference" refers to a determination reference such as whether or not shadowing lasting at least for a prescribed duration (0.5 second) occurs with a frequency more than a prescribed level (two times/60 seconds), for example.

[0179] When it is determined that shadowing exceeds the prescribed reference in step S302, subarray selector 32 selects antennas with different planes of polarization as an identical subarray (step S504).

[0180] On the other hand, when it is determined that shadowing does not exceed the prescribed reference in step S502, subarray selector 32 selects antennas with an identical plane of polarization as an identical subarray (step S506). Selection of a subarray in this case may follow the procedure described with reference to Fig. 11 or 12.

[0181] Fig. 15 is a flowchart illustrating a processing for allocating antennas in terminal 5000 to each path based on a reception level, when antennas having different planes of planarization are selected as an identical subarray in step S504 shown in Fig. 14.

[0182] First, terminal 5000 notifies base station CS 1 of the number of antenna elements N (step S600).

[0183] In succession, terminal 5000 is notified of the number of paths M to be set from base station CS1 (step S602).

[0184] Terminal 5000 includes an antenna group having x types (x≥M) of planes of polarization. Terminal 5000 ranks the antennas in accordance with reception sensitivity (levels of signals from a base station to be connected). Then, antennas are allocated to each subarray so that antennas in a high rank in terms of the reception sensitivity are not unevenly distributed in a specific subarray, that is, an average of the reception levels is proximate to each other in each subarray, for example (step S604).

[0185] An MIMO channel is set for each subarray constituted in the above-described manner for communication (step S606).

[0186] With the method described above, stable communication adapted to the MIMO scheme can be achieved even in the communication environment where shadowing frequently takes place.

[0187] Here, antennas having the reception level or the reception sensitivity proximate to each other may preferentially be allocated to an identical subarray in step S604 so that the reception level or the reception sensitivity of antennas are balanced in forming a spatial path.

(Fifth Embodiment)

[0188] The third and fourth embodiments have described the arrangement of the antennas in a terminal and how antennas are allocated to each subarray in accordance with the communication status in initiating communication in the MIMO scheme.

[0189] Meanwhile, even after communication in the MIMO scheme is once started, it is also possible to control communication in the MIMO scheme adaptively in accordance with the communication status, by changing antennas allocated to a subarray in accordance with a change in the communication status in each spatial path.

[0190] Here, the communication status in each spatial path may refer to the FER for each spatial path described with reference to Fig. 5, or an amount of interference for each spatial path described in connection with Fig. 6, or alternatively, change with time in the reception level for each antenna described with reference to Fig. 13.

[0191] Fig. 16 is a flowchart illustrating another method of allocating each antenna to each path based on the reception level.

[0192] For example, when it is determined based on FER or the interference value that the communication quality in a path PA has deteriorated during communication (step S700), quality in a path other than path PA is checked, and whether or not the number of antenna elements in a subarray corresponding to that other path can be reduced is determined (step S702).

[0193] When a path capable of maintaining quality even if the number of antenna elements is reduced is present (step S704), one antenna in a subarray corresponding to the path capable of maintaining quality even if the number of antenna elements is reduced is selected.

[0194] A selection reference here is chosen from a plurality of references below by setting priority among them in advance. Alternatively, one of the plurality of references below may be chosen as a reference.

(1) An antenna having a plane of polarization identical to that of an antenna already contained in the target subarray is selected.
(2) An antenna having a reception level proximate to that of an antenna already contained in the target subarray is selected.
(3) An antenna having reception sensitivity proximate to that of an antenna already contained in the target subarray is selected.
(4) An antenna is selected randomly or in the order of antenna identifier.

[0195] An antenna selected in such a manner is incorporated in the subarray corresponding to the path in which quality has deteriorated (step S706).

[0196] Alternatively, when there is no path for which the number of antennas can be reduced in step S704, the processing in step S706 is not performed but communication is maintained in current state.

[0197] Fig. 17 is a conceptual view illustrating a configuration before and after a combination of antennas forming a path is changed in the above-described manner.

[0198] Before changing the combination, antennas #1 and #3 form one path, while antennas #2 and #4 form one path. Here, antennas #1 and #3 may have an identical plane of polarization, while antennas #2 and #4 may have an identical plane of polarization. Alternatively, a configuration in which a set of antennas #1 and #3 and a set of antennas #2 and #4 form subarrays respectively may minimize a difference in the reception levels between the two sets.

[0199] Here, it is assumed that deterioration in the communication quality in path PA formed by antennas #2 and #3 has been determined.

[0200] Fig. 18 is a conceptual view illustrating a state after a combination in a subarray is changed as a result of detection of deterioration in communication quality as shown in Fig. 17.

[0201] As shown in Fig. 18, for example, antenna #3 is incorporated in a path PB, antennas #2, #3 and #4 form one path, and antenna #1 alone performs transmission/reception in path PA.

[0202] In this manner, even if the communication quality is deteriorated, the number of antennas constituting the subarray is changed so as to maintain desired communication quality, thereby enabling transmission/reception in the MIMO scheme.

[0203] Here, a processing such as an adaptive array processing, a modulation processing, a demodulation processing, or a control processing performed by any PDMA terminal described above can be performed, individually or as an integrated processing, with software by means of a digital signal processor.

[0204] As described above, according to the present invention, in a terminal or a base station in a mobile communication system adapted to the MIMO scheme, communication in each spatial path is established by antennas divided into subarrays. As the antennas corresponding to each path or the number of paths are adaptively controlled in accordance with a communication status, stable communication in the MIMO scheme can be achieved.

Industrial Applicability

[0205] The present invention is useful in a mobile communication system adapted to the MIMO scheme, because stable communication can be achieved by adaptively controlling the antennas corresponding to each path or the number of paths in accordance with a communication status, in a terminal or a base station in a mobile communication system adapted to the MIMO scheme.

Claims

1. A radio apparatus capable of communication by forming a plurality of spatial paths to another single radio apparatus, comprising:

    a plurality of antennas (#1 to #4) constituting an array antenna, said plurality of antennas being divided into a plurality of subarrays corresponding to said plurality of spatial paths respectively;
    adaptive array means (USP) capable of adaptive array processing for each of said plurality of subarrays;
    storage means (MMU) for storing in advance information on possible multiplicity associated with a number of spatial paths that can be formed by said array antenna; and
    control means (CNP) for controlling a processing to transmit said information on possible multiplicity to said another radio apparatus at a prescribed timing.

2. The radio apparatus according to claim 1, wherein
    said information on possible multiplicity is information on a total number of said plurality of antennas.

3. The radio apparatus according to claim 1, further comprising monitor means for detecting a communication status for each of said plurality of antennas, wherein
    said information on possible multiplicity is information associated with a maximum number of spatial paths that can be used for multiplex communication, determined based on a detection result by said monitor means.

4. The radio apparatus according to claim 3, wherein
    said monitor means detects a number of antennas that can attain normal reception, and
    said information on possible multiplicity is information on a maximum number of antennas that can attain normal reception.

5. The radio apparatus according to claim 3, wherein
    a signal transmitted/received by said radio apparatus is divided into a plurality of frames,
    said monitor means detects an error rate for each said frame in each of said spatial paths, and
    said information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

6. The radio apparatus according to claim 3, wherein
    said monitor means detects an amount of interference between said spatial paths, and
    said information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

7. The radio apparatus according to claim 1, wherein
    said adaptive array processing means can change a combination of said antennas allocated to each said subarray to perform said adaptive array processing, and
    said control means divides said plurality of antennas into a set or sets in a number corresponding to a number of paths, in accordance with said number of paths notified from said another radio apparatus, to implement said set or sets of said antennas as each said subarray.

8. The radio apparatus according to claim 1, wherein
    said adaptive array processing means can change a combination of said antennas allocated to each said subarray to perform said adaptive array processing, and
    said control means allocates one antenna out of said plurality of antennas to respective subarray or subarrays in a number corresponding to the number of paths notified from said another radio apparatus, and subsequently, allocates remaining antennas out of said plurality of antennas to each said subarray in a prescribed order.

9. The radio apparatus according to claim 7 or 8, wherein
    said control means preferentially allocates said antennas having an identical plane of polarization to identical said subarray.

10. The radio apparatus according to claim 7 or 8, further comprising means for detecting a reception level for each said antenna,
    wherein
    said control means preferentially allocates said antennas having planes of polarization different from each other to identical said subarray.

11. The radio apparatus according to claim 1, wherein
    said adaptive array processing means can change a combination of said antennas allocated to each said subarray to perform said adaptive array processing,

said radio apparatus further comprises monitor means for monitoring communication quality for each said spatial path during communication, and

said control means changes the number of said antennas allocated to each said subarray in accordance with a detection result of said monitor means.

12. A method of controlling a spatial path in a radio apparatus (1000) capable of communication by forming a plurality of spatial paths to another single radio apparatus, the radio apparatus including an array antenna constituted of a plurality of antennas (#1 to #4) that can be divided into a plurality of subarrays corresponding to said plurality of spatial paths respectively, and adaptive array means (USP) capable of adaptive array processing for each of said plurality of subarrays, the method comprising the steps of:

storing in advance information on possible multiplicity associated with a number of spatial paths that can be formed by said array antenna;
transmitting said information on possible multiplicity to said another radio apparatus from said radio apparatus at a prescribed timing; and
determining said antenna to be allocated to said subarray based on information specifying the number of said spatial paths provided from said another radio apparatus.

13. The method of controlling a spatial path according to claim 12, further comprising the step of detecting a number of antennas capable of normal reception in said radio apparatus, wherein

said information on possible multiplicity is information on a maximum number of antennas that can attain normal reception.

14. The method of controlling a spatial path according to claim 12, wherein

a signal transmitted/received by said radio apparatus is divided into a plurality of frames,

the method further comprises the step of detecting an error rate for each said frame for each of said spatial paths in said radio apparatus, and

said information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

15. The method of controlling a spatial path according to claim 12, further comprising the step of detecting an amount of interference between said spatial paths in said radio apparatus, wherein

said information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

16. The method of controlling a spatial path according to claim 12, wherein

said step of determining said antenna includes the step of dividing said plurality of antennas into a set or sets in a number corresponding to a number of paths, in accordance with said number of paths notified from said another radio apparatus, to allocate said set or sets of said antennas to each said subarray.

17. The method of controlling a spatial path according to claim 12, wherein

said step of determining said antenna includes the step of allocating one antenna out of said plurality of antennas to respective subarray or subarrays in a number corresponding to the number of paths notified from said another radio apparatus, followed by allocating remaining antennas out of said plurality of antennas to each said subarray in a prescribed order.

18. The method of controlling a spatial path according to claim 16 or 17,
wherein

in said step of allocating antennas to said subarray, said antennas having an identical plane of polarization are preferentially allocated to identical said subarray.

19. The method of controlling a spatial path according to claim 16 or 17,
wherein

in said step of allocating antennas to said subarray, said antennas having planes of polarization different from each other are preferentially allocated to identical said subarray.

20. A program for controlling a spatial path in a radio apparatus (1000) capable of communication by forming a plurality of spatial paths to another single radio apparatus, the radio apparatus including an array antenna constituted of a plurality of antennas (#1 to #4) that can be divided into a plurality of subarrays corresponding to said plurality of spatial paths respectively, and adaptive array means (USP) capable of adaptive array processing for each of said plurality of subarrays, the program causing a computer to execute the steps of:

storing in advance information on possible multiplicity associated with a number of spatial paths that can be formed by said array antenna;
transmitting said information on possible multiplicity to said another radio apparatus from said radio apparatus at a prescribed timing; and
determining said antenna to be allocated to said subarray based on information specifying the number of said spatial paths provided from

said another radio apparatus.

21. The program for controlling a spatial path according to claim 20, further comprising the step of detecting a number of antennas capable of normal reception in said radio apparatus, wherein

said information on possible multiplicity is information on a maximum number of antennas that can attain normal reception.

22. The program for controlling a spatial path according to claim 20, wherein

a signal transmitted/received by said radio apparatus is divided into a plurality of frames,

the method further comprises the step of detecting an error rate for each said frame for each of said spatial paths in said radio apparatus, and

said information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

23. The program for controlling a spatial path according to claim 20, further comprising the step of detecting an amount of interference between said spatial paths in said radio apparatus, wherein

said information on possible multiplicity is information on a number of spatial paths that can be used for multiplex communication.

24. The program for controlling a spatial path according to claim 20, wherein

said step of determining said antenna includes the step of dividing said plurality of antennas into a set or sets in a number corresponding to a number of paths, in accordance with said number of paths notified from said another radio apparatus, to allocate said set or sets of said antennas to each said subarray.

25. The program for controlling a spatial path according to claim 20, wherein

said step of determining said antenna includes the step of allocating one antenna out of said plurality of antennas to respective subarray or subarrays in a number corresponding to the number of paths notified from said another radio apparatus, followed by allocating remaining antennas out of said plurality of antennas to each said subarray in a prescribed order.

26. The program for controlling a spatial path according to claim 24 or 25,
wherein

in said step of allocating antennas to said subarray, said antennas having an identical plane of polarization are preferentially allocated to identical said subarray.

27. The program for controlling a spatial path according to claim 24 or 25,
wherein

in said step of allocating antennas to said subarray, said antennas having planes of polarization different from each other are preferentially allocated to identical said subarray.

FIG.1

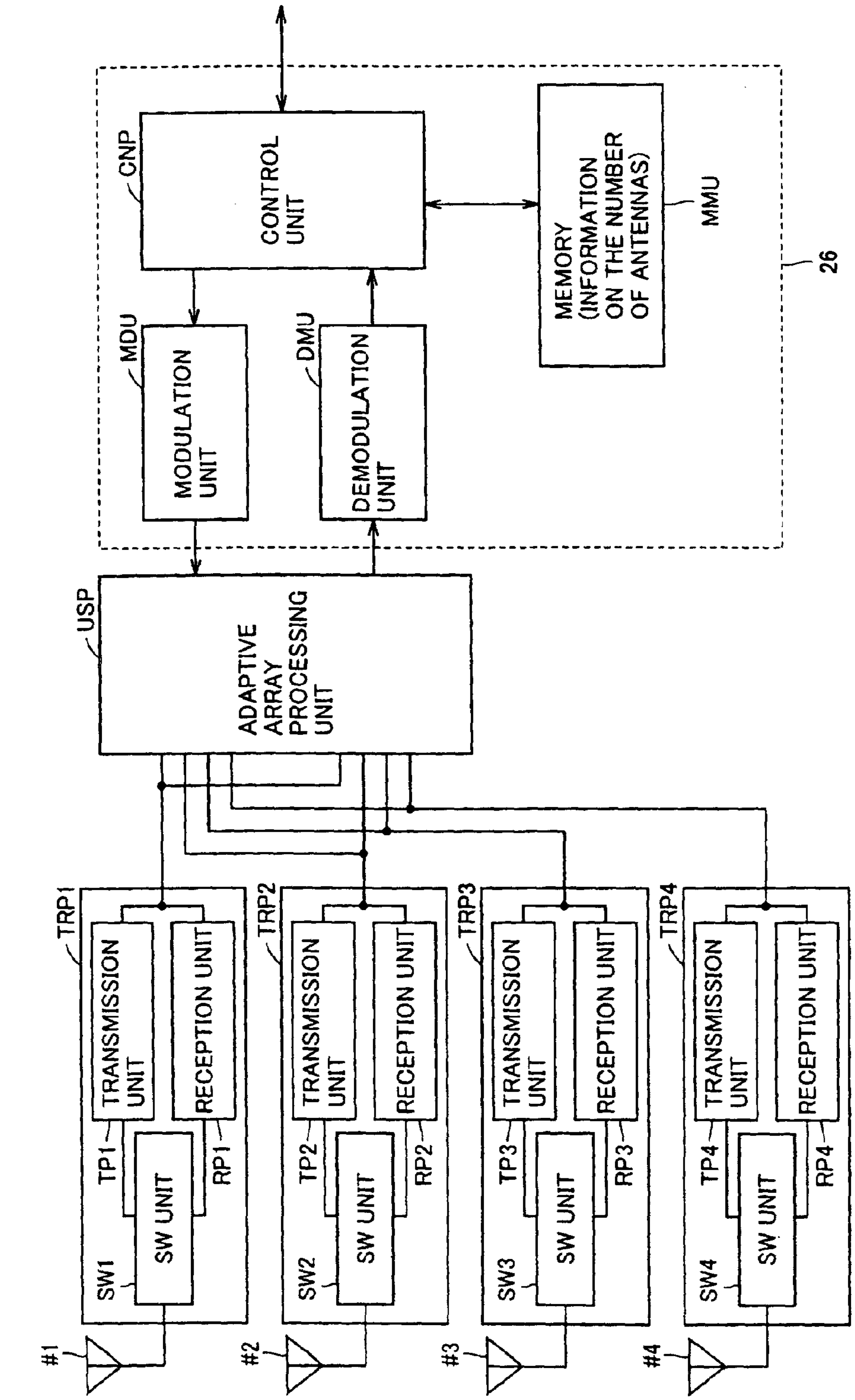

1000
CONTROL UNIT
CNP
MEMORY (INFORMATION ON THE NUMBER OF ANTENNAS)
MMU
26
MODULATION UNIT
MDU
DEMODULATION UNIT
DMU
ADAPTIVE ARRAY PROCESSING UNIT
USP
TRP1
TRANSMISSION UNIT
RECEPTION UNIT
TP1
RP1
SW UNIT
SW1
#1
TRP2
TRANSMISSION UNIT
RECEPTION UNIT
TP2
RP2
SW UNIT
SW2
#2
TRP3
TRANSMISSION UNIT
RECEPTION UNIT
TP3
RP3
SW UNIT
SW3
#3
TRP4
TRANSMISSION UNIT
RECEPTION UNIT
TP4
RP4
SW UNIT
SW4
#4

FIG.2

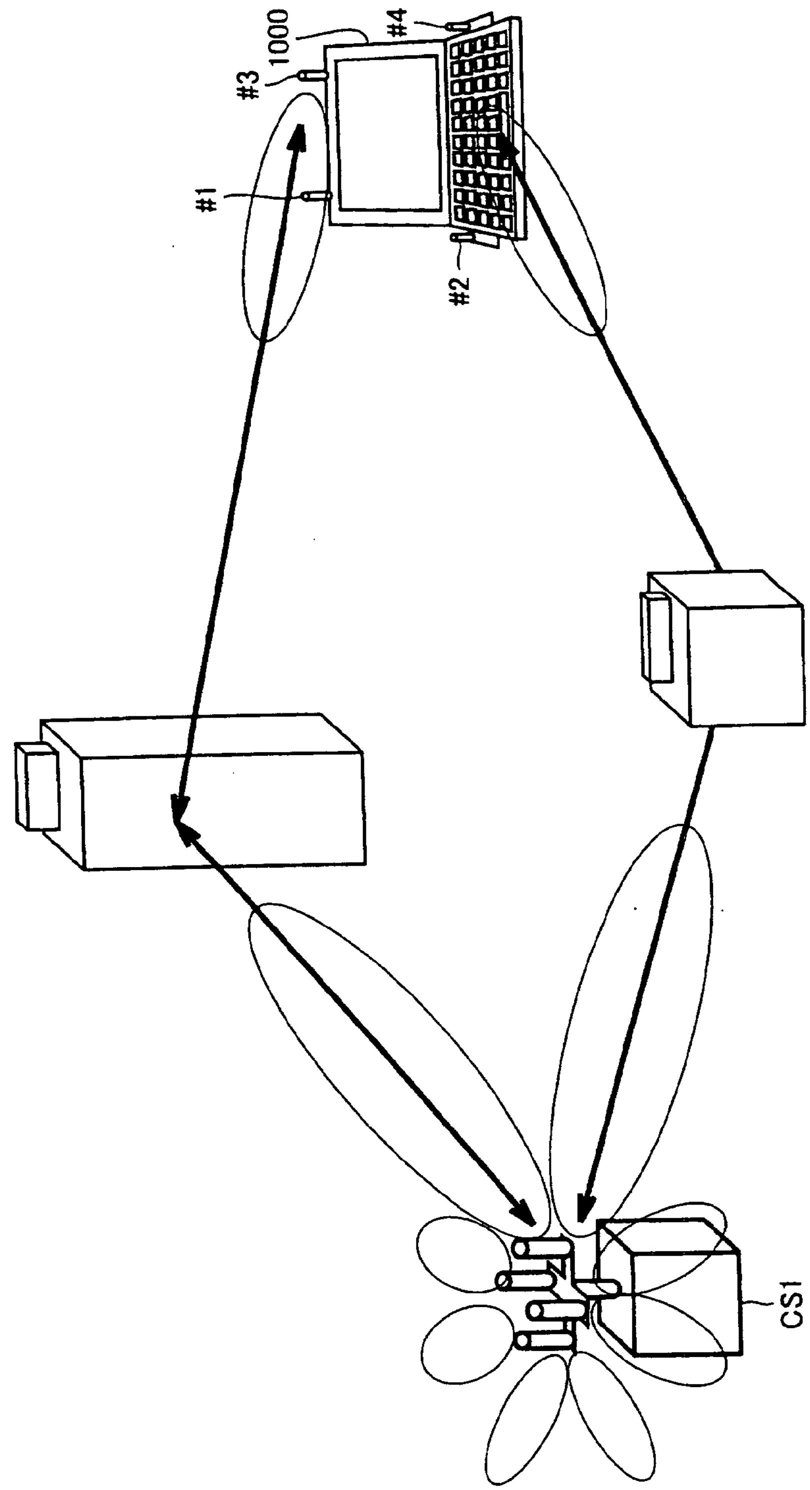


FIG.3

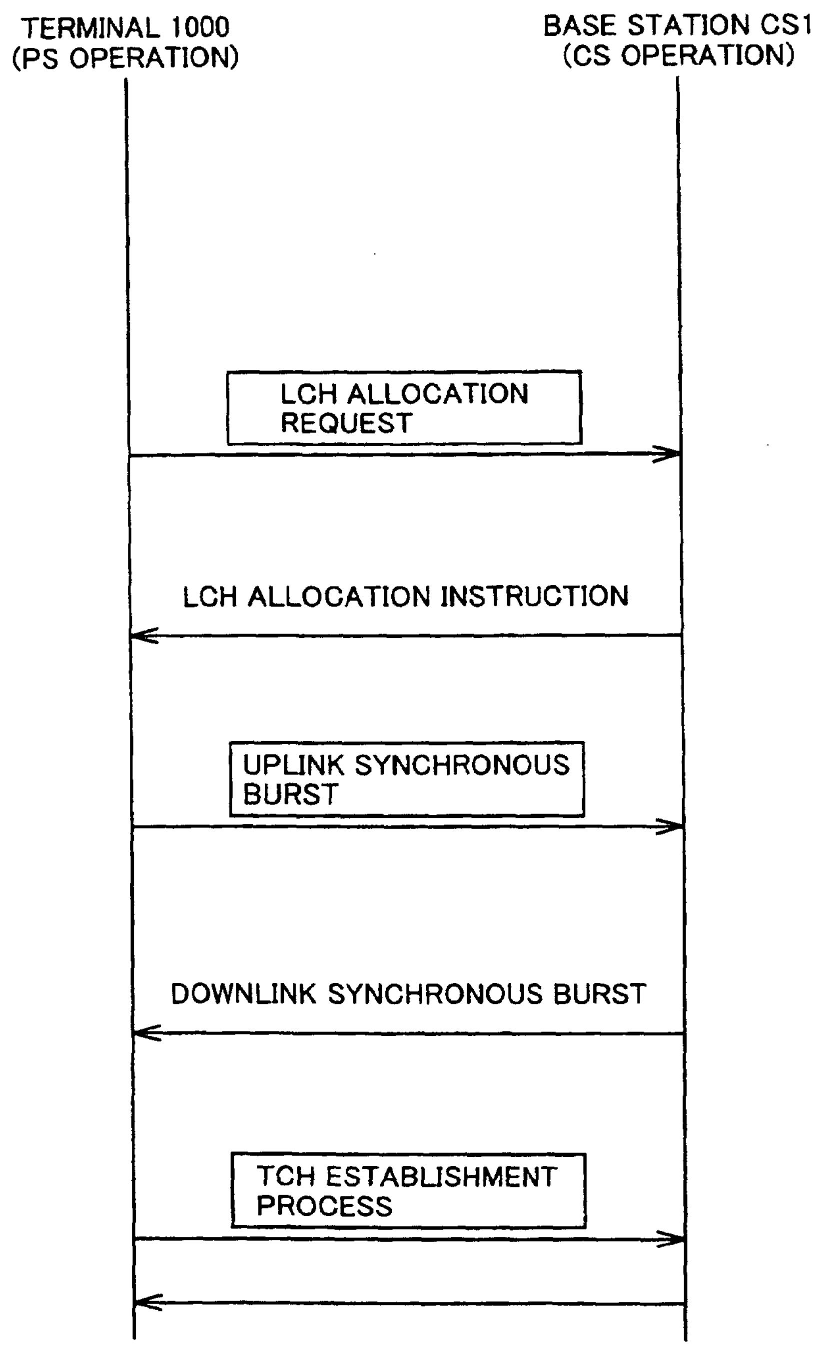

TERMINAL 1000
(PS OPERATION)
BASE STATION CS1
(CS OPERATION)
LCH ALLOCATION REQUEST
LCH ALLOCATION INSTRUCTION
UPLINK SYNCHRONOUS BURST
DOWNLINK SYNCHRONOUS BURST
TCH ESTABLISHMENT PROCESS

FIG.4

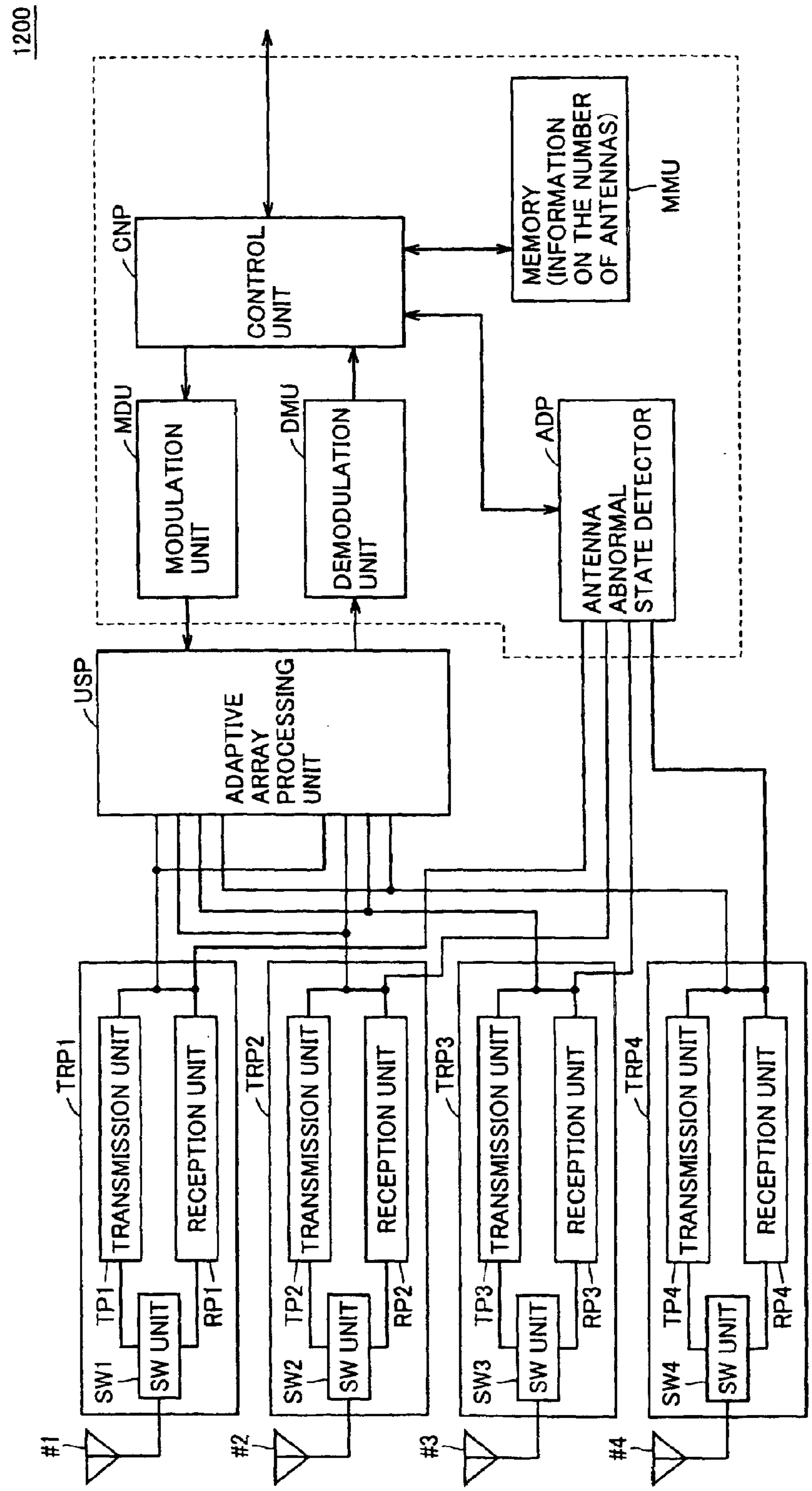

1200
CONTROL UNIT
CNP
MEMORY (INFORMATION ON THE NUMBER OF ANTENNAS)
MMU
MODULATION UNIT
MDU
DEMODULATION UNIT
DMU
ANTENNA ABNORMAL STATE DETECTOR
ADP
ADAPTIVE ARRAY PROCESSING UNIT
USP
TRP1
TRANSMISSION UNIT
RECEPTION UNIT
TP1
RP1
SW1
SW UNIT
#1
TRP2
TRANSMISSION UNIT
RECEPTION UNIT
TP2
RP2
SW2
SW UNIT
#2
TRP3
TRANSMISSION UNIT
RECEPTION UNIT
TP3
RP3
SW3
SW UNIT
#3
TRP4
TRANSMISSION UNIT
RECEPTION UNIT
TP4
RP4
SW4
SW UNIT
#4

FIG.5

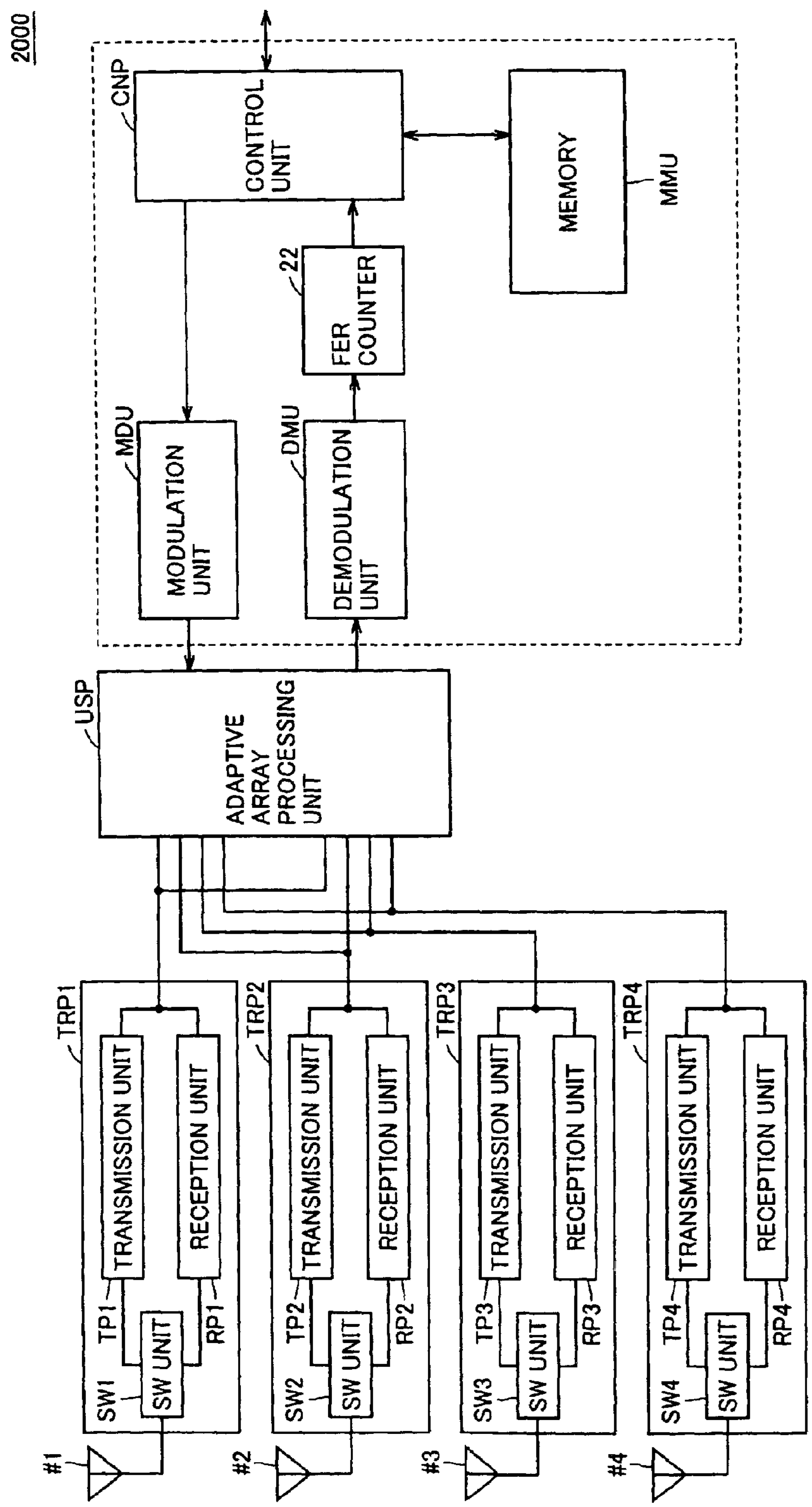

2000
CNP
CONTROL UNIT
MEMORY
MMU
22
FER COUNTER
MDU
MODULATION UNIT
DMU
DEMODULATION UNIT
USP
ADAPTIVE ARRAY PROCESSING UNIT
TRP1
TRP2
TRP3
TRP4
TRANSMISSION UNIT
RECEPTION UNIT
SW UNIT
TP1
TP2
TP3
TP4
RP1
RP2
RP3
RP4
SW1
SW2
SW3
SW4
#1
#2
#3
#4

FIG.6

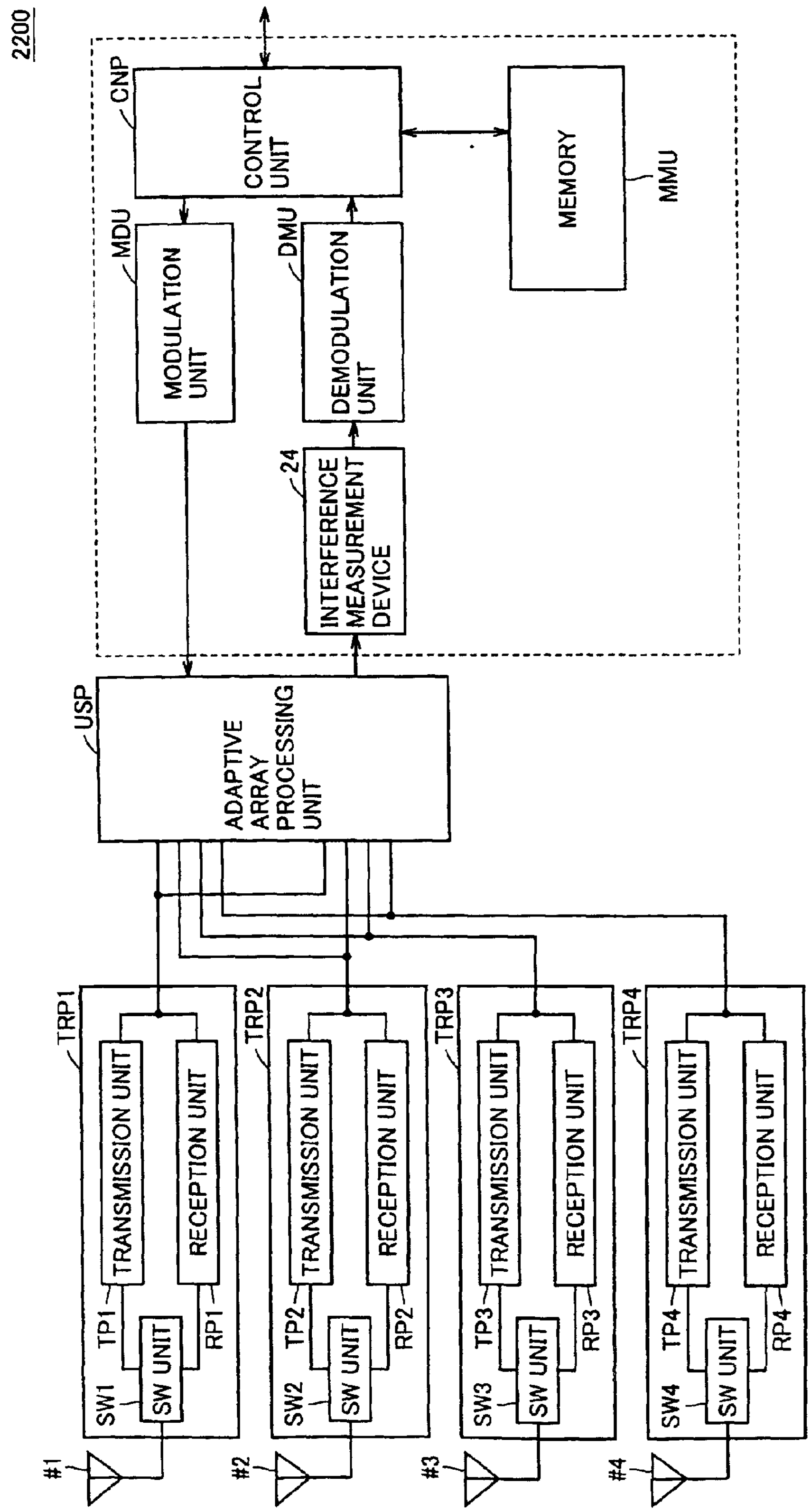

2200
CNP
CONTROL UNIT
MEMORY
MMU
MDU
MODULATION UNIT
DMU
DEMODULATION UNIT
24
INTERFERENCE MEASUREMENT DEVICE
USP
ADAPTIVE ARRAY PROCESSING UNIT
TRP1
TRANSMISSION UNIT
RECEPTION UNIT
TP1
RP1
SW1
SW UNIT
TRP2
TRANSMISSION UNIT
RECEPTION UNIT
TP2
RP2
SW2
SW UNIT
TRP3
TRANSMISSION UNIT
RECEPTION UNIT
TP3
RP3
SW3
SW UNIT
TRP4
TRANSMISSION UNIT
RECEPTION UNIT
TP4
RP4
SW4
SW UNIT
#1
#2
#3
#4

FIG.7

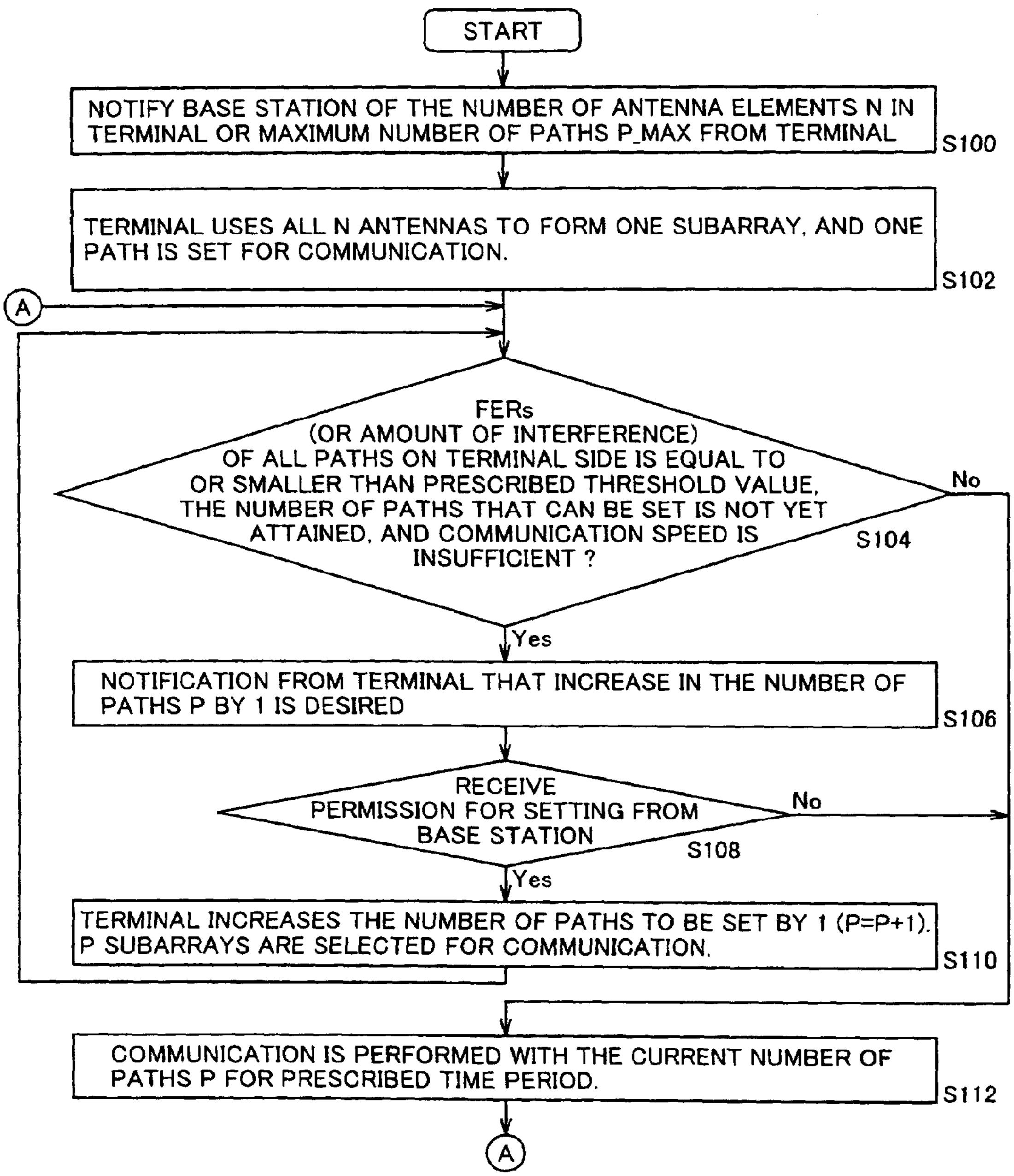

START
NOTIFY BASE STATION OF THE NUMBER OF ANTENNA ELEMENTS N IN TERMINAL OR MAXIMUM NUMBER OF PATHS P_MAX FROM TERMINAL
S100
TERMINAL USES ALL N ANTENNAS TO FORM ONE SUBARRAY, AND ONE PATH IS SET FOR COMMUNICATION.
S102
A
FERs (OR AMOUNT OF INTERFERENCE) OF ALL PATHS ON TERMINAL SIDE IS EQUAL TO OR SMALLER THAN PRESCRIBED THRESHOLD VALUE, THE NUMBER OF PATHS THAT CAN BE SET IS NOT YET ATTAINED, AND COMMUNICATION SPEED IS INSUFFICIENT ?
S104
No
Yes
NOTIFICATION FROM TERMINAL THAT INCREASE IN THE NUMBER OF PATHS P BY 1 IS DESIRED
S106
RECEIVE PERMISSION FOR SETTING FROM BASE STATION
S108
No
Yes
TERMINAL INCREASES THE NUMBER OF PATHS TO BE SET BY 1 (P=P+1). P SUBARRAYS ARE SELECTED FOR COMMUNICATION.
S110
COMMUNICATION IS PERFORMED WITH THE CURRENT NUMBER OF PATHS P FOR PRESCRIBED TIME PERIOD.
S112
A

FIG.8

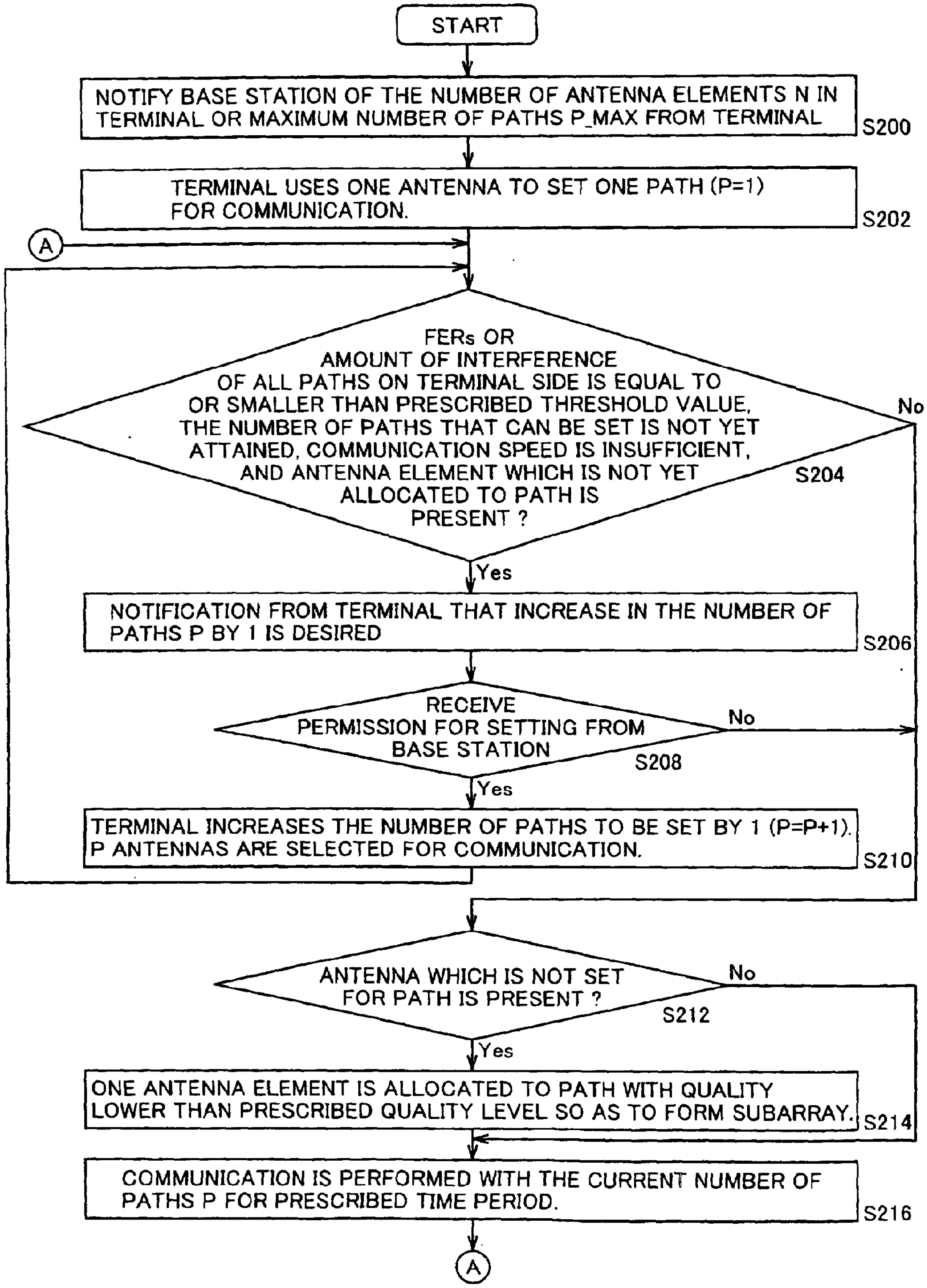

START
NOTIFY BASE STATION OF THE NUMBER OF ANTENNA ELEMENTS N IN TERMINAL OR MAXIMUM NUMBER OF PATHS P_MAX FROM TERMINAL
S200
TERMINAL USES ONE ANTENNA TO SET ONE PATH (P=1) FOR COMMUNICATION.
S202
A
FERs OR AMOUNT OF INTERFERENCE OF ALL PATHS ON TERMINAL SIDE IS EQUAL TO OR SMALLER THAN PRESCRIBED THRESHOLD VALUE, THE NUMBER OF PATHS THAT CAN BE SET IS NOT YET ATTAINED, COMMUNICATION SPEED IS INSUFFICIENT, AND ANTENNA ELEMENT WHICH IS NOT YET ALLOCATED TO PATH IS PRESENT ?
S204
No
Yes
NOTIFICATION FROM TERMINAL THAT INCREASE IN THE NUMBER OF PATHS P BY 1 IS DESIRED
S206
RECEIVE PERMISSION FOR SETTING FROM BASE STATION
S208
No
Yes
TERMINAL INCREASES THE NUMBER OF PATHS TO BE SET BY 1 (P=P+1). P ANTENNAS ARE SELECTED FOR COMMUNICATION.
S210
ANTENNA WHICH IS NOT SET FOR PATH IS PRESENT ?
S212
No
Yes
ONE ANTENNA ELEMENT IS ALLOCATED TO PATH WITH QUALITY LOWER THAN PRESCRIBED QUALITY LEVEL SO AS TO FORM SUBARRAY.
S214
COMMUNICATION IS PERFORMED WITH THE CURRENT NUMBER OF PATHS P FOR PRESCRIBED TIME PERIOD.
S216
A

FIG.9

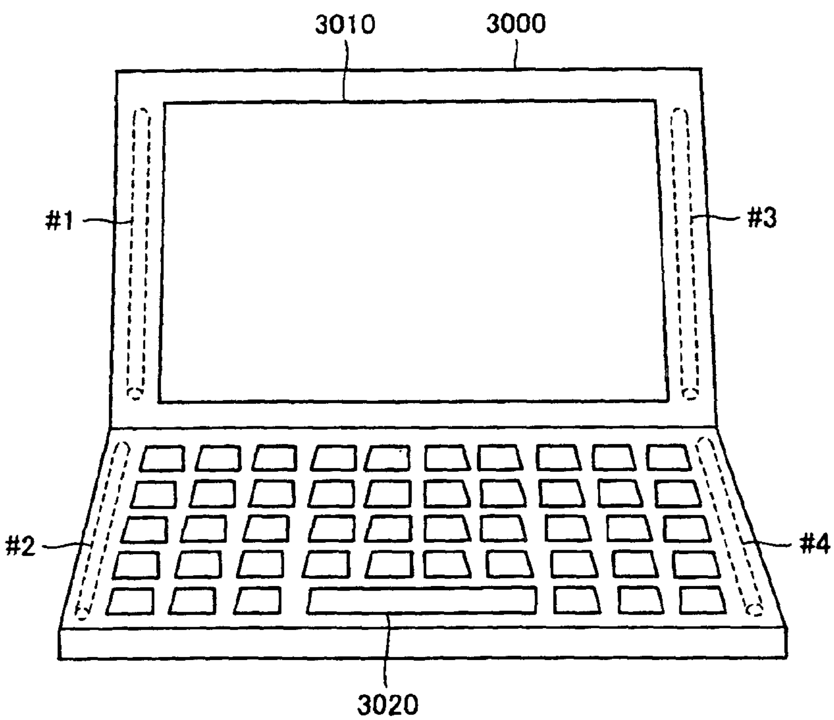


FIG.10

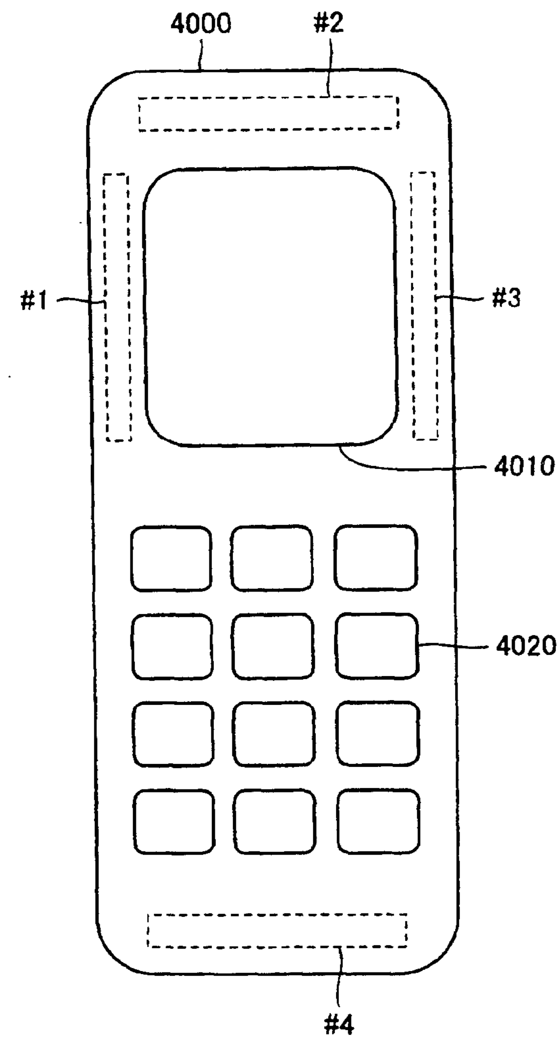


FIG.11

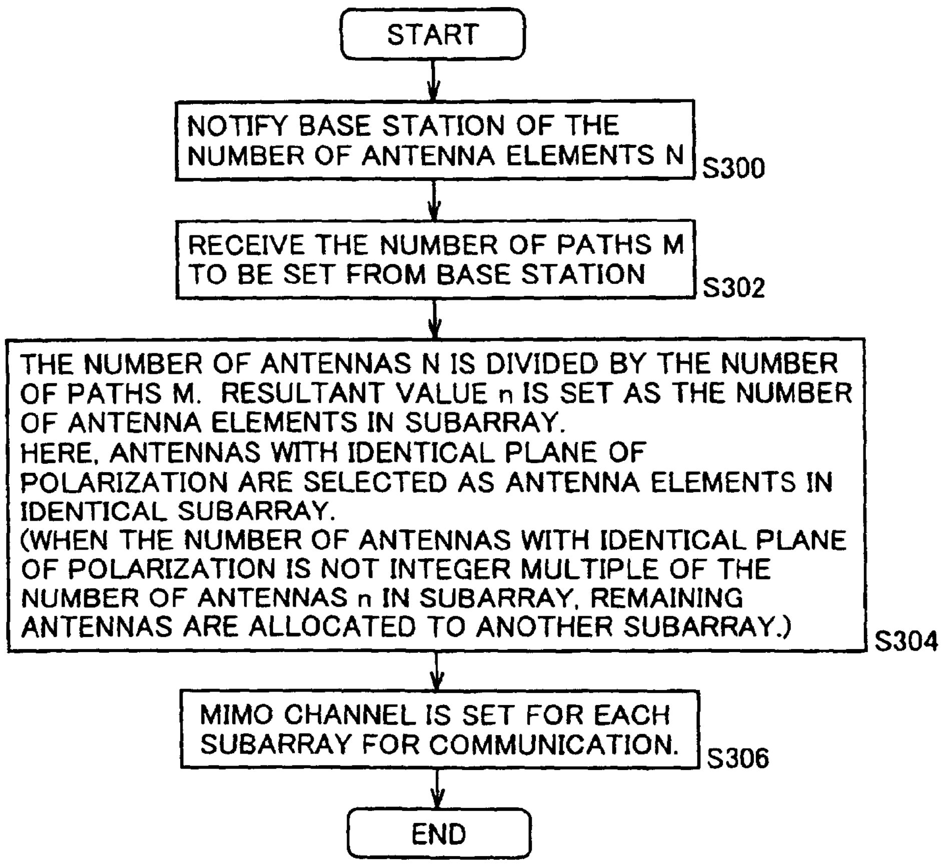

START
NOTIFY BASE STATION OF THE NUMBER OF ANTENNA ELEMENTS N
S300
RECEIVE THE NUMBER OF PATHS M TO BE SET FROM BASE STATION
S302
THE NUMBER OF ANTENNAS N IS DIVIDED BY THE NUMBER OF PATHS M. RESULTANT VALUE n IS SET AS THE NUMBER OF ANTENNA ELEMENTS IN SUBARRAY.
HERE, ANTENNAS WITH IDENTICAL PLANE OF POLARIZATION ARE SELECTED AS ANTENNA ELEMENTS IN IDENTICAL SUBARRAY.
(WHEN THE NUMBER OF ANTENNAS WITH IDENTICAL PLANE OF POLARIZATION IS NOT INTEGER MULTIPLE OF THE NUMBER OF ANTENNAS n IN SUBARRAY, REMAINING ANTENNAS ARE ALLOCATED TO ANOTHER SUBARRAY.)
S304
MIMO CHANNEL IS SET FOR EACH SUBARRAY FOR COMMUNICATION.
S306
END

FIG.12

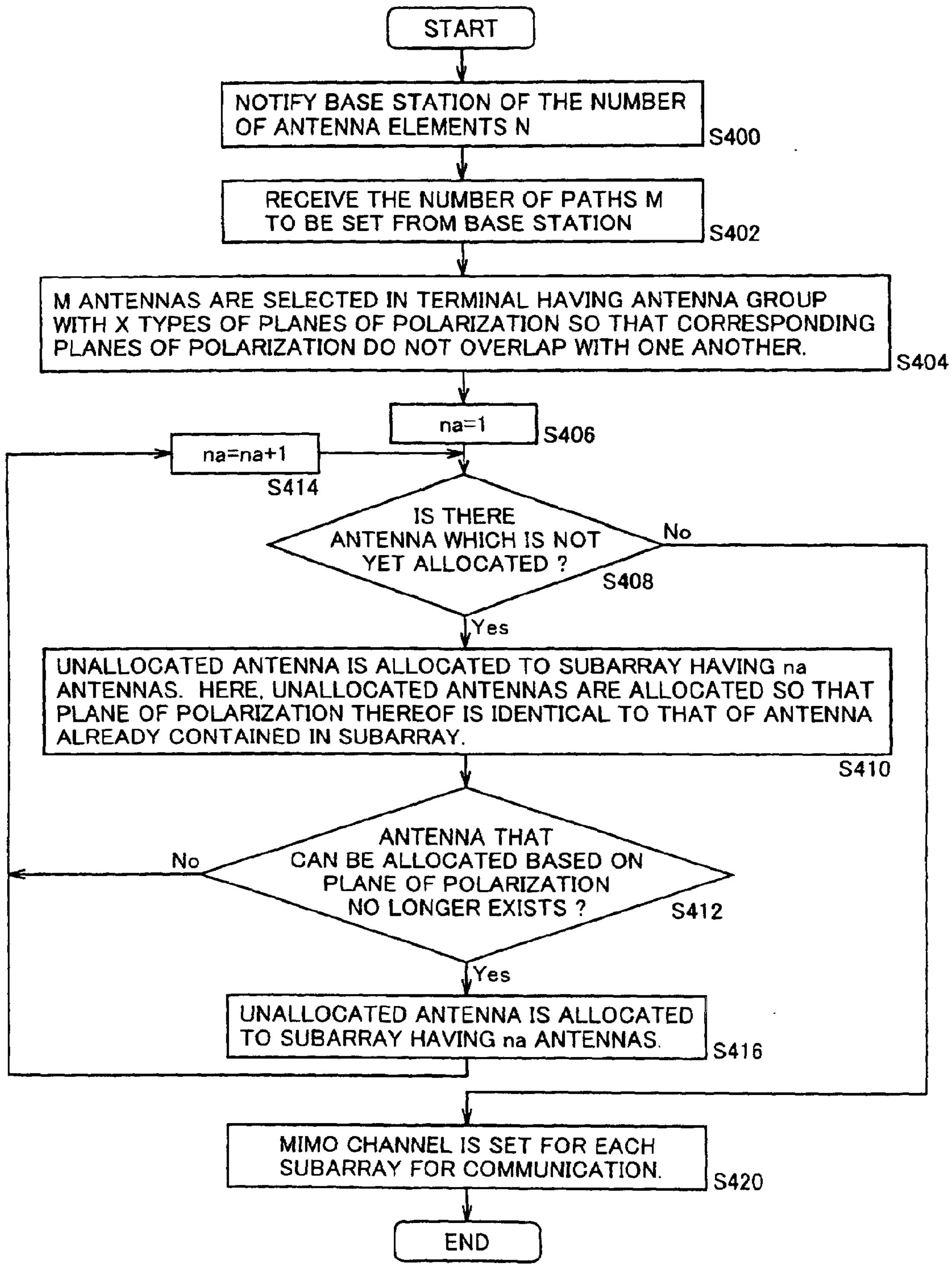

START
NOTIFY BASE STATION OF THE NUMBER OF ANTENNA ELEMENTS N
S400
RECEIVE THE NUMBER OF PATHS M TO BE SET FROM BASE STATION
S402
M ANTENNAS ARE SELECTED IN TERMINAL HAVING ANTENNA GROUP WITH X TYPES OF PLANES OF POLARIZATION SO THAT CORRESPONDING PLANES OF POLARIZATION DO NOT OVERLAP WITH ONE ANOTHER.
S404
na=1
S406
na=na+1
S414
IS THERE ANTENNA WHICH IS NOT YET ALLOCATED ?
S408
No
Yes
UNALLOCATED ANTENNA IS ALLOCATED TO SUBARRAY HAVING na ANTENNAS. HERE, UNALLOCATED ANTENNAS ARE ALLOCATED SO THAT PLANE OF POLARIZATION THEREOF IS IDENTICAL TO THAT OF ANTENNA ALREADY CONTAINED IN SUBARRAY.
S410
ANTENNA THAT CAN BE ALLOCATED BASED ON PLANE OF POLARIZATION NO LONGER EXISTS ?
S412
No
Yes
UNALLOCATED ANTENNA IS ALLOCATED TO SUBARRAY HAVING na ANTENNAS.
S416
MIMO CHANNEL IS SET FOR EACH SUBARRAY FOR COMMUNICATION.
S420
END

FIG.13

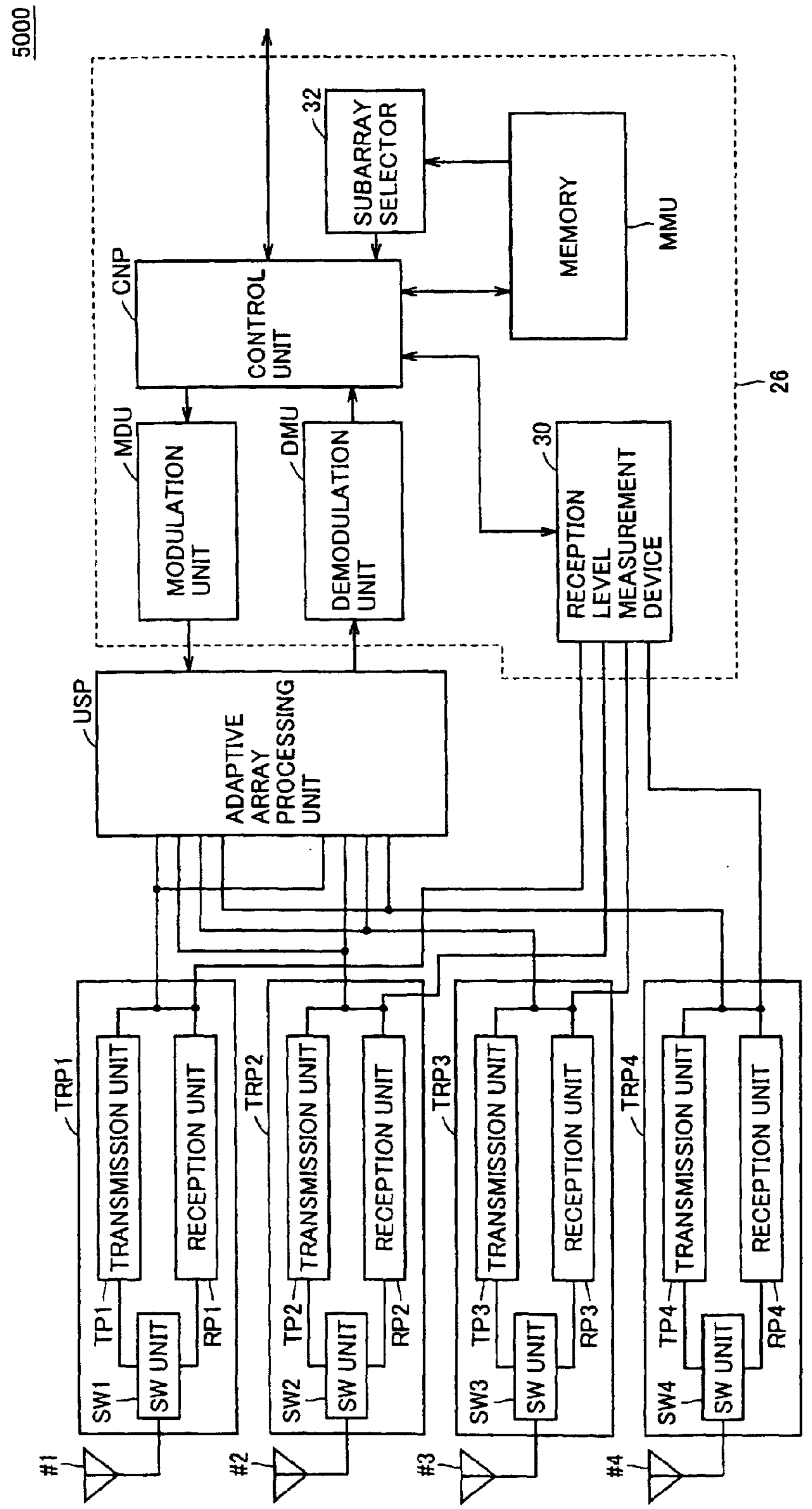

5000
26
CONTROL UNIT
CNP
SUBARRAY SELECTOR
32
MEMORY
MMU
MODULATION UNIT
MDU
DEMODULATION UNIT
DMU
RECEPTION LEVEL MEASUREMENT DEVICE
30
ADAPTIVE ARRAY PROCESSING UNIT
USP
TRP1
TRANSMISSION UNIT
RECEPTION UNIT
TP1
RP1
SW1
SW UNIT
#1
TRP2
TRANSMISSION UNIT
RECEPTION UNIT
TP2
RP2
SW2
SW UNIT
#2
TRP3
TRANSMISSION UNIT
RECEPTION UNIT
TP3
RP3
SW3
SW UNIT
#3
TRP4
TRANSMISSION UNIT
RECEPTION UNIT
TP4
RP4
SW4
SW UNIT
#4

FIG.14

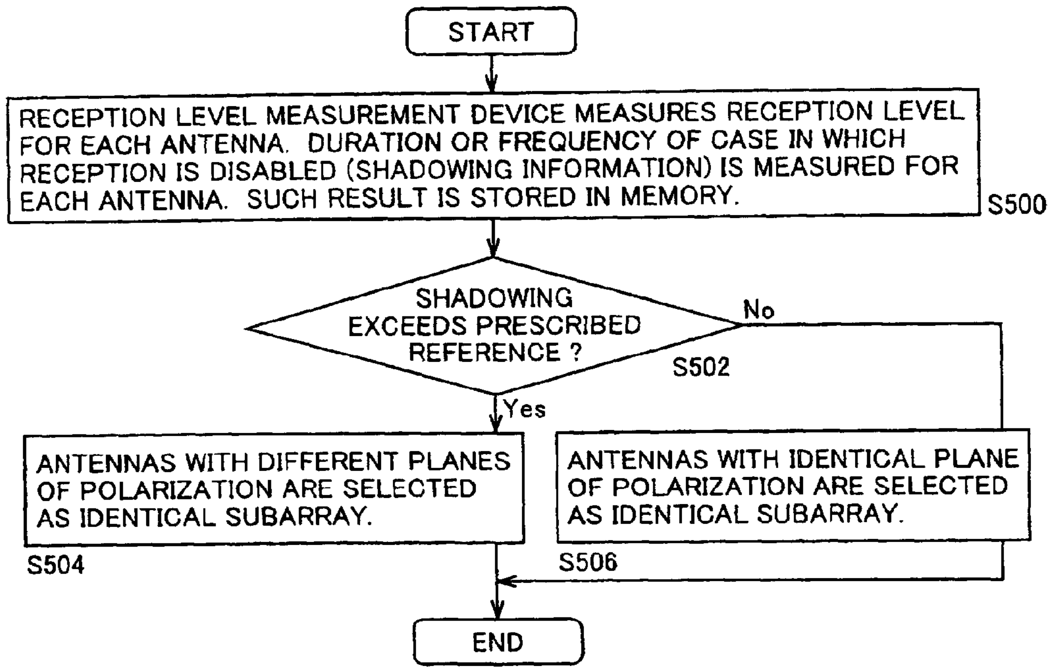

START
RECEPTION LEVEL MEASUREMENT DEVICE MEASURES RECEPTION LEVEL FOR EACH ANTENNA. DURATION OR FREQUENCY OF CASE IN WHICH RECEPTION IS DISABLED (SHADOWING INFORMATION) IS MEASURED FOR EACH ANTENNA. SUCH RESULT IS STORED IN MEMORY.
S500
SHADOWING EXCEEDS PRESCRIBED REFERENCE ?
S502
No
Yes
ANTENNAS WITH DIFFERENT PLANES OF POLARIZATION ARE SELECTED AS IDENTICAL SUBARRAY.
S504
ANTENNAS WITH IDENTICAL PLANE OF POLARIZATION ARE SELECTED AS IDENTICAL SUBARRAY.
S506
END

FIG.15

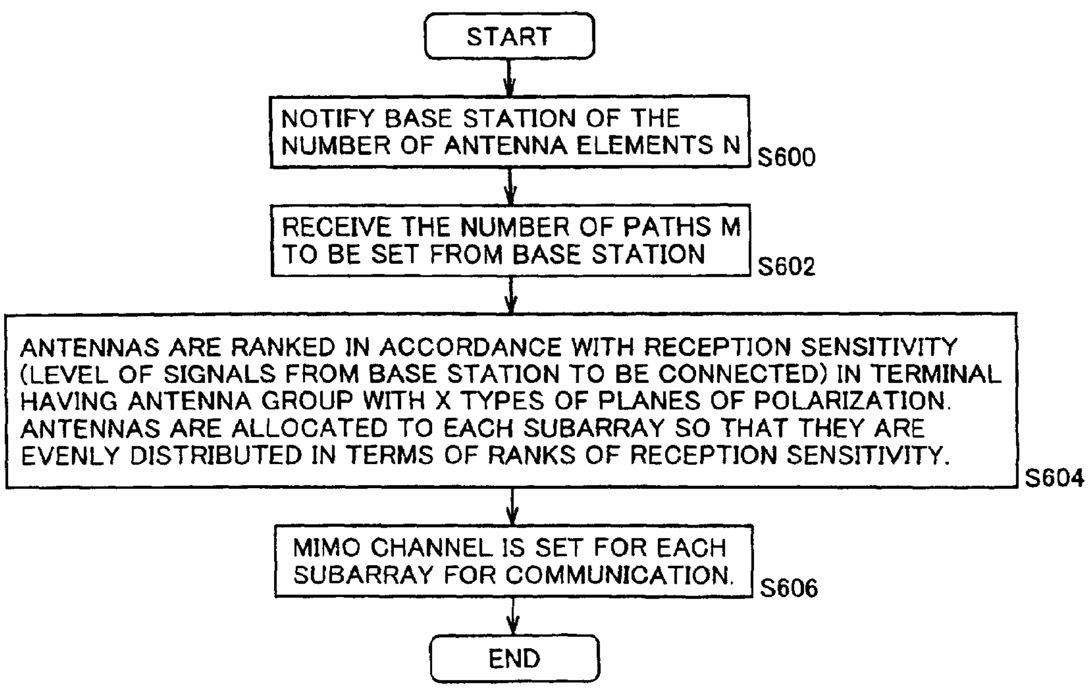

START
NOTIFY BASE STATION OF THE NUMBER OF ANTENNA ELEMENTS N
S600
RECEIVE THE NUMBER OF PATHS M TO BE SET FROM BASE STATION
S602
ANTENNAS ARE RANKED IN ACCORDANCE WITH RECEPTION SENSITIVITY (LEVEL OF SIGNALS FROM BASE STATION TO BE CONNECTED) IN TERMINAL HAVING ANTENNA GROUP WITH X TYPES OF PLANES OF POLARIZATION. ANTENNAS ARE ALLOCATED TO EACH SUBARRAY SO THAT THEY ARE EVENLY DISTRIBUTED IN TERMS OF RANKS OF RECEPTION SENSITIVITY.
S604
MIMO CHANNEL IS SET FOR EACH SUBARRAY FOR COMMUNICATION.
S606
END

FIG.16

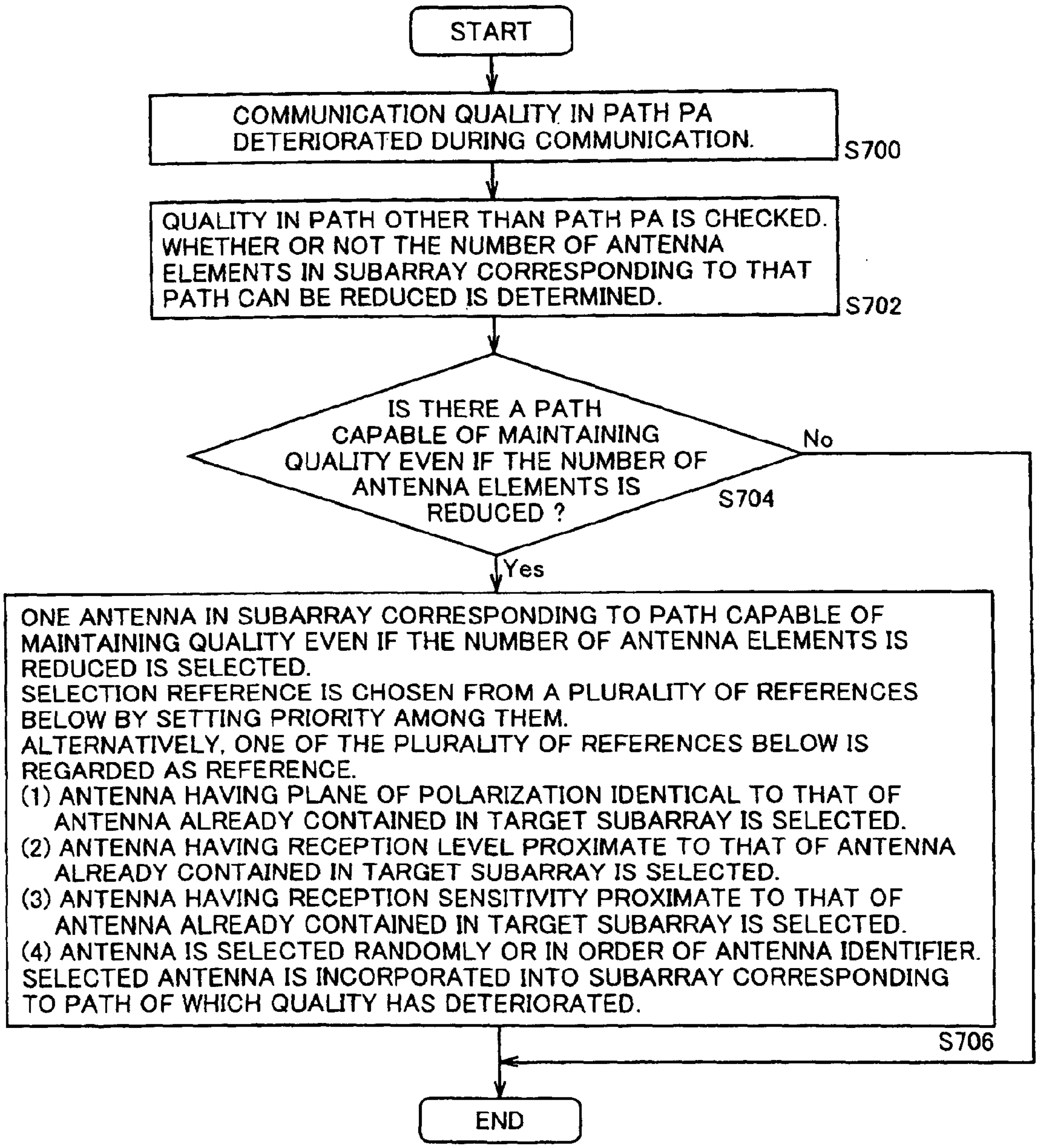
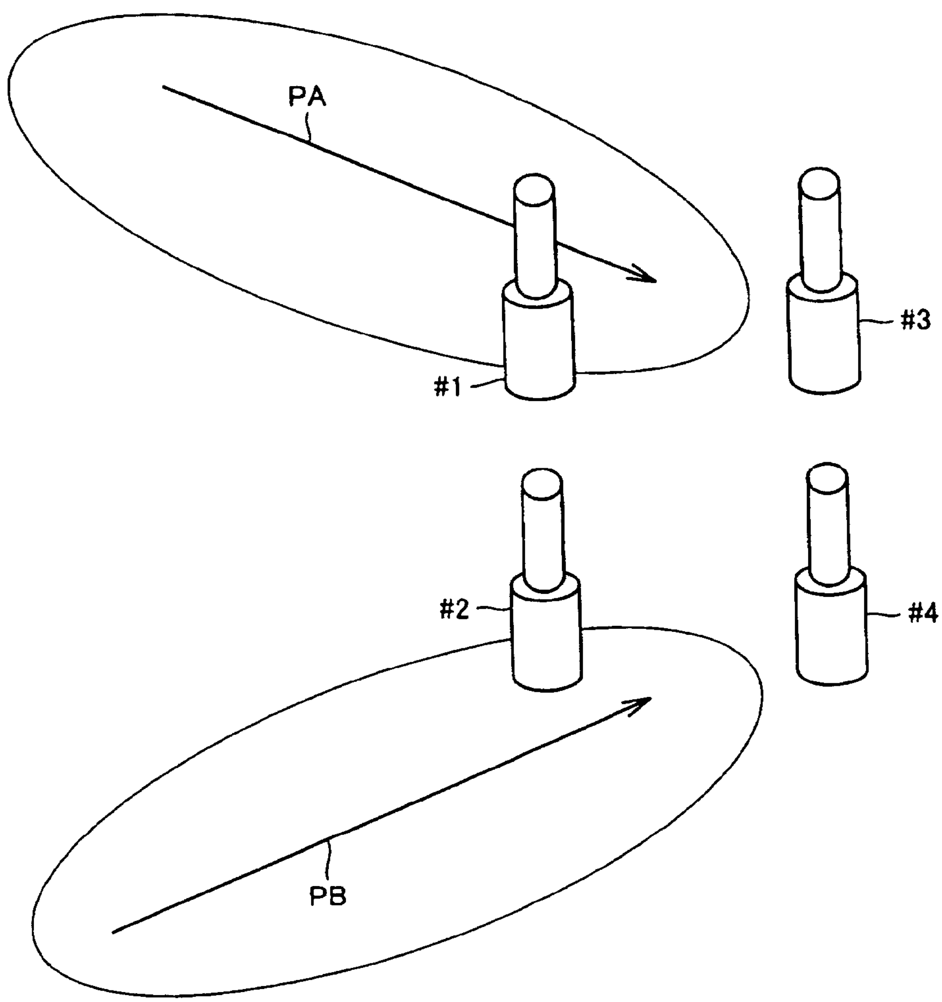

START
COMMUNICATION QUALITY IN PATH PA DETERIORATED DURING COMMUNICATION.
S700
QUALITY IN PATH OTHER THAN PATH PA IS CHECKED. WHETHER OR NOT THE NUMBER OF ANTENNA ELEMENTS IN SUBARRAY CORRESPONDING TO THAT PATH CAN BE REDUCED IS DETERMINED.
S702
IS THERE A PATH CAPABLE OF MAINTAINING QUALITY EVEN IF THE NUMBER OF ANTENNA ELEMENTS IS REDUCED ?
S704
No
Yes
ONE ANTENNA IN SUBARRAY CORRESPONDING TO PATH CAPABLE OF MAINTAINING QUALITY EVEN IF THE NUMBER OF ANTENNA ELEMENTS IS REDUCED IS SELECTED.
SELECTION REFERENCE IS CHOSEN FROM A PLURALITY OF REFERENCES BELOW BY SETTING PRIORITY AMONG THEM.
ALTERNATIVELY, ONE OF THE PLURALITY OF REFERENCES BELOW IS REGARDED AS REFERENCE.
(1) ANTENNA HAVING PLANE OF POLARIZATION IDENTICAL TO THAT OF ANTENNA ALREADY CONTAINED IN TARGET SUBARRAY IS SELECTED.
(2) ANTENNA HAVING RECEPTION LEVEL PROXIMATE TO THAT OF ANTENNA ALREADY CONTAINED IN TARGET SUBARRAY IS SELECTED.
(3) ANTENNA HAVING RECEPTION SENSITIVITY PROXIMATE TO THAT OF ANTENNA ALREADY CONTAINED IN TARGET SUBARRAY IS SELECTED.
(4) ANTENNA IS SELECTED RANDOMLY OR IN ORDER OF ANTENNA IDENTIFIER.
SELECTED ANTENNA IS INCORPORATED INTO SUBARRAY CORRESPONDING TO PATH OF WHICH QUALITY HAS DETERIORATED.
S706
END

FIG.17



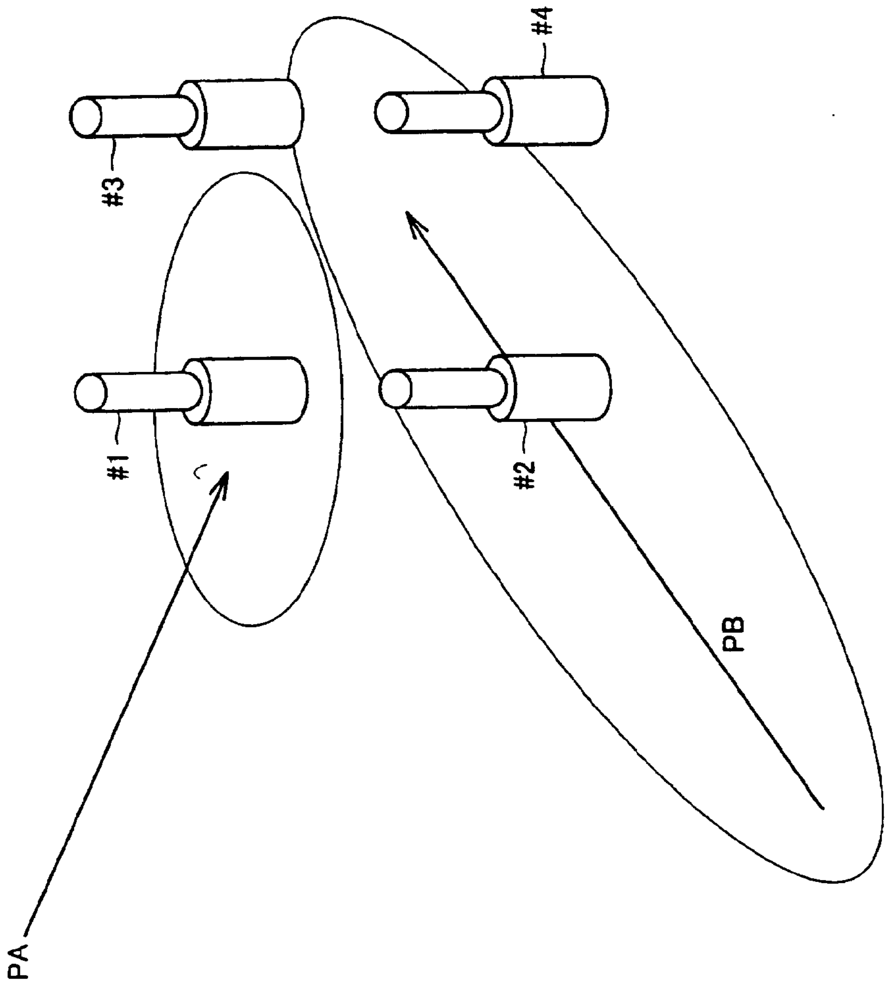


FIG.18

FIG.19

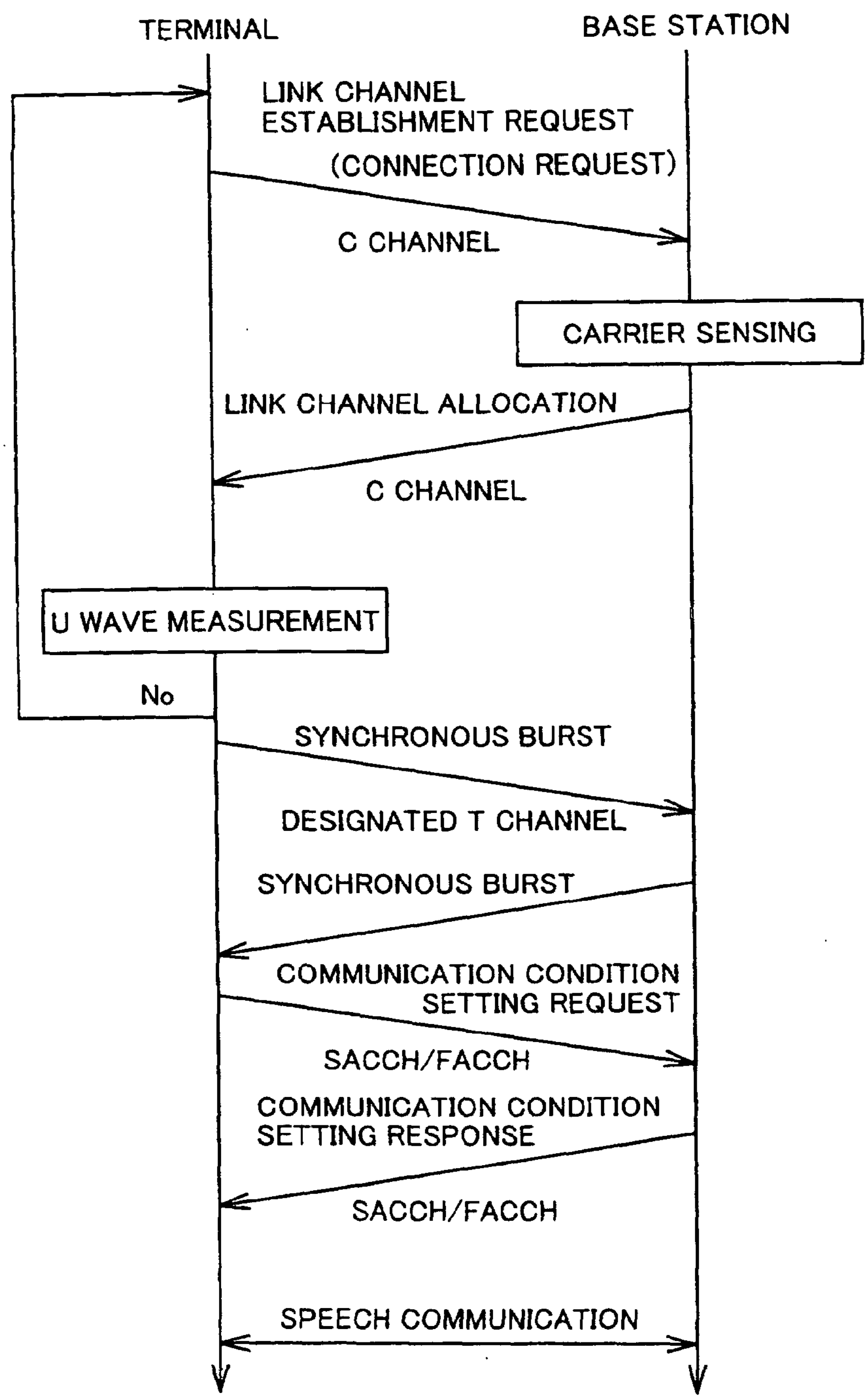

TERMINAL
BASE STATION
LINK CHANNEL
ESTABLISHMENT REQUEST
(CONNECTION REQUEST)
C CHANNEL
CARRIER SENSING
LINK CHANNEL ALLOCATION
C CHANNEL
U WAVE MEASUREMENT
No
SYNCHRONOUS BURST
DESIGNATED T CHANNEL
SYNCHRONOUS BURST
COMMUNICATION CONDITION
SETTING REQUEST
SACCH/FACCH
COMMUNICATION CONDITION
SETTING RESPONSE
SACCH/FACCH
SPEECH COMMUNICATION

FIG.20A

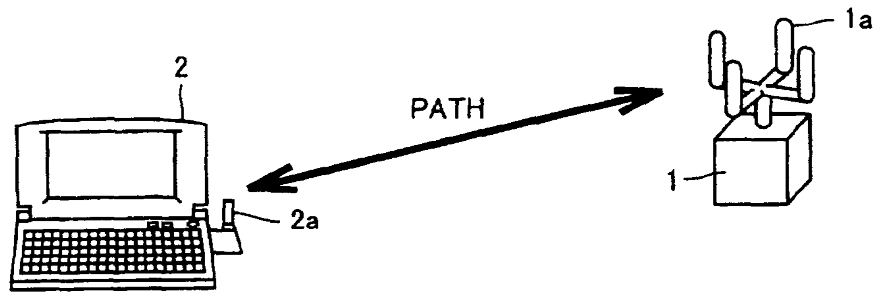


FIG.20B

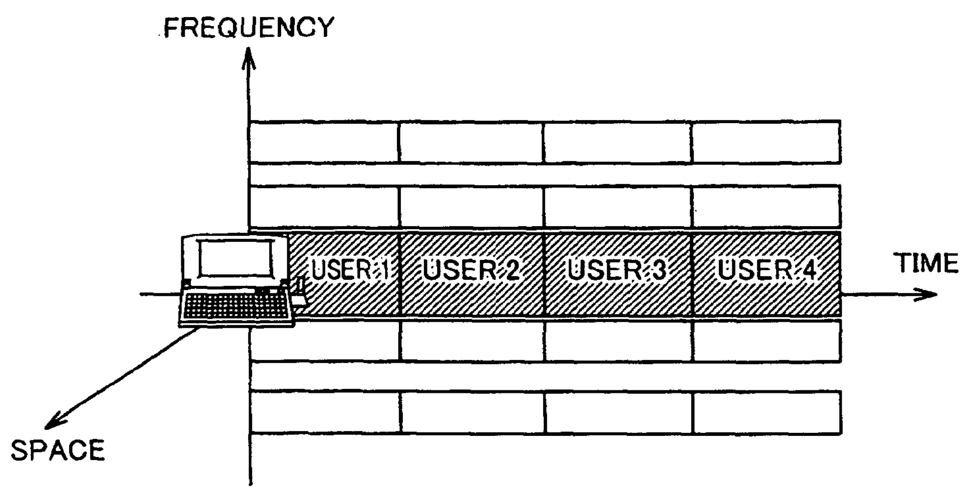


FIG.21

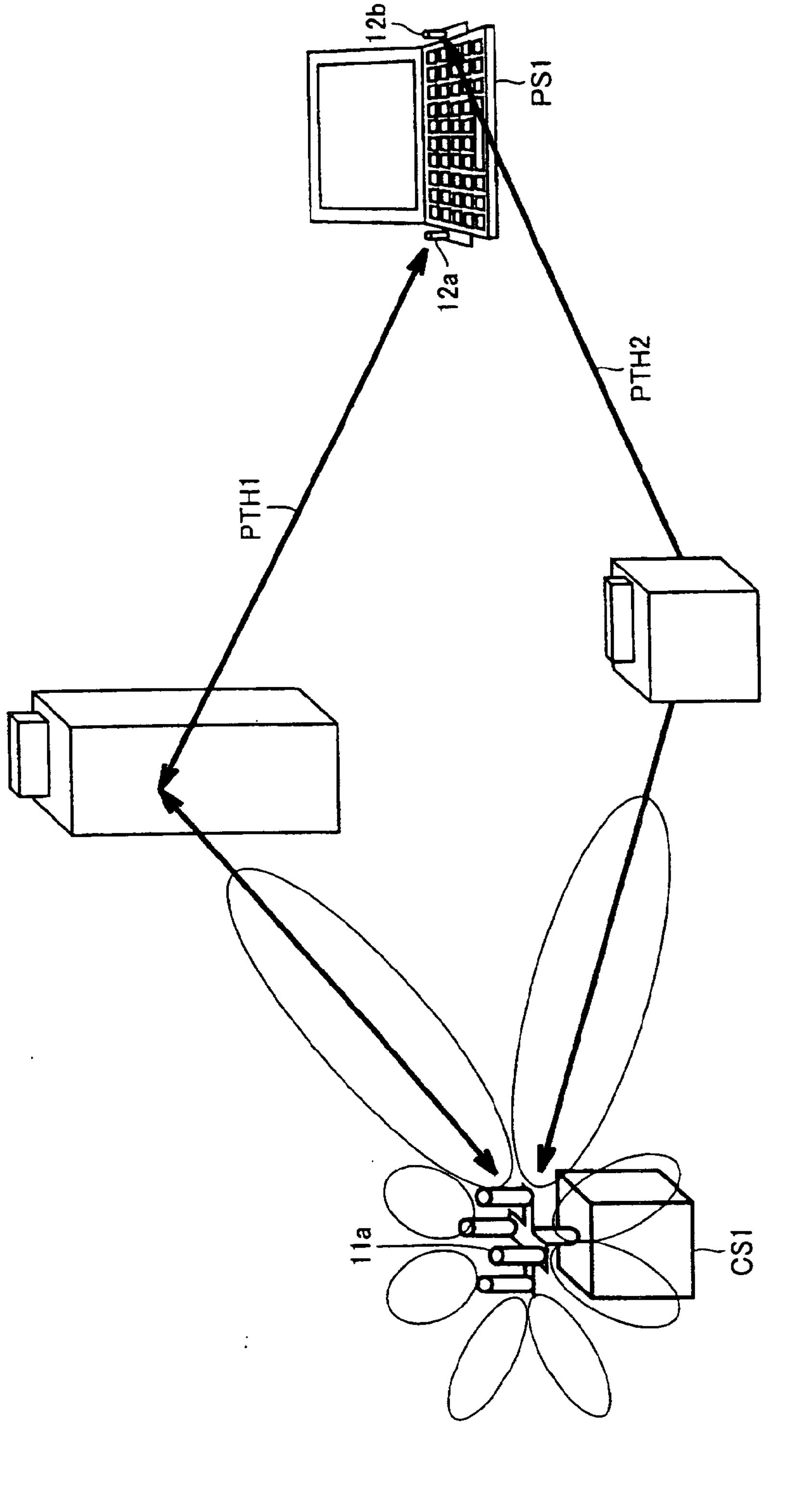
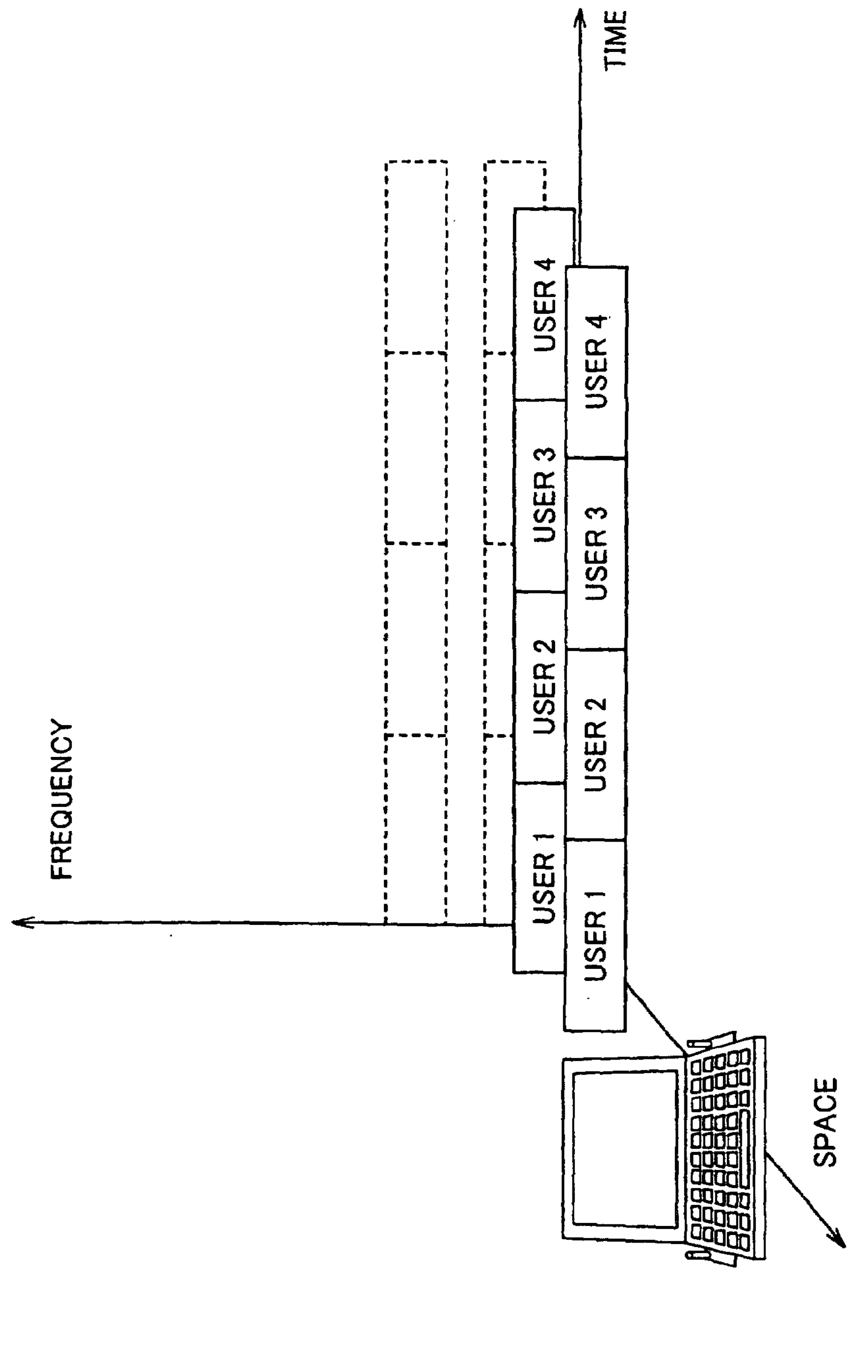


FIG.22


TIME
FREQUENCY
USER 1
USER 2
USER 3
USER 4
USER 1
USER 2
USER 3
USER 4
SPACE

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP03/02883

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[7] H04B7/10, H04B7/26, H01Q3/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[7] H04B7/02-7/12, H04L1/02-1/06, H04B7/24-7/26, H04Q7/00-7/38, H01Q3/26

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2003
Kokai Jitsuyo Shinan Koho	1971-2003	Toroku Jitsuyo Shinan Koho	1994-2003

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 5-291814 A (Mitsubishi Electric Corp.), 05 November, 1993 (05.11.93), Full text; Figs. 1 to 12 (Family: none)	1-27
A	JP 8-279780 A (Nippon Telegraph And Telephone Corp.), 22 October, 1996 (22.10.96), Full text; Figs. 1 to 9 (Family: none)	1-27
A	JP 2002-34064 A (Pioneer Electronic Corp.), 31 January, 2002 (31.01.02), Full text; Figs. 1 to 27 & EP 1180904 A1 & US 2002/49063 A1	1-27

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 09 June, 2003 (09.06.03)	Date of mailing of the international search report 24 June, 2003 (24.06.03)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1998)

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
2 March 2006 (02.03.2006)

PCT

(10) **International Publication Number**
WO 2006/023247 A1

(51) **International Patent Classification:**
H01Q 9/04 (2006.01)

(21) **International Application Number:** PCT/US2005/027023

(22) **International Filing Date:** 28 July 2005 (28.07.2005)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
60/602,711 18 August 2004 (18.08.2004) US
60/603,157 18 August 2004 (18.08.2004) US
11/010,076 9 December 2004 (09.12.2004) US

(71) **Applicant** *(for all designated States except US)*: **VIDEO54 TECHNOLOGIES, INC.** [US/US]; Building A, 1st Floor, 883 N Shoreline Blvd., Mountain View, California 94043 (US).

(72) **Inventors; and**
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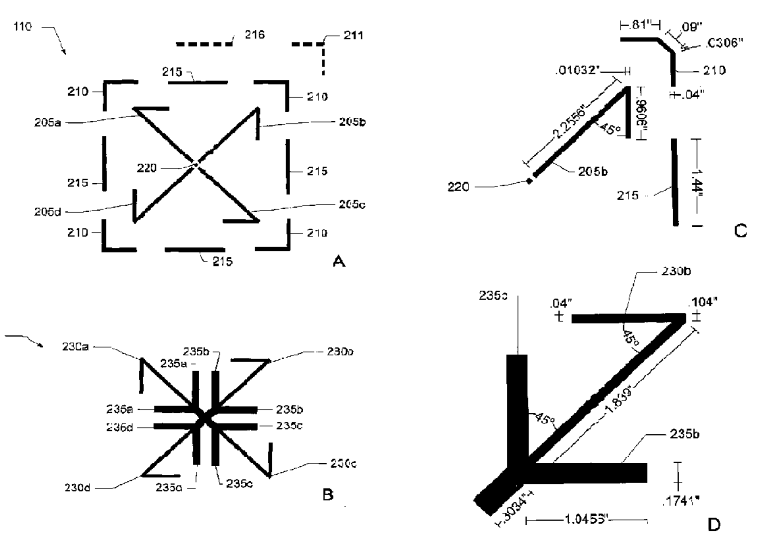
(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

[Continued on next page]

(54) **Title:** SYSTEM AND METHOD FOR AN OMNIDIRECTIONAL PLANAR ANTENNA APPARATUS WITH SELECTABLE ELEMENTS



(57) **Abstract:** A system and method for a wireless link to a remote receiver includes a communication device for generating RF and a planar antenna apparatus for transmitting the RF. The planar antenna apparatus includes selectable antenna elements, each of which has gain and a directional radiation pattern. The directional radiation pattern is substantially in the plane of the antenna apparatus. Switching different antenna elements results in a configurable radiation pattern. Alternatively, selecting all or substantially all elements results in an omnidirectional radiation pattern. One or more directors and/or one or more reflectors may be included to constrict the directional radiation pattern. The antenna apparatus may be conformally mounted to a housing containing the communication device and the antenna apparatus.

WO 2006/023247 A1

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

SYSTEM AND METHOD FOR AN OMNIDIRECTIONAL PLANAR ANTENNA APPARATUS WITH SELECTABLE ELEMENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[01] This application claims the benefit of U.S. Provisional Application no. 60/602,711 titled "Planar Antenna Apparatus for Isotropic Coverage and QoS Optimization in Wireless Networks," filed August 18, 2004, which is hereby incorporated by reference; and U.S. Provisional Application no. 60/603,157 titled "Software for Controlling a Planar Antenna Apparatus for Isotropic Coverage and QoS Optimization in Wireless Networks," filed August 18, 2004, which is hereby incorporated by reference.

BACKGROUND OF INVENTION

1. Field of the Invention

[02] The present invention relates generally to wireless communications networks, and more particularly to a system and method for an omnidirectional planar antenna apparatus with selectable elements.

2. Description of the Prior Art

[03] In communications systems, there is an ever-increasing demand for higher data throughput, and a corresponding drive to reduce interference that can disrupt data communications. For example, in an IEEE 802.11 network, an access point (i.e., base station) communicates data with one or more remote receiving nodes (e.g., a network interface card) over a wireless link. The wireless link may be susceptible to interference from other access points, other radio transmitting devices, changes or disturbances in the

wireless link environment between the access point and the remote receiving node, and so on. The interference may be such to degrade the wireless link, for example by forcing communication at a lower data rate, or may be sufficiently strong to completely disrupt the wireless link.

[04] One solution for reducing interference in the wireless link between the access point and the remote receiving node is to provide several omnidirectional antennas for the access point, in a "diversity" scheme. For example, a common configuration for the access point comprises a data source coupled via a switching network to two or more physically separated omnidirectional antennas. The access point may select one of the omnidirectional antennas by which to maintain the wireless link. Because of the separation between the omnidirectional antennas, each antenna experiences a different signal environment, and each antenna contributes a different interference level to the wireless link. The switching network couples the data source to whichever of the omnidirectional antennas experiences the least interference in the wireless link.

[05] However, one problem with using two or more omnidirectional antennas for the access point is that typical omnidirectional antennas are vertically polarized. Vertically polarized radio frequency (RF) energy does not travel as efficiently as horizontally polarized RF energy inside a typical office or dwelling space, additionally, most of the laptop computer wireless cards have horizontally polarized antennas. Typical solutions for creating horizontally polarized RF antennas to date have been expensive to manufacture, or do not provide adequate RF performance to be commercially successful.

[06] A further problem is that the omnidirectional antenna typically comprises an upright wand attached to a housing of the access point. The wand typically comprises a

hollow metallic rod exposed outside of the housing, and may be subject to breakage or damage. Another problem is that each omnidirectional antenna comprises a separate unit of manufacture with respect to the access point, thus requiring extra manufacturing steps to include the omnidirectional antennas in the access point.

[07] A still further problem with the two or more omnidirectional antennas is that because the physically separated antennas may still be relatively close to each other, each of the several antennas may experience similar levels of interference and only a relatively small reduction in interference may be gained by switching from one omnidirectional antenna to another omnidirectional antenna.

[08] Another solution to reduce interference involves beam steering with an electronically controlled phased array antenna. However, the phased array antenna can be extremely expensive to manufacture. Further, the phased array antenna can require many phase tuning elements that may drift or otherwise become maladjusted.

SUMMARY OF INVENTION

[09] An antenna apparatus comprises a substrate having a first side and a second side substantially parallel to the first side. Each of a plurality of antenna elements on the first side are configured to be selectively coupled to a communication device and form a first portion of a modified dipole having a directional radiation pattern. A ground component on the second side is configured to form a second portion of the modified dipole. In some embodiments, each of the plurality of antenna elements is on the same side of the substrate.

[010] In some embodiments, an antenna element selecting device may selectively couple one or more of the antenna elements to the communication device. The antenna apparatus may form an omnidirectional radiation pattern when two or more of the antenna elements are coupled to the communication device. The antenna element may comprise one or more reflectors and/or directors configured to concentrate the directional radiation pattern of one or more of the modified dipoles. A combined radiation pattern resulting from two or more antenna elements being coupled to the communication device may be more directional or less directional than the radiation pattern of a single antenna element. The combined radiation pattern may also be offset in direction. The plurality of antenna elements may be conformally mounted to a housing containing the communication device and the antenna apparatus.

[011] A system comprises a communication device for generating a radio frequency signal, a first means for generating a first directional radiation pattern, a second means for generating a second directional radiation pattern, and a selecting means for receiving a radio frequency signal from the communication device and selectively coupling the first

means and/or the second means to the communication device. The second directional radiation pattern may be offset in direction from the first directional radiation pattern. In some embodiments, the second directional radiation pattern may be more directional than the first directional radiation pattern, less directional than the first directional radiation pattern, or offset in direction and directivity as the first directional radiation pattern. The first means and the second means may form an omnidirectional radiation pattern when coupled to the communication device. The system may include means for concentrating the directional radiation pattern of the first means.

[012] A method comprises generating the radio frequency signal in the communication device and coupling at least one of the plurality of coplanar antenna elements to the communication device to result in the directional radiation pattern substantially in the plane of the antenna elements. The method may comprise coupling two or more of the plurality of coplanar antenna elements to the communication device to result in an omnidirectional radiation pattern. The method may comprise concentrating the directional radiation pattern with one or more directors and/or reflectors. Coupling at least one of the plurality of coplanar antenna elements to the communication device may comprise biasing a PIN diode or virtually any other means of switching RF energy. The method may comprise coupling at least two of the plurality of coplanar antenna elements to the communication device to result in a more directional radiation pattern. The method may further comprise coupling at least two of the plurality of coplanar antenna elements to the communication device to result in a less directional radiation pattern.

BRIEF DESCRIPTION OF DRAWINGS

[013] The present invention will now be described with reference to drawings that represent a preferred embodiment of the invention. In the drawings, like components have the same reference numerals. The illustrated embodiment is intended to illustrate, but not to limit the invention. The drawings include the following figures:

[014] FIG. 1 illustrates a system comprising an omnidirectional planar antenna apparatus with selectable elements, in one embodiment in accordance with the present invention;

[015] FIG. 2A and FIG. 2B illustrate the planar antenna apparatus of FIG. 1, in one embodiment in accordance with the present invention;

[016] FIGs. 2C and 2D illustrate dimensions for several components of the planar antenna apparatus of FIG. 1, in one embodiment in accordance with the present invention;

[017] FIG. 3A illustrates various radiation patterns resulting from selecting different antenna elements of the planar antenna apparatus of FIG. 2, in one embodiment in accordance with the present invention;

[018] FIG. 3B illustrates an elevation radiation pattern for the planar antenna apparatus of FIG. 2, in one embodiment in accordance with the present invention; and

[019] FIG. 4A and FIG. 4B illustrate an alternative embodiment of the planar antenna apparatus 110 of FIG. 1, in accordance with the present invention.

DETAILED DESCRIPTION

[020] A system for a wireless (i.e., radio frequency or RF) link to a remote receiving device includes a communication device for generating an RF signal and a planar antenna apparatus for transmitting and/or receiving the RF signal. The planar antenna apparatus includes selectable antenna elements. Each of the antenna elements provides gain (with respect to isotropic) and a directional radiation pattern substantially in the plane of the antenna elements. Each antenna element may be electrically selected (e.g., switched on or off) so that the planar antenna apparatus may form a configurable radiation pattern. If all elements are switched on, the planar antenna apparatus forms an omnidirectional radiation pattern. In some embodiments, if two or more of the elements is switched on, the planar antenna apparatus may form a substantially omnidirectional radiation pattern.

[021] Advantageously, the system may select a particular configuration of selected antenna elements that minimizes interference over the wireless link to the remote receiving device. If the wireless link experiences interference, for example due to other radio transmitting devices, or changes or disturbances in the wireless link between the system and the remote receiving device, the system may select a different configuration of selected antenna elements to change the resulting radiation pattern and minimize the interference. The system may select a configuration of selected antenna elements corresponding to a maximum gain between the system and the remote receiving device. Alternatively, the system may select a configuration of selected antenna elements corresponding to less than maximal gain, but corresponding to reduced interference in the wireless link.

[022] As described further herein, the planar antenna apparatus radiates the directional radiation pattern substantially in the plane of the antenna elements. When mounted horizontally, the RF signal transmission is horizontally polarized, so that RF signal transmission indoors is enhanced as compared to a vertically polarized antenna. The planar antenna apparatus is easily manufactured from common planar substrates such as an FR4 printed circuit board (PCB). Further, the planar antenna apparatus may be integrated into or conformally mounted to a housing of the system, to minimize cost and to provide support for the planar antenna apparatus.

[023] FIG. 1 illustrates a system 100 comprising an omnidirectional planar antenna apparatus with selectable elements, in one embodiment in accordance with the present invention. The system 100 may comprise, for example without limitation, a transmitter and/or a receiver, such as an 802.11 access point, an 802.11 receiver, a set-top box, a laptop computer, a television, a PCMCIA card, a remote control, and a remote terminal such as a handheld gaming device. In some exemplary embodiments, the system 100 comprises an access point for communicating to one or more remote receiving nodes (not shown) over a wireless link, for example in an 802.11 wireless network. Typically, the system 100 may receive data from a router connected to the Internet (not shown), and the system 100 may transmit the data to one or more of the remote receiving nodes. The system 100 may also form a part of a wireless local area network by enabling communications among several remote receiving nodes. Although the disclosure will focus on a specific embodiment for the system 100, aspects of the invention are applicable to a wide variety of appliances, and are not intended to be limited to the disclosed embodiment. For example, although the system 100 may be described as

transmitting to the remote receiving node via the planar antenna apparatus, the system 100 may also receive data from the remote receiving node via the planar antenna apparatus.

[024] The system 100 includes a communication device 120 (e.g., a transceiver) and a planar antenna apparatus 110. The communication device 120 comprises virtually any device for generating and/or receiving an RF signal. The communication device 120 may include, for example, a radio modulator/demodulator for converting data received into the system 100 (e.g., from the router) into the RF signal for transmission to one or more of the remote receiving nodes. In some embodiments, for example, the communication device 120 comprises well-known circuitry for receiving data packets of video from the router and circuitry for converting the data packets into 802.11 compliant RF signals.

[025] As described further herein, the planar antenna apparatus 110 comprises a plurality of individually selectable planar antenna elements. Each of the antenna elements has a directional radiation pattern with gain (as compared to an omnidirectional antenna). Each of the antenna elements also has a polarization substantially in the plane of the planar antenna apparatus 110. The planar antenna apparatus 110 may include an antenna element selecting device configured to selectively couple one or more of the antenna elements to the communication device 120.

[026] FIG. 2A and FIG. 2B illustrate the planar antenna apparatus 110 of FIG. 1, in one embodiment in accordance with the present invention. The planar antenna apparatus 110 of this embodiment includes a substrate (considered as the plane of FIGs. 2A and 2B) having a first side (e.g., FIG. 2A) and a second side (e.g., FIG. 2B) substantially parallel to the first side. In some embodiments, the substrate comprises a PCB such as FR4, Rogers 4003, or other dielectric material.

[027] On the first side of the substrate, the planar antenna apparatus 110 of FIG. 2A includes a radio frequency feed port 220 and four antenna elements 205a-205d. As described with respect to FIG. 4, although four antenna elements are depicted, more or fewer antenna elements are contemplated. Although the antenna elements 205a-205d of FIG. 2A are oriented substantially on diagonals of a square shaped planar antenna so as to minimize the size of the planar antenna apparatus 110, other shapes are contemplated. Further, although the antenna elements 205a-205d form a radially symmetrical layout about the radio frequency feed port 220, a number of non-symmetrical layouts, rectangular layouts, and layouts symmetrical in only one axis, are contemplated. Furthermore, the antenna elements 205a-205d need not be of identical dimension, although depicted as such in FIG. 2A.

[028] On the second side of the substrate, as shown in FIG. 2B, the planar antenna apparatus 110 includes a ground component 225. It will be appreciated that a portion (e.g., the portion 230a) of the ground component 225 is configured to form an arrow-shaped bent dipole in conjunction with the antenna element 205a. The resultant bent dipole provides a directional radiation pattern substantially in the plane of the planar antenna apparatus 110, as described further with respect to FIG. 3.

[029] FIGs. 2C and 2D illustrate dimensions for several components of the planar antenna apparatus 110, in one embodiment in accordance with the present invention. It will be appreciated that the dimensions of the individual components of the planar antenna apparatus 110 (e.g., the antenna element 205a, the portion 230a of the ground component 205) depend upon a desired operating frequency of the planar antenna apparatus 110. The dimensions of the individual components may be established by use of RF simulation software, such as IE3D from Zeland Software of Fremont, CA. For example, the planar antenna apparatus 110 incorporating the components of dimension according to FIGs. 2C and 2D is designed for operation near 2.4GHz, based on a substrate PCB of Rogers 4003 material, but it will be appreciated by an antenna designer of ordinary skill that a different substrate having different dielectric properties, such as FR4, may require different dimensions than those shown in FIGs. 2C and 2D.

[030] As shown in FIG. 2, the planar antenna apparatus 110 may optionally include one or more directors 210, one or more gain directors 215, and/or one or more Y-shaped reflectors 235 (e.g., the Y-shaped reflector 235b depicted in FIGs. 2B and 2D). The directors 210, the gain directors 215, and the Y-shaped reflectors 235 comprise passive elements that concentrate the directional radiation pattern of the dipoles formed by the antenna elements 205a-205d in conjunction with the portions 230a-230d. In one embodiment, providing a director 210 for each antenna element 205a-205d yields an additional 1-2 dB of gain for each dipole. It will be appreciated that the directors 210 and/or the gain directors 215 may be placed on either side of the substrate. In some embodiments, the portion of the substrate for the directors 210 and/or gain directors 215 is scored so that the directors 210 and/or gain directors 215 may be removed. It will also be appreciated that additional directors (depicted in a position shown by dashed line 211 for the antenna element 205b) and/or additional gain directors (depicted in a position shown by a dashed line 216) may be included to further concentrate the directional radiation pattern of one or more of the dipoles. The Y-shaped reflectors 235 will be further described herein.

[031] The radio frequency feed port 220 is configured to receive an RF signal from and/or transmit an RF signal to the communication device 120 of FIG. 1. An antenna element selector (not shown) may be used to couple the radio frequency feed port 220 to one or more of the antenna elements 205a-205d. The antenna element selector may comprise an RF switch (not shown), such as a PIN diode, a GaAs FET, or virtually any RF switching device, as is well known in the art.

[032] In the embodiment of FIG. 2A, the antenna element selector comprises four PIN diodes, each PIN diode connecting one of the antenna elements 205a-205d to the radio frequency feed port 220. In this embodiment, the PIN diode comprises a single-pole single-throw switch to switch each antenna element either on or off (i.e., couple or decouple each of the antenna elements 205a-205d to the radio frequency feed port 220). In one embodiment, a series of control signals (not shown) is used to bias each PIN diode. With the PIN diode forward biased and conducting a DC current, the PIN diode switch is on, and the corresponding antenna element is selected. With the diode reverse biased, the PIN diode switch is off. In this embodiment, the radio frequency feed port 220 and the PIN diodes of the antenna element selector are on the side of the substrate with the antenna elements 205a-205d, however, other embodiments separate the radio frequency feed port 220, the antenna element selector, and the antenna elements 205a-205d. In some embodiments, the antenna element selector comprises one or more single-pole multiple-throw switches. In some embodiments, one or more light emitting diodes (not shown) are coupled to the antenna element selector as a visual indicator of which of

the antenna elements 205a-205d is on or off. In one embodiment, a light emitting diode is placed in circuit with the PIN diode so that the light emitting diode is lit when the corresponding antenna element 205 is selected.

[033] In some embodiments, the antenna components (e.g., the antenna elements 205a-205d, the ground component 225, the directors 210, and the gain directors 215) are formed from RF conductive material. For example, the antenna elements 205a-205d and the ground component 225 may be formed from metal or other RF conducting foil. Rather than being provided on opposing sides of the substrate as shown in FIGs. 2A and 2B, each antenna element 205a-205d is coplanar with the ground component 225. In some embodiments, the antenna components may be conformally mounted to the housing of the system 100. In such embodiments, the antenna element selector comprises a separate structure (not shown) from the antenna elements 205a-205d. The antenna element selector may be mounted on a relatively small PCB, and the PCB may be electrically coupled to the antenna elements 205a-205d. In some embodiments, the switch PCB is soldered directly to the antenna elements 205a-205d.

[034] In the embodiment of FIG. 2B, the Y-shaped reflectors 235 (e.g., the reflectors 235a) may be included as a portion of the ground component 225 to broaden a frequency response (i.e., bandwidth) of the bent dipole (e.g., the antenna element 205a in conjunction with the portion 230a of the ground component 225). For example, in some embodiments, the planar antenna apparatus 110 is designed to operate over a frequency range of about 2.4GHz to 2.4835GHz, for wireless LAN in accordance with the IEEE 802.11 standard. The reflectors 235a-235d broaden the frequency response of each dipole to about 300 MHz (12.5% of the center frequency) to 500 MHz (~20% of the center frequency). The combined operational bandwidth of the planar antenna apparatus 110 resulting from coupling more than one of the antenna elements 205a-205d to the radio frequency feed port 220 is less than the bandwidth resulting from coupling only one of the antenna elements 205a-205d to the radio frequency feed port 220. For example, with all four antenna elements 205a-205d selected to result in an omnidirectional radiation pattern, the combined frequency response of the planar antenna apparatus 110 is about 90 MHz. In some embodiments, coupling more than one of the antenna elements 205a-205d to the radio frequency feed port 220 maintains a match with less than 10dB return loss over 802.11 wireless LAN frequencies, regardless of the number of antenna elements 205a-205d that are switched on.

[035] FIG. 3A illustrates various radiation patterns resulting from selecting different antenna elements of the planar antenna apparatus 110 of FIG. 2, in one embodiment in accordance with the present invention. FIG. 3A depicts the radiation pattern in azimuth (e.g., substantially in the plane of the substrate of FIG. 2). A line 300 displays a generally cardioid directional radiation pattern resulting from selecting a single antenna element (e.g., the antenna element 205a). As shown, the antenna element 205a alone yields approximately 5 dBi of gain. A dashed line 305 displays a similar directional radiation pattern, offset by approximately 90 degrees, resulting from selecting an adjacent antenna element (e.g., the antenna element 205b). A line 310 displays a combined radiation pattern resulting from selecting the two adjacent antenna elements 205a and 205b. In this embodiment, enabling the two adjacent antenna elements 205a and 205b results in higher directionality in azimuth as compared to selecting either of the antenna elements 205a or 205b alone, with approximately 5.6 dBi gain.

[036] The radiation pattern of FIG. 3A in azimuth illustrates how the selectable antenna elements 205a-205d may be combined to result in various radiation patterns for the planar antenna apparatus 110. As shown, the combined radiation pattern resulting from two or more adjacent antenna elements (e.g., the antenna element 205a and the antenna element 205b) being coupled to the radio frequency feed port is more directional than the radiation pattern of a single antenna element.

[037] Not shown in FIG. 3A for improved legibility, is that the selectable antenna elements 205a-205d may be combined to result in a combined radiation pattern that is less directional than the radiation pattern of a single antenna element. For example, selecting all of the antenna elements 205a-205d results in a substantially omnidirectional radiation pattern that has less directionality than that of a single antenna element. Similarly, selecting two or more antenna elements (e.g., the antenna element 205a and the antenna element 205c on opposite diagonals of the substrate) may result in a substantially omnidirectional radiation pattern. In this fashion, selecting a subset of the antenna elements 205a-205d, or substantially all of the antenna elements 205a-205d, may result in a substantially omnidirectional radiation pattern for the planar antenna apparatus 110.

[038] Although not shown in FIG. 3A, it will be appreciated that additional directors (e.g., the directors 211) and/or gain directors (e.g., the gain directors 216) may further concentrate the directional radiation pattern of one or more of the antenna elements 205a-205d in azimuth. Conversely, removing or eliminating one or more of the directors 211, the gain directors 216, or the Y-shaped reflectors 235 expands the directional radiation pattern of one or more of the antenna elements 205a-205d in azimuth.

[039] FIG. 3A also shows how the planar antenna apparatus 110 may be advantageously configured, for example, to reduce interference in the wireless link between the system 100 of FIG. 1 and a remote receiving node. For example, if the remote receiving node is situated at zero degrees in azimuth relative to the system 100 (at the center of FIG. 3A), the antenna element 205a corresponding to the line 300 yields approximately the same gain in the direction of the remote receiving node as the antenna element 205b corresponding to the line 305. However, as can be seen by comparing the line 300 and the line 305, if an interferer is situated at twenty degrees of azimuth relative to the system 100, selecting the antenna element 205a yields approximately a 4 dB signal strength reduction for the interferer as opposed to selecting the antenna element 205b. Advantageously, depending on the signal environment around the system 100, the planar antenna apparatus 110 may be configured (e.g., by switching one or more of the antenna elements 205a-205d on or off) to reduce interference in the wireless link between the system 100 and one or more remote receiving nodes.

[040] FIG. 3B illustrates an elevation radiation pattern for the planar antenna apparatus 110 of FIG. 2. In the figure, the plane of the planar antenna apparatus 110 corresponds to a line from 0 to 180 degrees in the figure. Although not shown, it will be appreciated that additional directors (e.g., the directors 211) and/or gain directors (e.g., the gain directors 216) may advantageously further concentrate the radiation pattern of one or more of the antenna elements 205a-205d in elevation. For example, in some embodiments, the system 110 may be located on a floor of a building to establish a wireless local area network with one or more remote receiving nodes on the same floor. Including the additional directors 211 and/or gain directors 216 in the planar antenna apparatus 110

further concentrates the wireless link to substantially the same floor, and minimizes interference from RF sources on other floors of the building.

[041] FIG. 4A and FIG. 4B illustrate an alternative embodiment of the planar antenna apparatus 110 of FIG. 1, in accordance with the present invention. On the first side of the substrate as shown in FIG. 4A, the planar antenna apparatus 110 includes a radio frequency feed port 420 and six antenna elements (e.g., the antenna element 405). On the second side of the substrate, as shown in FIG. 4B, the planar antenna apparatus 110 includes a ground component 425 incorporating a number of Y-shaped reflectors 435. It will be appreciated that a portion (e.g., the portion 430) of the ground component 425 is configured to form an arrow-shaped bent dipole in conjunction with the antenna element 405. Similarly to the embodiment of FIG. 2, the resultant bent dipole has a directional radiation pattern. However, in contrast to the embodiment of FIG. 2, the six antenna element embodiment provides a larger number of possible combined radiation patterns.

[042] Similarly with respect to FIG. 2, the planar antenna apparatus 110 of FIG. 4 may optionally include one or more directors (not shown) and/or one or more gain directors 415. The directors and the gain directors 415 comprise passive elements that concentrate the directional radiation pattern of the antenna elements 405. In one embodiment, providing a director for each antenna element yields an additional 1-2 dB of gain for each element. It will be appreciated that the directors and/or the gain directors 415 may be placed on either side of the substrate. It will also be appreciated that additional directors and/or gain directors may be included to further concentrate the directional radiation pattern of one or more of the antenna elements 405.

[043] An advantage of the planar antenna apparatus 110 of FIGs 2-4 is that the antenna elements (e.g., the antenna elements 205a-205d) are each selectable and may be switched on or off to form various combined radiation patterns for the planar antenna apparatus 110. For example, the system 100 communicating over the wireless link to the remote receiving node may select a particular configuration of selected antenna elements that minimizes interference over the wireless link. If the wireless link experiences interference, for example due to other radio transmitting devices, or changes or disturbances in the wireless link between the system 100 and the remote receiving node, the system 100 may select a different configuration of selected antenna elements to change the radiation pattern of the planar antenna apparatus 110 and minimize the interference in the wireless link. The system 100 may select a configuration of selected antenna elements corresponding to a maximum gain between the system and the remote receiving node. Alternatively, the system may select a configuration of selected antenna elements corresponding to less than maximal gain, but corresponding to reduced interference. Alternatively, all or substantially all of the antenna elements may be selected to form a combined omnidirectional radiation pattern.

[044] A further advantage of the planar antenna apparatus 110 is that RF signals travel better indoors with horizontally polarized signals. Typically, network interface cards (NICs) are horizontally polarized. Providing horizontally polarized signals with the planar antenna apparatus 110 improves interference rejection (potentially, up to 20dB) from RF sources that use commonly-available vertically polarized antennas.

[045] Another advantage of the system 100 is that the planar antenna apparatus 110 includes switching at RF as opposed to switching at baseband. Switching at RF means

that the communication device 120 requires only one RF up/down converter. Switching at RF also requires a significantly simplified interface between the communication device 120 and the planar antenna apparatus 110. For example, the planar antenna apparatus provides an impedance match under all configurations of selected antenna elements, regardless of which antenna elements are selected. In one embodiment, a match with less than 10dB return loss is maintained under all configurations of selected antenna elements, over the range of frequencies of the 802.11 standard, regardless of which antenna elements are selected.

[046] A still further advantage of the system 100 is that, in comparison for example to a phased array antenna with relatively complex phase switching elements, switching for the planar antenna apparatus 110 is performed to form the combined radiation pattern by merely switching antenna elements on or off. No phase variation, with attendant phase matching complexity, is required in the planar antenna apparatus 110.

[047] Yet another advantage of the planar antenna apparatus 110 on PCB is that the planar antenna apparatus 110 does not require a 3-dimensional manufactured structure, as would be required by a plurality of "patch" antennas needed to form an omnidirectional antenna. Another advantage is that the planar antenna apparatus 110 may be constructed on PCB so that the entire planar antenna apparatus 110 can be easily manufactured at low cost. One embodiment or layout of the planar antenna apparatus 110 comprises a square or rectangular shape, so that the planar antenna apparatus 110 is easily panelized.

[048] The invention has been described herein in terms of several preferred embodiments. Other embodiments of the invention, including alternatives, modifications, permutations and equivalents of the embodiments described herein, will be apparent to those skilled in the art from consideration of the specification, study of the drawings, and practice of the invention. The embodiments and preferred features described above should be considered exemplary, with the invention being defined by the appended claims, which therefore include all such alternatives, modifications, permutations and equivalents as fall within the true spirit and scope of the present invention.

CLAIMS

What is claimed is:

1. An antenna apparatus, comprising:

a substrate having a first side and a second side substantially parallel to the first side;

a plurality of antenna elements on the first side, each antenna element selectively coupled to a communication device and configured to form a first portion of a modified dipole having a directional radiation pattern with polarization substantially in the plane of the substrate; and

a ground component on the second side, the ground component configured to form a second portion of the modified dipole.

2. The antenna apparatus of claim 1, further comprising an antenna element selector coupled to each antenna element, the antenna element selector configured to selectively couple the antenna element to the communication device.

3. The antenna apparatus of claim 2, wherein the antenna element selector comprises a PIN diode.

4. The antenna apparatus of claim 2, further comprising a visual indicator coupled to the antenna element selector, the visual indicator configured to indicate which of the antenna elements is selected.

5. The antenna apparatus of claim 1, wherein the ground component is further configured to concentrate the directional radiation pattern of the modified dipole.

6. The antenna apparatus of claim 1, wherein the ground component is further configured to broaden a frequency response of the modified dipole.

7. The antenna apparatus of claim 1, wherein a match with less than 10dB return loss is maintained when more than one antenna element is coupled to the communication device.

8. The antenna apparatus of claim 1, wherein the modified dipole comprises an arrow-shaped bent dipole.

9. The antenna apparatus of claim 1, wherein the plurality of antenna elements has an omnidirectional radiation pattern when two or more of the antenna elements are coupled to the communication device.

10. The antenna apparatus of claim 1, wherein the substrate comprises a substantially rectangular surface and each of the antenna elements is oriented substantially on one of the diagonals of the substrate.

11. The antenna apparatus of claim 1, wherein the substrate comprises a printed circuit board.

12. The antenna apparatus of claim 1, wherein the substrate comprises a dielectric, and the antenna elements and the ground component are formed on the dielectric.

13. The antenna apparatus of claim 1, further comprising one or more reflectors for at least one of the antenna elements, the reflector configured to concentrate the radiation pattern of the antenna element.

14. The antenna apparatus of claim 1, further comprising one or more Y-shaped reflectors for at least one of the antenna elements, the Y-shaped reflector configured to concentrate the radiation pattern of the antenna element.

15. The antenna apparatus of claim 1, further comprising one or more directors, each director configured to concentrate the radiation pattern of the antenna element.

16. The antenna apparatus of claim 1, wherein a combined radiation pattern resulting from two or more antenna elements being coupled to the communication device is more directional than the radiation pattern of a single antenna element.

17. The antenna apparatus of claim 1, wherein a combined radiation pattern resulting from two or more antenna elements being coupled to the communication device is less directional than the radiation pattern of a single antenna element.

18. An antenna apparatus, comprising:

a plurality of individually selectable planar antenna elements, each antenna element having a directional radiation pattern with polarization substantially in the plane of the antenna elements;

an antenna element selecting device configured to communicate a radio frequency signal with a communication device and selectively couple one or more of the antenna elements to the communication device.

19. The antenna apparatus of claim 18, wherein the plurality of antenna elements are formed from radio frequency conducting material coupled to the antenna element selecting device.

20. The antenna apparatus of claim 19, wherein the radio frequency conducting material comprises a metal foil.

21. The antenna apparatus of claim 18, wherein the antenna element selecting device comprises a PIN diode for each antenna element.

22. The antenna apparatus of claim 18, wherein the antenna element selecting device comprises a single-pole single-throw RF switch for each antenna element.

23. The antenna apparatus of claim 18, further comprising a visual indicator coupled to the antenna element selecting device, the visual indicator configured to indicate whether each antenna element is selectively coupled to the communication device.

24. The antenna apparatus of claim 18, wherein the plurality of antenna elements are configured to be conformally mounted to a housing containing the communication device and the antenna apparatus.

25. The antenna apparatus of claim 18, wherein one or more of the plurality of antenna elements comprises means for concentrating the radiation pattern of the antenna element.

26. The antenna apparatus of claim 18, wherein the plurality of antenna elements form an omnidirectional radiation pattern when two or more of the antenna elements are coupled to the communication device.

27. A system, comprising:

a communication device for generating a radio frequency signal;

a first means for generating a first directional radiation pattern;

a second means for generating a second radiation pattern, the second radiation pattern being offset in direction from the first directional radiation pattern;

a selecting means for receiving the radio frequency signal from the communication device and selectively coupling the first means and the second means to the communication device.

28. The antenna apparatus of claim 27, wherein a match with less than 10dB return loss is maintained when the first means and the second means are both coupled to the communication device.

29. The antenna apparatus of claim 27, further comprising means for expanding the directional radiation pattern of the first means.

30. The antenna apparatus of claim 27, wherein the first means and the second means form an omnidirectional radiation pattern when coupled to the communication device.

31. The antenna apparatus of claim 27, further comprising means for concentrating the directional radiation pattern of the first means.

32. The antenna apparatus of claim 27, further comprising means for expanding the directional radiation pattern of the first means.

33. A method, comprising:

generating a radio frequency signal in a communication device; and

coupling at least one of a plurality of coplanar antenna elements to the communication device to result in a directional radiation pattern substantially in the plane of the antenna elements.

34. The method of claim 33, wherein at least one of the plurality of coplanar antenna elements comprises a portion of a dipole, and coupling the at least one of the plurality of coplanar antenna elements comprises enabling the portion of the dipole to receive the radio frequency signal from the communication device and enabling a ground component to complete the dipole.

35. The method of claim 34, wherein the dipole comprises a bent dipole.

36. The method of claim 33, further comprising coupling two or more of the plurality of planar antenna elements to the communication device to result in an omnidirectional radiation pattern.

37. The method of claim 33, further comprising concentrating the directional radiation pattern with one or more reflectors.

38. The method of claim 33, further comprising concentrating the directional radiation pattern with one or more Y-shaped reflectors.

39. The method of claim 33, further comprising concentrating the directional radiation pattern with one or more directors.

40. The method of claim 33, wherein coupling at least one of the plurality of coplanar antenna elements to the communication device comprises biasing a PIN diode.

41. The method of claim 33, further comprising coupling at least two of the plurality of coplanar antenna elements to the communication device to result in a more directional radiation pattern.

42. The method of claim 33, further comprising coupling at least two of the plurality of coplanar antenna elements to the communication device to result in a less directional radiation pattern.

43. The method of claim 33, further comprising coupling at least two of the plurality of coplanar antenna elements to the communication device to result in a radiation pattern in an offset direction from the original.

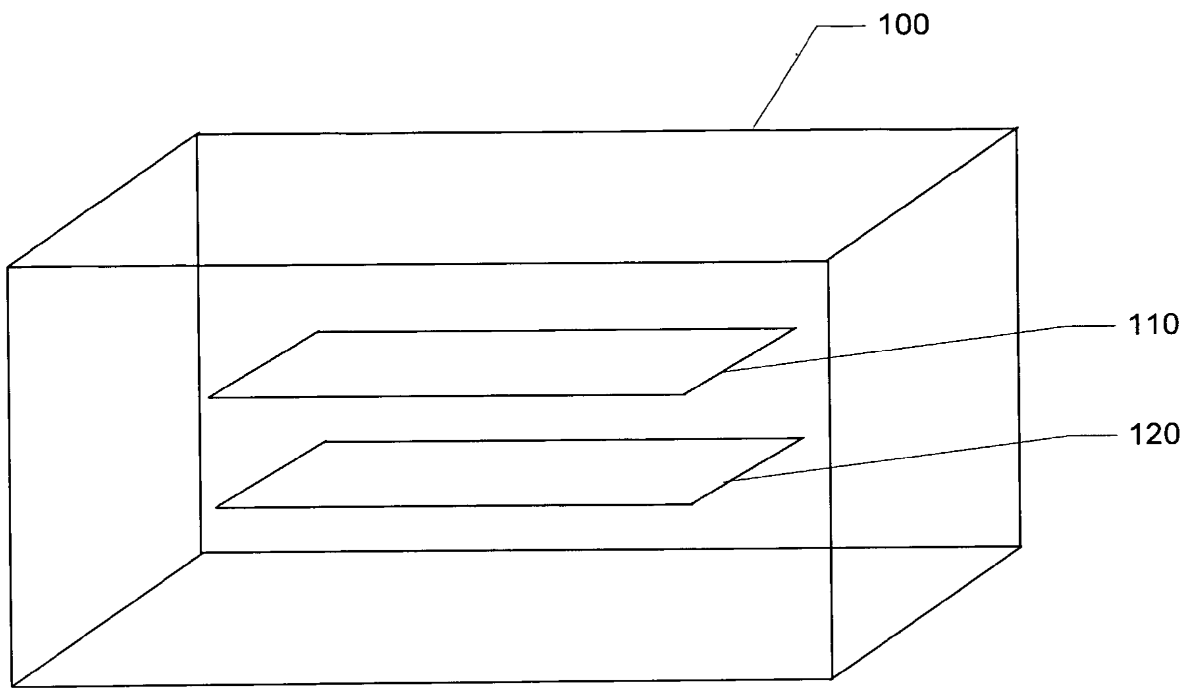
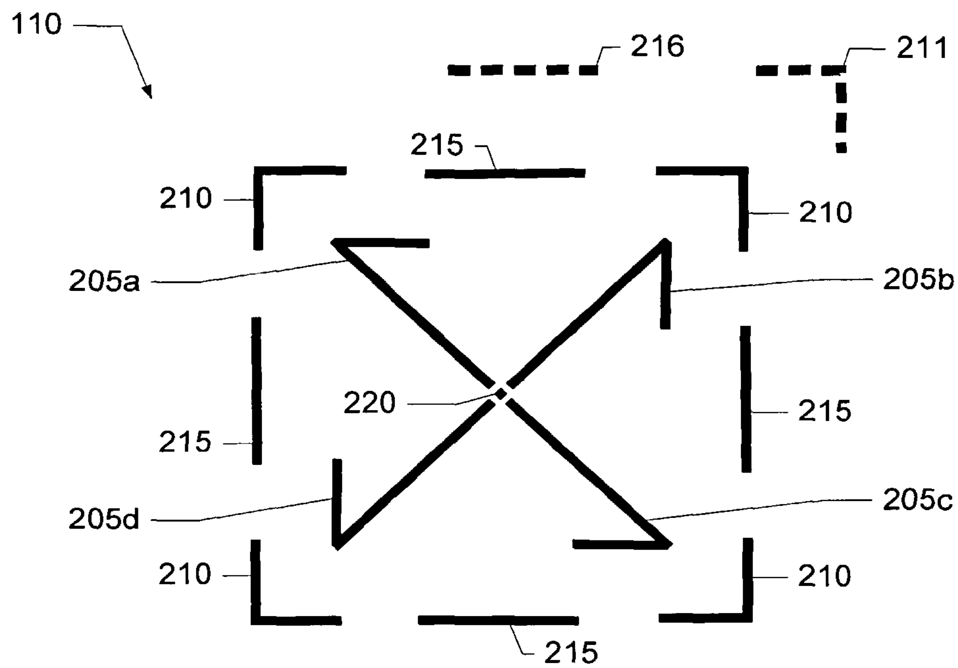


FIG. 1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205b
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215
205d
205c
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210
215

FIG. 2A

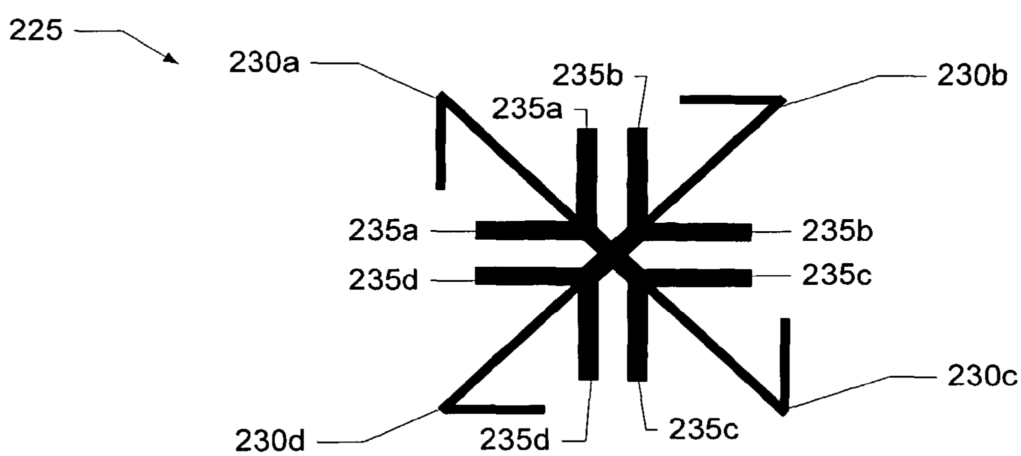
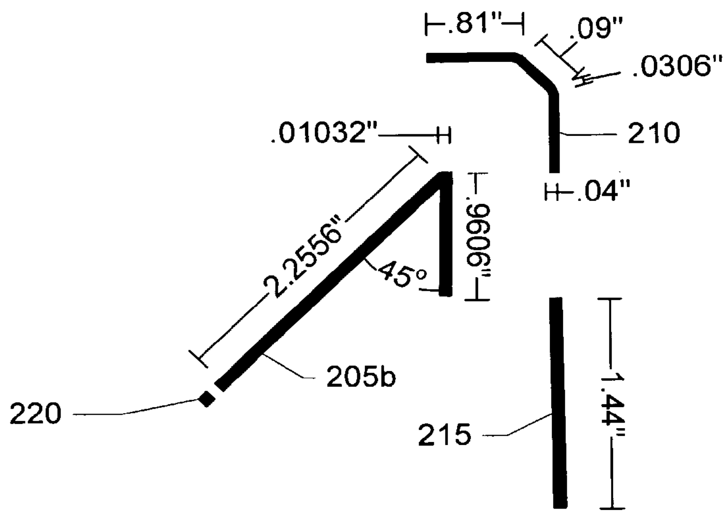

225
230a
235b
230b
235a
235a
235b
235d
235c
230c
230d
235d
235c

FIG. 2B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.09"
.0306"
.01032"
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.04"
2.2556"
.9606"
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205b
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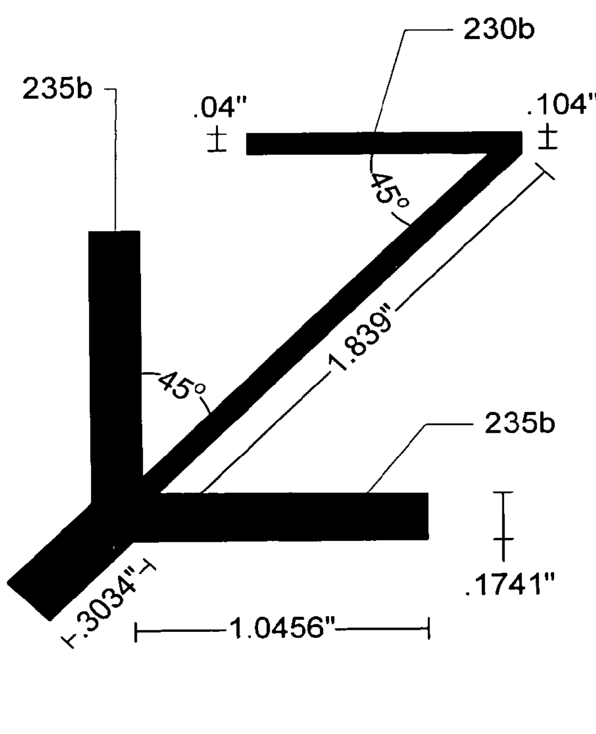
215
1.44"

FIG. 2C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45°
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235b
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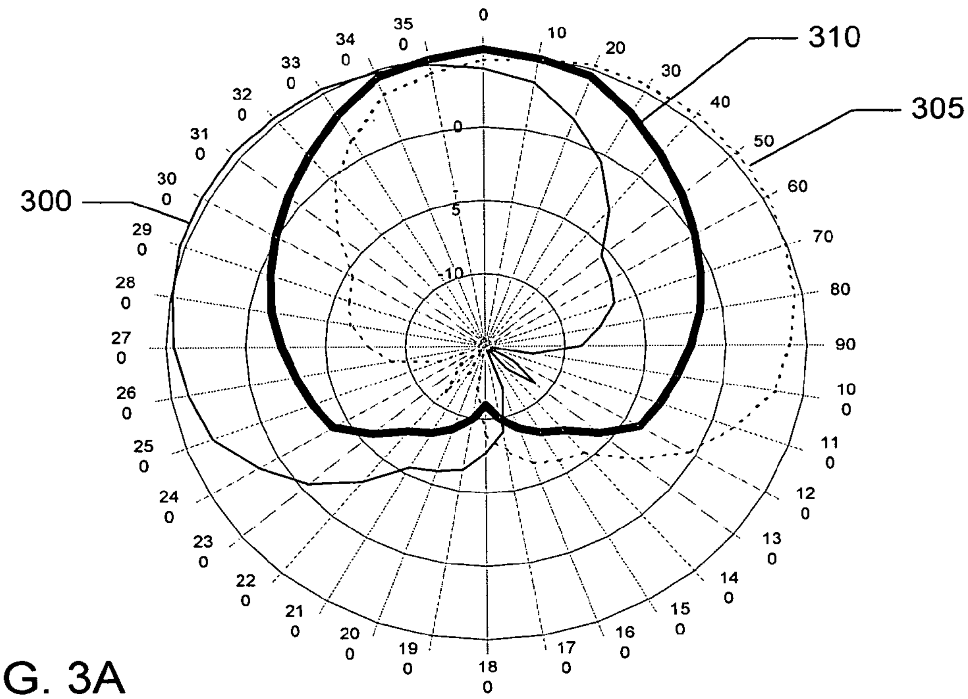
1.0456"

FIG. 2D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305
300
0
10
20
30
40
50
60
70
80
90
10 0
11 0
12 0
13 0
14 0
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16 0
17 0
18 0
19 0
20 0
21 0
22 0
23 0
24 0
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30 0
31 0
32 0
33 0
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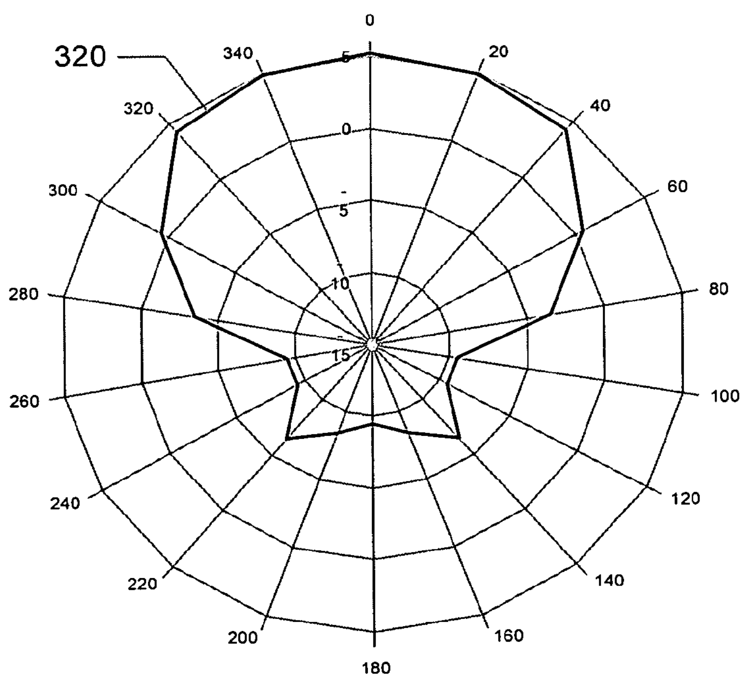
35 0
0
-5
-10

FIG. 3A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40
60
80
100
120
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160
180
200
220
240
260
280
300
320
340
5
0
-5
-10
-15

FIG. 3B

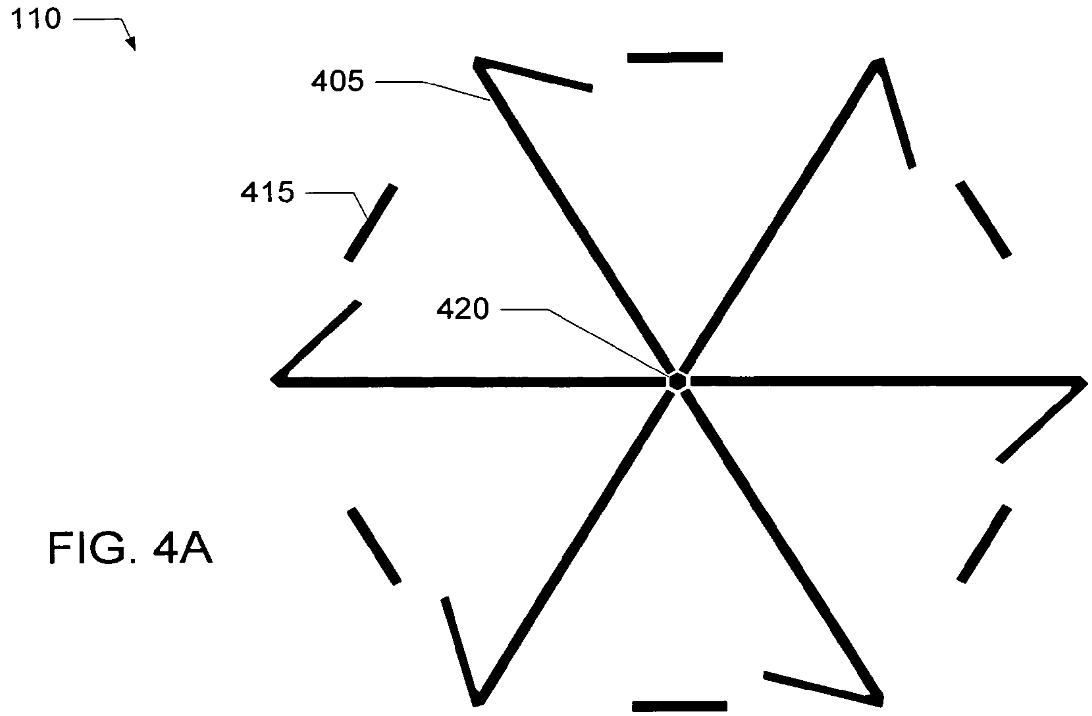

FIG. 4A

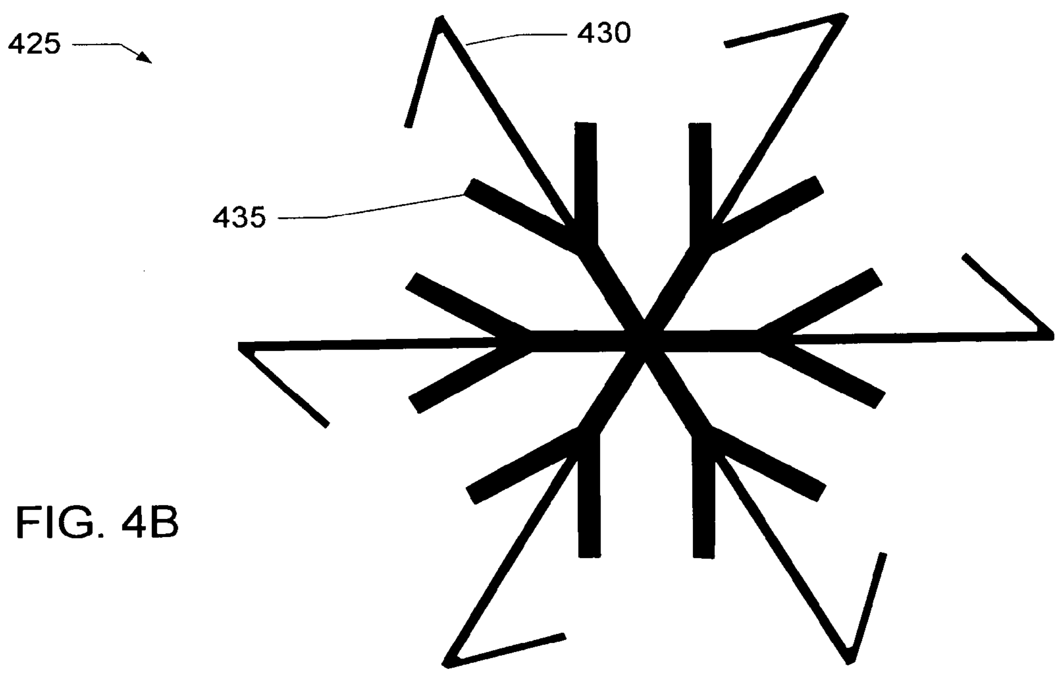

FIG. 4B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US05/27023

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8): H01Q 9/04
US CL: 343/700MS
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
343/700MS

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPTO EAST: US, US-PGPUB, EPO, JPO; MicroPatent, IEEE Xplore, Ei Compendex, INSPEC, NTIS: National Technical Information Service, JICST-EPlus- Japanese Science & Technology, PASCAL, Current Contents

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,754,145 A (EVANS) 19 May 1998 (19.05.1998) abstract; figure 1; figure 5; figure 6; column 2, lines 2-14; column 2, lines 47-64	1-3, 5, 6, 8-10, 12, 18-22, 26, 33-36, 40
Y		4, 7, 11, 13-17, 23-25, 27-32, 37-39, 41-43
Y	US 6,498,589 B1 (HORII) 24 December 2002 (24.12.2002) column 16 lines 39-51	4, 23
Y	US 6,339,404 B1 (JOHNSON et al) 15 January 2002 (15.01.2002) column 2, lines 60-62; abstract; figure 5	7, 11, 13, 25, 28, 37
Y	US 6,507,321 B2 (OBERSCHMIDT et al) 14 January 2003 (14.01.2003) abstract	14, 38
Y	US 6,326,922 B1 (HEGENDOERFER) 04 December 2001 (04.12.2001) figure 4	15, 39
Y	US 6,377,227 B1 (ZHU et al) 23 April 2002 (23.04.2002) figure 1; figure 2a & 2b; figure 5; figure 6a & 6b; column 3, lines 19-20; column 3, lines 44-46	16, 41
Y	US 2003/0210207 A1 (SUH et al) 13 November 2003 (13.11.2003) figure 20	17, 27, 28-32, 42, 43
Y	US 6,762,723 B2 (NALLO et al) 13 July 2004 (13.07.2004) figure 15	24

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search
09 November 2005 (09.11.2005)

Date of mailing of the international search report
23 DEC 2005

Name and mailing address of the ISA/US
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Facsimile No. 571-273-3201

Authorized officer:
Blaine R. Copenheaver
Telephone No. 571-272-7774

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
15 February 2007 (15.02.2007)

PCT

(10) **International Publication Number**
WO 2007/019185 A2

(51) **International Patent Classification:**
H04J 1/04 (2006.01)

(21) **International Application Number:** PCT/US2006/030141

(22) **International Filing Date:** 3 August 2006 (03.08.2006)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
11/196,804 3 August 2005 (03.08.2005) US

(63) **Related by continuation (CON) or continuation-in-part (CIP) to earlier application:**
US 11/196,804 (CON)
Filed on 3 August 2005 (03.08.2005)

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(74) **Agent: WINSTON, R., Whitney**; PureWave Networks, Inc., PO Box R, McLean, VA 22101 (US).

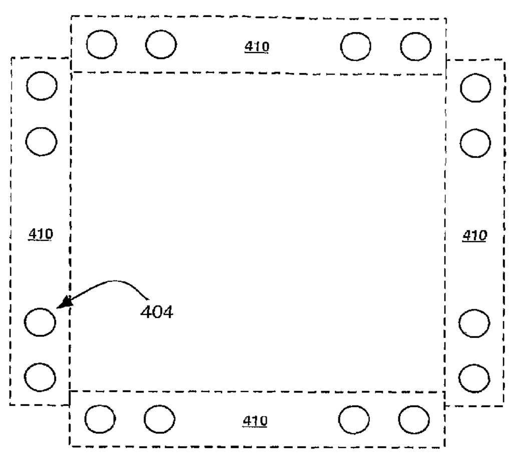
(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US (patent), UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

[Continued on next page]

(54) **Title:** BEAMFORMING USING SUBSET OF ANTENNA ARRAY



(57) **Abstract:** A radio communication system including multiple antenna elements divided into subgroups of at least two antenna elements, and multiple line cards operable to employ spatial processing techniques. Each line card is coupled to a subgroup such that the line card may transmit and receive signals using the subgroup. A base station for use in a radio communication system includes one or more line cards. Each line card includes an antenna interface used to couple the line card to a subgroup of multiple antenna elements, a radio frequency component coupled to the antenna interface, and a signal processing component coupled to the radio frequency component such that the line card is operable to transmit and receive radio frequency communications. A method for providing increased capacity in a radio communication system includes dividing an antenna array, creating N subgroups of antenna elements, and for each of the N subgroups of antenna elements, coupling a line card to the subgroup of antenna elements. Each line card is operable to communicate using its coupled subgroup of antenna elements.

WO 2007/019185 A2

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

BEAMFORMING USING SUBSET OF ANTENNA ARRAY

TECHNICAL FIELD

This disclosure is directed to a radio communication system and, more particularly, to the use of transmit and/or receive beamforming with a subset of the antennas of an antenna array.

BACKGROUND

A metropolitan area network is a class of network between a local area network and a wide-area network that typically covers an area from the size of a group of small buildings to the size of a large city. For example, a data network using cable television infrastructure may be deployed in one or more neighborhoods, forming a metropolitan area network providing high-speed Internet access.

In recent years, wireless networks based on the IEEE 802.11 standard have been widely deployed to provide high-speed data service across local area networks. Because these systems may be deployed using relatively low-powered radios, it has been possible to embed 802.11 radios in laptops, mobile phones, and other electronic devices. These wireless local area networks have provided convenient, high-speed Internet access in cafes, hotels, businesses, and homes. It is desirable to provide the same convenience available using 802.11 in a local area network across a wider, metropolitan area network.

The IEEE 802.16-2004 standard was promulgated to facilitate development of wireless metropolitan area network systems. While wireless metropolitan area networks may employ technology similar to that used in wireless local area networks, many new technical challenges arise in designing systems that operate effectively over a wider area. The performance of these wireless systems is limited by the link budget between base and remote stations. By increasing the link budget, the overall capacity, coverage, and bandwidth may be improved.

To improve performance of wireless metropolitan area networks, some have proposed employing spatial processing techniques with an antenna array (i.e., an antenna system having multiple antenna elements arranged in any fashion). One such spatial processing technique, beamforming, may be employed to vary the gain and phase characteristics of signals radiated or received by each of the antenna elements to form a radiation pattern designed to attenuate interference and to improve signal gain in one or more directions, thus increasing the link budget and improving system performance.

While beamforming and other spatial processing techniques may be effective, they do not come without cost. These techniques are computation intensive and require hardware support to couple multiple antennas. This additional hardware and computational capability may significantly increase the cost of a wireless system. Accordingly, it is desirable to provide a radio communication system capable of employing spatial processing techniques with reduced hardware support and computational complexity.

As discussed above, it is desirable to increase the capacity and performance of wireless metropolitan area network systems in a cost-effective manner. However, each deployment provides differing requirements. Some wireless metropolitan area networks may need to support large numbers of users in a small geographical area, while other networks may need to support a small number of users over a large geographical area. In addition, the bandwidth requirements of different customers may vary greatly. Instead of designing a system that meets the needs of the most demanding deployments at the expense of less demanding deployments, it is desirable to provide a scalable architecture that can be configured to meet the needs of most wireless network providers.

SUMMARY

In one general aspect, a radio communication system including multiple antenna elements divided into subgroups of at least two antenna elements, and multiple line cards operable to employ spatial processing techniques. Each line card is coupled to a subgroup such that the line card may transmit and receive signals using the subgroup. The subgroups may be non-overlapping or overlapping such that one or more antenna elements may belong to multiple subgroups.

In some implementations, the radio communication system includes a radio frequency combiner such that multiple line cards may be coupled to an antenna element using the radio frequency combiner. Using the radio frequency combiner, the radio communication system may combine signals such that multiple line cards may simultaneously transmit signals through the same antenna element.

Each line card may be implemented using multiple radio frequency components such that each radio frequency component is coupled to an antenna element of the subgroup, and a signal

processing component coupled to the multiple radio frequency components, the signal processing component operable to employ spatial processing techniques.

In some implementations, the multiple antenna elements are disposed about multiple faces. Each subgroup may correspond to one of the multiple faces and may include one or more antenna elements from an additional face. For example, 16 antenna elements may be disposed about four faces with the antenna elements divided into four subgroups, one subgroup corresponding to each of the four faces.

In another general aspect, a base station for use in a radio communication system includes one or more line cards. Each line card includes an antenna interface used to couple the line card to a subgroup of multiple antenna elements, a radio frequency component coupled to the antenna interface, and a signal processing component coupled to the radio frequency component such that the line card is operable to transmit and receive radio frequency communications. An additional line card may be added to the base station to increase the capacity of the base station. In some implementations, additional line cards may be coupled to different subgroups of the antenna elements to increase capacity of the base station.

Base stations may further include a radio frequency combiner coupled to a subgroup of the multiple antenna elements such that the line card is coupled to the subgroup of the multiple antenna elements through the radio frequency combiner. Multiple line cards may be coupled to the same antenna elements using a radio frequency combiner to increase system capacity by supporting additional spectrum. For example, in some implementations, each line card supports 5 megahertz of spectrum.

In another general aspect, a method for providing increased capacity in a radio communication system includes dividing an antenna array, creating N subgroups of antenna elements, and for each of the N subgroups of antenna elements, coupling a line card to the subgroup of antenna elements. Each line card is operable communicate using its coupled subgroup of antenna elements.

In some implementations, the method further includes dividing available spectrum, creating M subgroups of the available spectrum such that each line card is operable to service a subgroup of the available spectrum. In these implementations, capacity of the radio communication system may be increased by configuring multiple line cards to service different subgroups of the available spectrum using the same subgroup of antenna elements. The antenna array may include at least one antenna element that is not within the N subgroups of antenna elements.

For example, a radio communication system may include 16 antennas divided into four subgroups of four antennas. If the 16 antennas are situated about four faces, then each of the four subgroups may correspond to a face. In some implementations, an antenna element is included in more than one of the subgroups.

The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram of a radio communication system.

FIG. 2 is diagram of a metropolitan area network.

FIGS. 3A and 3B are antenna arrays that can be used in the radio communication system shown in FIG. 1.

FIG. 3C is a diagram of one face of an antenna array such as those shown in FIGS. 3A and 3B.

FIGS. 4A, 4B, and 4C are block diagrams showing various ways to configure antenna subgroubs in a 16-element antenna array.

FIGS. 5A, 5B, and 5C are diagrams of desired antenna radiation patterns for singles transmitted to or received from each of three devices in a multi-device beamforming system.

FIG. 5D shows the desired combination of the component signals of FIGS. 5A-5C to simultaneously communicate with multiple devices.

FIG. 6 is a block diagram of a radio communication system using spatial processing techniques.

FIG. 7A is a block diagram of a line card coupled to two antennas for use in a radio communication system.

FIG. 7B is a detailed block diagram of a line card.

FIG. 8 is a block diagram of a radio frequency component for use in a line card such as that shown in FIG. 7B.

FIG. 9 is a block diagram of a line card including details of the digital component.

FIGS. 10A and 10B are block diagrams of radio communication systems showing connections between line cards and antenna elements.

FIG. 11A is a table showing line card allocations to spectrum and antenna subgroups in an exemplary radio communication system.

FIG. 11B is a block diagram of a base station including a radio frequency combiner.

FIG. 11C is a block diagram of a base station including a radio frequency combiner for an antenna assigned to multiple subgroups.

DETAILED DESCRIPTION

Referring to FIG. 1, a radio communication system 100 comprises a base station 102 coupled to an antenna array 104 and operable to communicate with one or more remote stations 106. The base station 102 is coupled to a network 108 such that the base station 102 can transfer information between the network 108 and the remote stations 106. The radio communication system 100 may be used to provide wireless services, such as, for example, wireless metropolitan area networks, wireless local area networks, wireless video-on-demand, and/or wireless voice services.

For example, the radio communication system 100 may be used to implement a wireless local area network (WLAN) based on the IEEE 802.11 standard. In this implementation, the base station 102 serves as an access point or as a router, connecting one or more remote stations 106 to a network 108, which can be a local area network (LAN) or a wide area network (WAN), such as the Internet. The remote stations 106 typically are laptop or desktop computers configured with wireless network interface cards.

The base station 102 is a hardware device that facilitates radio frequency (RF) communications with remote stations 106. The RF communications is typically two-way (with the base station 102 and remote station 106 transmitting and receiving information from one another); however, the techniques described herein may also be used with one-way RF communications, such as, for example, a video or information broadcast system, or a pager system.

To facilitate two-way RF communications, the base station 102 includes at least one antenna and a signal processing unit. The signal processing unit typically includes components to filter and amplify signals, to convert signals between analog and digital, and to interpret and process received data.

The base station 102 and remote stations 106 may be implemented using conventional electronic design and manufacturing techniques using application-specific integrated circuits and/or commercial off-the-shelf components. Portions of the implementations may be carried out in software-configured digital signal processors (DSPs) or general-purpose microprocessors.

Referring to FIG. 2, in one implementation of the radio communication system 100 a base station 102 is coupled to an antenna array 204 situated off the ground so as to provide wireless communication services across a wide area. In addition, the base station 102 is coupled to a high-speed communications network 206 (e.g., the Internet) to provide a wireless link 208 between the network 206 and various remote stations 106. For example, the radio communication system 100 may be used to provide high-speed Internet access to users in cars 210, boats 211, homes 212, public transportation 213, and office buildings 214. Users may access the radio communication system 100 using a wide variety of electronic devices including mobile phones 212 and computers 216.

To perform spatial processing techniques, the radio communication system 100 is coupled to the antenna array 104. The antenna array may be implemented using two or more antenna elements arranged in any fashion. FIGS. 3A and 3B illustrate two exemplary antenna array 104 designs.

Referring to FIG. 3A, an antenna array 310 includes 12 antenna elements situated about three faces using six antenna panels 312. In this design, the antenna panels 312 on each face are situated far enough apart (distance 314) so that there is sufficient spatial diversity between antenna elements. In this example, the distance 314 is at least approximately 10 times the wavelength of signals transmitted and received by the antenna array 310. It is advantageous to mount the antenna panels 312 as high as possible to maximize coverage. In this example, the antenna panels 312 are mounted on a structure attached to a pole. Alternatively, the antenna panels 312 may be placed on buildings or affixed to other structures.

Each of the antenna panels 312 provides a connection to each of its antenna elements. In this example, twelve wires may be run (2 to each antenna panel 312) to a base station 102. The base station 102 is typically situated near the base of the antenna array's 310 supporting structure. For example, a base station 102 may be placed in a small building at the base of the antenna array 312 with 12 lines running up the pole or other support structure to the 12 antenna elements.

Referring to FIG. 3B, an antenna array 320 (similar to that described above with reference to FIG. 3A) includes 16 antenna elements situated about four faces using eight antenna panels 312. As in the previous antenna design, the antenna panels 312 on each face are situated a sufficient distance 314 from one another to provide sufficient spatial diversity. This antenna array 320 may be installed in the manner discussed above using 16 wires, one for each antenna element, between a base station 102 and the antenna array 320.

Referring to FIG. 3C, each face of the antenna arrays 310 and 320 includes two antenna panels 312 with each panel 312 including a case 402 enclosing two antenna elements 404. Typically, the antenna elements 404 are sized based on the frequencies to be transmitted and/or received. For example, the antenna elements 404 may be sized to be approximately one wavelength. In this implementation, the case 402 is a plastic enclosure to protect the antenna elements 404 from the elements and to facilitate mounting. As such, the case 402 is optional—antenna elements 404 may be installed individually in an antenna array 104 without using antenna panels 312 or the antenna panels 312 may be formed using non-enclosing hardware.

In a conventional beamforming system, each antenna element of an antenna array 104 is coupled to a base station 102 and the base station 102 performs spatial processing for the array as a whole. When a large number of antenna elements are used, these spatial processing techniques require substantial computational resources.

The computational complexity of a radio communication system 100 employing spatial processing may be reduced by dividing the antenna elements of the antenna array 104 into subgroups. Then, spatial processing techniques may be applied using the antenna elements in each of the subgroups. This technique retains much of the benefit of spatial processing while reducing the overall computational complexity.

Referring to FIG. 4A, an antenna array 104 containing 16 antenna elements 404 may be divided into four subgroups 410 with a group corresponding to each of four faces, as shown. This configuration provides the ability to steer beams and/or nulls to provide increased performance in many situations.

FIG. 4B shows an alternative way to divide an antenna array 104 containing 16 antenna elements 404 into four subgroups 420. In this example, each subgroup largely corresponds to a face; however, the subgroups are shifted so as to include an antenna from a different face. By including an antenna element from a different face, the antenna subgroup 420 may provide increased spatial diversity in some situations. For example, a remote station situated near a corner of antenna array 104 may not have sufficient spatial diversity with a single face (i.e., with antenna subgroup 410). However, an antenna subgroup spanning multiple faces (e.g., subgroup 420) may provide increased spatial diversity, resulting in increased overall performance.

Referring to FIG. 4C, the antenna subgroup 420 (described above with reference to FIG. 4B) shifts subgroups so that they overlap face boundaries. An alternative way to achieve increased spatial diversity is to allow an antenna element 404 to fall within multiple subgroups. In the example show in FIG. 4C, each subgroup 430 includes six antenna elements 404 (i.e., all four elements from one face and one antenna element from each adjacent face. This technique may provide increased spatial diversity for each subgroup.

Allowing a single antenna element 404 to belong to multiple subgroups 430 introduces some complications. Two subgroups 430 may simultaneously receive and process signals using spatial processing; however, simultaneous transmission requires special consideration. Several approaches may be used to facilitate a shared transmission channel. For example, scheduling may be used to allow subgroups 430 to share a single antenna. Many conventional scheduling approaches may be used, such as, for example, two time periods (A and B) may be designated for transmission with subgroups 430 on opposite faces sharing the same time period. Thus, at time period A, two of the subgroups 430 on opposite faces may simultaneously transmit and at time period B, the remaining two subgroups 430 may transmit. This prevents a single antenna element from being used to transmit by multiple subgroups at one time.

In another approach, antenna elements 404 shared by two subgroups 430 may be coupled to the multiple subgroups using a radio frequency combiner. This allows two subgroups 430 to transmit using the same antenna element 404 at the same time; however, if both subgroups 430 are using the same frequencies at the same time, there is the potential for interference.

The antenna subgroups and techniques described above are provided for purposes of example. One skilled in the art will appreciate that the antenna subgroups may be arranged in any fashion. For example, antenna elements 404 may be randomly assigned to subgroups; an antenna array 104 having four faces may be divided into three subgroups; and an antenna subgroup may be noncontiguous. Many other variations should be apparent.

Using the antenna arrays 104 and subgroup configurations described above, a radio communication system 100 may be implemented using beamforming technology to simultaneously transmit to multiple devices using the same frequencies.

FIGS. 5A-5D show the application of beamforming technology to one subgroup of antenna elements within an antenna array 104. In FIG. 5A, a multi-user system provides communication between a base station antenna 502 and various devices 504, 506, and 508. By using spatial processing techniques (e.g., beamforming), a set of complex weights may be calculated to steer maximum gain towards a particular device (in this case device 504). Conventional spatial processing techniques vary the radiation pattern of transmitted signals with maximum gain focused in one general direction; however, radiation patterns usually include one or more side-lobes whereby the signal is transmitted in a direction other than that of the intended target of communication. In this example, a set of complex weights is calculated to produce radiation pattern 510 with maximum gain focused towards device 504.

Referring to FIGS. 5B and 5C, complex weights also may be calculated to steer signals towards devices 506 and 508 by producing radiation patterns 520 and 530. In a radio communication system that communicates with a single device at a time, each of the radiation patterns 510, 520, and 530 may be separately applied when communicating with the corresponding intended device 504, 506, or 508. However, the radiation patterns also may be combined such that the radio communication may simultaneously communicate with multiple devices. For example, when transmitting to multiple devices simultaneously, a radio system can apply each of the three sets of complex weights generating radiation patterns 510, 520, and 530 to a different transmission signal. The resulting signals may be combined and transmitted to each intended device 504, 506, and 508. Because signals between the antenna 502 and each of the devices 504, 506, and 508 are processed using weights to generate radiation patterns 510, 520, and 530, communications between the antenna 502 and a single device should not interfere with communications with the other devices. Accordingly, it is even possible for each of the devices 504, 506, and 508 to simultaneously use the same frequencies without inter-device interference.

FIG. 5D shows the result of combining radiation patterns 510, 520, and 530. Each radiation pattern may be applied to the same signal or to different signals, such that information may be simultaneously communicated to multiple devices. In this example, an antenna 502 communicates with devices 504, 506, and 508 by applying complex weights to produce antenna radiation patterns 510, 520, and 530. When antenna 502 is simultaneously receiving information from devices 504, 506, and 508, a signal processor may successively apply the weights corresponding to the radiation patterns 510, 520, and 530 to isolate the desired communication signal.

For example, if antenna 502 is excited by signals from devices 504 and 508, then an attached radio can isolate the desired signal by applying the complex weights corresponding to the intended device. To receive a signal from device 504, signal processing techniques may be used on a signal received by antenna 502 to apply complex weights corresponding to radiation pattern 510. This effectively amplifies signals received from the direction of device 504 and filters out signals received from other directions. Similarly, signal processing can be used to isolate communications from other devices.

A multi-user radio system using spatial processing, such as, for example, beamforming, can transmit communication signals to various devices 504, 506, and/or 508 by determining one or more communication signals to transmit, applying appropriate signal processing to each communication signal, combining the processed signals together, and transmitting the combined signal. For example, a radio using beamforming to transmit a first communication signal to device 504 and a second communication signal to device 506 can apply complex weights corresponding to radiation pattern 510 to the first communication signal and complex weights corresponding to radiation pattern 520 to the second communication signal. The resulting two communication signals may be combined and transmitted using antenna 502. Because the complex weights vary radiation patterns, the first signal should be primarily transmitted in the direction of device 504 and the second signal should be primarily transmitted in the direction of device 506.

If both communication signals use the same frequency, they could potentially interfere with one another; however, so long as the spatial processing sufficiently isolates the two signals, such communication is possible. Often a system using spatial processing will calculate certain parameters (such as the complex weights in beamforming) based on received signals. These parameters then may be used to control transmitted signals. Because transmit and receive paths may differ, variations in phase and amplitude are possible.

Referring to FIG. 6, a typical radio communication system 600 using spatial processing techniques applies a set of complex weights (i.e., w_1, w_2, ... w_n) to an output signal $y(t)$ to provide increased spectral efficiency. In some implementations, radio communication system 600 performs transmit beamforming by calculating a set of complex weights (w_1, w_2, ... w_n) with each weight corresponding to an antenna (602, 604, or 606). The antennas (602, 604, and 606) operate together as an antenna array that may include any number of antennas. The complex weights (w_1, w_2, ... w_n) are applied to an output signal $y(t)$ and the resulting signals are transmitted by the antennas 602, 604, and 606. Because the complex weights (w_1, w_2, ... w_n) are calculated based on received signals, the transmission path may introduce some unwanted variations in phase and/or gain.

Referring to FIG. 7A, a line card 700 may be used for each antenna subgroup in a radio communication system 100. The line card 700 is coupled to each antenna element 702 within the subgroup. In a conventional beamforming system, a single monolithic signal processor typically is coupled to each antenna in an array to perform spatial processing. As discussed above, an antenna array 104 may be subdivided such that spatial processing is performed separately for each subgroup of antenna elements. Accordingly, a line cards 700 may be assigned to antenna subgroups to reduce the overall computational complexity and reduce the required hardware. In addition, line cards 700 may be incrementally added to a base station 102 to provide a scalable architecture that grow with a wireless provider's business.

Referring to FIG. 7B, a line card 700 is coupled to multiple antennas 702 and includes an RF component 704 associated with each antenna, and at least one digital component 706. Though a line card 700 may employ as few as two antennas 702, a typical implementation will usually employ a greater number, such as, for example four antennas. By using multiple antennas, the digital component 706 can implement spatial processing techniques, varying the signals sent to or received from each of the RF components 704 to improve performance. In an implementation of a broadband wireless radio implementing transmit beamforming, a line card 700 is coupled to 4 antennas 702 with each of the antennas 702 associated with an RF component 704, such as the RF component 704 described below with respect to FIG. 8. The RF components 704 are coupled to the digital component 706 which may be implemented using an application-specific integrated circuit (ASIC) or a digital signal processor (DSP) or other processing device.

In this implementation, the RF components 704 provide two modes: transmit and receive. In transmit mode, a signal to be transmitted is received from the digital component 706, up converted to a transmit frequency or frequencies, amplified, and then transmitted. Various filtering also may be implemented to improve the quality of the transmitted signal. For example, the signal received from the digital component 706 is typically modulated at a baseband frequency. This signal may be passed through a low-pass filter to prevent amplication of any extraneous artifacts. Once the signal has been up converted and amplified, it may be passed through a band-pass filter to prevent any out-of-band transmissions.

Similarly, the RF component 704 may be placed in a receive mode such that signals received by antenna 702 are passed through a low-noise amplifier, then down converted to baseband frequency, and then passed to the digital component 706 for processing. Various filtering may be added to improve performance, such as, for example, a band-pass filter may be applied to signals received through antenna 702 to prevent the processing of out-of-band signals, and a low-pass filter may be used on the down converted signal. In some implementations, the RF component may include components to convert signals between digital and analog representations; however, in this implementation, the signal conversion takes place in the digital component 706.

Referring to FIG. 8, an exemplary implementation of RF component 704 includes a band pass filter (BPF) 802 coupled to the antenna 702 and used on both that transmit and receive paths to filter out signals outside the frequency or frequencies of interest. The BPF 802 is coupled to a switch 804 that selectively enables the receive path or the transmit path to use the antenna 802. The switch 804 is coupled to the receive path where signals pass through a low noise amplifier (LNA) 806, then a down converter 808, and, finally, a low pass filter (LPF) 810, before being passed to the digital component 706. When transmitting, signals are received from the digital component 706, passed through a low pass filter (LPF) 812, converted to transmission frequency or frequencies by up converter 814, and passed through a power amplifier (PA) 816. The transmit path is coupled to antenna 702 using switch 804 such that the amplified signal is passed through BPF 802 and then transmitted using antenna 702.

Referring to FIG. 9, an exemplary implementation of the digital component 706 of FIG. 8 receives signals from multiple RF components 704. To process the received signals, the digital component includes one or more analog-to-digital converters (ADC) 902. In this implementation, orthogonal frequency division multiplexing (OFDM) to provide increased bandwidth utilization while supporting multiple users. To process OFDM signals, this implementation of digital component 706 includes a fast Fourier transform (FFT) component 904. The transformed digital signal is then passed to baseband 906 for processing. Baseband 906 is typically implemented using a digital signal processor. To transmit signals, the baseband 906 sends signals through an inverse fast Fourier transform 908 and a digital to analog converter

(DAC) 910. The converted signals are then passed through RF component 704 to be transmitted using antenna 702.

FIGS. 10A and 10B show exemplary line cards 700 configurations in a base station 102. In FIG. 10A, line cards 700 are coupled to the antenna subgroups 410 shown in FIG. 4A. The line cards 700 may be added incrementally as capacity requirements grow. For example, a wireless service provider may deploy a base station 102 including a single line card 700 coupled to antenna subgroup 410. As capacity grows, the wireless service provider may add line cards 700 to meet growing capacity with only the incremental expense of adding a line card 700. Similarly, in FIG. 10B, line cards 700 are coupled to the antenna subgroups 420 shown in FIG. 4B. These examples show line cards 700 coupled to separate antenna subgroups; however, line cards 700 also may be added to the same or overlapping antenna subgroups.

Referring to FIG. 11A, the available spectrum for a base station 102 may be divided into subgroups (such as, for example, spectrum A, B, C, and D) and the available antenna elements may be divided into subgroups (such as, for example, subgroups 1, 2, 3 and 4). Each combination of spectrum and antenna subgroups may be assigned to a particular line card. In this manner, a base station 102 may be fully populated using 16 line cards 700. For example, a wireless metropolitan area network may use a total of 20 megahertz spectrum divided into 5 megahertz blocks, and 16 antenna elements divided into four subgroups (such as, for example, in the manner shown in FIGS. 4A-4C). Then, line cards 700 may be assigned to a 5 megahertz block and a group of four antenna elements. In this example, line card 1101 is associated to Spectrum A/Antenna Group 1 (designated "A/1"). Line card 1102 is assigned to A/2, line card 1103 is assigned to A/3, and line card 1104 is assigned to A/4. Since each of these line cards (1101, 1102, 1103, and 1104) are configured to use the same spectrum across different antennas, they may operate independently; however, there may be some occasional interference between line cards.

Referring to FIG. 11B, the table shown in FIG. 11A shows line cards 1101, 1105, 1109, and 1113 assigned to different portions of the spectrum using antenna group 1. Since each is using the same antenna, a radio frequency combiner 1120 may be used to combine the signals from each line card 1101, 1105, 1109, and 1113 so that they may simultaneously transmit using the same antenna element.

Referring to FIG. 11C, a radio frequency combiner 1130 also may be used to combine radio frequency signals for an antenna assigned to multiple subgroups. The example described above with respect to FIGS. 11A and 11B shows how a radio communication system may be implemented to provide incremental increases in the overall system capacity. As more capacity is required, additional line cards may be added. The radio frequency combiner 1120 combines signals from two or more line cards so that they may use the same antenna element for transmission. FIG. 11A shows how a single antenna group may be assigned to multiple line card. However, two antenna groups may include some overlap.

If a single antenna element is assigned to multiple subgroups (e.g., overlapping subgroups shown in FIG. 4C), then a radio frequency combiner 1130 may be used to combine signals from two line cards. FIG. 11C shows a radio frequency combiner 1130 coupled to two line cards 1113 and 1114. In this example, the line cards 1113 and 1114 are each coupled to four antennas with a single antenna element overlapping the two. In some implementations, scheduling or other techniques are used such that radio frequency combining is unnecessary. By subdividing spectrum and/or antenna arrays, the computational and hardware requirements for spatial processing may be reduced in a manner that facilitates a scalable deployment. A number of implementations have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other implementations are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A radio communication system comprising:

multiple antenna elements divided into subgroups, each subgroup including at least two of the multiple antenna elements; and

multiple line cards operable to employ spatial processing techniques, each line card coupled to a subgroup such that the line card may transmit and receive signals using the subgroup.

2. The radio communication system of claim 1 wherein the subgroups are non-overlapping.

3. The radio communication system of claim 1 wherein one of the multiple antenna elements belongs to at least two subgroups.

4. The radio communication system of claim 1 further comprising a radio frequency combiner such that at least two line cards may be coupled to an antenna element of the multiple antenna elements using the radio frequency combiner, the radio frequency combiner combining signals such that the at least two line cards may simultaneously transmit signals through the antenna element

5. The radio communication system of claim 1 wherein each of the multiple line cards includes:

multiple radio frequency components such that each radio frequency component is coupled to an antenna element of the subgroup; and

a signal processing component coupled to the multiple radio frequency components, the signal processing component operable to employ spatial processing techniques.

6. The radio communication system of claim 1 wherein the multiple antenna elements are disposed about multiple faces.

7. The radio communication system of claim 6 wherein each subgroup corresponds to one of the multiple faces.

8. The radio communication system of claim 7 wherein each subgroup includes an antenna element that is not situated on the corresponding face of the subgroup.

9. The radio communication system of claim 6 wherein the multiple antenna elements include 16 antenna elements that are disposed about four faces.

10. The radio communication system of claim 9 wherein multiple antenna elements are divided into 4 subgroups, each subgroup corresponding to one of the four faces.

11. A base station for use in a radio communication system, the base station comprising:

a line card comprising:

an antenna interface used to couple the line card to a subgroup of multiple antenna elements;

a radio frequency component coupled to the antenna interface; and

a signal processing component coupled to the radio frequency component such that the line card is operable to transmit and receive radio frequency communications,

wherein an additional line card may be added to the base station to increase the capacity of the base station.

12. The base station of claim 11 wherein the additional line card is coupled to a different subgroup of the multiple antenna elements to increase capacity of the base station.

13. The base station of claim 11 further comprising a radio frequency combiner coupled to a subgroup of the multiple antenna elements such that the line card is coupled to the subgroup of the multiple antenna elements through the radio frequency combiner.

14. The base station of claim 13 further comprising a second line card such that the line card and the second line card are coupled to the subgroup of the multiple antenna elements using the radio frequency combiner.

15. The base station of claim 11 wherein the additional line card is coupled to the same subgroup of the multiple antenna elements to increase capacity of the base station by supporting additional spectrum.

16. The base station of claim 15 wherein each line card supports 5 megahertz of spectrum.

17. A method for providing increased capacity in a radio communication system, the method comprising:

dividing an antenna array, creating N subgroups of antenna elements; and

for each of the N subgroups of antenna elements, coupling a line card to the subgroup of antenna elements;

wherein each line card is operable communicate using its coupled subgroup of antenna elements.

18. The method of claim 17 further comprising dividing available spectrum, creating M subgroups of the available spectrum such that each line card is operable to service a subgroup of the available spectrum; wherein capacity of the radio communication system may be increased by configuring multiple line cards to service different subgroups of the available spectrum using the same subgroup of antenna elements.

19. The method of claim 17 wherein the antenna array includes at least one antenna element that is not within the N subgroups of antenna elements.

20. The method of claim 17 wherein each subgroup of antenna elements includes 4 antennas.

21. The method of claim 17 wherein the antenna array includes four faces and each of the subgroups of antenna elements corresponds to one of the four faces.

22. The method of claim 17 wherein at least one antenna element is included in more than one of the N subgroups of antenna elements.

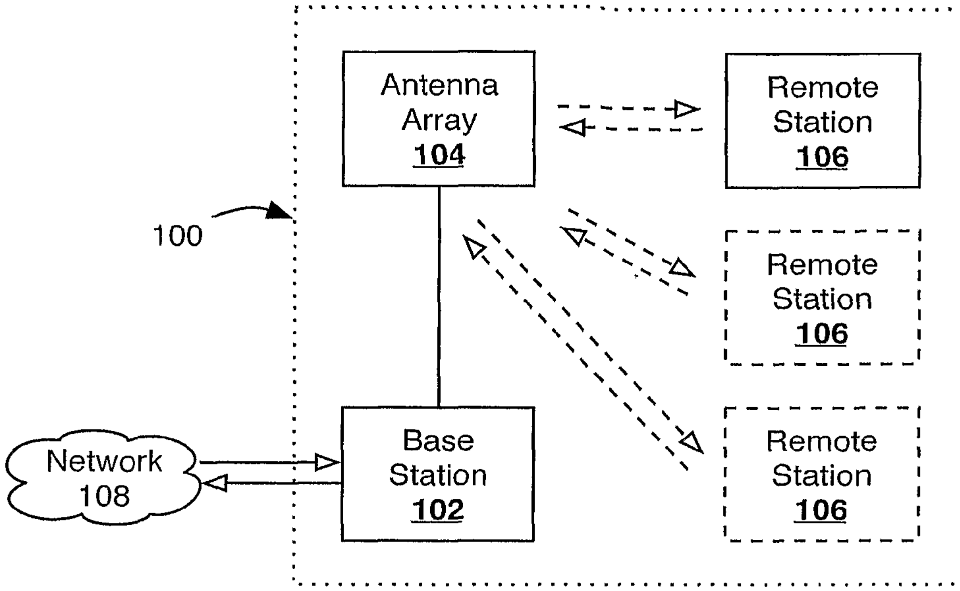

Antenna Array 104
Remote Station 106
100
Remote Station 106
Network 108
Base Station 102
Remote Station 106

FIG. 1

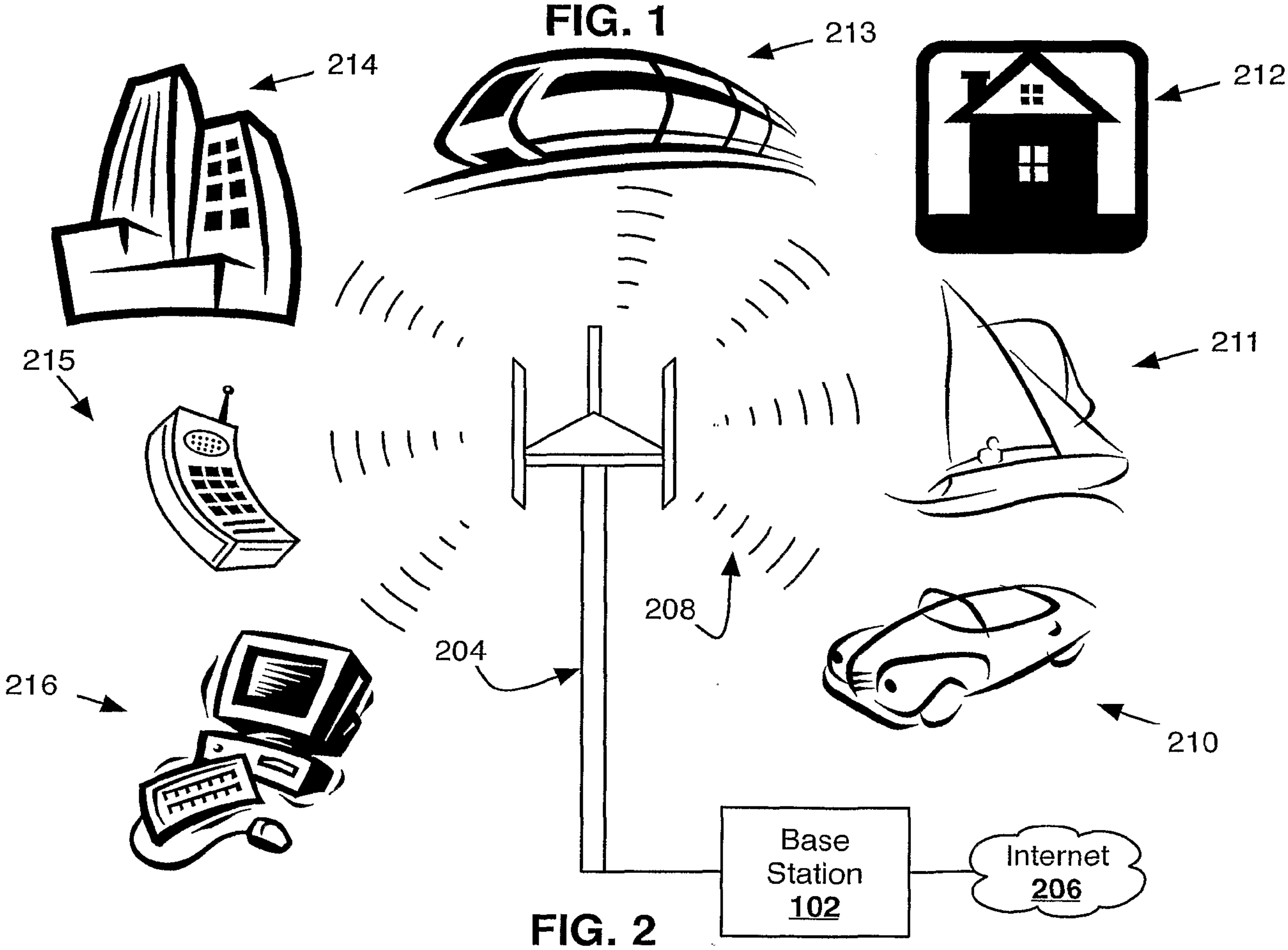

213
214
212
211
215
208
204
216
210
Base Station 102
Internet 206

FIG. 2

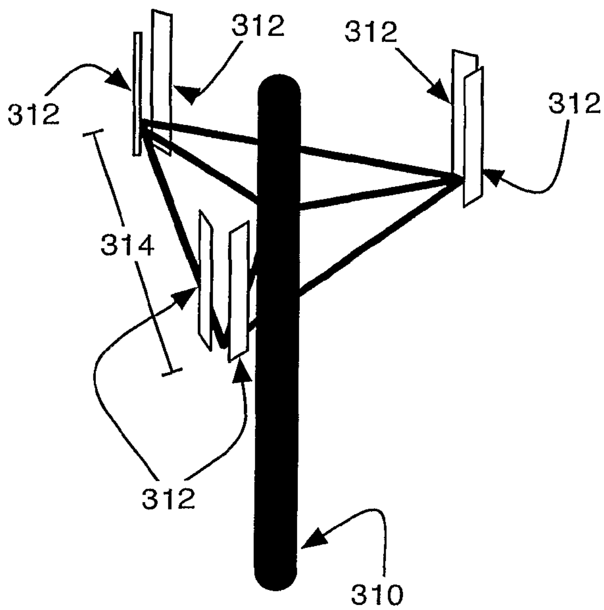


FIG. 3A

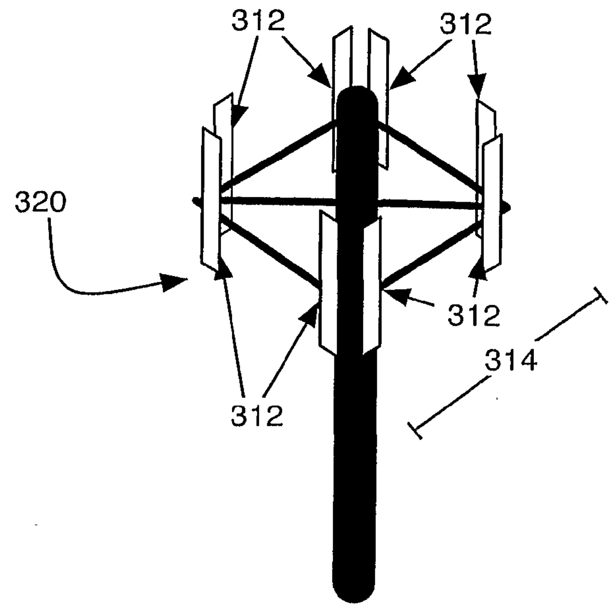


FIG. 3B

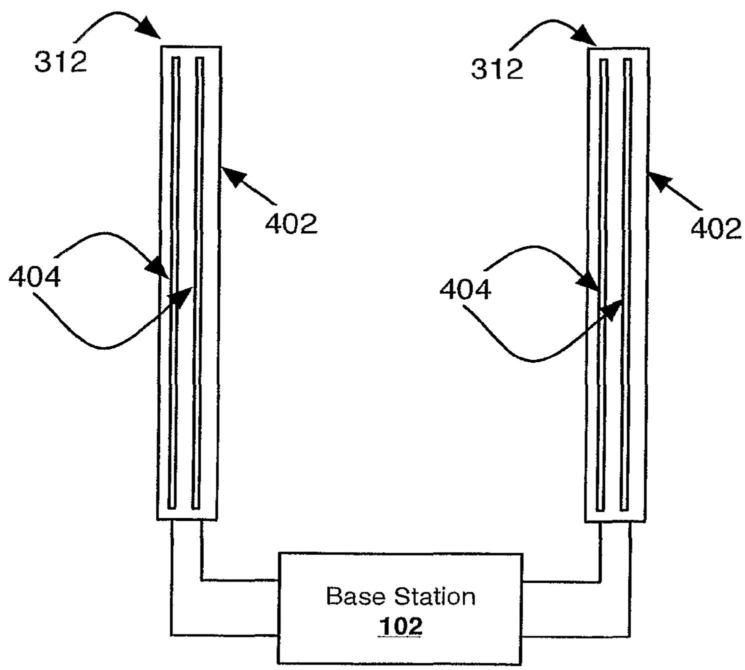


FIG. 3C

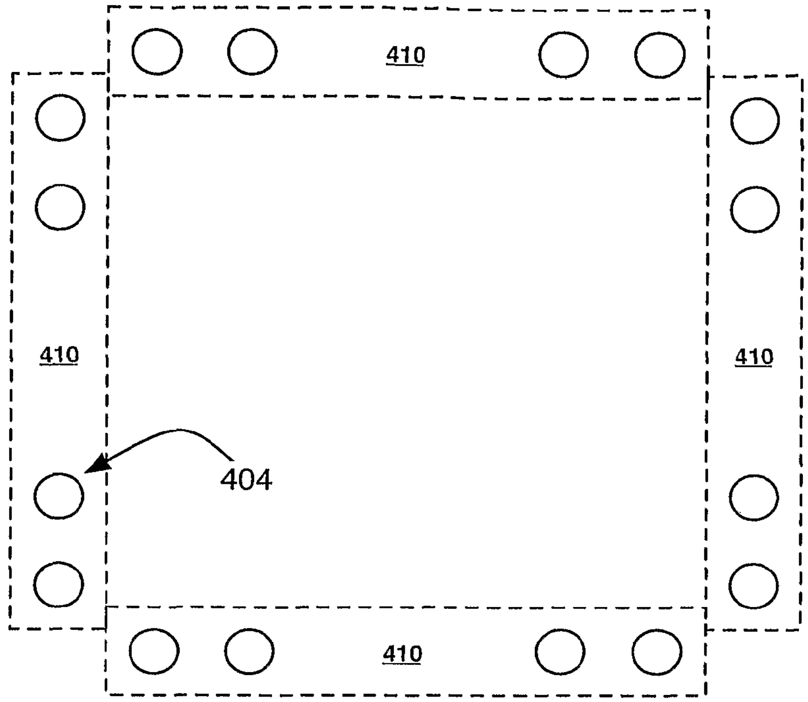


FIG. 4A

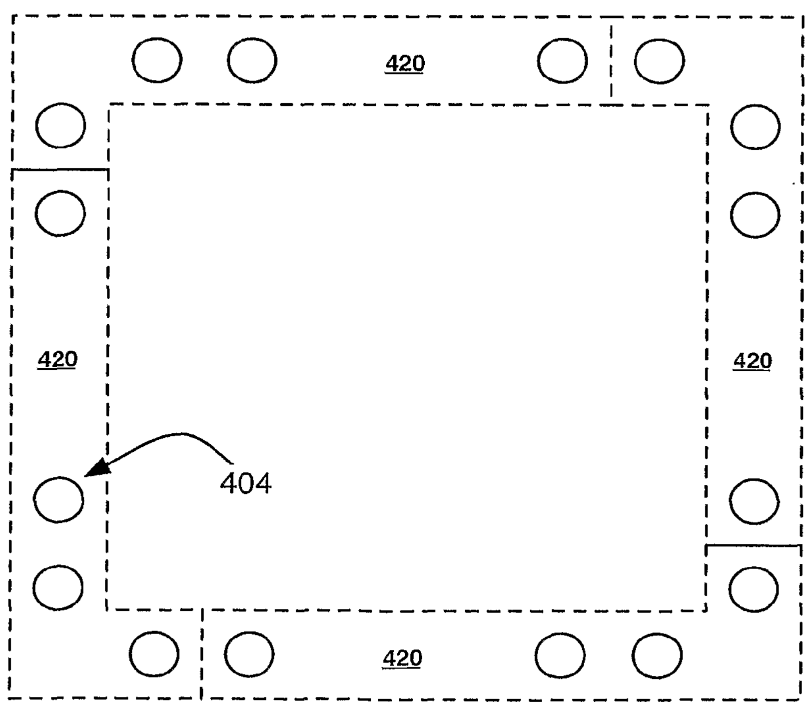


FIG. 4B

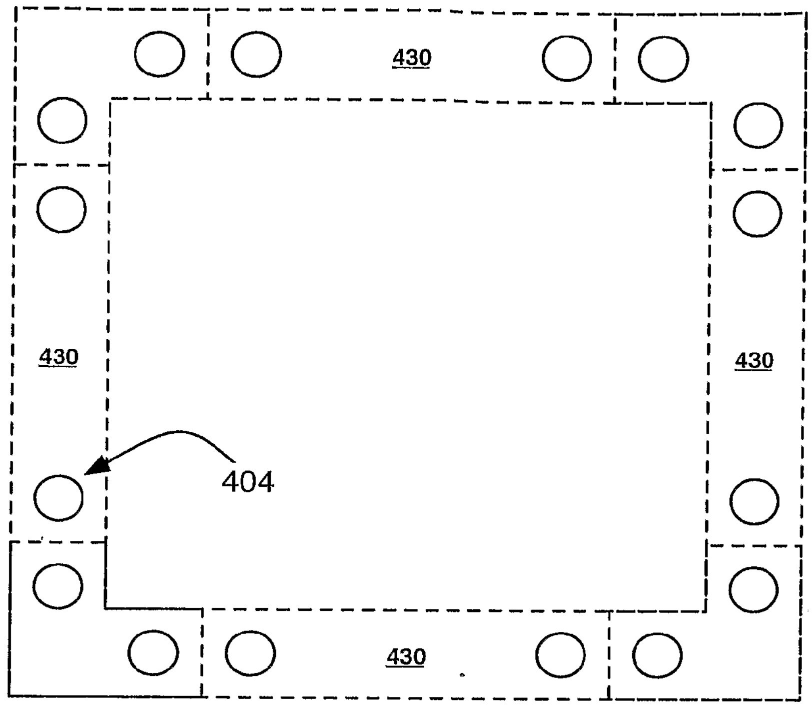


FIG. 4C

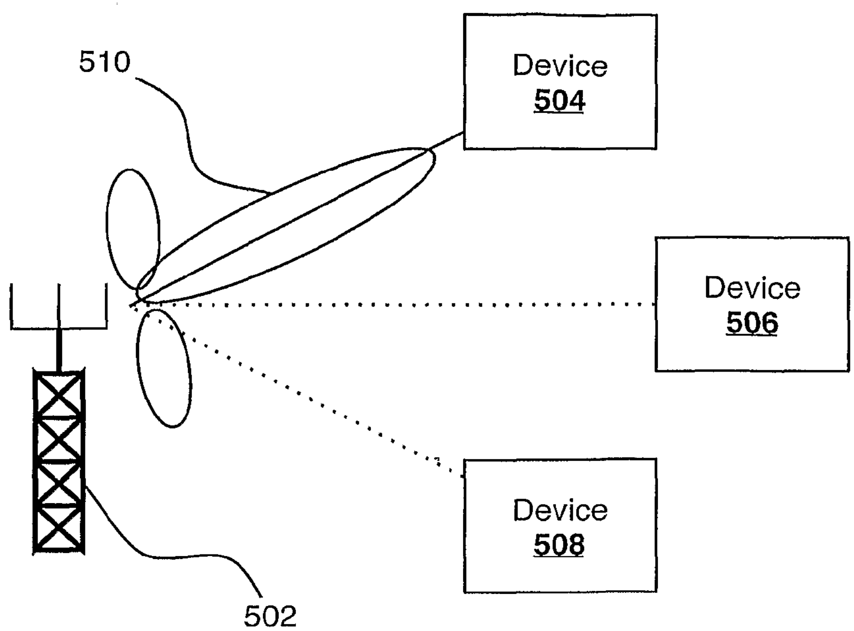

510
Device
504
Device
506
Device
508
502

FIG. 5A

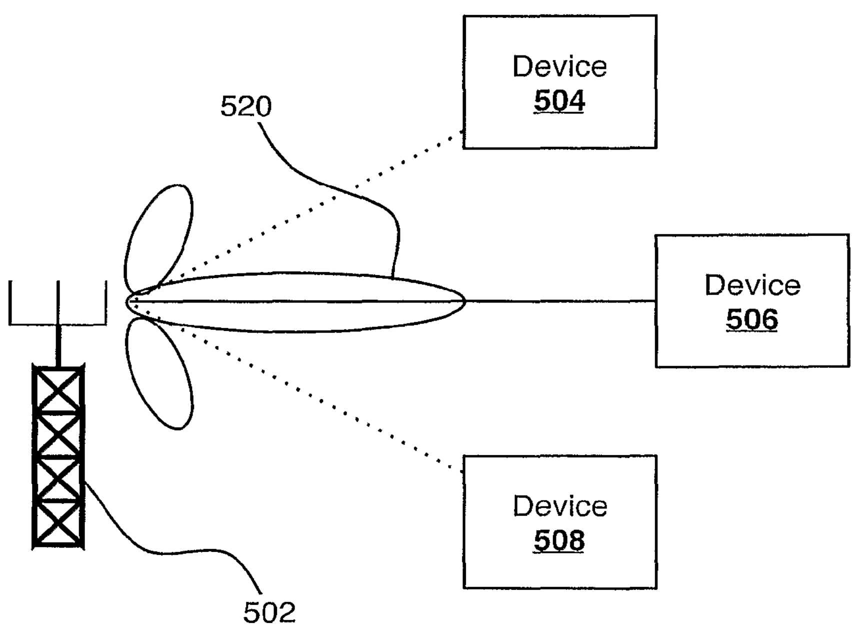

520
Device
504
Device
506
Device
508
502

FIG. 5B

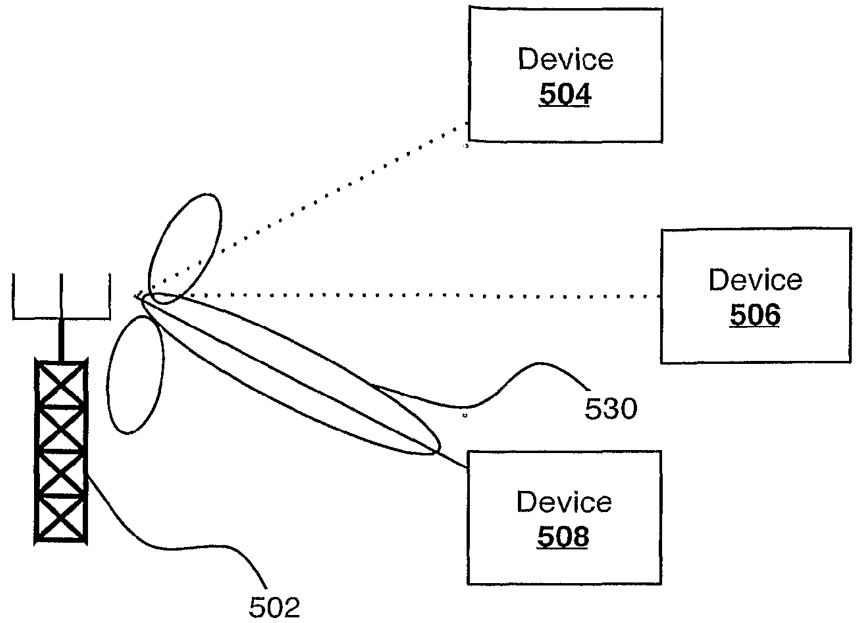

Device
504
Device
506
530
Device
508
502

FIG. 5C

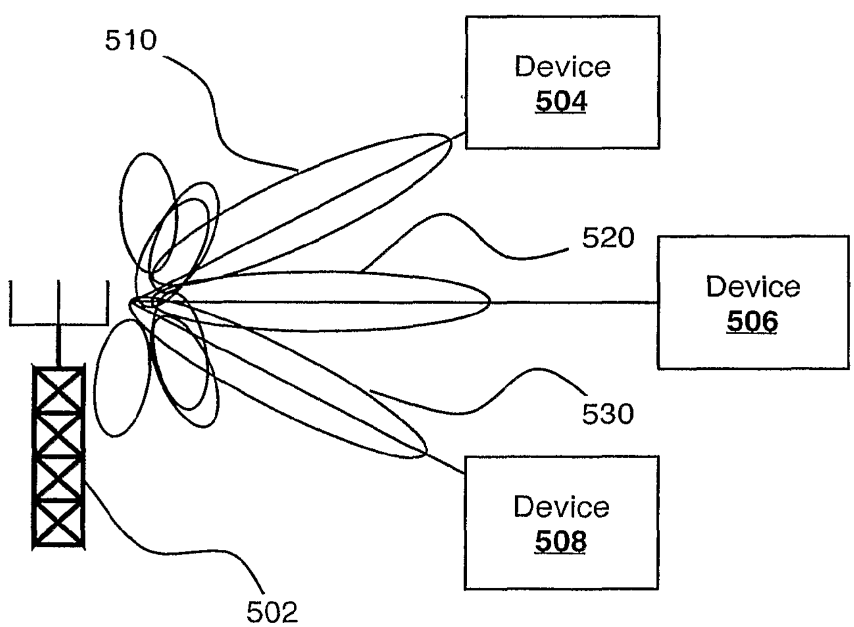

510
Device
504
520
Device
506
530
Device
508
502

FIG. 5D

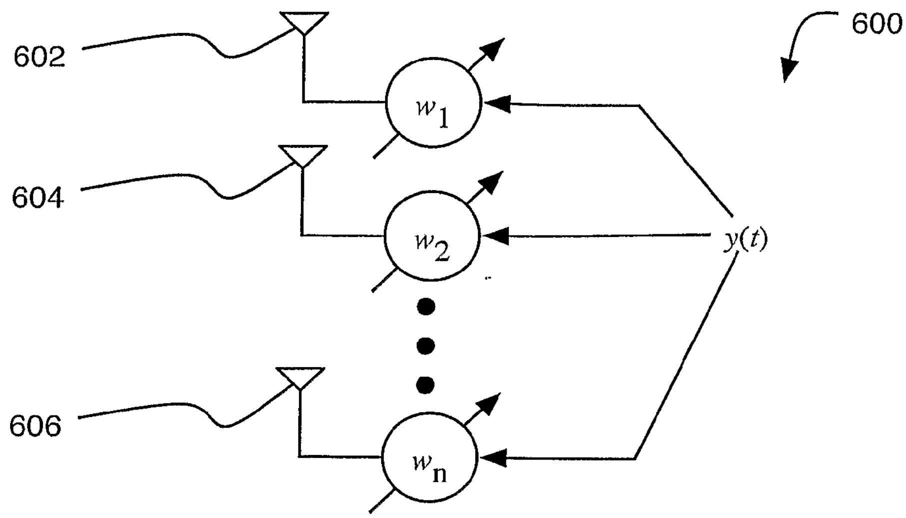


FIG. 6

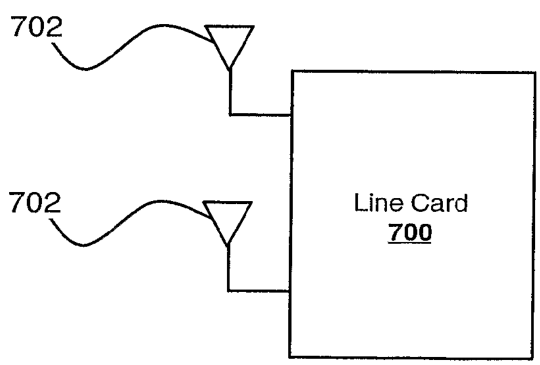
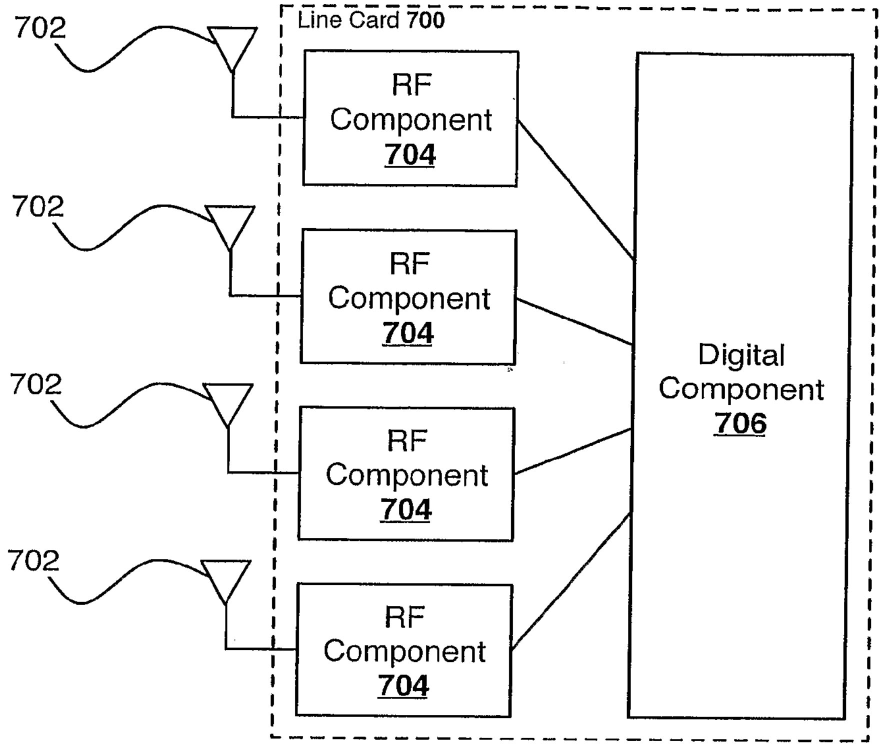
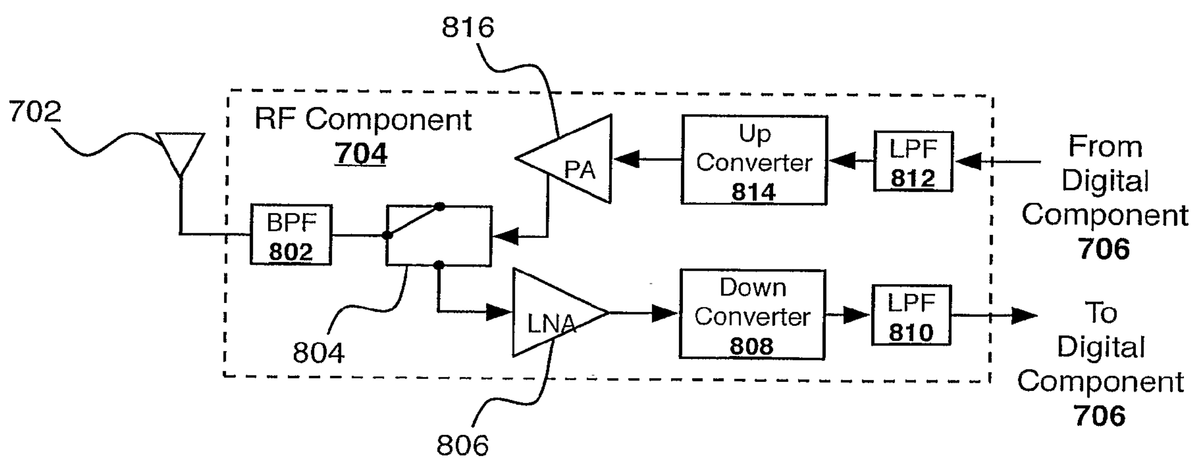


FIG. 7A



702
702
702
702
Line Card 700
RF Component 704
RF Component 704
RF Component 704
RF Component 704
Digital Component 706

FIG. 7B



816
702
RF Component 704
PA
Up Converter 814
LPF 812
From Digital Component 706
BPF 802
804
LNA
Down Converter 808
LPF 810
To Digital Component 706
806

FIG. 8

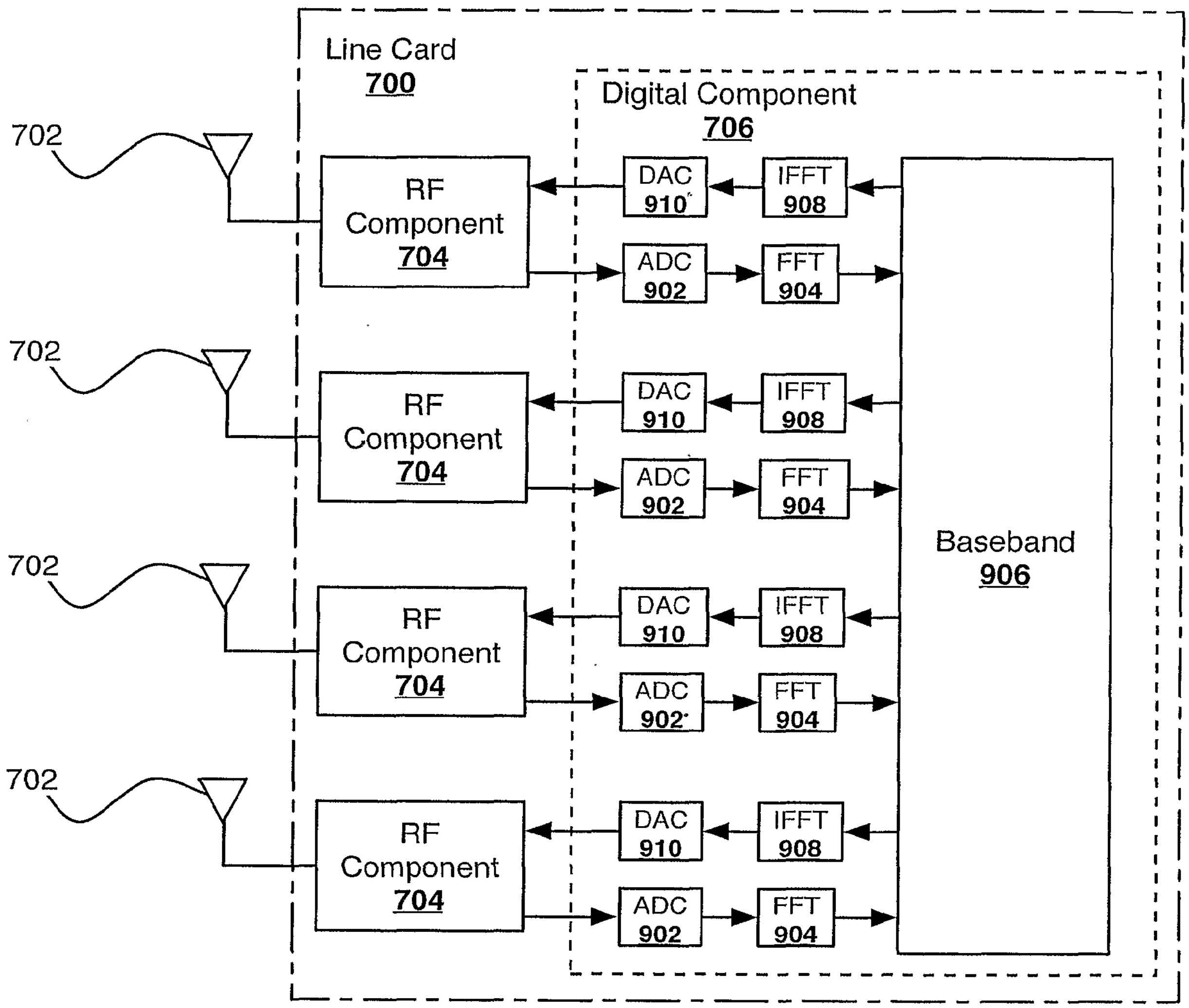

Line Card
700
Digital Component
706
702
702
702
702
RF
Component
704
RF
Component
704
RF
Component
704
RF
Component
704
DAC
910
IFFT
908
ADC
902
FFT
904
DAC
910
IFFT
908
ADC
902
FFT
904
DAC
910
IFFT
908
ADC
902
FFT
904
DAC
910
IFFT
908
ADC
902
FFT
904
Baseband
906

FIG. 9

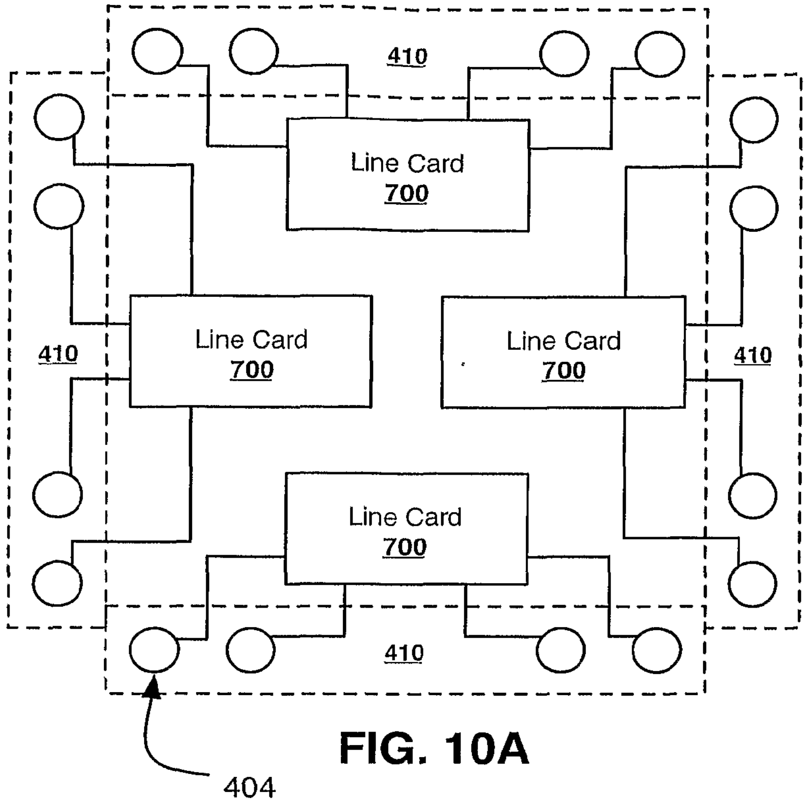


FIG. 10A

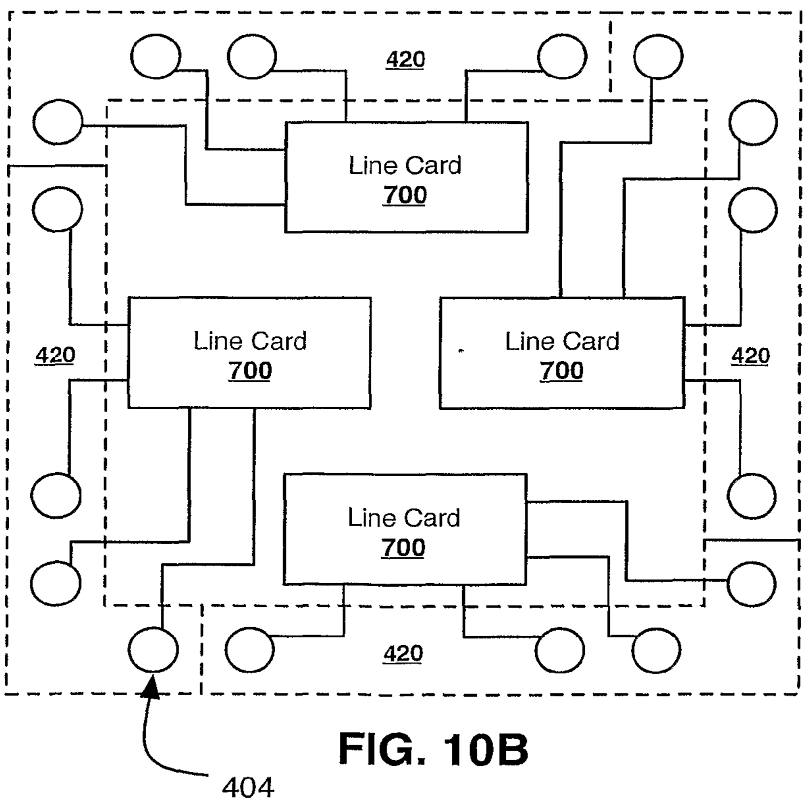


FIG. 10B

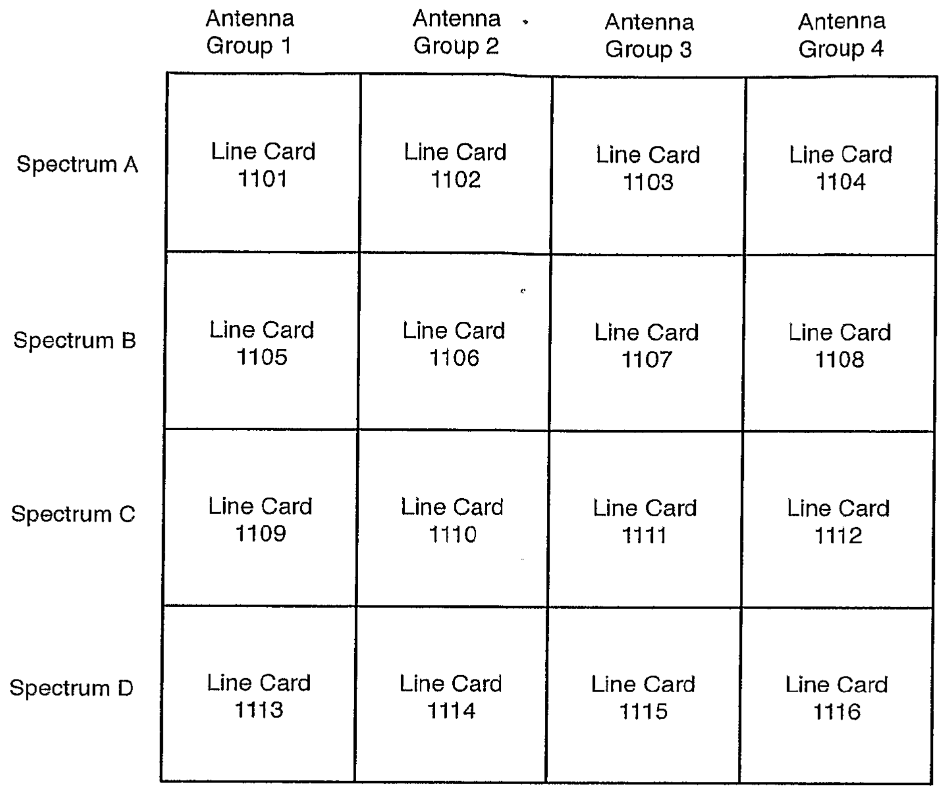


FIG. 11A

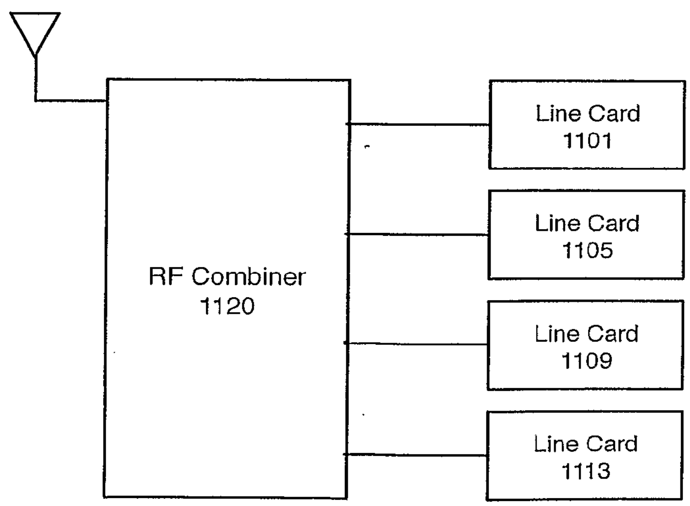


FIG. 11B

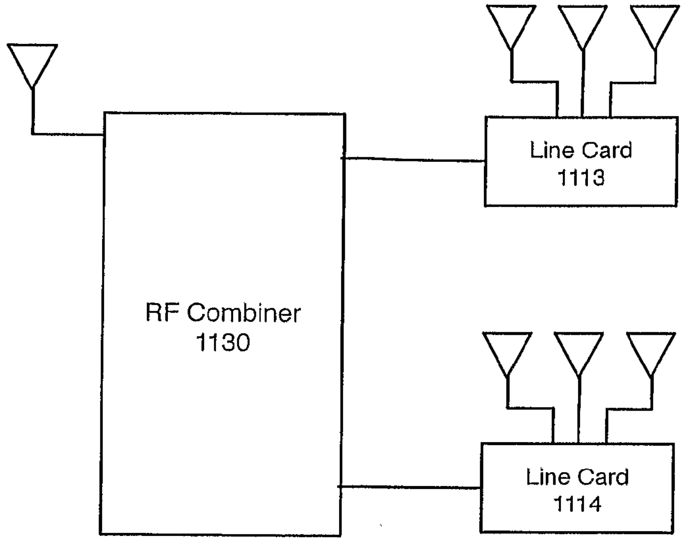


FIG. 11C

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 June 2008 (05.06.2008)

PCT

(10) International Publication Number
WO 2008/064696 A1

(51) International Patent Classification:
H04B 7/08 (2006.01)

(21) International Application Number:
PCT/EP2006/011430

(22) International Filing Date:
29 November 2006 (29.11.2006)

(25) Filing Language: English

(26) Publication Language: English

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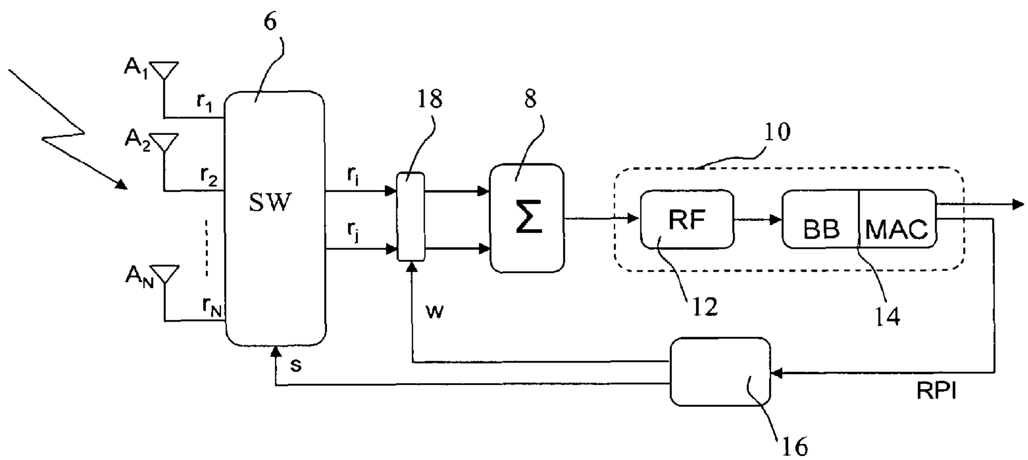
(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

(54) **Title:** SWITCHED BEAM ANTENNA SYSTEM AND METHOD WITH DIGITALLY CONTROLLED WEIGHTED RADIO FREQUENCY COMBINING



(57) **Abstract:** A wireless communication system, wherein a sub-set of RF signals received from corresponding antenna elements (A111AN) is selected and combined (8) into a single RF signal, the single RF signal being processed and demodulated in a single processing chain (10), comprising a RF phasing network (18) for co-phasing the selected RF signals before combining and a processor (16) for controlling combining (8) and phasing (18) in order to obtain a single RF signal having a radio performance indicator (RPI) which satisfies predetermined conditions.

WO 2008/064696 A1

SWITCHED BEAM ANTENNA SYSTEM AND METHOD WITH DIGITALLY CONTROLLED WEIGHTED RADIO FREQUENCY COMBINING

Field of the invention

The present invention relates in general to wireless communication systems, in particular to a method and an apparatus for recombining received/transmitted signals in a switched beam antenna. The present invention also relates to a Wireless Local Area Network (WLAN) device provided with a switched beam antenna with radio frequency combining of received/transmitted signals.

Description of the related art

A Wireless Local Area Network uses radio frequency (RF) signals to transmit and receive data over the air. WLAN systems transmit on unlicensed spectrum as agreed upon by the major regulatory agencies of countries around the world, such as ETSI (European Telecommunications Standard Institute) for Europe and FCC (Federal Communications Commission) for United States.

Wireless LANs allow the user to share data and Internet access without the inconvenience and cost of pulling cables through walls or under floors. The benefits of WLANs are not limited to computer networking. As the bandwidth of WLANs increases, audio/video services might be the next target, replacing device-to-device cabling as well as providing distribution throughout home, offices and factories.

Fundamentally, a WLAN configuration consists of two essential network elements: an Access Point (AP) and a client or mobile station (STA). Access points act as network hubs and routers. Typically, at the back end, an access point connects to a wider LAN or even to the Internet itself. At the front-end the access point acts as a contact point for a flexible number of clients. A station (STA) moving into the effective broadcast radius of an access point (AP) can then connect to the local network served by the AP as well as to the wider network connected to the AP back-end.

In WLAN deployment, coverage and offered throughput are impacted by several interacting factors that must be considered to meet the correspondent requirements. Wireless signals suffer attenuations as they propagate through space, especially inside buildings where walls, furniture and other obstacles cause absorption, reflections and refractions. In general the farther is the STA from the AP, the weaker is the signal it receives and the lower the physical rates that it can reliably achieve. The radio link throughput is a function of a number of factors including the used transmission format and the packet error rate (PER) measured at the receiver. A high PER may defeat the speed advantage of a transmission format with higher nominal throughput by causing too many retransmissions. However, WLAN devices constantly monitor the quality of the signals received from devices with which they communicate. When their turn to transmit comes, they use this information to select the transmission format that is expected to provide the highest throughput. In any case, on the average, the actual data rate falls off in direct relation to the distance of the STA from the AP.

Nowadays, high performance WLAN systems are required to provide high data rate services over more and more extended coverage areas. Furthermore, they have to operate reliably in different types of environments (home, office). In other words, future high performance WLAN systems are expected to have better quality and coverage, be more power and bandwidth efficient, and to be deployed in different environments.

Most current local area network equipment operates in the 2.4GHz industrial, scientific and medical (ISM) band. This band has the advantage of being available worldwide on a license-exempt basis, but it is expected to congest rapidly. Thus, the spectrum regulatory body of each country restricts signal power levels of various frequencies to accommodate needs of users and avoid RF interference. Most countries deem wireless LANs as license free. In order to qualify for license free operation, however, the radio devices must limit power levels to relatively low values. In Europe, the Electronic Communications Committee (ECC) has defined a limiting condition in the ECC Report 57: "(O)RLANS in the Frequency Band 2400-2483.5 MHz", specifying the current regulations concerning the maximum allowed Equivalent Isotropic Radiated Power (EIRP). The limiting condition has been fixed so that the output power of the equipment results in a maximum radiated power of 100mW EIRP or less. It follows that, depending on the type of antenna used, it might be necessary to reduce the output power of the equipment to result in a maximum radiated power of 100 mW EIRP or less. Combinations of power levels and antennas resulting in a radiated power level above 100 mW are considered as not compliant with national radio interface regulation.

The EIRP represents the combined effect of the power supplied to the antenna and the antenna gain, minus any loss due to cabling and connections:

$$EIRP(dBm) = P_{TX}(dBm) + G_{TX}(dB) - L_{TX}(dB)$$

where P_{TX} is the power supplied to the transmitting antenna, G_{TX} is the antenna gain defined with respect to an isotropic radiator and L_{TX} is the cabling loss.

Since the EIRP includes the antenna gain, this introduces a limitation to the kind of antennas that can be used at the transmitter. In order to employ an antenna with higher gain, the transmitted power must be reduced, so that the EIRP remains below 20 dBm.

Solutions to the coverage range enhancement problem, which are already known in literature, use system configurations that exploit multiple omni-directional antennas in which the different signals are demodulated separately by means of distinct radio frequency (RF) processing chains and subsequently recombined digitally at baseband (BB) level, as illustrated e.g. in US 6,907,272 and in US 6,438,389.

More advanced antenna architectures are based on the combination of multiple directional antennas. Among these systems, Switched Beam (SB) antenna architectures are based on multiple directional antennas having fixed beams with heightened sensitivity in particular directions. These antenna systems detect the value of a particular quality of service (QoS) indicator, such as for example the signal strength or the signal quality, received from the different beams and choose the particular beam providing the best value of QoS. The procedure for the beam selection is periodically repeated in order to track the variations of the propagation channel so that a WLAN RF transceiver is continuously switched from one beam to another.

An antenna apparatus with selectable antenna elements is illustrated in WO 2006/023247, which discloses a planar antenna apparatus comprising a plurality of individually selectable planar antenna elements, each of which has a directional radiation pattern with gain and with polarization substantially in the plane of the planar antenna apparatus. Each antenna element may be electrically selected (e.g., switched on or off) so that the planar antenna apparatus may form a configurable radiation pattern. If all elements are switched on, the planar apparatus forms an omnidirectional radiation pattern. The system may select a particular configuration of selected antenna elements that minimizes interference of the wireless link or that maximizes the gain between the system and the remote device.

Object and summary of the invention

The Applicant has observed that in the solutions exploiting multiple RF processing chains for demodulating signals received by multiple antenna elements, the antennas are generally spaced in such a way to guarantee that the received signals are independent, thus introducing a spatial diversity gain together with an array gain obtained thanks to the coherent combining of the signals received from the different antennas. The drawback of such solutions resides in the receiver complexity, and correspondent costs, which are related to the introduction of a plurality of RF processing chains.

The Applicant has also observed that, as regards solutions exploiting selectable antenna elements, the large overall gain values obtained, on the receiving side, may become critical when the same antenna configuration is used in a WLAN client or access point on the transmitting side, due to the aforementioned EIRP limitations. Such systems are typically aimed to increase the range, neglecting limitations due to regional power limitation regulations. Thus a reduction of the transmitted power must be eventually introduced, leading to a loss of part of the overall performance enhancement.

The Applicant has tackled the problem of enhancing the coverage range of a switched beam antenna while fulfilling regulations concerning limitations on the power emissions.

In particular, the Applicant has tackled the problem of providing a switched beam antenna which is compliant with the EIRP limitation and, at the same time, increases the coverage range of a WLAN. An increased coverage range may contribute in decreasing installation costs, because of the need of a reduced number of access points.

The Applicant has found that this problem can be solved by selecting, in a switched beam antenna, at least two beams providing two corresponding RF signals which are co-phased and recombined in a single RF signal, for being demodulated in a single modem. Co-phasing and recombining comprises a multiplication of at least one of the signals for a complex-valued weight and combining by means of an adder. The same weights are used in transmission for weighting two separate signals which are obtained from a single RF signal to be transmitted by means of a splitter that divides it into two separate signals with the same power level.

The selection of the beams and the complex-valued weights to be used in the co-phasing operation are chosen with the goal of maximizing a radio performance indicator, or a combination of different indicators, such as the Received Signal Strength Indicator RSSI, the throughput or by minimizing the PER of the combined signal.

The switched beam antenna according to the present invention is able to enhance the overall coverage range, fulfilling the regional regulations concerning limitations on the power emissions, with a smaller reduction of the transmitted power.

In particular, such antenna architecture can be exploited by a WLAN client both in the downlink direction (i.e. the Access Point is transmitting and the WLAN client is receiving) and in the uplink direction (i.e. the WLAN client is transmitting and the Access Point is receiving).

As the weighted combining of the signals is performed at RF, this solution requires generally no modifications within the modem receiver and hence can be easily applied on existing WLAN clients as an add-on device.

Brief description of the annexed drawings

Further features and advantages of the present invention will be made clearer by the following detailed description of some examples thereof, provided purely by way of example and without restrictive intent. The detailed description will refer to the following figures, in which:

Figure 1 illustrates schematically a switched beam antenna system realised according to the present invention employed in the downlink direction;

Figure 2 illustrates a spatial antenna configuration for the antenna system of Figure 1;

Figure 3 shows schematically a switching network for the antenna system of Figure 1;

Figure 4 shows a RF phasing network according to an aspect of the present invention:

Figure 5 illustrates in a diagram a performance comparison between antenna architectures according to reference designs and the present invention;

Figures 6a and 6b show two alternative RF phasing circuits for the system of Figure 1;

Figures 7a and 7b show two possible implementations for the RF phasing networks of Figures 6a and 6b;

Figure 8 illustrates power reduction, downlink and uplink gains in a reference switched beam antenna;

Figure 9 illustrates schematically a switched beam antenna system realised according to the present invention employed in the uplink direction.

Detailed description of preferred embodiments of the invention

With reference to Figure 1, a multiple directional antenna system according to the present invention comprises a plurality of directional antennas $A_1..A_N$ which are deployed in such a way that almost all the possible directions of arrival of the received signal are covered. In a typical configuration, shown schematically in Figure 2, eight antennas $A_1..A_8$ are used in order to cover the entire azimuth plane. Each antenna has a radiation pattern shown in figure as a lobe having gain G0.

Signals $r_1..r_N$ from antennas $A_1..A_N$ are fed to a RF switching network 6 that allows the selection, by means of selection signal S, of a sub-set of signals, in particular two (or more than two) strongest beams providing the signals r_i and r_J that maximize a given radio performance indicator, as explained in detail hereinafter. This decision is made in block 16 at base-band (BB) level by measuring one or more radio performance indicator RPI provided by a modem receiver 10, such as for example the Received Signal Strength Indicator (RSSI), the throughput or the Packet Error Rate (PER). A suitable recombination technique, applied at RF, is then performed on the signals r_i, r_j selected by the switching network. The recombined signal is then sent to a single RF processing chain 12 and demodulated through a conventional modem 14 which carries out the BB and MAC receiving operations.

The recombination technique, referenced hereinafter as Weighted Radio Frequency (WRF) combining, operates as follows. The two (or in general the sub-set) selected signals r_i and r_j are first co-phased, in block 18, by means of a multiplication operation for appropriate complex-valued weights, referenced globally by signal W in Figure 1, and then added together in a combiner 8. In fact, as the signal propagation takes place generally through multiple directions of arrival (DOA), such recombination technique, performed at RF, gives a reduction of fading and produces an output signal with a better quality, even when none of the individual signals of the different directions of arrival (DOA) are themselves acceptable. This is obtained by weighting the signals from different directions of arrival (two in the embodiment described herein but in general a subset of all directions) according to an appropriate complex value, co-phasing them individually and finally summing them together. The information will hence be gathered from the selected directions of arrival, each of which gives its own weighted contribution to the output signal.

The complex-valued weights W and the selection of the sub-set of beams, to be used in the co-phasing operation, are chosen with the goal of obtaining a radio performance indicator RPI comprised within a predetermined range, e.g. maximizing a particular indicator, or a combination of different indicators, such as the RSSI or the throughput, or by minimizing the PER of the combined signal.

With particular reference to a first preferred embodiment, shown in Figure 6a, which illustrates a first version of the RF phasing circuit 18 of the system of Figure 1, when two signals r_i and r_J are selected after the switching network, one of the two signals r_i is maintained as it is and the other r_J is co-phased by a complex-valued weight w_J with unitary modulus. The two signals are then recombined in block 8 and sent to the single RF processing chain 12 and demodulated through the modem 14 which carries out the BB and MAC receiving operations, as shown in Figure 1.

According to a particular embodiment of the invention, considering the configuration of eight antennas shown in Figure 2 the switching network 6 is realized as schematically shown in Figure 3. Two symmetrical switching sub-networks 6a and 6b, having an "8 to 1" configuration, are fed with same signals $r_1..r_8$ coming from antennas $A_1..A_8$, resulting in an "8 to 2" switching network scheme. Each sub-network 6a, 6b has a plurality of switches, indicated altogether in Figure 3 by references 20a and 20b, allowing to select, in each network, any of input signal $r_1..r_8$. Any combination of output signals r_i, r_J can thus be selected by the switching network 6.

The beam selection technique, performed by block 16, operates, according to a preferred embodiment, as follows. Eight pairs of signals r_i, r_J, derived from the eight different antennas, are subsequently selected by means of the switching network 6 and sent to the RF phasing circuit 18, in particular the phasing circuit shown in Figure 6a. In particular the pairs of signals are sent in the following order: (A_1, A_2), (A_2, A_3), (A_3, A_4), (A_4, A_5), (A_5, A_6), (A_6, A_7), (A_7, A_8), (A_8, A_1) and, for each pair, a certain radio performance indicator, or a combination of different indicators (such as the RSSI, the throughput or the PER of the combined signal) is measured. In particular, in this first step, no phasing operation is introduced, hence $w_i = \exp(-j\cdot 0)$. It follows that, at this step, the signals received from the switching network are simply added together by adder 8 without introducing any phase modification. Once the above eight radio performance indicator measurements have been calculated, the two pairs of beams (A_i, A_j) and (A_h, A_k), providing the best two performance indicator values, are selected and the related received signals are identified.

The next step is to provide the above four optimal signals (related to the two optimal pairs of beams) at the input of the circuit shown in Figure 6a in all the possible six different combinations (A_i, A_h), (A_i, A_k), (A_j, A_h), (A_j, A_k), (A_i, A_j), (A_h, A_k) and with all the four possible weights $w_i = \exp(-j\cdot\beta)$ corresponding to the quantized phase values chosen from the following set: $\beta \in \{0°, 90°, 180°, 270°\}$, as detailed in the following with reference to Figure 7a. Once again, twenty-four radio performance indicator measurements are evaluated, and the optimal pair of signals together with the related optimal weights, corresponding to the maximum values of the radio performance indicator, is selected to complete the procedure, thus obtaining optimal beam selection signal S and weight(s) W from decision block 16.

According to an embodiment of the present invention, the complex-valued weights with unitary modulus can be introduced in a quantized form in order to use only a limited set of values. In particular, in order to define a quantization step providing a good trade-off between performance and complexity, we have supposed to divide the entire azimuth plane of 360° in a certain number L of quantized angular values corresponding to multiples of a certain elementary angle resolution with a value α = 360° / L. It is evident that the L quantized angular values can be represented, with a binary notation, on a certain number of bits equal to $\log_2(L)$.

This elementary angle resolution α represents the discrete step to be applied at RF level in order to co-phase one of the two selected signals. In the case of unitary modulus complex-valued weight w, an optimal number L of quantized angular values introducing the phase shift, necessary for the co-phasing operation, can be chosen, for example, by optimizing the performance, in terms of PER, computed on the combined signal.

In Table 1 the values of PER, evaluated in correspondence of C/N=10dB, for a 12 Mbps physical layer data rate service, transmitted over a typical home environment propagation channel model (MIMO Model B channel model) are summarized as a function of the elementary angle resolution α = 360° / L. It is possible to observe that angle resolutions of 90° or 45° are a good trade-off between complexity (2 or 3 bits for the quantization of the phase shift value) and performance in terms of PER.

Table 1: PER performance for different phase shift angle resolutions.

Number L of Quantized Angular Values	Number of Bits	Angle Resolution α [deg]	PER
256	8	1.4°	0.049
128	7	2.8°	0.049
64	6	5.6°°	0.049
32	5	11.2°	0.049
16	4	22.5°	0.050
8	3	45°	0.052
4	2	90°	0.056

2	1	180°	0.097

The discrete phase shift step, to be applied at RF level in order to co-phase one of the two selected signals, can be obtained, for example, by exploiting a suitable RF co-phasing network that, for example, can be implemented according to the scheme shown in Figure 4. The implementation of the RF co-phasing network, shown in Figure 4, can be, for instance, realized by means of two switches 22, 24 with single input and L outputs (each switch is realised e.g by means of a PIN diode network) and L delay lines with different lengths introducing, on the received signal, a delay d_i which is related to the correspondent value of RF phase rotation w_i by the following equation

$$w_i = \exp(-j \cdot 2 \cdot \pi \cdot d_i / \lambda) \quad \text{for } i = 0, \ldots, L-1 \qquad (1)$$

where λ is the wavelength of the signal carrier.

From equation (1) it follows that, in order to obtain quantized phase shift values corresponding to multiples of a certain elementary angle resolution $\alpha = 360° / L$ so that $w_i = \exp(-j \cdot \varphi_i)$ with $\varphi_i = 360° / L \cdot i$ and i = 0, 1, 2,...L-1, it is necessary to employ values d_i of delay given by the following equation

$$d_i = \lambda / L \cdot i \quad \text{for } i = 0, \ldots, L-1 \qquad (2)$$

A performance comparison in the downlink direction (i.e. the Access Point is transmitting and the WLAN client is receiving) of different antenna architectures is shown in Figure 5. Without loss of generality a 12 Mbps physical layer data rate service has been considered. Transmission is referred to typical home environment propagation conditions. It is possible to observe that the switched beam antenna according to the present invention, curve 30, achieves a gain, in terms of signal-to-noise ratio (C/N), of about 1-2 dB with respect to a reference Switched Beam antenna, curve 32, in the range of PER values comprised in between 0.01 and 0.001, when adopting an elementary phase shift value quantized over 2 bits. Curve 32 refers in fact to a reference Switched Beam (SB) antenna architecture, based on multiple directional antennas, wherein the value of a particular quality of service (QoS) indicator received from the different antennas, such as for example the signal strength, is periodically monitored and the beam providing the best value of QoS is selected. Curve 34 refers to a reference antenna architecture having two antennas and a RF switching circuit for periodically selecting the antenna providing a strongest signal, while curve 36 refers to a prior art antenna architecture having a single antenna.

The antenna architecture according to the invention, while providing a performance improvement, advantageously requires only one RF processing chain, thus reducing the required complexity and related costs. Moreover, as no substantial modifications are required within the modem receiver 10, this solution can be applied on existing WLAN clients as an add-on device, reducing the required costs in the related deployment.

With reference to a second preferred embodiment, shown in Figure 6b which illustrates a second version of the RF phasing circuit 18 of the system of Figure 1, both signals r_i and r_J are weighted by the weights w_i and w_J respectively. In this case the signal at the output of the co-phasing network 18 and combining network 8 can be expressed as follows

$$r = r_i \cdot w_i + r_j \cdot w_j$$

where the weighting factors can be expressed as complex phase shift weights

$$w_i = e^{j\alpha} \qquad\qquad w_j = e^{j\beta}$$

and the signals at the output of the RF switching network can be expressed considering, for simplicity, only the phase term

$$r_i = e^{j\vartheta_1} \qquad\qquad r_j = e^{j\vartheta_2}$$

The combined signal is then expressed as follows

$$r = e^{j\vartheta_1 + \alpha} + e^{j\vartheta_2 + \beta}$$

In order to coherently combine the two signals the following condition must be fulfilled

$$\vartheta_1 + \alpha = \vartheta_2 + \beta \quad \Rightarrow \quad \vartheta_2 - \vartheta_1 = \alpha - \beta$$

As the phases of the two selected signals ϑ_1 and ϑ_2 are independent, it follows that the difference between the two phase weights α and β must cover all the possible angles between 0° and 360·(L-1)/L

$$\alpha - \beta \in \left[0^\circ ;\ \frac{360^\circ (L-1)}{L} \right]$$

Several choices are possible for the phase weights α and β. For example if L=4, it is possible to use the following two phase sets

$$\alpha = \{ 0^\circ, 180^\circ \} \qquad \beta = \{ 0^\circ, 90^\circ \}$$

Notice that the difference between α and β takes a set of values that covers all the possible angles between 0° and 360·(L-1)/L

$$\alpha - \beta = \{ 0^\circ, 90^\circ, 180^\circ, -90^\circ \} = \{ 0^\circ, 90^\circ, 180^\circ, 270^\circ \}$$

An advantage of the configuration shown in Figure 6b, when compared to the configuration shown in Figure 6a, is a reduction of the complexity of the RF switching network. A comparison in terms of number of RF switches for L = 4 is given in Figure 7a and 7b. We may notice that the configuration in Figure 7a, in which the phase shift is applied only on one signal r_J, requires 6 RF switches SW1..SW6 with 1 input and 2 outputs. On the contrary, the configuration in which the phase shift is applied on both signals r_i and r_J requires only 4 RF switches SW1..SW4 with 1 input and 2 outputs. In general, as the value of L increases, the reduced complexity of configuration 6b becomes more relevant.

Under the hypothesis of ideal channel reciprocity, i.e. the uplink transmission channel is equivalent to the downlink transmission channel, when using a reference Switched Beam WLAN client, the uplink propagation path and the downlink propagation path can be assumed to have similar characteristics if the same beam is used for the reception and transmission links. Thus the gain G_{DL}, with respect to a single antenna WLAN client, achieved during the downlink reception when the WLAN client is equipped with a reference Switched Beam antenna architecture can be assumed true also when the same WLAN client is used as a transmitter in the uplink direction, gain G_{UL}, and the transmission occurs from the beam that has been previously selected during the downlink reception.

Nevertheless we must recall that, during the transmission of the WLAN client in the uplink direction, the specified EIRP maximum emission conditions must be fulfilled. Thus a reduction of the transmitted power by a factor equal to P_{red} has to be introduced. The reduction of the transmitted power affects the gain on the uplink direction. The above considerations lead to the following equations:

$$G_{DL} = G_{dB} \quad (3)$$

$$G_{UL} = G_{DL} - P_{red} \quad (4)$$

$$P_{red} = P_{client} + G_{ant} - 20dBm \quad (5)$$

where G_{ant} is the gain of the single directional antenna employed and P_{client} is the transmission power of the WLAN client. A typical value for P_{client} is between 16 and 18 dBm and G_{ant} values vary between 6 dB and 10 dB. It is evident that these values lead to a power emission, given by P_{client} + G_{ant}, that clearly exceeds the 20 dBm limit. If we suppose, for instance, a value of G_{ant} equal to 8 dB and a value of P_{client} equal to 17 dBm, in the absence of cables loss, the EIRP transmitted by the WLAN client is equal to 25 dBm that exceeds the 20 dBm limit. In this particular case a power reduction P_{red} equal to 5 dB has to be introduced. According to equation (4) it is possible to conclude that, because of the power reduction P_{red}, the gain on the uplink direction G_{UL} is correspondently reduced by a factor equal to 5 dB.

The above considerations are summarized in Figure 8, wherein curves 80, 82 and 84 represent packet error rates PER as a function of signal-to-noise ratio (C/N) for, respectively, a single antenna architecture, a reference Switched Beam (SB) antenna in downlink and a reference Switched Beam antenna in uplink. In order to achieve a given target PER the performance enhancement G_{DL}, gained in the downlink transmission by adopting a reference Switched Beam antenna instead of a single antenna receiver, is reduced by a factor equal to P_{red} in the uplink direction because of the compliance with the EIRP limitation.

It is important to observe that the overall coverage range extension obtained is given by the minimum between the coverage range extension obtained on the downlink and uplink path. Since the downlink and uplink coverage ranges are strictly dependent on the correspondent values of gain G_{DL} and G_{UL} we can define the overall gain G_{SB} of a reference Switched Beam antenna with respect to a single antenna transceiver as follows

$$G_{SB} = \min (G_{DL}, G_{UL}) \quad (6)$$

If we combine now equation (6) with equation (4) we conclude that G_{SB} is given by

$$G_{SB} = G_{UL} = G_{DL} - P_{red} \quad (7)$$

As a consequence, when using WLAN clients equipped with a reference Switched Beam antenna architecture, the limiting link in terms of coverage is the uplink direction because of the reduction of the transmission power required in order to satisfy emission limitations.

In existing WLAN configurations, the clients typically use a single omni-directional antenna in the transmission towards the access point. Transmit diversity techniques can, instead, be used in the transmission path from the access point to the client (downlink). In these systems omni-directional antennas are used in order not to exceed the power emission limitations.

The switched beam antenna architecture according to the present invention, with WRF combining and single RF processing chain, described above with reference to Figure 1, can also be used in the uplink direction during the transmission from the WLAN client to the Access Point, as shown schematically in Figure 9.

The configuration shown in Figure 9 is based on the same antenna architecture employed in the downlink direction, realized with a certain number of directional antennas which are deployed in a way that all the possible Directions of Departure (DOD) of the transmitted signal are covered. During the uplink transmission two antennas A_i and A_j (or in general a sub-set of antennas), selected by means of beam selector 30 among all the directional antennas $A_1..A_N$ in correspondence of the two strongest received signals during the downlink reception, are used for transmission. In similar way the value of the complex weight w selected during the downlink reception is employed also for uplink transmission.

In particular, after the conventional BB and MAC modem 34 and the single RF processing chain 32, the signal to be transmitted is sent to a splitter 36 that divides it into two (or in general a plurality of) separate signals with the same power level, that is equal, in dBm, to $P_{client} - 3\ dB$. Thanks to the hypothesis of channel reciprocity, one of the two signals is digitally weighted exploiting the complex-valued weight w evaluated during the downlink reception, in phasing block 38. This enables the signals reaching the access point to be coherently recombined at the receiver end, leading to performance enhancement.

In any case the main benefit of this solution resides in the fact that the power transmitted from each of the two antennas of the antenna architecture according to the present invention is equal to half of the power transmitted by the single antenna of a reference Switched Beam antenna. This means that, in order to be compliant with the

EIRP limitation, the power transmitted by each of the two antennas has to be reduced by the following quantity

$$P_{red} = P_{client} - 3\ dB + G_{ant} - 20\ dBm \qquad (8)$$

If we compare now the power reduction to be employed in the reference SB antenna, defined in equation (4), with the power reduction to be employed in the SB antenna matter of the present invention defined in equation (8), we observe that, in the latter system, thanks to the fact that, for the transmission two directional antennas fed with half of the overall transmission power of the client are employed, the value of the power reduction is 3 dB smaller than the correspondent value to be employed in the former system. This is obtained thanks to the hypothesis that the overall power in each point of the azimuth plane does not overcome the maximum emission power of the single radiation element of the antenna system that has been dimensioned in order to satisfy the power emission limitations.

Since the gain in the uplink direction G_{UL} is related to the gain in the downlink direction G_{DL} by equation (4) we observe that a smaller reduction of the transmission power corresponds to a higher value of the uplink gain G_{UL} and, in turn, to a larger value of the overall antenna gain G_{SB} as defined in equation (7).

Therefore, the switched beam antenna architecture according to the present invention, thanks to the higher gain on the downlink direction G_{DL} and to the larger power transmitted by each of the two directional antennas, has better performance, in terms of overall antenna gain G_{SB} and therefore in terms of coverage range extension, with respect to a reference Switched Beam antenna.

In case the second version of the RF phasing circuit 18, the circuit of Figure 6b, is used at the receiver, wherein both signals r_i and r_J are weighted by the weights w_i and w_J respectively, both signals coming from the splitter 36 are digitally weighted exploiting the complex-valued weights w_i and w_J evaluated during the downlink reception.

The application of the switched beam antenna with WRF combining is not limited to WLAN systems but can be also envisaged for cellular systems as, for example, third generation (3G) mobile communication systems. Examples of possible application are the evolution of the UMTS and CDMA2000 radio interfaces denoted respectively as HSDPA (High Speed Downlink Packet Access) and 1xEV-DO (EVolution, Data-Optimized). These two transmission technologies are optimized for the provision of high speed packet data services in downlink, including mobile office applications, interactive games, download of audio and video contents, etc. The switched beam antenna architecture according to the invention can be easily integrated in an HSDPA or 1xEv-DO modem in order to provide benefits in terms of average and peak throughput with respect to a conventional modem equipped with one omnidirectional antenna.

The benefits of the switched beam antenna according to the invention are twofold. A first benefit is the reduction of the inter-cell interference obtained through the spatial filtering of the signals transmitted by the interfering cells. By using a directional antenna system it is possible to maximize the signal received from the serving cell and at the same time minimize the interfering signals arriving from the other directions. A reduction of the inter-cell interference corresponds to an increment of the geometry factor G, defined as the ratio between the power of the signal received from the serving cell and the power of the signals received from the interfering cells. The users near to the cell edge typically face a low value of the geometry factor and thus the switched beam antenna can provide significant benefits in terms of throughput.

A second benefit of the switched beam antenna is obtained for users near to the serving base station. For these users the inter-cell interference is minimal but the link performance is degraded by the intra-cell interference caused by the other channels (common and dedicated) transmitted by the serving base station. This self interference is a consequence of the multipath propagation that reduces the orthogonality among the different spreading codes. The utilization of the switched beam antenna reduces the delay spread and consequently increases the orthogonality of the propagation channel. The effect of the switched beam antenna is equivalent to an equalization of the channel frequency response in the spatial domain that reduces the intra-cell interference and thus brings an increment of the data throughput.

CLAIMS

1. A wireless communication system comprising:

- a plurality of antenna elements ($A_1..A_N$);
- a selector (6) for selecting a sub-set of received RF signals from said antenna elements;
- a combiner (8) for combining said sub-set of received RF signals into a single RF signal;
- a processing chain (10) for processing and demodulating said single RF signal and for generating at least a radio performance indicator (RPI) representative of the quality of said single RF signal, characterised in that it further comprises:
- a RF phasing network (18) for co-phasing said selected RF signals before combining in said combiner (8), by applying a phase shift to at least one signal in said sub-set.

2. A system according to claim 1, further comprising:

- a processor (16), detecting said radio performance indicator (RPI), for generating a selection signal (s) for said selector (6) and a phase shift signal (w) for said RF phasing network (18) in order to obtain a single RF signal having a radio performance indicator (RPI) comprised within a predetermined range.

3. A system according to claim 2, wherein said selector (6) selects two received RF signals (r_i, r_J).

4. A system according to claim 3, wherein said RF phasing network (18) applies a phase shift to both said selected RF signals (r_i, r_J).

5. A system according to any of claims 1 to 4, wherein said radio performance indicator (RPI) is an indicator selected out of the following group, or a combination thereof:

- Received Signal Strength Indicator (RSSI),
- the throughput,
- the Packet Error Rate (PER).

6. A system according to claim 5, wherein said selection signal (s) and said phase shift signal (w) are generated in order to maximize the Received Signal Strength Indicator (RSSI) or the throughput or a combination of them.

7. A system according to claim 5, wherein said selection signal (s) and said phase shift signal (w) are generated in order to minimize the Packet Error Rate (PER) of said single RF signal .

8. A system according to any of claims 1 to 4, wherein said phase shift is applied by multiplying a signal by a complex-valued weight having unitary modulus.

9. A system according to claim 8, wherein said phase shift is applied in quantized form.

10. A system according to claim 9, wherein said phase shift is applied by means of a plurality of delay lines selectively switched.

11. A system according to any of claims 3 to 10, wherein said phase shift signal (w) and said selection signal (s) are used, in transmission, for phasing (38) at least two signals to be transmitted and for selecting (40) at least two antenna elements, respectively.

12. A system according to claim 11, wherein two signals to be transmitted are obtained by splitting (36) a single signal into two separate signals with the same power level.

13. A method of processing an RF signal in a radio communication system, said signal being received by a plurality of antenna elements ($A_1..A_N$), comprising the steps of:

- selecting a sub-set of received RF signals from said antennas elements;
- combining said sub-set of received RF signals into a single RF signal; and
- processing and demodulating said single RF signal for generating at least a radio performance indicator (RPI) representative of the quality of said single RF signal;

characterised in that it further comprises the step of:

- subjecting signals in said sub-set of received RF signals to co-phasing, by applying a phase shift to at least one signal in said sub-set.

14. A method according to claim 13, further comprising the steps of:

- detecting said radio performance indicator (RPI);
- selecting a combination of sub-set of received RF signals and a phase shift for said co-phasing step, in order to obtain a single RF signal having a radio performance indicator (RPI) comprised within a predetermined range.

15. A method according to claim 14, wherein said selecting comprises selecting two received RF signals (r_i, r_J).

16. A method according to claim 15, wherein said co-phasing comprises applying a phase shift to both said selected RF signals (r_i, r_J).

17. A method according to claim 15, wherein said selecting comprises:

- subsequently selecting pairs of received RF signals and, for each pair, measuring said radio performance indicator (RPI);

- selecting the two pairs of signals providing higher radio performance indicator values;

- subjecting the six possible different combination pairs of the four signals in said two pairs to different phase shifts;

- measuring for each combination pair and for each phase shift said radio performance indicator (RPI) in order to obtain a single pair of received RF signals corresponding to an higher value of said radio performance indicator (RPI).

18. A method according to claim 17, wherein in said step of selecting the two pairs of signals providing higher radio performance indicator values no phase shift is applied to said pairs of signals.

19. A method according to any of claims 13 to 16, wherein said radio performance indicator (RPI) is an indicator selected out of the following group, or a combination thereof:

- Received Signal Strength Indicator (RSSI),
- the throughput,
- the Packet Error Rate (PER).

20. A method according to claim 19, wherein said combination of sub-set of received RF signals and phase shift for said co-phasing step is selected in order to maximize the Received Signal Strength Indicator (RSSI) or the throughput or a combination of them.

21. A method according to claim 19, wherein said combination of sub-set of received RF signals and phase shift for said co-phasing step is selected in order to minimize the Packet Error Rate (PER) of said single RF signal .

22. A method according to any of claims 13 to 16, wherein said phase shift is applied by multiplying a signal by a complex-valued weight having unitary modulus.

23. A method according to claim 22, wherein said phase shift is applied in quantized form.

24. A method according to any of claims 13 to 23, wherein said combination of sub-set of received RF signals and phase shift for said co-phasing step are used, in transmission, for phasing (38) at least two signals to be transmitted and for selecting (40) at least two antenna elements, respectively.

25. A method according to claim 24, wherein two signals to be transmitted are obtained by splitting (36) a single signal into two separate signals with the same power level.

26. A Wireless Local Area Network device comprising a wireless communication system according to any of claims 1 to 12.

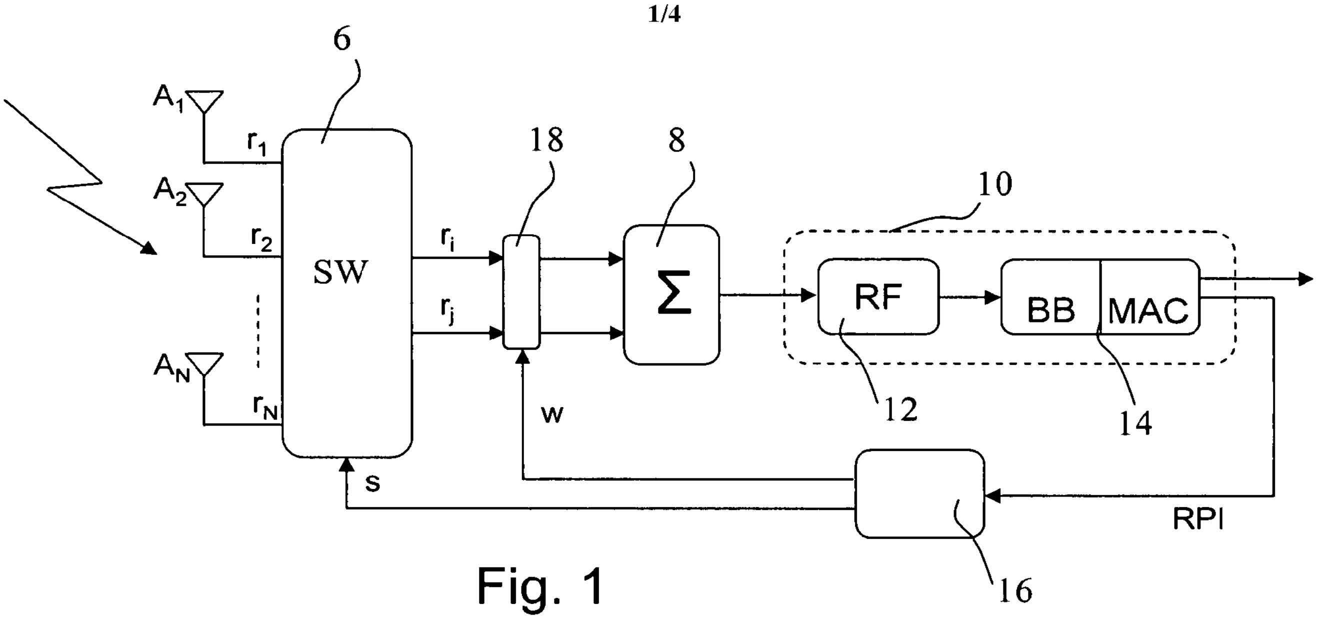


Fig. 1

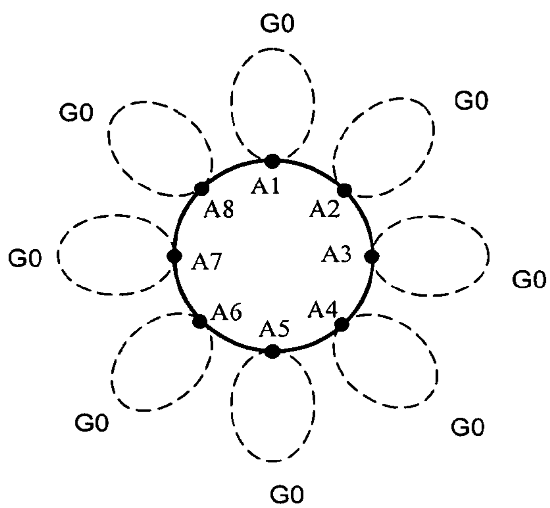


Fig. 2

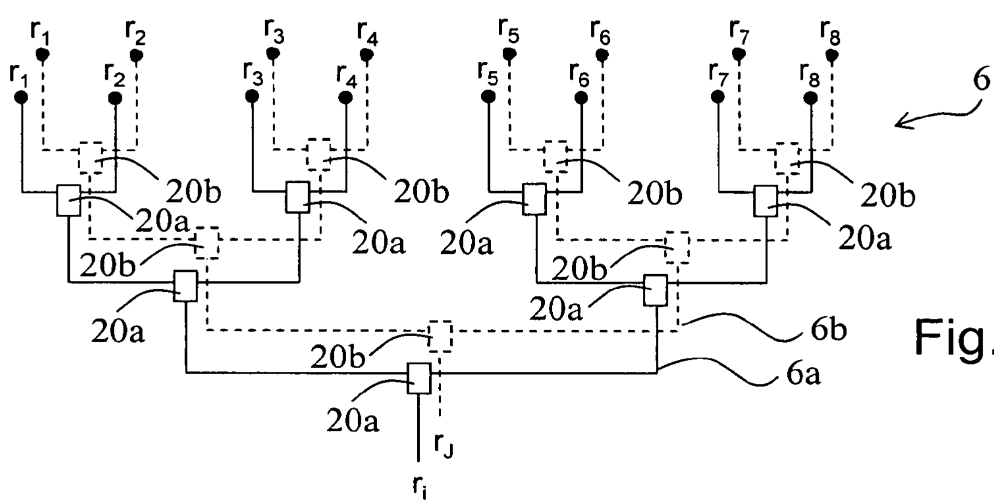


Fig. 3

rj

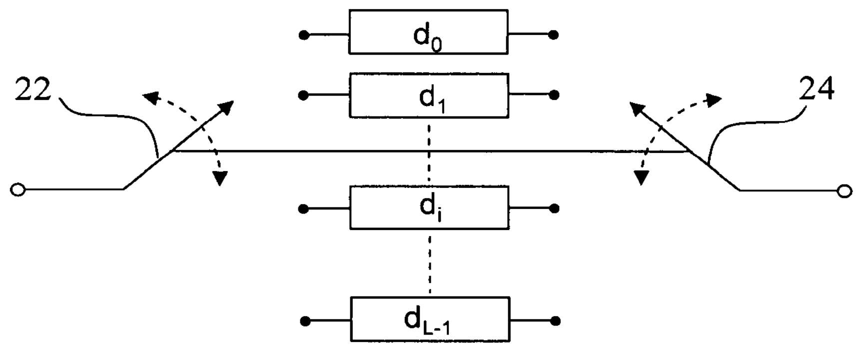

d0
d1
di
dL-1
22
24

Fig. 4

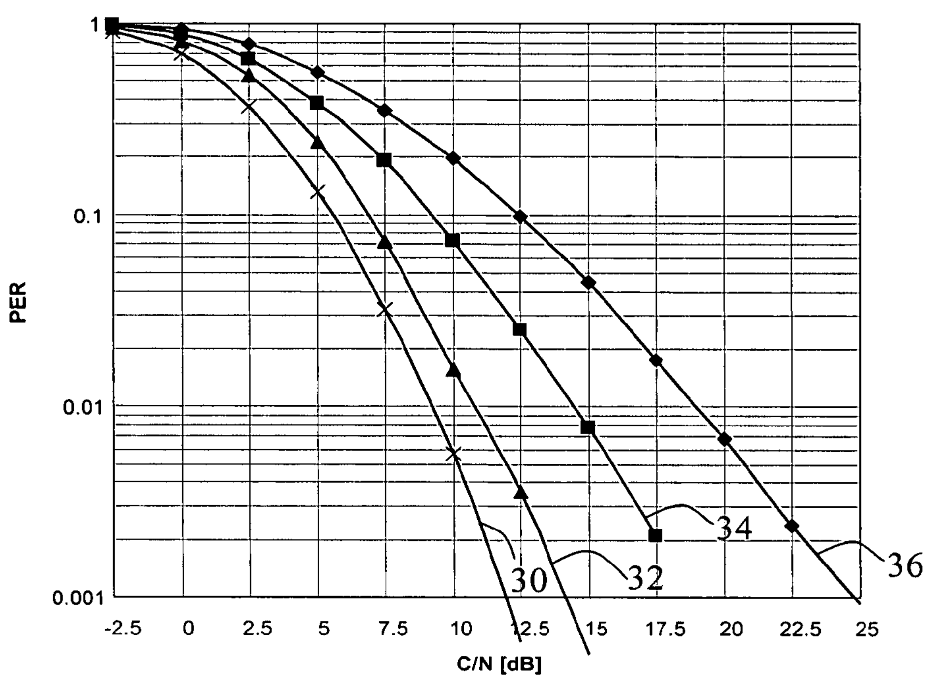

PER
1
0.1
0.01
0.001
-2.5
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
C/N [dB]
30
32
34
36

Fig. 5

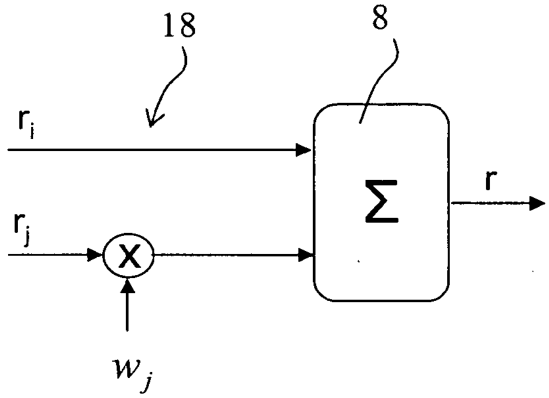


Fig. 6a

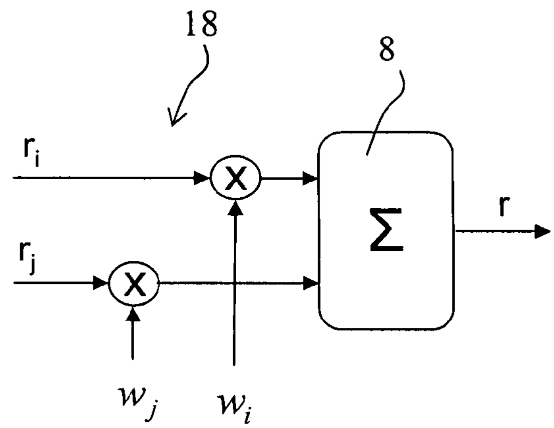


Fig. 6b

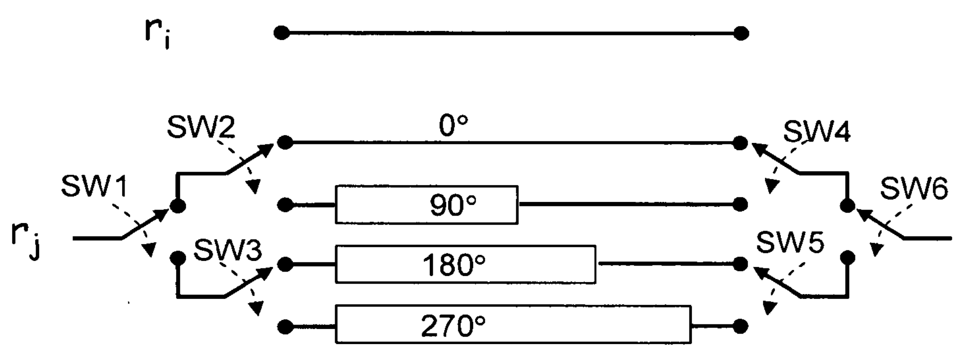


Fig. 7a

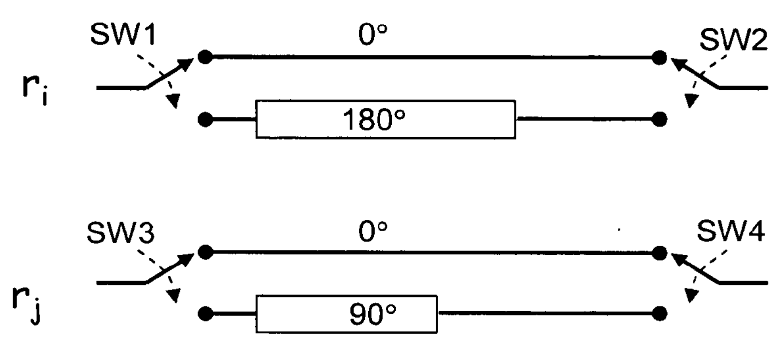


Fig. 7b

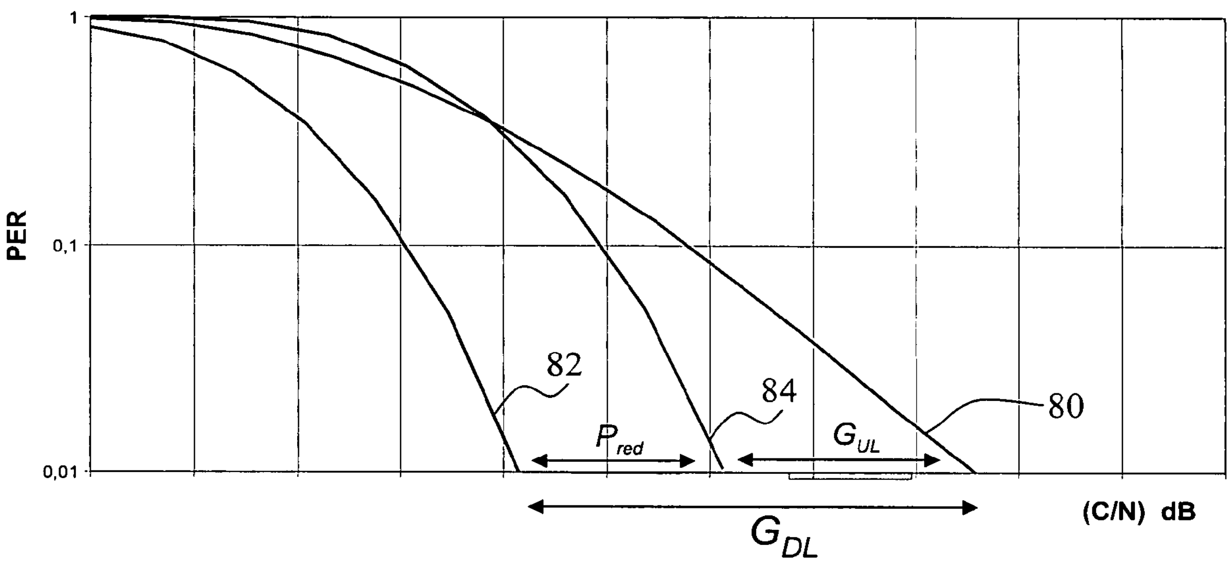

PER
1
0,1
0,01
82
84
80
P_{red}
G_{UL}
G_{DL}
(C/N) dB

Fig. 8

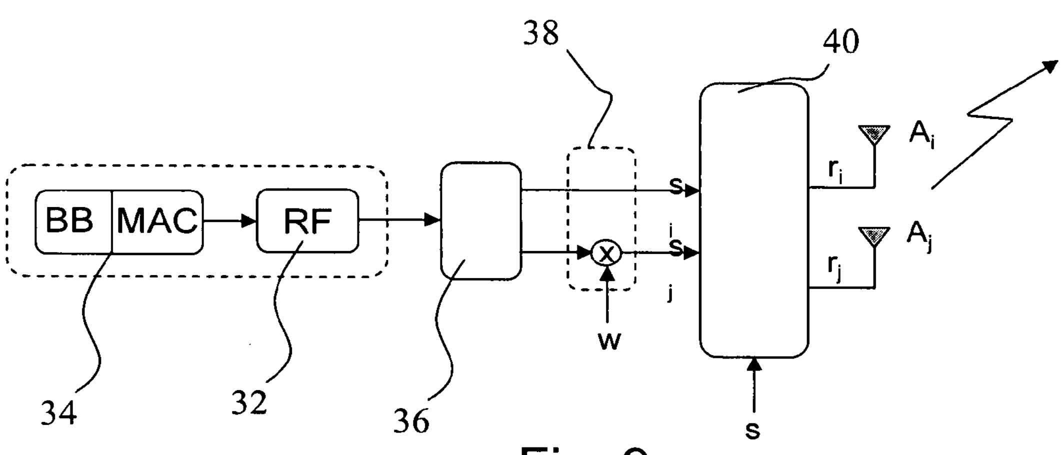

38
40
BB
MAC
RF
s_i
s_j
w
r_i
r_j
A_i
A_j
s
34
32
36

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2006/011430

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	EP 1 475 904 A (AMI SEMICONDUCTOR INC [US]) 10 November 2004 (2004-11-10) abstract column 3, paragraph 13 - paragraph 16 column 5, paragraph 33 - column 6, paragraph 37 column 6, paragraph 39 column 8, paragraph 47 - column 9, paragraph 49 ----- -/--	1,13 2-4,8, 11,12, 14-16, 22,24-26

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 July 2007	01/08/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	LOPEZ MARQUEZ, T

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005/287692 A1 (KIM BO-SUNG [KR] ET AL) 29 December 2005 (2005-12-29) page 3, paragraph 44 - paragraph 48 page 4, paragraph 65 page 4, paragraph 71 page 5, paragraph 83 - page 6, paragraph 96	2-4,8, 11,12, 14-16, 22,24-26
A	US 2005/025271 A1 (MOLISCH ANDREAS [US] ET AL) 3 February 2005 (2005-02-03) abstract page 1, paragraph 11 - paragraph 12 page 1, paragraph 16 - page 2, paragraph 17 page 3, paragraph 36 - paragraph 48	1,13
A	US 2005/163270 A1 (AKITA KOJI [JP] ET AL) 28 July 2005 (2005-07-28) page 1, paragraph 11 - page 2, paragraph 13	1,13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2006/011430

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 1475904	A	10-11-2004	US	2004224655	A1	11-11-2004
US 2005287692	A1	29-12-2005	JP	2006018281	A	19-01-2006
			KR	20060000639	A	06-01-2006
US 2005025271	A1	03-02-2005	CN	1701555	A	23-11-2005
			EP	1527544	A1	04-05-2005
			WO	2005011186	A1	03-02-2005
US 2005163270	A1	28-07-2005	CN	1649283	A	03-08-2005
			DE	102004062759	A1	18-08-2005
			JP	3906209	B2	18-04-2007
			JP	2005210617	A	04-08-2005

Electronic Patent Application Fee Transmittal

Application Number:	12084134
Filing Date:	27-Aug-2009
Title of Invention:	Method and System for Multiple Antenna Communications Using Multiple Transmission Modes, Related Apparatus and Computer Program Product
First Named Inventor/Applicant Name:	Bruno Melis
Filer:	Charles C. Hagadorn III/Kimberly Mason
Attorney Docket Number:	09952.0468-00000

Filed as Large Entity

U.S. National Stage under 35 USC 371 Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Miscellaneous:				
Submission- Information Disclosure Stmt	1806	1	180	180
		Total in USD ($)		**180**

Electronic Acknowledgement Receipt

EFS ID:	14349816
Application Number:	12084134
International Application Number:	
Confirmation Number:	5280
Title of Invention:	Method and System for Multiple Antenna Communications Using Multiple Transmission Modes, Related Apparatus and Computer Program Product
First Named Inventor/Applicant Name:	Bruno Melis
Customer Number:	22852
Filer:	Charles C. Hagadorn III/Kimberly Mason
Filer Authorized By:	Charles C. Hagadorn III
Attorney Docket Number:	09952.0468-00000
Receipt Date:	30-NOV-2012
Filing Date:	27-AUG-2009
Time Stamp:	12:12:12
Application Type:	U.S. National Stage under 35 USC 371

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$180
RAM confirmation Number	10826
Deposit Account	
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)

1		09952_0468Reply.pdf	716546 15ee49314f0e24508489c4f8cfd3bb190a4b6e18	yes	17

Multipart Description/PDF files in .zip description

Document Description	Start	End
Amendment/Req. Reconsideration-After Non-Final Reject	1	1
Claims	2	7
Applicant Arguments/Remarks Made in an Amendment	8	17

Warnings:

Information:

2		09952_0468IDS.pdf	232155 97d3780b9ecad1c7d6cc7485a9d353f13c2d99db	yes	4

Multipart Description/PDF files in .zip description

Document Description	Start	End
Transmittal Letter	1	2
Information Disclosure Statement (IDS) Form (SB08)	3	4

Warnings:

Information:

3	Foreign Reference	WO0203568A1.pdf	1841087 d992bfe8a5004ee479087dfeca734a52fce1ab42	no	54

Warnings:

Information:

4	Foreign Reference	EP1267501A2.pdf	532068 5cc7ded03dc9a70904e44f6083df160efb01ca80	no	15

Warnings:

Information:

5	Foreign Reference	EP1475904A2.pdf	970389 d4708cfa551be1173b4390554cd2f0f5c945482f	no	19

Warnings:

Information:

6	Foreign Reference	EP1489758A1.pdf	1837461 fddae4ac36ce0add75f122f05df0f33c32a19ea8	no	38

Warnings:

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7	Foreign Reference	WO2006023247A1.pdf	1178495 9aa4eae051b8fced8f1ab2fef126e3004533 59e5	no	36
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8	Foreign Reference	WO2007019185A2.pdf	1257865 253f0e7daef41e4b8105bf785545a2df8346 0f7f	no	32
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9	Foreign Reference	WO2008064696A1.pdf	1139478 64e921395da4e1e6f2a439eaaf5f1e38a061 6f9a	no	27
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Information:					
10	Non Patent Literature	ECC_Report_2004.pdf	695546 c41bb6ef94580b200c7fe2c84dd8b9b8905 e00cd	no	17
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Information:					
11	Non Patent Literature	Fahmy.pdf	397301 ff5426ea049ce305fc15c7a4fec3571b15298 960	no	5
Warnings:					
Information:					
12	Non Patent Literature	EISR_PCTEP2007011140.pdf	97673 ae787394dfe66f00a00033394fbfe53462b3 c7cd	no	3
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Information:					
13	Fee Worksheet (SB06)	fee-info.pdf	30445 8c71b3bc43c96726bedd5856bbbc6cb041 c2ddfb	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	10926509		

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New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/084,134	08/27/2009	Bruno Melis	09952.0468-00000	5280

22852 7590 08/30/2012

FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

EXAMINER	
CHOW, CHARLES CHIANG	
ART UNIT	**PAPER NUMBER**
2618	

MAIL DATE	DELIVERY MODE
08/30/2012	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Office Action Summary	Application No.	Applicant(s)	
	12/084,134	MELIS ET AL.	
	Examiner	**Art Unit**	
	CHARLES CHOW	2618	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE *3* MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *27 August 2009*.

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.

4)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

5)☒ Claim(s) *1-68* is/are pending in the application.

5a) Of the above claim(s) *1-45* is/are withdrawn from consideration.

6)☐ Claim(s) _____ is/are allowed.

7)☒ Claim(s) *46-68* is/are rejected.

8)☒ Claim(s) *46* is/are objected to.

9)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

10)☐ The specification is objected to by the Examiner.

11)☒ The drawing(s) filed on *25 April 2008* is/are: a)☒ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

12)☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

Priority under 35 U.S.C. § 119

13)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☐ All b)☐ Some * c)☐ None of:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)
2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)
3) ☒ Information Disclosure Statement(s) (PTO/SB/08) Paper No(s)/Mail Date *8/27/09, 4/25/08*.
4) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date. _____ .
5) ☐ Notice of Informal Patent Application
6) ☐ Other: _____.

Detailed Action

Information Disclosure Statement

1. The information disclosure statement (IDS) submitted on 8/27/2009, 4/25/2008 are in compliance with the previsions of 37 CFR 1.97. According, the information disclosure statement is being considered by the examiner.

Claim Objected

2. Claim 46 is objected to because of the following informalities:

In claim 46, the typographical error for "to", in "said at least to diversity antennas", needs to be corrected to "two", so after correction it shall be "said at least two diversity antennas."

Appropriate correction is required.

Claim Rejections - 35 USC § 102

The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:
A person shall be entitled to a patent unless –

(e) the invention was described in a patent granted on an application for patent by another filed in the United States before the invention thereof by the applicant for patent, or on an international application by another who has fulfilled the requirements of paragraphs (1), (2), and (4) of section 371(c) of this title before the invention thereof by the applicant for patent.
The changes made to 35 U.S.C. 102(e) by the American Inventors Protection Act of 1999 (AIPA) and the Intellectual Property and High Technology Technical Amendments Act of 2002 do not apply when the reference is a U.S. patent resulting directly or indirectly from an international application filed before November 29, 2000. Therefore, the prior art date of the reference is determined under 35 U.S.C. 102(e) prior to the amendment by the AIPA (pre-AIPA 35 U.S.C. 102(e)).

2. Claim 46, 61, 68 are rejected under 35 U.S.C. 102(e) as being anticipated by Schmidl et al. [US 6917597].

For claim 46, Schmidl discloses a method of diversity processing [method in description of Fig. 4b/Fig. 4a/summary of invention, method claims 1-19. The delay diversity is to transmit same signal via diversity antenna 1-N, with derivation of versions of signal by scaling the amplitude/phase shifting, col. 6, lines 7-14] at **least one signal** [signals outputted from channel-1/402 to 452/454, Fig. 4b] propagated via at least two diversity antennas 1/2

[signals outputted from channel 1/402 to 414/antenna-1 & 416/antenna 2, col. 6, lines 35-65] comprising the steps of

propagating at least two replicas of said at least one signal [same signals outputted from channel-1/402, propagated to multiplies 452/454 or 456, to antenna] over respective propagation paths coupled to said at least to diversity antennas

[path of 452/414 to antenna-1/408, path 454/416 to antenna-2/410], whereby said replicas [signals outputted from channel-1/402 to 452-456] are propagated via **different antennas** [propagated via different antennas 1/408 to antenna N/412];

subjecting at least one of said replicas to a time variable delay

[replicas outputted from channel-1 via multiplier 454/456, to delay 4416/418, as shown in Fig. 4b; the delay 414-430 can be variable/altered, for strongest signal paths do not overlap, according to the changing path profile between base station and mobile stations, for maximizing number of users, col. 7, lines 11-26]; and

adjusting the power levels of said at least two replicas to produce a level imbalance there between [452/454 scaling the amplitude of replica signals outputted from channel-1/402, col. 6, lines 59-65, it is well known that amplitude squaring is for power level calculation].

For claim 61, Schmidl discloses a system for diversity processing at least one signal propagated via at least two diversity antennas by means of the method of claim 46 [as shown in claim 46 above, system in Fig. 4b/4a], comprising:

respective propagation paths for propagating at least two replicas of said at least one signal [Fig. 4b, channel -1 to antenna 408, channel-2 to antenna 410], said respective propagation paths being coupled to said at least two diversity antennas [408/410],

whereby said replicas are propagated via different antennas [replica from channel-1 is transmitted, propagated, via antenna 408, replica from channel-2 is transmitted, propagated, via antenna 410, col. 6, lines 50-65/Fig. 4b];

at least one time variable delay element for subjecting at least one of said replicas to a time variable delay [time delay 414, or 422, Fig. 4b]; and

level adjusting elements arranged on said respective propagation paths to produce a level imbalance between the power levels of said at least two replicas [the path amplitude scaling via w1,1 to multiplier 452, path amplitude scaling via w2,2 to multiplier 460, col. 6, lines 50-65; Solondz- US 6259730 also discloses this feature in description of Fig. 6 in column 4].

For claim 68, Schmidl discloses a computer program product, loadable into the memory of at least one computer and comprising software code portions capable of performing the method of claim 46 [the computer readable storage medium stored with program code executed by digital signal processor to perform the invention features, col. 9, lines 6-28].

Claim Rejections - 35 USC § 103

The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

3. Claims 47, 62 are rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Rowitch [US 20040266338].

For claims 47, 62, Schmidl discloses the wherein said at least two replicas comprise replicas having respectively higher and lower power levels and wherein the method comprises the step of subjecting to said time variable delay; respective propagation paths for at least two said replicas having respectively higher and lower power levels

[0 dB -10 dB, replicas of the signal path for antenn-1, antenna 2, with the delay profile 600 associated with delay 414-430, received by mobile station, col. 7, lines 11-18].

Schmidl fails to discloses the lower level subjecting to time delay.

Rowitch discloses the step of subjecting to said time variable delay, said replica having a lower power level; said at least one time variable delay element being arranged on the propagation path of said replica having a lower power level

[one of the output of splitter 312 has delay 310 gain stage 312 for increasing the signal amplitude with positive gain/0063, of the low power replica from splitter output ; 250 coupled to diversity 260, diplexer 218, antenna 246, in Fig. 2/Fig. 3, parag. 0063, 0054/0055; it is well known the amplitude squaring is for power level of a signal]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Rowitch' s technique, such that the power level of the low level signal outputted from splitter could be compensated with a positive gain & delay.

4. Claim 48 is rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Shurvinton et al. [US 7450907].

For claim 48, Schmidl fails to disclose the dB range with gain.

Shurvinton discloses the step of selecting said level imbalance in the range of 3 to 10 dB

[0 to +30 dB/col. 8, line 50, from selecting gain at each gain control 37, Fig. 6, splitter 35 to 37 to power amplifier 39, col. 8, lines 20-63; 0 to 31.8 dB, col. 6, line 63 to col. 7, line 16]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Shurvinton's technique, such that the proper could be selected in the range, without distortion.

5. Claims 49-51 are rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Park et al. [US 6154652].

For claim 49, Schmidl fails to disclose the mode, associated with imbalance.

Park discloses the steps [Fig. 7, description of Fig. 5] of, selectively using one of a plurality of transmission modes for said at least one signal; and selecting said level imbalance as a function of a selected transmission mode

[in Fig. 5/Fig. 9, in handoff-mode, instead of normal-mode, the controller increases the gain amplifier 515, with fast data clock, for the shorter length for orthogonal codes, as higher coding rate, controller increases the gain of amplifier 515, col. 6, lines 48-67;

the gain of 515 is set higher than the first amplifier 514 in proportional to the converted data rate, mode, in order to compensate for Ber, which is increasing with data rate, as the transmission mode, col. 6, lines 8-23, for transmitting the same input data to 511, 911/912]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Park's technique, such that the gain for different amplifier could be controlled to compensate the coding rate/Ber.

For claim 50, Schmidl fails to disclose the imbalance, with coding rate.

Park discloses the wherein said plurality of transmission modes have respective coding rates and comprises the step of selecting said level imbalance as a function of said coding rates, wherein higher level imbalance values are selected for higher coding rates

[in Fig. 5/Fig. 9, in handoff-mode, instead of normal-mode, the controller increases the gain of amplifier 515, with fast data clock, for the shorter length for orthogonal codes, as higher coding rate, controller increases the gain of amplifier 515, col. 6, lines 48-67;

the gain of 515 is set higher than the first amplifier 514 in proportional to the converted data rate, mode, in order to compensate for Ber, which is increasing with data rate, as the transmission mode, col. 6, lines 8-23, for transmitting the same input data to 511, 911/912]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Park's technique, such that the gain for different amplifier could be controlled to compensate the coding rate/Ber.

For claim 51, Schmidl fails transmission mode.

Park discloses the steps of, selectively varying the transmission mode used; and adaptively varying said level imbalance as a function of the selected current transmission mode [in handoff mode for transmission, the imbalance is from increasing the gain of amplifier 515, for higher power than normal mode, col. 6, lines 48-67/ col. 6, lines 8-23]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Park's technique, such that the transmitted power lever could be adjusted based for handoff, or normal, mode.

6. Claim 52 is rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Tsujimoto [US 5982825].

For claim 52, Schmidl fails to disclose the time delay, with same diversity antenna.

Tsuimoto discloses the step of subjecting to time variable delays two of said replicas propagating over propagation paths associated with the same of said diversity antennas

[method steps claim 25; in description of Fig.4, replicas from divider 126 passing respective time delay 122-1 to 122-n, then, combined at 127, for transmitting via antenna 107, col. 9, lines 6-16/abstract; cancelling interference, col. 3, lines 30-30]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Tsujimoto's technique, such that the interference could be removed for better reception.

7. Claim 53 is rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Tsujimoto, as applied to claim 52 above, and further in view of Strich et al. [US 7653149].

For claim 53, Schmidl fails to disclose the combined propagation portion.

Tsujimoto discloses the step of subjecting to time variable delays the replicas propagating over at **least** two of said propagation paths by [path for 103/104, Fig. 1], providing, in the propagation paths for said at least two replicas associated with the same of said diversity antennas [same antenna 107, for paths of 103/104], respective distinct propagation portions and a combined propagation portion for said at least two replicas

[combiner 105 combined replica of path 103/104, col. 5, lines 24-48]; and

subjecting one of said at least two replicas to a fixed delay over a respective distinct portion of said propagation paths [In Fig. 1, fixed delay 102, ζ , col. 5, line 26, for one of the replica outputted from divider 100]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Tsujimoto's technique, such that the delay could be conveniently set to a fixed delay value.

Schmidl, Tsujimoto fail to disclose the delay over common portion.]

Strich discloses the subjecting said at least two replicas to a time variable delay over the common portion of said propagation paths [in Fig. 2, delay 95 can be desired delay value, for antenna 85, col. 8, line 47 to col. 9, line 10, output 92 of summer]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl, Tsujimoto with Strich's technique, such that the delay could be located at the output of summer.

8. Claim 54 is rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Haskell et al. [US 7433713].

For claim 54, Schmidl fails to disclose the splitting.

Haskell discloses the applied to at least one signal transmitted in the form of at least two replicas propagated over respective propagation paths toward said at least two diversity antennas [description of Fig. 8], comprising

the step of splitting [description of Fig. 8/Fig. 2; method claims 24-27] said at least one signal transmitted [input to splitter 132/Fig .8] to produce said at least two replicas [output of splitter 132] of said at least one signal propagated over respective propagation paths coupled to said at least two diversity antennas [via respective controller 133s/power amplifier 134 to output #1/#2, to diversity antenna stack #1/#2, col. 11, lines 34-50; description of Fig. 2]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Haskell's technique, such that the splitter could conveniently produce signals for antennas.

9. Claim 55 is rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Haskell, as applied to claim 54 above, and further in view of Chen et al. [US 20020190790].

For claim 55, Schmidl, Haskell fail to disclose the asymmetric splitting.

Chen discloses the wherein said splitting is an asymmetric splitting producing said level imbalance between said replicas [Fig. 3, replicas outputted from asymmetric power driver 306 outputting asymmetric power 0.19mw/0.81mw, parag. 0048]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl, Haskell with Chen's technique, such that the desired asymmetric signal power level could be properly outputted to the amplifier.

10. Claim 56 is rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Haskell, Chen, as applied to claim 55 above, and further in view of Golemon et al. [US 6658269].

For claim 56, Schmidl, Haskell, Chen fail to disclose the symmetric, with different gains.

Golemon discloses the wherein said splitting is a symmetric splitting, and further comprising the step of applying different gains over said respective propagation paths coupled to said at least two diversity antennas to produce said level imbalance between said replicas

[Fig. 2, symmetrically sending signal on 40T to both circuitry branches, amplifies with respective gain from variable amplifier 32, to diversity antenna 36T-1/2, col. 5, line 31 to col. 6, line 19, abstract]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl, Haskell, Chen with Golemon's technique, such that the desired transmit power could be adjusted via different gain of the amplifier.

11. Claims 57, 59, 63, 65 are rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Haskell-‘713.

For claims 57, 63, Schmidl fails to disclose the combining of received replicas.

Haskell discloses the applied to at least one signal received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas [Fig. 8, antennas for propagating replicas from splitter 132, to output#1/#2, having vector controller 133/col. 11, lines 8-33, & lower paragraph/paragraph of col. 11, lines 34-50; steps in method claims 7-9] comprising for, the step of, combining said at least two replicas to produce said at least one signal received

[Fig. 9/Fig. 2, inputs signal 135/136 from antennas, & 139 combing signals/replicas, outputted from vector controller 138/col. 11, lines 8-33, to one received signal from 139, & col. 11, line 51 to col. 12, line 3; in Fig. 2, antenna to 8c/8d to Lna 13c/13d, combiner 15; respective propagation path in the air]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Haskell’s technique, such that the received signal could be demodulated to data via proper combining.

For claims 59,65, Schmidl fail to disclose the combing.

Haskell discloses the wherein said combining, wherein said at least on combiner, is a symmetric combining, and further comprising, the steps of, gain elements for, applying different gains to said respective propagation paths of said replicas, from said at least two diversity antennas, to produce said level imbalance between said replicas

[symmetric combining at 139/Fig. 9, 15/Fig. 2, with gain from Lna 137, antenna in Fig. 2, with 8c/8d to 13a/13d, col. 11, line 51 to col. 12, line 3; ; in Fig. 2, antenna to 8c/8d to Lna 13c/13d, combiner 15; respective propagation path in the air]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Haskell’s technique, such that the received signal could be demodulated to data via proper combining.

12. Claims 58, 64 are rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Haskell, as applied to claim 57, and further in view of Chen’790.

For claims 58, 64, Schmidl, Haskell, fail to disclose the asymmetric combining.

Kim discloses the wherein said combining is an asymmetric combining producing said level imbalance between said replicas; wherein said at least one combiner is an asymmetric combiner producing said level imbalance between said replicas

[Fig. 3, output combiner 308 combines asymmetric 190mw/810mw, parag. 0049]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl, Haskell with Chen's technique, such that the desired asymmetric signal power level could be properly combined to produce desired output.

13. Claim 60 is rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Haskell, as applied to claim 57, and further in view of Strich-‘149.

For claim 60, Schmidl discloses the applied to at least two signals received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas [Fig. 4b, two replicas from channel -1/2 to antenna 408/410].

Schmidl, Haskell fail to disclose the splitting at said two diversity antennas.

Strich discloses the step of splitting at each of said diversity antennas the respective propagation paths of said at least two signals received [in Fig. 6, splitter 230/212, antenna 85, splitter 230/211, antenna 86, col. 11, lines 15-55, for the received replicas, from output of 66/68, Fig. 2, being transmitted from antenna 85/86]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl, Haskell with Strich's technique, such that the received signal could be properly split for demodulation.

14. Claim 66 is rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Strich-'149 and Yung et al. [US 5504465]

For claim 66, Schmidl fails to disclose the received by diversity antenna.

Strich discloses the discloses the wherein said at least one signal transmitted and received by means of said at least two diversity antennas [generating replicas from splitter 66-68/Fig. 2, transmitting via circuitry & transmit antenna 85-90 in Fig. 2, & receiving antenna 85-90 as shown in Fig. 6], comprises:

at least one splitter for splitting said at least one signal transmitted to produce at least two replicas transmitted over respective transmission paths toward said diversity antennas

[splitter 66-68, generates replicas towards antenna 85-90, Fig. 2, col. 8, line 20 to col. 9, line 10].

the at least one combiner for combining said at least two replicas propagated over respective propagation paths from said at least two diversity antennas to produce said at least one signal received

[the combiner 240-242, Fig. 2, combining signal from antenna 85-90, col. 11, lines 15-55, replicas being generated from splitter 66-70 in Fig. 2]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl with Strich's technique, such that the received signal could be properly combined for demodulation.

Schmidl fails to indicate the reciprocal element.

Yung discloses the wherein said at least one splitter and combiner comprise at least one reciprocal element [the power slit 26A/Fig. 3 is provided by the combiner 38 & modulator 20 is operated in reciprocal fashion, Fig. 4/col. 5, lines 34-43]. Therefore, one of ordinary skill in the art at the time of invention was made would have been obvious to modify Schmidl, Strich with Yung's technique, such that the splitter and combiner could be conveniently performed by one hardware, for functioning as splitter and combiner.

15. Claim 67 is rejected under 35 U.S.C. 103(a) as being unpatentable over Schmidl in view of Solondz [US 6259730].

For claim 67, Schmidl indicated base station in claims 1, 27 but not clearly disclose the wireless apparatus.

Solondz discloses a wireless communication apparatus comprising the system of claim 61 [the wireless base station in Fig. 6, col. 4, lines 8-57 discloses the feature of claim 61 above, having delay 32o/32N, amplifier 33l/33n, antenna 30-2/30-N, the amplifier has shown to be variable as Schmidl's scaling multiplier 452 in claim 46 above]. Therefore, one of ordinary skill in the art at the time the invention was made would have been obvious to improve Schmidl with Solondz's technique, such that the wireless base station could be reducing the interference by transmitting replica signals.

Conclusion

16. The prior arts made of record are not relied upon are considered pertinent to applicant's disclosure.

A. Goodman et al. [US 20120147943], SAKATA et al. [US 20120099668], Abelow [US 20120069131], Feher [US 20120039410], Judd et al. [US 20110312269], Feher [US 20110274194], Landry et al. [US 20110261805], Goransson et al. [US 20110097992].

17. Any inquiry concerning this communication or earlier communications from the examiner should be directed to Charles Chow whose telephone number is (571) 272 7889. The examiner can normally be reached on 8:00am-5:30pm.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Duc Nguyen can be reached on (571) 272-7503. The fax phone number for the organization where this application or proceeding is assigned is (571) 273-8300. Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system.

Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free).

/Charles Chow/
Examiner, Art Unit 2618
August 14, 2012.

/DUC NGUYEN/

Supervisory Patent Examiner, Art Unit 2618

Notice of References Cited

Application/Control No. 12/084,134	Applicant(s)/Patent Under Reexamination MELIS ET AL.	
Examiner CHARLES CHOW	Art Unit 2618	Page 1 of 2

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*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-6,917,597	07-2005	Schmidl et al.	370/280
*	B	US-2004/0266338	12-2004	Rowitch, Douglas Neal	455/007
*	C	US-7,450,907	11-2008	Shurvinton et al.	455/67.11
*	D	US-6,154,652	11-2000	Park et al.	455/437
*	E	US-5,982,825	11-1999	Tsujimoto, Ichiro	375/347
*	F	US-7,653,149	01-2010	Strich et al.	375/310
*	G	US-7,433,713	10-2008	Haskell et al.	455/562.1
*	H	US-2002/0190790	12-2002	Cheng et al.	330/51
*	I	US-6,658,269	12-2003	Golemon et al.	455/562.1
*	J	US-5,504,465	04-1996	Yung et al.	332/145
*	K	US-6,259,730	07-2001	Solondz, Max Aaron	375/232
*	L	US-2012/0069131	03-2012	Abelow, Daniel H.	348/14.01
*	M	US-2012/0099668	04-2012	SAKATA et al.	375/267

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
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NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
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	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

Notice of References Cited	Application/Control No. 12/084,134	Applicant(s)/Patent Under Reexamination MELIS ET AL.	
	Examiner CHARLES CHOW	Art Unit 2618	

U.S. PATENT DOCUMENTS

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*	A	US-2012/0069131	03-2012	Abelow, Daniel H.	348/14.01
*	B	US-2012/0039410	02-2012	Feher, Kamilo	375/261
*	C	US-2011/0312269	12-2011	Judd et al.	455/11.1
*	D	US-2011/0274194	11-2011	Feher, Kamilo	375/261
*	E	US-2011/0261805	10-2011	Landry et al.	370/342
*	F	US-2011/0097992	04-2011	Goransson et al.	455/7
	G	US-			
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FOREIGN PATENT DOCUMENTS

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Index of Claims	Application/Control No. 12084134	Applicant(s)/Patent Under Reexamination MELIS ET AL.
	Examiner CHARLES CHOW	Art Unit 2618

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIM		DATE								
Final	Original	08/13/2012								
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Index of Claims	Application/Control No. 12084134	Applicant(s)/Patent Under Reexamination MELIS ET AL.
	Examiner CHARLES CHOW	Art Unit 2618

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
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☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIM		DATE								
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Search Notes	Application/Control No. 12084134	Applicant(s)/Patent Under Reexamination MELIS ET AL.
	Examiner CHARLES CHOW	Art Unit 2618

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Class	Subclass	Date	Examiner
455	424,425,456.5,456.6,561,550.1,575.1,11.1,67.11,437,562.1,	8/13/2012	C.C.
375	261,232,347,310,267, 347,267,349,	8/14/2012	C.C.
370	280,294	8/14/2012	C.C.
333	159	8/14/2012	C.C.

SEARCH NOTES

Search Notes	Date	Examiner
See East search inside posted folder or in eDAN.	8/13/2012	C.C.
searched inventor's name in Palm for related limitations.	8/13/2012	C.C.

INTERFERENCE SEARCH

Class	Subclass	Date	Examiner

Receipt date: 08/27/2009

IDS Form PTO/SB/08: Substitute for form 1449A/PTO				*Complete if Known*	
INFORMATION DISCLOSURE STATEMENT BY APPLICANT				*Application Number*	12/084,134
				Filing Date	April 25, 2008
				First Named Inventor	Bruno MELIS
				Art Unit	2611
(Use as many sheets as necessary)				*Examiner Name*	Not Yet Assigned
Sheet	1	of	1	*Attorney Docket Number*	09952.0468-00000

U.S. PATENTS AND PUBLISHED U.S. PATENT APPLICATIONS

Examiner Initials	Cite No.	Document Number Number-Kind Code (if known)	Issue or Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear

Note: Copies of the U.S. Patent Documents are not Required in IDS filed after October 21, 2004

FOREIGN PATENT DOCUMENTS

Examiner Initials	Cite No.	Foreign Patent Document Country Code/Number-Kind Code (If known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear	Translation

NON PATENT LITERATURE DOCUMENTS

Examiner Initials	Cite No.	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation
/C.C./		A. WITTNEBEN, "A New Bandwidth Efficient Transmit Antenna Modulation Diversity Scheme for Linear Digital Modulation," ICC Conference, pages 1630-1634, Geneva (May 1993).	
/C.C./		S. KIM et al., "Time-Delay Phase Shifter Controlled by Piezoelectric Transducer on Coplanar Waveguide," IEEE Microwave and Wireless Components Letters, Vol. 13, No. 1, pp. 19-20 (January 2003).	
/C.C./		J. LEE et al., "CDMA Systems Engineering Handbook, pp. 256-262 (1998).	

Examiner Signature	/Charles Chow/	Date Considered	08/13/2012

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

FPD/acd

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /C.C./

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L2	1	12/084,134	US-PGPUB; USPAT; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2012/08/13 17:30
L3	1	12/084,134 and propagation	US-PGPUB; USPAT; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2012/08/13 17:30
L7	7	EP with ("1164718" or "1487134") or WO with ("2003055097" or "20060373364" or "2007038969")	US-PGPUB; USPAT; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2012/08/13 17:53
L8	4	"20040087294".pn. or "5930293".pn.	US-PGPUB; USPAT; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2012/08/13 17:54
L11	166	(split$4 with one with signal or two with replica) and power with amplifiers and (both or dual or more or second$4) and antenna$1 and delay$4 and adjust$4 with gain with amplifier	US-PGPUB; USPAT; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2012/08/13 17:59

8/13/2012 6:03:09 PM
C:\Users\cchow1\Documents\EAST\Workspaces\Default EAST Workspace (Flat Panel).wsp

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UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
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P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

BIB DATA SHEET

CONFIRMATION NO. 5280

SERIAL NUMBER	FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
12/084,134	08/27/2009 **RULE**	455	2618	09952.0468-00000

APPLICANTS

Bruno Melis, Torino, ITALY;
Alfredo Ruscitto, Torino, ITALY;
Paolo Semenzato, Roma, ITALY;
Renata Mele, Milano, ITALY;
Giuseppe Grassano, Milano, ITALY;

** **CONTINUING DATA** *************************

This application is a 371 of PCT/EP2005/011529 10/27/2005

** **FOREIGN APPLICATIONS** *************************

** **IF REQUIRED, FOREIGN FILING LICENSE GRANTED** **

10/01/2009

		STATE OR COUNTRY	SHEETS DRAWINGS	TOTAL CLAIMS	INDEPENDENT CLAIMS
Foreign Priority claimed ☐ Yes ☑ No 35 USC 119(a-d) conditions met ☐ Yes ☑ No Verified and Acknowledged /CHARLES CHOW/ Examiner's Signature	☐ Met after Allowance C.C. Initials	ITALY	27	23	1

ADDRESS

FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413
UNITED STATES

TITLE

Method and System for Multiple Antenna Communications Using Multiple Transmission Modes, Related Apparatus and Computer Program Product

FILING FEE RECEIVED	FEES: Authority has been given in Paper	
1210	No.____________ to charge/credit DEPOSIT ACCOUNT No.____________ for following:	☐ All Fees ☐ 1.16 Fees (Filing) ☐ 1.17 Fees (Processing Ext. of time) ☐ 1.18 Fees (Issue) ☐ Other ________________ ☐ Credit

C.C.
8/13/2012.

IAP02Rec'd PCT 25 APR 2008
12/084134

Customer No. 22,852
Attorney Docket No. 09952.0468-00000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. National Phase Application of International Application No.:	)
PCT/EP2005/011529	)
Inventors: Bruno MELIS et al.	) Group Art Unit: Not Yet Assigned
Application No.: Not Yet Assigned	) Examiner: Not Yet Assigned
Filed: April 25, 2008	)
For: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT	)

MAIL STOP PCT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

INFORMATION DISCLOSURE STATEMENT UNDER 37 C.F.R. § 1.97(b)

Pursuant to 37 C.F.R. §§1.56 and 1.97(b), Applicant brings to the Examiner's attention the documents listed on attached Form PTO/SB/08 and cited in the international search report. Copies of the listed foreign patent documents are attached. Applicant respectfully requests that the Examiner consider the documents listed on attached Form PTO/SB/08 and indicate that they were considered by making an appropriate notation on this form.

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /C.C./

This Information Disclosure Statement is being filed with the above-referenced application.

This submission does not represent that a search has been made or that no better art exists and does not constitute an admission that each or all of the listed documents are material or constitute "prior art." If the Examiner applies any of the documents as prior art against any claim in the application and Applicant determines that the cited documents do not constitute "prior art" under United States law, Applicant reserves the right to present to the Office the relevant facts and law regarding the appropriate status of such documents. Applicant further reserves the right to take appropriate action to establish the patentability of the disclosed invention over the listed documents, should one or more of the documents be applied against the claims of the present application.

If there is any fee due in connection with the filing of this Statement, please charge the fee to our Deposit Account No. 06-0916.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: April 25, 2008

By: [signature]
Ernest F. Chapman
Reg. No. 25,961

Enclosures
EFC/FPD/acd

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /C.C./

Receipt date: 04/25/2008

IAP02Rec'd PCT 25 APR 2008

12/084134

IDS Form PTO/SB/08: Substitute for form 1449A/PTO				Complete if Known	
INFORMATION DISCLOSURE STATEMENT BY APPLICANT				*Application Number*	Not Yet Assigned
				Filing Date	April 25, 2008
				First Named Inventor	Bruno MELIS
				Art Unit	Not Yet Assigned
(Use as many sheets as necessary)				*Examiner Name*	Not Yet Assigned
Sheet	1	of	1	*Attorney Docket Number*	09952.0468-00000

U.S. PATENTS AND PUBLISHED U.S. PATENT APPLICATIONS

Examiner Initials*	Cite No.[1]	Document Number Number-Kind Code[2] (if known)	Issue or Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
/C.C./		US 2004/0087294 A1	05-06-2004	Wang	
/C.C./		US 5,930,293	07-27-1999	Light et al.	

Note: Copies of the U.S. Patent Documents are not Required in IDS filed after October 21, 2004

FOREIGN PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	Foreign Patent Document Country Code[3] Number[4] Kind Code[5] (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear	Translation[6]
/C.C./		EP 1 164 718 A2	12-19-2001	NEC Corporation		
/C.C./		EP 1 487 134 A1	12-15-2004	Nokia Corporation		
/C.C./		WO 2003/055097 A3	07-03-2003	Motorola, Inc.		
/C.C./		WO 2006/037364 A1	04-13-2006	Telecom Italia S.p.A.		
/C.C./		WO 2007/038969 A1	04-12-2007	Telecom Italia S.p.A. et al.		

NON PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No.[1]	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation[6]

Examiner Signature	/Charles Chow/	Date Considered	08/13/2012

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

FPD/acd

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /C.C./

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L17	73	divid$5 with input same (replica or duplicat$4 or repeat$3 or cop$3) and (adjust$4 or vary$4 or decreas$4 with power) and amplifiers and (variable or vary$3 or adjust$4) with delay$4 and antenna	US-PGPUB; USPAT; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2012/08/14 09:58

8/14/2012 10:46:15 AM
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Receipt date: 04/25/2008

IAP02Rec'd PCT 25 APR 2008

12/084134

IDS Form PTO/SB/08: Substitute for form 1449A/PTO

INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(Use as many sheets as necessary)

Sheet	1	of	1

Complete if Known	
Application Number	Not Yet Assigned
Filing Date	April 25, 2008
First Named Inventor	Bruno MELIS
Art Unit	Not Yet Assigned
Examiner Name	Not Yet Assigned
Attorney Docket Number	09952.0468-00000

U.S. PATENTS AND PUBLISHED U.S. PATENT APPLICATIONS

Examiner Initials	Cite No.	Document Number Number-Kind Code (if known)	Issue or Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
/C.C./		US 2004/0087294 A1	05-06-2004	Wang	
/C.C./		US 5,930,293	07-27-1999	Light et al.	

Note: Copies of the U.S. Patent Documents are not Required in IDS filed after October 21, 2004

FOREIGN PATENT DOCUMENTS

Examiner Initials	Cite No.	Foreign Patent Document Country Code Number Kind Code (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear	Translation
/C.C./		EP 1 164 718 A2	12-19-2001	NEC Corporation		
/C.C./		EP 1 487 134 A1	12-15-2004	Nokia Corporation		
/C.C./		WO 2003/055097 A3	07-03-2003	Motorola, Inc.		
/C.C./		WO 2006/037364 A1	04-13-2006	Telecom Italia S.p.A.		
/C.C./		WO 2007/038969 A1	04-12-2007	Telecom Italia S.p.A. et al.		

NON PATENT LITERATURE DOCUMENTS

Examiner Initials	Cite No.	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation

Examiner Signature	/Charles Chow/	Date Considered	08/13/2012

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
12/084,134	08/27/2009	Bruno Melis	09952.0468-00000

CONFIRMATION NO. 5280

PUBLICATION NOTICE

OC000000039902380

22852
FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER
LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

Title: Method and System for Multiple Antenna Communications Using Multiple Transmission Modes, Related Apparatus and Computer Program Product

Publication No.US-2010-0022193-A1
Publication Date:01/28/2010

NOTICE OF PUBLICATION OF APPLICATION

The above-identified application will be electronically published as a patent application publication pursuant to 37 CFR 1.211, et seq. The patent application publication number and publication date are set forth above.

The publication may be accessed through the USPTO's publically available Searchable Databases via the Internet at www.uspto.gov. The direct link to access the publication is currently http://www.uspto.gov/patft/.

The publication process established by the Office does not provide for mailing a copy of the publication to applicant. A copy of the publication may be obtained from the Office upon payment of the appropriate fee set forth in 37 CFR 1.19(a)(1). Orders for copies of patent application publications are handled by the USPTO's Office of Public Records. The Office of Public Records can be reached by telephone at (703) 308-9726 or (800) 972-6382, by facsimile at (703) 305-8759, by mail addressed to the United States Patent and Trademark Office, Office of Public Records, Alexandria, VA 22313-1450 or via the Internet.

In addition, information on the status of the application, including the mailing date of Office actions and the dates of receipt of correspondence filed in the Office, may also be accessed via the Internet through the Patent Electronic Business Center at www.uspto.gov using the public side of the Patent Application Information and Retrieval (PAIR) system. The direct link to access this status information is currently http://pair.uspto.gov/. Prior to publication, such status information is confidential and may only be obtained by applicant using the private side of PAIR.

Further assistance in electronically accessing the publication, or about PAIR, is available by calling the Patent Electronic Business Center at 1-866-217-9197.

Office of Data Managment, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

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United States Patent and Trademark Office
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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
12/084,134	08/27/2009	2611	1210	09952.0468-00000	23	1

CONFIRMATION NO. 5280

22852
FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

FILING RECEIPT

OC000000038095639

Date Mailed: 10/19/2009

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Bruno Melis, Torino, ITALY;
Alfredo Ruscitto, Torino, ITALY;
Paolo Semenzato, Roma, ITALY;
Renata Mele, Milano, ITALY;
Giuseppe Grassano, Milano, ITALY;

Power of Attorney: The patent practitioners associated with Customer Number 22852

Domestic Priority data as claimed by applicant

This application is a 371 of PCT/EP2005/011529 10/27/2005

Foreign Applications

If Required, Foreign Filing License Granted: 10/01/2009

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 12/084,134**

Projected Publication Date: 01/28/2010

Non-Publication Request: No

Early Publication Request: No

Title

Method and System for Multiple Antenna Communications Using Multiple Transmission Modes, Related Apparatus and Computer Program Product

Preliminary Class

375

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

UNITED STATES PATENT AND TRADEMARK OFFICE

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United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

U.S. APPLICATION NUMBER NO.	FIRST NAMED APPLICANT	ATTY. DOCKET NO.
12/084,134	Bruno Melis	09952.0468-00000

22852
FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

INTERNATIONAL APPLICATION NO.	
PCT/EP2005/011529	
I.A. FILING DATE	PRIORITY DATE
10/27/2005	

CONFIRMATION NO. 5280
371 ACCEPTANCE LETTER

OC000000038095640

Date Mailed: 10/19/2009

NOTICE OF ACCEPTANCE OF APPLICATION UNDER 35 U.S.C 371 AND 37 CFR 1.495

The applicant is hereby advised that the United States Patent and Trademark Office in its capacity as a Designated / Elected Office (37 CFR 1.495), has determined that the above identified international application has met the requirements of 35 U.S.C. 371, and is ACCEPTED for national patentability examination in the United States Patent and Trademark Office.

The United States Application Number assigned to the application is shown above and the relevant dates are:

08/27/2009	08/27/2009
DATE OF RECEIPT OF 35 U.S.C. 371(c)(1), (c)(2) and (c)(4) REQUIREMENTS	DATE OF COMPLETION OF ALL 35 U.S.C. 371 REQUIREMENTS

A Filing Receipt (PTO-103X) will be issued for the present application in due course. **THE DATE APPEARING ON THE FILING RECEIPT AS THE " FILING DATE" IS THE DATE ON WHICH THE LAST OF THE 35 U.S.C. 371 (c)(1), (c)(2) and (c)(4) REQUIREMENTS HAS BEEN RECEIVED IN THE OFFICE. THIS DATE IS SHOWN ABOVE.** *The filing date of the above identified application is the international filing date of the international application (Article 11(3) and 35 U.S.C. 363).* Once the Filing Receipt has been received, send all correspondence to the Group Art Unit designated thereon.

The following items have been received:

- Copy of the International Application filed on 04/25/2008
- Copy of the International Search Report filed on 04/25/2008
- Preliminary Amendments filed on 04/25/2008
- Information Disclosure Statements filed on 08/27/2009
- Oath or Declaration filed on 08/27/2009
- U.S. Basic National Fees filed on 04/25/2008
- Power of Attorney filed on 08/27/2009
- Specification filed on 04/25/2008
- Claims filed on 04/25/2008
- Abstracts filed on 04/25/2008
- Drawings filed on 04/25/2008

Applicant is reminded that any communications to the United States Patent and Trademark Office must be mailed to the address given in the heading and include the U.S. application no. shown above (37 CFR 1.5)

NISA F GILCHRIST

Telephone: (703) 756-1418

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A SUBMISSION UNDER 35 U.S.C. 371		CUSTOMER NO. 22,852 ATTORNEY'S DOCKET NUMBER: 09952.0468-00000 U.S. APPLICATION NO. (if known, see 37 C.F.R. 1.5) 12/084,134
INTERNATIONAL APPLICATION NO. PCT/EP2005/011529	INTERNATIONAL FILING DATE October 27, 2005	PRIORITY DATE CLAIMED

TITLE OF INVENTION
METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT

APPLICANT(S) FOR DO/EO/US
Bruno MELIS; Alfredo RUSCITTO; Paolo SEMENZATO; Renata MELE; Giuseppe GRASSANO

Applicant(s) herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☐ This is a **FIRST** submission of items concerning a filing under 35 U.S.C 371.
2. ☒ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a submission under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. ☐ The US has been elected (Article 31).
5. ☐ A copy of the International Application as filed (35 U.S.C. 371 (c)(2)).
   a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   b. ☐ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed with the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3)).
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. ☒ Supplemental Information Disclosure Statement under 37 CFR 1.97 and 1.98
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☐ A preliminary amendment.
14. ☐ An Application Data Sheet under 37 CFR 1.76.
15. ☐ A Substitute specification.
16. ☒ A power of attorney and/or change of address letter. (Copy of Assignment attached.)
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13*ter*.2 and 35 U.S.C. 1.821-1.825.
18. ☐ A second copy of the published International Application under 35 U.S.C. 154 (d)(4).
19. ☐ A second copy of the English language translation of the international application 35 U.S.C. 154 (d)(4).
20. ☐ Other items or information:
   a. ☐
   b. ☐
   c. ☐
   d. ☐
   e. ☐
   f. ☐
   g. ☐

U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 12/084,134	INTERNATIONAL APPLICATION NO. PCT/EP2005/011529	ATTORNEY'S DOCKET NUMBER 09952.0468-00000	
The following fees have been submitted:		**CALCULATIONS**	**PTO Use Only**
21. ☐ BASIC NATIONAL FEE (37 CFR 1.492(a)): **$330**		$0	
22. ☐ Examination fee (37 CFR 1.492(c)) If the Written opinion prepared by ISA/US or the International preliminary examination report prepared by IPEA/US indicates all claims satisfy provisions of PCT Article 33(1)-(4) .... **$ 0** All other situations **$220**		$0	
23. ☐ Search fee (37 CFR 1.492(b)) If the written opinion of the ISA/US or the International preliminary examination report prepared by IPEA/US indicates all claims satisfy provisions of PCT Article 33(1)-(4) .... **$ 0** Search fee (37 CFR 1.445(a)(2)) has been paid on the international application to the USPTO as an International Searching Authority .... **$100** International Search Report prepared by an ISA other than the US and provided to the Office or previously communicated to the US by the IB .... **$430** All other situations **$540**		$0	
TOTAL of 21, 22 and 23 =		$0	
☐ Additional fee for specification and drawings filed in paper over 100 sheets (excluding sequence listing in compliance with 37 CFR 1.821(c) or (e) or computer program listing in an electronic medium) (37 CFR 1.492(j)). The fee is **$270** for each additional 50 sheets of paper or fraction thereof.			

Total Sheets	Extra Sheets	Number of each additional 50 or fraction thereof (round **up** to a whole number)	Rate		
- 100 =	/50=		x $270.00	$0	

Surcharge of **$130.00** for furnishing any of the search fee, examination fee, or the oath or declaration after the date of commencement of the national stage (37 CFR 1.492(h)).	$130.00	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total Claims	- 20 =		x $52.00	$0	
Independent Claims	- 3 =		x $220.00	$0	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+$390.00	$0	

TOTAL OF ABOVE CALCULATIONS =	$130.00	
☐ Applicant claims small entity status. See 37 CFR 1.27. Fees above are reduced by ½.	$0	
SUBTOTAL =	$130.00	
Processing fee of **$130.00** for furnishing the English translation later than 30 months from the earliest priority date (37 CFR 1.492(i)). +	$0	
TOTAL NATIONAL FEE =	$130.00	
Fee for recording the enclosed assignment (37 CFR 1.21 (h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property. +	$0	
TOTAL FEES ENCLOSED =	$130.00	
	Amount to be refunded:	$
	charged:	$

a. ☐ A check in the amount of $____________ to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. ______________ in the amount of $____________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **06-0916**. A duplicate copy of this sheet is enclosed.

d. ☒ Fees are to be charged to a credit card or to Deposit Account No. 06-0916. **WARNING**: Information on this form may become public. **Credit card information should not be included on this form**. Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the International Application to pending status.

SEND ALL CORRESPONDENCE TO:

Finnegan, Henderson, Farabow, Garrett & Dunner, L.L.P.
901 New York Avenue, N.W.
Washington, DC 20001-4413

SIGNATURE

Ernest F. Chapman, Reg. No. 25,961
NAME/REGISTRATION NUMBER

DATED: August 27, 2009

FPD/acd

1047

DECLARATION

As a below named inventor, I hereby declare that: my residence, post office address and citizenship are as stated below next to my name; I believe I am the original, first, and sole inventor (if only one name is listed below) or an original, first, and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT

the specification of which is attached and/or was filed on **27 October 2005** as PCT International Application No. **PCTEP2005/011529** and was amended on ____________________ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate or § 365(a) of any PCT international application(s) designating at least one country other than the United States, listed below and have also identified below, any foreign application(s) for patent or inventor's certificate, or any PCT International application(s) having a filing date before that of the application(s) of which priority is claimed:

Country	Application Number	Date of Filing	Priority Claimed Under 35 U.S.C. 119
			☐ YES ☐ NO
			☐ YES ☐ NO

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below:

Application Number	Date of Filing

I hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s) or § 365(c) of any PCT International application(s) designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application(s) in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application(s) and the national or PCT International filing date of this application:

Application Number	Date of Filing	Status (Patented, Pending, Abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Full Name of First Inventor	Inventor's Signature	Date
Bruno MELIS	Bruno Melis	2 2 DIC. 2005
Residence: TORINO, ITALY		Citizenship: ITALY
Post Office Address: Telecom Italia S.p.A., Via G. Reiss Romoli, 274 - 10148 TORINO - Italy		

Full Name of Second Inventor	Inventor's Signature	Date
Alfredo RUSCITTO	Alfredo Ruscitto	12 DIC. 2005
Residence: TORINO, ITALY		Citizenship: ITALY
Post Office Address: Telecom Italia S.p.A., Via G. Reiss Romoli, 274 - 10148 TORINO - Italy		

Full Name of Third Inventor	Inventor's Signature	Date
Paolo SEMENZATO	Paolo Semenzato	12 DIC. 2005
Residence: Roma, ITALY		Citizenship: ITALY
Post Office Address: TIM Italia S.p.A., Via del Giorgione, 159 - 00147 ROMA - Italy		

Listing of Inventors Continued on Page 2 hereof. ☐ Yes ☐ No

Listing of Inventors Continued From Page 1 hereof

Full Name of Fourth Inventor Renata MELE	Inventor's Signature	Date 12 DIC. 2005
Residence MILANO, ITALY		Citizenship ITALY
Post Office Address Pirelli Labs, Viale Sarca, 222 – 20126 MILANO - Italy		
Full Name of Fourth Inventor Giuseppe GRASSANO	Inventor's Signature	Date 12 DIC. 2005
Residence MILANO, ITALY		Citizenship ITALY
Post Office Address Pirelli Labs, Viale Sarca, 222 – 20126 MILANO - Italy		

Tel 12?

POWER OF ATTORNEY FROM ASSIGNEE

In accordance with 37 C.F.R. § 3.73(b), **TELECOM ITALIA S.p.A.** ("Assignee") duly organized under the laws of **Italy** and having its principal place of business at **I-20123 Milan, Piazza degli Affari, 2** and **PIRELLI & C. S.p.A.** ("Assignee"), duly organized under the laws of **Italy** and having its principal place of business at **I-20123 Milan, Gaetano Negri, 10**, and represent that they are jointly the assignees of the entire right, title and interest in and to a patent application entitled **"METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT"**, which was filed on **October 27, 2005,** as PCT International Application No. **PCT/EP2005/011529** in the names of **MELIS Bruno, RUSCITTO Alfredo, SEMENZATO Paolo, MELE Renata** and **GRASSANO Giuseppe**, as indicated by assignment(s) duly recorded in the United States Patent and Trademark Office at Reel ______________, Frame ______ on ____________________, or the assignment documents being concurrently filed herewith for recordation, a copy of which is attached hereto.

Assignees hereby appoint the following attorney and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: **FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER, L.L.P., CUSTOMER NUMBER 22,852.**

The undersigned is authorized to act on behalf of Assignees.

Respectfully submitted,

Assignee: Telecom Italia S.p.A.

By: Francesco Battipede
Signature

Name: Francesco BATTIPEDE

Title: Proxy Holder

Assignee: Pirelli & C. S.p.A.

By: Piergiovanni Giannesi
Signature

Name: Pier Giovanni GIANNESI

Title: Proxy Holder

Date: April 21, 2008

ASSIGNMENT

WHEREAS I/We, the below named inventor(s), [hereinafter referred to as Assignor(s)], have made an invention entitled:

METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT

for which I/We filed an international patent application having no. **PCT/EP2005/011529** under the Patent Cooperation Treaty (PCT) on **27 October 2005**; and

WHEREAS, TELECOM ITALIA S.p.A., a corporation of Italy whose post office address is Piazza degli Affari, 2 - 20123 Milano Italy (hereinafter referred to as Assignees) and PIRELLI & C. S.p.A., a corporation of Italy whose post office address is Via G. Negri, 10 – 20123 Milano Italy, are desirous of securing jointly to themselves the entire right, title, and interest in and to this invention in all countries throughout the world, and in and to the application for Letters Patent on this invention and the Letters Patent to be issued upon this application;

NOW THEREFORE, be it known that, for good and valuable consideration the receipt of which from Assignee is hereby acknowledged, I/We, as Assignor(s), have sold, assigned, transferred, and set over, and do hereby sell, assign, transfer, and set over unto the Assignees, their lawful successors and assigns, my/our entire right, title, and interest in and to this invention, provisional Application No. __________, filed __________ (if any), and this application, and all divisions, and continuations thereof, and all Letters Patent which may be granted thereon, and all reissues thereof, and all rights to claim priority on the basis of the above provisional application (if any), as well as all rights to claim priority on the basis of this application, and all applications for Letters Patent which may hereafter be filed for this invention in any country and all Letters Patent which may be granted on this invention in any country, and all extensions, renewals, and reissues thereof; and I/We hereby authorize and request any official of any country whose duty it is to issue patents on applications as described above, to issue all Letters Patent for this invention to Assignees, their successors and assigns, in accordance with the terms of this Assignment;

AND, I/WE HEREBY covenant that I/We have the full right to convey the interest assigned by this Assignment, and I/We have not executed and will not execute any agreement in conflict with this Assignment;

AND, I/WE HEREBY further covenant and agree that I/We will, without further consideration, communicate with Assignees, their successors and assigns, any facts known to me/us respecting this invention, and testify in any legal proceeding, sign all lawful papers when called upon to do so, execute and deliver any and all papers that may be necessary or desirable to perfect the title to this invention in said Assignees, their successors or assigns, execute all divisional, continuation, and reissue applications, make all rightful oaths and generally do everything possible to aid Assignees, their successors and assigns, to obtain and enforce proper patent protection for this invention in any country, it being understood that any expense incident to the execution of such papers shall be borne by the Assignees, their successors and assigns;

AND, I/WE HEREBY authorize and request the attorneys empowered by an appropriate Power of Attorney in any national patent application claiming priority to this international application to provide any further identification of the national patent application that may be necessary or desirable for purposes of recordation of this Assignment in a Patent Office of any country, such as by inserting the application number and filing date of the national application here in parentheses (Application No. 12/084,134, filed April 25, 2008).

IN TESTIMONY WHEREOF, I/We have hereunto set our hand(s).

1. FULL NAME OF SOLE OR FIRST ASSIGNOR Bruno MELIS	ASSIGNOR'S SIGNATURE	DATE 12 DIC. 2005
ADDRESS TELECOM ITALIA S.p.A., Via G. Reiss Romoli 274, Torino, Italy		CITIZENSHIP ITALY
SIGNATURE OF WITTNESS (WHERE APPLICABLE)		

Listing of Assignors Continued From Page 1 hereof

2. FULL NAME OF SECOND ASSIGNOR, IF ANY Alfredo RUSCITTO	ASSIGNOR'S SIGNATURE Alfredo Ruscitto	DATE 12 DIC. 2005
ADDRESS TELECOM ITALIA S.p.A., Via G. Reiss Romoli 274, Torino, Italy		CITIZENSHIP ITALY
SIGNATURE OF WITTNESS (WHERE APPLICABLE)		

3. FULL NAME OF THIRD ASSIGNOR, IF ANY Paolo SEMENZATO	ASSIGNOR'S SIGNATURE Paolo Semenzato	DATE 12 [illegible] 2005
ADDRESS TIM Italia S.p.A., Via del Giorgione 159, Roma, Italy		CITIZENSHIP ITALY
SIGNATURE OF WITTNESS (WHERE APPLICABLE)		

4. FULL NAME OF FOURTH ASSIGNOR, IF ANY Renata MELE	ASSIGNOR'S SIGNATURE Renata Mele	DATE
ADDRESS PIRELLI LABS, Viale Sarca, 222, Milano, Italy		CITIZENSHIP ITALY
SIGNATURE OF WITTNESS (WHERE APPLICABLE)		

5. FULL NAME OF FIFTH ASSIGNOR, IF ANY Giuseppe GRASSANO	ASSIGNOR'S SIGNATURE Giuseppe Grassano	DATE
ADDRESS PIRELLI LABS, Viale Sarca, 222, Milano, Italy		CITIZENSHIP ITALY
SIGNATURE OF WITTNESS (WHERE APPLICABLE)		

6. FULL NAME OF SIXTH ASSIGNOR, IF ANY	ASSIGNOR'S SIGNATURE	DATE
ADDRESS		CITIZENSHIP
SIGNATURE OF WITTNESS (WHERE APPLICABLE)		

7. FULL NAME OF SEVENTH ASSIGNOR, IF ANY	ASSIGNOR'S SIGNATURE	DATE
ADDRESS		CITIZENSHIP
SIGNATURE OF WITTNESS (WHERE APPLICABLE)		

8. FULL NAME OF EIGHTH ASSIGNOR, IF ANY	ASSIGNOR'S SIGNATURE	DATE
ADDRESS		CITIZENSHIP
SIGNATURE OF WITTNESS (WHERE APPLICABLE)		

9. FULL NAME OF NINTH ASSIGNOR, IF ANY	ASSIGNOR'S SIGNATURE	DATE
ADDRESS		CITIZENSHIP
SIGNATURE OF WITTNESS (WHERE APPLICABLE)		

Customer No. 22,852
Attorney Docket No. 09952.0468-00000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. National Phase Application of International Application No.:	)
PCT/EP2005/011529	)
Inventors: Bruno MELIS et al.	) Confirmation No. 5280
Application No.: 12/084,134	) Group Art Unit: 2611
Filed: April 25, 2008	) Examiner: Not Yet Assigned
For: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT	)

MAIL STOP PCT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT UNDER 37 C.F.R. § 1.97(b)

Pursuant to 37 C.F.R. §§1.56 and 1.97(b), Applicant brings to the Examiner's attention the documents listed on attached Form PTO/SB/08 and cited in the international search report. Copies of the listed non-patent documents are attached. Applicant respectfully requests that the Examiner consider the documents listed on attached Form PTO/SB/08 and indicate that they were considered by making an appropriate notation on this form.

This Information Disclosure Statement is being filed before the mailing date of a first Office Action on the merits for the above-referenced application.

This submission does not represent that a search has been made or that no better art exists and does not constitute an admission that each or all of the listed documents are material or constitute "prior art." If the Examiner applies any of the documents as prior art against any claim in the application and Applicant determines that the cited documents do not constitute "prior art" under United States law, Applicant reserves the right to present to the Office the relevant facts and law regarding the appropriate status of such documents. Applicant further reserves the right to take appropriate action to establish the patentability of the disclosed invention over the listed documents, should one or more of the documents be applied against the claims of the present application.

If there is any fee due in connection with the filing of this Statement, please charge the fee to our Deposit Account No. 06-0916.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: August 27, 2009

By: ____________________
Ernest F. Chapman
Reg. No. 25,961

Enclosures
EFC/FPD/acd

IDS Form PTO/SB/08: Substitute for form 1449A/PTO

INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(Use as many sheets as necessary)

Sheet	1	of	1

Complete if Known	
Application Number	12/084,134
Filing Date	April 25, 2008
First Named Inventor	Bruno MELIS
Art Unit	2611
Examiner Name	Not Yet Assigned
Attorney Docket Number	09952.0468-00000

U.S. PATENTS AND PUBLISHED U.S. PATENT APPLICATIONS

Examiner Initials	Cite No.	Document Number Number-Kind Code (if known)	Issue or Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear

Note: Copies of the U.S. Patent Documents are not Required in IDS filed after October 21, 2004

FOREIGN PATENT DOCUMENTS

Examiner Initials	Cite No.	Foreign Patent Document Country Code/Number-Kind Code (If known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear	Translation

NON PATENT LITERATURE DOCUMENTS

Examiner Initials	Cite No.	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation
		A. WITTNEBEN, "A New Bandwidth Efficient Transmit Antenna Modulation Diversity Scheme for Linear Digital Modulation," ICC Conference, pages 1630-1634, Geneva (May 1993).	
		S. KIM et al., "Time-Delay Phase Shifter Controlled by Piezoelectric Transducer on Coplanar Waveguide," IEEE Microwave and Wireless Components Letters, Vol. 13, No. 1, pp. 19-20 (January 2003).	
		J. LEE et al., "CDMA Systems Engineering Handbook, pp. 256-262 (1998).	

Examiner Signature		Date Considered	

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

FPD/acd

Electronic Patent Application Fee Transmittal

Application Number:	12084134
Filing Date:	
Title of Invention:	Method and System for Multiple Antenna Communication Using Multiple Transmission Modes, Related Apparatus and Computer Program Product
First Named Inventor/Applicant Name:	Bruno Melis
Filer:	Ernest F. Chapman/Ann Denikos
Attorney Docket Number:	09952.0468-00000

Filed as Large Entity

U.S. National Stage under 35 USC 371 Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Oath/decl > 30 months from priority date	1617	1	130	130
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Miscellaneous:				
		Total in USD ($)		**130**

Electronic Acknowledgement Receipt

EFS ID:	5965089
Application Number:	12084134
International Application Number:	
Confirmation Number:	5280
Title of Invention:	Method and System for Multiple Antenna Communication Using Multiple Transmission Modes, Related Apparatus and Computer Program Product
First Named Inventor/Applicant Name:	Bruno Melis
Customer Number:	22852
Filer:	Ernest F. Chapman/Ann Denikos
Filer Authorized By:	Ernest F. Chapman
Attorney Docket Number:	09952.0468-00000
Receipt Date:	27-AUG-2009
Filing Date:	
Time Stamp:	14:23:35
Application Type:	U.S. National Stage under 35 USC 371

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$130
RAM confirmation Number	543
Deposit Account	
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)

1	Applicant Response to Pre-Exam Formalities Notice	MR_Transmittal.pdf	35292 b57d7e1e76c7dce80f2ac8f4bfb5a49f54fd5f8d	no	2
Warnings:					
Information:					
2	Oath or Declaration filed	Dec.pdf	30641 5a06dade055e89396a7c844889a0c4e8d621f28d	no	2
Warnings:					
Information:					
3	Power of Attorney	POA.pdf	63403 c00b2a6879009c75aa5f767946ab156549ece2bc	no	3
Warnings:					
Information:					
4		SuppIDS_SB08.pdf	42225 16f5dd100e1e830aace2436ffe3f3429262678b3	yes	3
	Multipart Description/PDF files in .zip description				
	Document Description		**Start**	**End**	
	Transmittal Letter		1	2	
	Information Disclosure Statement (IDS) Filed (SB/08)		3	3	
Warnings:					
Information:					
5	NPL Documents	Wittneben.pdf	299056 d2800cc4cd8e8396881758290d817b73dc3bba3d	no	5
Warnings:					
Information:					
6	NPL Documents	KimEtAl.pdf	55088 9d74788556d25079dc863ba747709945fc627b78	no	2
Warnings:					
Information:					
7	NPL Documents	LeeEtAl.pdf	200212 4bc9a7275f70858e5cba8ab60f65dfe164f97bcf	no	6
Warnings:					
Information:					
8	Fee Worksheet (PTO-875)	fee-info.pdf	30153 089e623adc77d549e2dacdc01b2108a4dc8bbd76	no	2

Warnings:	
Information:	
Total Files Size (in bytes):	756070

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

U.S. APPLICATION NUMBER NO.	FIRST NAMED APPLICANT	ATTY. DOCKET NO.
12/084,134	Bruno Melis	09952.0468-00000

INTERNATIONAL APPLICATION NO.	
PCT/EP2005/011529	
I.A. FILING DATE	PRIORITY DATE
10/27/2005	

22852
FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413

CONFIRMATION NO. 5280
371 FORMALITIES LETTER

OC000000036685369

Date Mailed: 06/29/2009

NOTIFICATION OF MISSING REQUIREMENTS UNDER 35 U.S.C. 371 IN THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US)

The following items have been submitted by the applicant or the IB to the United States Patent and Trademark Office as a Designated Office (37 CFR 1.494):

- Copy of the International Application filed on 04/25/2008
- Copy of the International Search Report filed on 04/25/2008
- Preliminary Amendments filed on 04/25/2008
- Information Disclosure Statements filed on 04/25/2008
- U.S. Basic National Fees filed on 04/25/2008
- Specification filed on 04/25/2008
- Claims filed on 04/25/2008
- Abstracts filed on 04/25/2008
- Drawings filed on 04/25/2008

The applicant needs to satisfy supplemental fees problems indicated below.

The following items **MUST** be furnished within the period set forth below in order to complete the requirements for acceptance under 35 U.S.C. 371:

- Oath or declaration of the inventors, in compliance with 37 CFR 1.497(a) and (b), identifying the application by the International application number and international filing date.
- To avoid abandonment, a surcharge (for late submission of filing fee, search fee, examination fee or oath or declaration) as set forth in 37 CFR 1.492(h) of $130 for a non-small entity, must be submitted with the missing items identified in this letter.

SUMMARY OF FEES DUE:

Total additional fees required for this application is $**130** for a Large Entity:

- $**130** Surcharge.

ALL OF THE ITEMS SET FORTH ABOVE MUST BE SUBMITTED WITHIN TWO (2) MONTHS FROM THE DATE OF THIS NOTICE OR BY 32 MONTHS FROM THE PRIORITY DATE FOR THE APPLICATION, WHICHEVER IS LATER. FAILURE TO PROPERLY RESPOND WILL RESULT IN ABANDONMENT.

The time period set above may be extended by filing a petition and fee for extension of time under the provisions of 37 CFR 1.136(a).

Applicant is reminded that any communications to the United States Patent and Trademark Office must be mailed to the address given in the heading and include the U.S. application no. shown above (37 CFR 1.5)

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

For more information about EFS-Web please call the USPTO Electronic Business Center at **1-866-217-9197** or visit our website at http://www.uspto.gov/ebc.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

NADINE V CLARK

Telephone: (703) 756-1411

DO/ EO WORKSHEET

Patent Application Specialist/ National Stage Division

U.S. Appl. No. 12/084,134 International Appl. No. PCT/EP2005/011529

WIPO PUBLICATION INFORMATION :

Publication No.: WO2007/048427 Publication Language : ☑ English (LA used as specification) ☐ German ☐ Japanese ☐ Chinese ☐ Korean ☐ French ☐ Spanish ☐ Russian ☐ Other : ____

Publication Date : 3 MAY 2007 Not Published : ☐ U.S. only ☐ Early Pub. Request Published : ☐ Early Pub.

INTERNATIONAL APPLICATION PAPERS IN THE APPLICATION FILE :

☑ International Application *(RECORD COPY)*

☐ Article 19 Amendments

☐ PCT/IPEA/409 - IPER (check Examination Authority) : ☐ EP ☐ JP ☐ SE ☐ AU ☐ US ☐ FR ☐ CN ☐ ES ☐ RU ☐ AT ☐ CA ☐ KR ☐ ___

☐ Annexes to 409

☐ PCT/ISA/237 (check Searching Authority) : ☐ EP ☐ JP ☐ SE ☐ AU ☐ US ☐ FR ☐ CN ☐ ES ☐ RU ☐ AT ☐ CA ☐ KR ☐ ___

☐ Other : ______

☐ PCT/IB/306

☐ Request form PCT/RO/101

☑ PCT/ISA/210 - Search Report (check Searching Authority) : ☑ EP ☐ JP ☐ SE ☐ AU ☐ US ☐ FR ☐ CN ☐ ES ☐ RU ☐ AT ☐ CA ☐ KR ☐ ___ ☐ NONE

☐ Search Report References

☐ Priority Document (s) No. _____
☐ N/A
☐ Priority Document was NOT AVAILABLE at the time of paralegal review

☐ Other : ______

RECEIPTS FROM THE APPLICANT *(filed with the application unless noted otherwise)* :

☑ Basic National Fee *(or authorization to charge)*

☑ Description 39 ☑ Claims 13 ☑ Abstract 1

☑ Number of Drawing Sheets : 27

☐ Translation of Article 19 Amendments
☐ entered ☐ not entered :
☐ not a page for page substitution
☐ replaced by Article 34 Amendment

☐ Annexes to 409
☐ entered ☐ not entered :
☐ not a page for page substitution
☐ no translation ☐ other : ______

☐ Application Data Sheet

☐ Power of Attorney

☐ Change of Address

☐ PG Pub Early Publication Request

☐ Express Request to Begin Nat'l Examination Procedures

☑ Preliminary Amendment(s) Filed on :
1. ☑ same as 371 request date 2. ______ 3. ______

☑ Information Disclosure Statement(s) Filed on :
1. ☑ same as 371 request date 2. ______ 3. ______

☐ Assignee Statement Under 37 CFR 3.73(b)

☐ Assignee PG Publication Notice

☐ Substitute Specification Filed on :
1. ☐ same as 371 request date 2. ______ 3. ______

☐ Verified Small Status Statement

☐ Oath/ Declaration (executed)

☐ Defective Oath/ Declaration ☐ unsigned ☐ no citizenship ☐ other

☐ DNA Diskette ☐ Sequence Listing

☐ Other : ______

☐ Other : ______

NOTES :

35 U.S.C. 371 - Receipt of Request (PTO-1390)	4-25-08
Date Acceptable Oath/ Declaration Received	
Date of Completion of requirements under 35 U.S.C. 371	
Date of Completion of DO/ EO 903 - Notification of Acceptance	
Date of Completion of DO/ EO 905 - Notification of Missing Requirements	6-26-09
Date of Completion of DO/ EO 909 - Notification of Abandonment	
Date of Completion of DO/ EO 916 - Notification of Defective Response	
Date of Completion of DO/ EO 922 - Notification to Comply w/ Requirements for Patent Applications Containing Nucleotide and/or Amino Acid Sequence Disclosures	
Date of Completion of DO/ EO 923	

MULTIPLE DEPENDENT CLAIM FEE CALCULATION SHEET
(FOR USE WITH FORM PTO-875)

SERIAL NO. 12/084,134

FILING DATE

APPLICANT(S)

CLAIMS

	AS FILED		AFTER 1st AMENDMENT		AFTER 2nd AMENDMENT	
	IND.	DEP.	IND.	DEP.	IND.	DEP.
1	1					
2		1				
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44		1				
45		1				
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50				1		
TOTAL IND.		↓	1	↓		↓
TOTAL DEP.		←	22	←		←
TOTAL CLAIMS			23			

	AS FILED		AFTER 1st AMENDMENT		AFTER 2nd AMENDMENT	
	IND.	DEP.	IND.	DEP.	IND.	DEP.
51				1		
52				1		
53				1		
54				1		
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100						
TOTAL IND.		↓		↓		↓
TOTAL DEP.		←		←		←
TOTAL CLAIMS						

PATENT APPLICATION FEE DETERMINATION RECORD
Effective December 8, 2004

Application or Docket Number
12/084,134

CLAIMS AS FILED - PART I

	(Column 1)	(Column 2)	SMALL ENTITY RATE	SMALL ENTITY FEE	OR	LARGE ENTITY RATE	LARGE ENTITY FEE
U.S. NATIONAL STAGE FEES			RATE	FEE		RATE	FEE
BASIC FEE			BASIC FEE		OR	BASIC FEE	310
EXAMINATION FEE			EXAM. FEE			EXAM. FEE	410
SEARCH FEE			SEARCH FEE			SEARCH FEE	210
FEE FOR EXTRA SPEC. PGS.	minus 100 =	/ 50 =	X $ 125 =			X $ 250 =	
TOTAL CHARGEABLE CLAIMS	23 minus 20 =	3	X $ 25 =		OR	X $ 50 =	150
INDEPENDENT CLAIMS	1 minus 3 =		X $ 100 =		OR	X $ 200 =	
MULTIPLE DEPENDENT CLAIM PRESENT		☐	+ $ 180 =		OR	+ $ 360 =	
			TOTAL		OR	TOTAL	1080

* If the difference in column 1 is less than zero, enter "0" in column 2

CLAIMS AS AMENDED - PART II

SMALL ENTITY OR OTHER THAN SMALL ENTITY

AMENDMENT A		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE	ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	ADDITIONAL FEE
	Total	*	Minus	**	=	X $ 25 =		OR	X $ 50 =	
	Independent	*	Minus	***	=	X $ 100 =		OR	X $ 200 =	
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				☐	+ $ 180 =		OR	+ $ 360 =	
						TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

AMENDMENT B		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE	ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	ADDITIONAL FEE
	Total	*	Minus	**	=	X $ 25 =		OR	X $ 50 =	
	Independent	*	Minus	***	=	X $ 100 =		OR	X $ 200 =	
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				☐	+ $ 180 =		OR	+ $ 360 =	
						TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than '20', enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than '3', enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

IAP07Rec'd PCT 25 APR 2008

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A SUBMISSION UNDER 35 U.S.C. 371		CUSTOMER NO. 22,852 ATTORNEY'S DOCKET NUMBER: 09952.0468-00000
		U.S. APPLICATION NO. (if known, see 37 C.F.R. 1.5) 12/084134
INTERNATIONAL APPLICATION NO. PCT/EP2005/011529	INTERNATIONAL FILING DATE October 27, 2005	PRIORITY DATE CLAIMED

TITLE OF INVENTION
METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT

APPLICANT(S) FOR DO/EO/US
Bruno MELIS; Alfredo RUSCITTO; Paolo SEMENZATO; Renata MELE; Giuseppe GRASSANO

Applicant(s) herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a submission under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. ☐ The US has been elected (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c)(2)).
   a. ☒ is attached hereto (required only if not communicated by the International Bureau).
   b. ☐ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed with the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3)).
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. ☒ Information Disclosure Statement under 37 CFR 1.97 and 1.98
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A preliminary amendment.
14. ☐ An Application Data Sheet under 37 CFR 1.76.
15. ☐ A Substitute specification.
16. ☐ A power of attorney and/or change of address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13*ter*.2 and 35 U.S.C. 1.821-1.825.
18. ☐ A second copy of the published International Application under 35 U.S.C. 154 (d)(4).
19. ☐ A second copy of the English language translation of the international application 35 U.S.C. 154 (d)(4).
20. ☒ Other items or information:
   a. ☒ Copy of cover page of International Publication No. WO 2007/048427 A1
   b. ☒ Copy of International Search Report
   c. ☐
   d. ☐
   e. ☐
   f. ☐
   g. ☐

IAP02Rec'd PCT 25 APR 2008

U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 12/084134	INTERNATIONAL APPLICATION NO. PCT/EP2005/011529	ATTORNEY'S DOCKET NUMBER 09952.0468-00000

The following fees have been submitted:	CALCULATIONS	PTO Use Only
21. ☒ BASIC NATIONAL FEE (37 CFR 1.492(a)): $310	$310.00	
22. ☒ Examination fee (37 CFR 1.492(c)) If the Written opinion prepared by ISA/US or the International preliminary examination report prepared by IPEA/US indicates all claims satisfy provisions of PCT Article 33(1)-(4) .... $ 0 All other situations $210	$210.00	
23. ☒ Search fee (37 CFR 1.492(b)) If the written opinion of the ISA/US or the International preliminary examination report prepared by IPEA/US indicates all claims satisfy provisions of PCT Article 33(1)-(4) .... $ 0 Search fee (37 CFR 1.445(a)(2)) has been paid on the international application to the USPTO as an International Searching Authority .... $100 International Search Report prepared by an ISA other than the US and provided to the Office or previously communicated to the US by the IB .... $410 All other situations $510	$410.00	
TOTAL of 21, 22 and 23 =	$930.00	
☒ Additional fee for specification and drawings filed in paper over 100 sheets (excluding sequence listing in compliance with 37 CFR 1.821(c) or (e) or computer program listing in an electronic medium) (37 CFR 1.492(j)). The fee is **$260** for each additional 50 sheets of paper or fraction thereof.		

Total Sheets	Extra Sheets	Number of each additional 50 or fraction thereof (round up to a whole number)	Rate	CALCULATIONS	PTO Use Only
79 - 100 =	0/50=	0	x $260.00	$0	

	CALCULATIONS	PTO Use Only
Surcharge of **$130.00** for furnishing any of the search fee, examination fee, or the oath or declaration after the date of commencement of the national stage (37 CFR 1.492(h)).	$0	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	CALCULATIONS	PTO Use Only
Total Claims	23 - 20 =	3	x $50.00	$150.00	
Independent Claims	2 - 3 =	0	x $210.00	$0	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+$370.00	$0	

	CALCULATIONS	PTO Use Only
TOTAL OF ABOVE CALCULATIONS =	$1080.00	
☐ Applicant claims small entity status. See 37 CFR 1.27. Fees above are reduced by ½.	$0	
SUBTOTAL =	$1080.00	
Processing fee of **$130.00** for furnishing the English translation later than 30 months from the earliest priority date (37 CFR 1.492(i)). +	$0	
TOTAL NATIONAL FEE =	$1080.00	
Fee for recording the enclosed assignment (37 CFR 1.21 (h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property. +	$0	
TOTAL FEES ENCLOSED =	$1080.00	
	Amount to be refunded:	$
	charged:	$

a. ☒ A check in the amount of $1080.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. ______________ in the amount of $____________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **06-0916**. A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card or to Deposit Account No. 06-0916. **WARNING**: Information on this form may become public. **Credit card information should not be included on this form**. Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the International Application to pending status.

SEND ALL CORRESPONDENCE TO:

Finnegan, Henderson, Farabow, Garrett & Dunner, L.L.P.
901 New York Avenue, N.W.
Washington, DC 20001-4413

SIGNATURE

Ernest F. Chapman, Reg. No. 25,961
NAME/REGISTRATION NUMBER

DATED: April 25, 2008

FPD/acd

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 May 2007 (03.05.2007)

PCT

(10) International Publication Number
WO 2007/048427 A1

(51) International Patent Classification:
H04B 7/06 (2006.01) *H04B 7/08* (2006.01)

(21) International Application Number:
PCT/EP2005/011529

(22) International Filing Date: 27 October 2005 (27.10.2005)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicants *(for all designated States except US)*: **TELECOM ITALIA S.P.A.** [IT/IT]; Piazza degli Affari, 2, I-20123 Milano (IT). **PIRELLI & C. S.p.A.** [IT/IT]; Via G. Negri, 10, I-20123 Milano (IT).

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(74) Agents: **GIANNESI, Pier, Giovanni** et al.; Pirelli & C. S.p.A., Viale Sarca, 222, I-20126 Milano (IT).

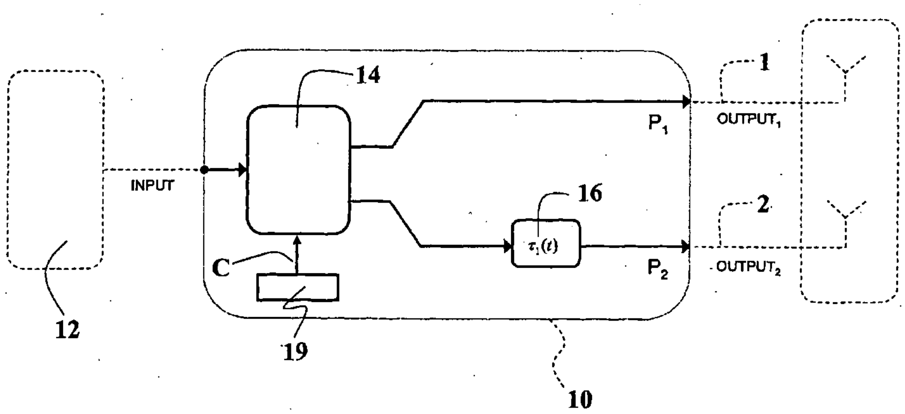
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT



(57) **Abstract:** A system for diversity processing a signal (INPUT) propagated via two diversity antennas (1, 2) includes: respective propagation paths for propagating two replicas of the signal (INPUT), these propagation paths being coupled to the two diversity antennas (1, 2), so that the replicas are propagated via different antennas (1, 2) ; a time variable delay element (16) for subjecting at least one of the replicas to a time variable delay; and a level adjusting element, such as an asymmetric 15 splitter (14) to produce a level imbalance (A) between the power levels of the replicas propagated via the two diversity antennas (1, 2).

WO 2007/048427 A1

"Method and system for multiple antenna communications using multiple transmission modes, related apparatus and computer program product"

* * *

Field of the invention

The present invention relates to wireless communication systems. The invention was developed by paying specific attention to the possible application in radio transmitters and receivers.

Description of the related art

Radio transmitters and receivers used in systems that provide voice and data services by means of multiple transmission mode currently adopt different transmission modes characterized by different transmission parameters such as e.g. the channel coding rate.

Examples of these communication systems are GPRS (General Packet Radio Service), EDGE (Enhanced Data rates for Global Evolution) and HSDPA (High Speed Downlink Packet Access) that has been recently introduced in the UTRA (UMTS Terrestrial Radio Access) Release 5 specifications.

The idea underlying the wireless communication systems listed above is to adapt the transmission parameters in order to take advantage of prevailing channel conditions. The basic parameters adapted typically include channel coding rate and modulation. However, other quantities can be adjusted during communication for the benefit of the system. This adaptive approach, denoted in literature as Link

Adaptation (LA), is now widely recognized as a key solution to increase the spectral efficiency of wireless communication systems.

Figure 1 of the annexed drawing illustrates a set of transmission modes (MCS-1 to MCS-9) suitable for use in an EDGE system. Each mode listed in the left-hand column (Transmisson Mode or TM) is identified by the type of modulation (MOD - i.e. 8 PSK or GMSK) and the channel coding rate (i.e. the ratio of the "useful", payload bits to the total number of bits transmitted – right-hand column CR). The modes are listed in the figure in a decreasing order in terms of the maximum throughput (third column TM) in kbps, whereby MCS-9 and MCS-1 are the first and the last mode in the list, respectively. Since each mode has a different maximum data rate (expressed in bits per second) and robustness level (minimum signal-to noise ratio needed to activate the mode), the modes are optimal for use in different channel quality regions.

The goal of link adaptation is thus always to ensure that the most efficient mode is used, over varying channel conditions, based on a mode selection criterion (maximum data rate, minimum transmit power, and so on). For instance, by considering the example of the EDGE system in Figure 1, the transmission mode denoted as MCS-1 ensures the highest protection of the transmitted information as it uses a low channel coding rate, of about 0.5, and a robust modulation scheme such the GMSK (Gaussian Minimum Shift Keying) modulation. Similarly, the transmission mode denoted as MCS-5 provides a high level of protection of the transmitted information because it uses a channel coding rate of about 0.37 and uses the 8-PSK modulation scheme, which is less robust than the GMSK but is able to provide a throughput three times higher. These two transmission modes are selected under unfavourable channel conditions, as it may occur when the user is located at the cell edge.

On the other hand, the transmission mode denoted as MCS-9 ensures the lowest protection of the information transmitted as it does not use any channel coding scheme and the coding rate is unitary. This transmission mode ensures the highest throughput and is used under very good channel conditions, as for example when the user is located near to the base station.

HSDPA may be considered as a further example of a wireless system that uses multiple transmissions modes with different coding rates and modulations. HDSPA (High Speed Downlink Packet Access) is a new feature introduced in 3GPP Release 5 specifications of UTRA. It includes a wide range of physical layer solutions able to increase user peak data rate and cell throughput, supporting a new downlink shared transport channel. The physical layer solutions include in particular multiple transmission modes characterized by different modulation and coding rates.

The characteristics of some of the HSDPA transmission modes (1 to 22 - column labelled TM) are listed in Figure 2, for the User Equipment (UE) categories 1 to 6, with a number of spreading codes allocated to the High Speed Physical Downlink Shared CHannel (HS-PDSCH) between 1 and 5 (column labelled NC). Modulation (MOD) may be either QPSK (for modes 1 to 15) or 16-QAM (for modes 16 to 22). The modes are listed in increasing order in terms of maximum throughput (MT) in kbps. Here again, the channel coding rate (CR) varies from very low values of about 1/5 to rather high values of about 3/4.

Unless otherwise indicated, the acronyms and abbreviations appearing in Figures 1 and 2 are well known to those of skill in the art, thus making it unnecessary to provide more detailed explanations herein.

Even when using link adaptation techniques, the spectral efficiency of current wireless networks may still be insufficient to satisfy the growing throughput demand by the users, originated by the increased penetration of new data services. Moreover, these new data services are likely to be used in - potentially adverse - low mobility conditions by still or walking users in indoor or pedestrian scenarios.

Antenna diversity is a technique that can be used to improve spectral efficiency and to reduce the negative effects of prolonged multi-path fading in wireless systems. In diversity transmission (and, similarly, in diversity reception), two or more physically separated antennas (space diversity) or one or more cross-polarized antenna (polarization diversity) are respectively used to transmit or receive a given signal. By placing the antennas at a sufficient distance or by using a +/-45 degrees slant cross-polarized antennas it is possible minimize the amplitude correlation of the signals transmitted or received by the different antennas. In practice, the physical separation between the antennas is limited due to size or environmental constraints and thus the signals can have a significant amplitude correlation. A significant signal correlation can also be present in the signals transmitted or received through cross polarized antennas, in particular when the vertical to horizontal polarization power ratio, also referred to as cross-polar discrimination (XPD), takes high values.

The arrangement described in the article of A. Wittneben "A New Bandwidth Efficient Transmit Antenna Modulation Diversity Scheme for Linear Digital Modulation", ICC Conference - pages 1630-1634, Geneva, May 1993 is exemplary of antenna diversity including a fixed delay diversity (DD) between antennas.

Another fixed DD receiver arrangement is described in US-A-5 930 293. This document describes the application of the fixed DD technique for achieving antenna receive diversity in a wireless repeater. The repeater is equipped with two receiving antennas for receiving a signal from a wireless terminal. The signal received from one of the antennas is subject to a fixed delay and is recombined at RF with the other received signal. The combined signal is subsequently transmitted to the base station by means of a third antenna. The fixed delay is chosen at least equal to two chip periods in order to enable the Rake receivers in the base station to resolve and coherently combine the two signals.

The document WO-A-03/055097 describes a method for providing Phase Shift Transmit Diversity (PSTD) in a wireless communication system. A base station modulates the phase of a first signal with a reference signal to produce a first phase modulated signal. Further, the base station modulates the phase of a second signal with a different reference signal to produce a second phase modulated signal. The second phase shift is distinct from the first phase shift such that the second phase modulated signal is diverse relative to the first phase modulated signal. Accordingly, the base station transmits the first phase modulated signal via a first antenna and the second phase modulated signal via a second antenna to a plurality of mobile stations.

PCT Applications PCT/EP2004/011204 and PCT/EP2005/010799 disclose antenna diversity techniques that improve radio link performance by reducing the temporal autocorrelation of the signals transmitted/received in low mobility scenarios and also minimize the cross-correlation among the signals received by the different antennas. These arrangements are applicable in wireless systems that have already been standardized, with minimal modifications on the deployed equipments and networks.

These antenna diversity arrangements essentially rely on Dynamic Delay Diversity (DDD), i.e. a time variable delay diversity. These DDD techniques introduce a time variable delay on the signals transmitted and/or received by the different antennas. The delay required to make the technique effective is significantly smaller when compared to other diversity techniques. In general, the required delay varies between zero and the period of the RF (carrier) signal T_0. Because of the low value of delay to be introduced, the implementation problems related to size, cost and transmission losses of the delay line, are significantly reduced in case of the DDD technique with respect to other antenna diversity techniques such fixed Delay Diversity (fixed DD). The DDD technique also dispenses with certain problems that are intrinsic to Phase Shift Transmit Diversity (PSTD) techniques, such as e.g. high insertion loss and non-linearity of RF phase shifter devices.

These systems lead to significant improvements in terms of link level performance in slow fading scenarios and for wireless systems that use robust channel coding techniques with coding rates lower or equal to 1/2.

Object and summary of the invention

Despite the significant improvement represented by the Dynamic Delay Diversity techniques discussed in the foregoing, the need is still felt for a diversity technique that may be advantageously applied in those wireless systems as those discussed in the introductory part of this description, namely those system that use multiple transmission modes and are characterized by different channel coding rates ranging from one (unencoded transmission) to low values (e.g. ≤ 1/2) obtained with powerful coding schemes.

The object of the present invention is thus to provide an arrangement suitable for application in those communication systems that adapt to varying channel conditions by using different transmission modes. A specific object of the present invention is to provide an arrangement that, in the case of uncoded (e.g. EDGE mode MCS-9) or near-to-uncoded transmission, avoids that the distribution of the errors over the received data stream may cause an increase of the Block Error Rate (BLER) and thus a reduction of the user data rate.

According to the present invention, that object is achieved by means of a method having the features set forth in the claims that follow. The invention also relates to a corresponding system, a related apparatus as well as a related computer program product, loadable in the memory of at least one computer and including software code portions for performing the steps of the method of the invention when the product is run on a computer. As used herein, reference to such a computer program product is intended to be equivalent to reference to a computer-readable medium containing instructions for controlling a computer system to coordinate the performance of the method of the invention. Reference to "at least one computer" is evidently intended to highlight the possibility for the present invention to be implemented in a distributed/ modular fashion. The claims are an integral part of the disclosure of the invention provided herein.

A preferred embodiment of the invention is thus a method of diversity processing at least one signal propagated (i.e. transmitted and/or received) via at least two diversity antennas, the method including the steps of:

- propagating at least two replicas of said at least one signal over respective propagation (i.e. transmission and/or reception) paths coupled to said at least two diversity antennas, whereby said replicas are propagated via different antennas;

- subjecting at least one of said replicas to a time variable delay; and

- adjusting the power levels of said at least two replicas (e.g. via asymmetric splitters and/or combiners and/or or by applying different gains/attenuations over the respective propagation paths) to produce a level imbalance therebetween.

The arrangement described herein thus comprises a new method and a related circuit for the application of a Dynamic Delay Diversity (DDD) technique. The method and DDD circuit described herein are suitable for application in communication systems that adapt to varying channel conditions by using different transmission modes. The transmission modes are typically characterized by channel coding rates variable from 1 (unencoded transmission) to very low values (e.g. 1/3 or 1/5) obtained with powerful coding schemes.

Typically, the arrangement described herein is applied to at least one signal transmitted by selectively using one of a plurality of transmission modes (e.g. MCS-1 to MCS-9; 1 to 22, as discussed previously) and said level imbalance is selected as a function of the transmission modes used, e.g. by using the level imbalance/difference giving the best results in connection with the transmission mode having the highest probability of being used. In the case where the transmission mode used is varied during transmission (e.g. to cope with varying channel characteristics) the level imbalance can be adaptively varied as a function of the current transmission mode used.

GPRS, EDGE, HSDPA (i.e. UMTS), and HDR (i.e. CDMA-2000) are exemplary of wireless systems that represent a possible field of application of the arrangement described herein. However, other wireless communication systems that use multiple transmission modes with large variation of the channel coding rates represent a possible field of application for the arrangement described herein.

A preferred field of application of the arrangement described herein is in multi-carrier cell sites, in which the available carrier frequencies are divided among different transmission systems such GSM and GPRS/EDGE providing voice and packet data services respectively.

Brief description of the annexed representations

The invention will now be described, by way of non-limiting example only, with reference to the annexed representations, wherein:

- Figures 1 and 2 have been already described in the foregoing;

- Figure 3 includes two portions, designated 3a and 3b, representative of the general context of application of the arrangement described herein within a transmitter and a receiver, respectively;

- Figure 4 again includes two portions, designated 4a and 4b, that are exemplary of the basic characteristics of certain components included in the arrangement described herein;

- Figures 5 and 6 are schematic block diagrams of possible embodiments of a diversity arrangement as described herein when applied on the transmitter side;

- Figure 7 includes two portions, designated 7a and 7b, that are exemplary of the basic characteristics of certain components included in the arrangement described herein;

- Figure 8 is a diagram representative of a parameter involved in operation of the arrangement described herein;

- Figure 9 is a functional block diagram representative of the basic principle underlying operation of the diversity arrangement as described herein;

- Figures 10 to 14 are diagrams illustrative of the results that may be achieved by using a diversity arrangement as described herein;

- Figures 15 and 16 are schematic block diagrams of possible embodiments of a diversity arrangement as described herein when applied on the receiver side; and

- Figures 17 to 27 are block diagrams that illustrate various system architectures involving diversity arrangements as described herein.

Detailed description of exemplary embodiments of the invention

As indicated in the foregoing, the diversity arrangement described herein relies on the introduction of a time variant delay on the signals transmitted and/or received by the different antennas. Typically the delay is significantly smaller when compared to other diversity techniques. In general, if RF or IF signals modulated over a carrier are being processed according to the diversity arrangement described herein, the delay applied varies between zero and the period T_0 of the carrier signal.

For example, the application of the technique described herein in a base station transceiver compliant with the GPRS/EDGE standard involves the introduction of a delay that varies between zero and the carrier period T_0 =1/890 MHz = 1.1 nanoseconds. More generally, the delays typically considered for the arrangement described herein vary between zero and values in the range between tenths of nanoseconds (ns) and units of nanoseconds (ns).

The technique is realized by means of a diversity processor 10 (transmission or TX) that is connected at the output of a conventional transmitter 12, as shown in Figure 3a, or a diversity processor 20 (reception or RX) that is connected at the input of a conventional receiver 22 as shown in Figure 3b.

Specifically, in figures 3a and 3b digital signals (e.g. Layer 2 data in a mobile communication system - not shown as a whole) are transmitted (figure 3a) or received (figure 3b) via two diversity antennas 1 and

2. The transmitter 12 and the receiver 22 include otherwise conventional circuitry such as e.g. baseband processors, digital-to-analog (DAC) and analog-to-digital (ADC) converters, IF/RF transmitters/receivers, and so on. At least some of the embodiments detailed in the following relate to diversity processors that are "reciprocal" in that they may act both on signals being transmitted and on signals being received via the antennas 1, 2. These reciprocal arrangements will thus be in a position to be connected to and to cooperate with (in an otherwise known manner) with a "transceiver" that combines a transmitter 12 and a receiver 22.

In the following, various alternative implementations of diversity processors exploiting the principle of Dynamic Delay Diversity DDD are described. These will be generally denoted DDD TX processors (transmit diversity) or DDD RX processors (receive diversity). In the various specific embodiments considered, these TX or RX (or TX/RX, in the case of "reciprocal" embodiments) diversity processors will include various elements or components such as signal splitters, combiners, Time Variant Delay Lines (TVDL), Power Amplifiers (PA), Low Noise Amplifiers (LNA), etc. Unless otherwise specified, these elements are substantially the same in the various embodiments; these embodiments thus essentially differ in the number, type and way the various elementary blocks are combined to produce different structures of a diversity processor.

As better detailed in the following, the time varying delay required can be obtained using a delay line based on a waveguide or a microstrip device. Both devices, obtained using standard technologies as in commercial devices, are limited in power handling, where the limiting values are presently in the range of 33 - 35 dBm. This is not an issue for receive diversity applications, but might represent a limiting factor for transmission diversity applications: in several cases, in particular in the case of macro base station (for both 2G and 3G), this limiting value may not be compatible with the typical value of the transmitted power.

However, the asymmetric DDD TX processors described here involve i.a. an asymmetric splitting of the power transmitted. The power level associated to the signal replica(s) subjected to the time varying delay may thus be reduced, which largely facilitates the implementation of several architectures proposed in the following by using commercial devices.

In the following description, the designation signal splitter - see figure 4a - will apply to any device capable of splitting (i.e. dividing) an input signal S_{in} in two parts or replicas.

Such a splitter may either be:

- a symmetric splitter (see figure 4a – left hand side), capable of splitting (i.e. dividing) an input signal S_{in} in two parts or replicas α. S_{in} having the same power level; or

- an asymmetric splitter (see figure 4a - right hand side), capable of splitting an input signal S_{in} in two parts or replicas α_1. S_{in} and α_2. S_{in}, with α_1 different from α_2, having different power levels.

Similarly, the designation signal combiner - see figure 4b - will apply to any device capable of combining (i.e. adding) two parts or replicas $S_{in,1}$, $S_{in,2}$ of a given signal S_{in}.

Such a combiner may either be:

- a symmetric combiner (see figure 4b - left hand side), capable of combining (i.e. adding) two parts or replicas $S_{in,1}$, $S_{in,2}$ by applying to both the same "weights" α, to produce a combined signal $S_{in} = \alpha .\ S_{in,1} + \alpha .\ S_{in,2}$ or $S_{in} = \alpha(S_{in,1} + S_{in,2})$; or

- an asymmetric combiner (see figure 4b - right hand side), capable of combining (i.e. adding) the two parts or replicas $S_{in,1}$, $S_{in,2}$ by applying to them different "weights" α_1, α_2, with α_1 different from α_2, to produce a combined signals $S_{in} = \alpha_1 . S_{in,1} + \alpha_2 . S_{in,2}$.

Practical implementations of splitters/dividers - both symmetric and asymmetric - also for RF/IF operation, are conventional in the art and do not require to be described in detail here. A splitter implemented with passive components (e.g. as a resistor voltage divider) will generally be reciprocal, in that it will act as a combiner for the signals that propagate in the opposite direction. This characteristic is exploited in the reciprocal DDD processors described in the following, which can be used simultaneously for transmission and reception.

The right hand side portions of figures 4a and 4b highlight the possibility for an asymmetric splitter/combiner to include a control line C whereby the factors/weights α_1 and α_2 can be changed to correspondingly vary the difference/imbalance Δ. As better detailed in the following, these factors/weights may be adjusted as a function of a transmission mode used e.g. by selecting the level imbalance/difference giving the best results in connection with the transmission mode having the highest probability of being used. Alternatively these factors/weights may be adaptively varied during transmission as a function of the current transmission mode used.

A first architecture of a DDD TX processor 10 is shown in Figure 5. This processor is suitable for application with conventional transmitters 12 that do not support any form of transmission antenna diversity. Thus, in this case the conventional transmitter provides a single output signal. The DDD TX processor 10 includes an asymmetric splitter 14 that divides the input signal in two parts or replicas. The powers of the signals at the output of the asymmetric splitter are different.

The power imbalance or difference thus created between the two signals to be transmitted via the diversity antennas 1 and 2 is a design parameter that allows the application of the DDD processor in wireless systems that use multiple transmission modes with different coding rates.

Specifically, by denoting with P_1 and P_2 the powers radiated by the two antennas, the DDD power imbalance Δ (in dB) is defined as follows

$$\Delta = 10 \cdot \log_{10}\left(\frac{P_1}{P_2}\right) \qquad [\text{dB}] \qquad (1)$$

The first signal with power P_1 is propagated (i.e. radiated) by the first antenna 1. The second signal with power P_2 is provided to a Time Variant Delay Line (TVDL) 16 that introduces a time variant delay $\tau_1(t)$ on the signal radiated by the second antenna 2.

By denoting with $x(t)$ the signal at the output of the conventional transmitter, the two transmitted signal $y_1(t)$ and $y_2(t)$ can be expressed as follows

$$y_1(t) = \alpha_1 \cdot x(t)$$
$$y_2(t) = \alpha_2 \cdot x(t - \tau_1(t)) \qquad (2)$$

where the amplitude coefficients α_1 and α_2 depend on the characteristic of the asymmetric splitter.

These coefficients may be possibly varied via the line C. This may either be in the form of a "*una tantum*" trimming of the system or in the form of automatic adjustment under the control of a block 19 sensitive to the current transmission mode used (e.g. any of the modes MCS-1 to MCS-9 or 1 to 22 contemplated in figures 1 and 2).

A power imbalance between the signals transmitted by the two antennas 1, 2 can also be obtained by resorting to the alternative arrangement illustrated in figure 6, where the same reference numerals already appearing in figure 5 are used to denote identical/equivalent components to those already described.

In the arrangement of figure 6, the splitter 14 is a symmetric splitter and two power amplifiers (PA) 14a and 14b with different gains G_1 and G_2 are inserted in the propagations paths of the two replicas of the signal produced by the splitter 14 towards the antennas 1, 2.

The symmetric splitter 14 provides in this case two output signals with the same power. The power imbalance or difference between the two signals to be transmitted via the diversity antennas 1 and 2 is thus produced by acting on the two gains G_1 and G_2 of the amplifiers 14a and 14b. The power imbalance or difference thus created allows the application of the DDD processor in wireless systems that use multiple transmission modes with different coding rates. Here again, a first signal with a first power level is propagated (i.e. radiated) by the first antenna 1, and the second signal with a second power level is processed (preferably before amplification at 14b) to a Time Variant Delay Line (TVDL) 16 that introduces a time variant delay $\tau_1(t)$ on the signal radiated by the second antenna 2.

The amplitude coefficients α_1 and α_2 of the formulas introduced in the foregoing are here dictated by the gains G_1 and G_2 of the amplifiers 14a and 14b. These gains/coefficients may again be possibly varied via respective control inputs C. This may be in the form of trimming of the system or in the form of automatic adjustment under the control of the block 19.

The architecture illustrated in figure 6 has the advantage that the delay element 16 can be realized with low power handling components.

The DDD TX processor architecture illustrated in Figure 6 is particularly adapted for communication networks that use Remote Radio Head (RRH) units. A RRH is a compact unit that is mounted near the antenna and integrates several base station functions for transmission and reception. The transmission functions that are typically integrated in the RRH unit are digital to analog conversion (DAC), frequency up-conversion, digital pre-distortion and MCPA (Multi Carrier Power Amplifier). The receiving functions that are integrated in the RRH are the RF front-end, frequency down-conversion and analog to digital conversion (ADC).

The RRH unit is fed from the remainder of the base station with baseband (I/Q) signals via optical fibre cables. The interface between the RRH and the baseband modem is normally compliant with the Common Public Radio Interface (CPRI) standard or with the interface defined by the OBSAI (Open Base Station Standard Initiative) forum. The baseband modem can be relocated from a cabinet near to the antenna to a remote location with clear benefits in terms of deployment costs and network management.

Figure 7a shows a first exemplary implementation of the time variable delay line 16 (and any other time variable delay line referred to in the rest of this description) in the form of a tapped delay line, namely as the cascade of elementary delay units. Each of such delay unit (e.g. a transmission line stub) generates for example a delay T_D of 0.1 ns. The various tap points in the line come down to a RF switch 18. The switch is controlled by a delay control unit (DCU) making it possible to select a particular tap of the tapped delay line and therefore a given value of the delay introduced by the block. Changing the position of the switch 18 makes it possible to change the value of the delay.

Figure 7b shows a second exemplary implementation of the time variable delay line 16 (and any other time variable delay line referred to in the rest of this description) in the form of a plurality of delay elements (these may again be comprised of transmission line stubs) each producing for example a respective delay of TD1 = 0.1 ns., TD2 = 0.2 ns., TD3 = 0.3 ns., and so on. Two switches 181, 182 are controlled in a coordinated manner by the delay control unit (DCU) making it possible to select a particular delay element and therefore a given value of the delay introduced by the block. Changing the position of the switches 181, 182 makes it possible to change the value of the delay.

As an alternative to varying the delay in discrete steps, as shown in connection with the exemplary embodiments of Figure 7a and Figure 7b, in other possible implementations (not shown) of the delay line/element the delay is caused to vary continuously. A possible implementation of the delay line with continuous variation of the introduced delay can be found in the article "Time Delay Phase Shifter Controlled by Piezoelectric Transducer on Coplanar Waveguide", IEEE Microwave and Wireless Components Letters, Vol. 13, No. 1, pag. 19-20, January 2003. In particular, the continuous delay line may be implemented by inserting on a coplanar waveguide a piezoelectric transducer whose perturbations vary the effective dielectric constant of the coplanar waveguide.

The delay function $\tau_1(t)$, according to which the delay varies as a function of time, is not restricted to particular functions and can be a continuous function (e.g. linear, sinusoidal) or a discrete step function. An example of continuous delay function $\tau_1(t)$ is shown in Figure 8, where T_0 is the carrier period and T_{DDD} is the period of the delay function $\tau_1(t)$, which in the following will be designated the period of the DDD. T_{DDD} is typically selected in the range between aprroximately one to tens of milliseconds.

The effect of the Dynamic Delay Diversity technique discussed here can be explained in connection with figure 9 by considering a single frequency component of the received signal. Here the antennas 1, 2 are assumed to be fed two signals $a_1x(t)$ and $a_2x(t-\tau)$.

The coefficients a_1 and a_2 incorporate the amplitude coefficients α_1 and α_2, plus other gain factors (assumed to be identical for both signals) inherent in the transmission chain through which the "useful" signal x(t) is propagated, while τ is representative of the (dynamic) time delay applied to the signal transmitted via the antenna 2.

As a result of propagation over a transmission channel having channel coefficients $c_1(t)$ and $c_2(t)$ for the antennas 1 and 2, respectively, the signals received (again for the sake of simplicity, a single receiving antenna A_{RX} will be considered) will take the form:

$$r_1(t) = a_1x(t)c_1(t)$$

$$r_2(t) = a_2x(t-\tau)c_2(t)$$

and will be summed as a resulting signal $r(t) = r_1(t) + r_2(t)$.

This is in fact equivalent to the sum of two phasors. The phasor $r_1(t)$ related to the signal transmitted by the first antenna, not subject to variable delay, varies according to the characteristic of the propagation channel. For example in indoor environments characterized by low user mobility, the amplitude and phase of this phasor have very slow variations. The second phasor $r_2(t)$, related to the signal transmitted by the antenna subject to variable delay, rotates with a frequency that is imposed by the period of the dynamic delay diversity DDD, as shown at the bottom of Figure 9. The second phasor completes a rotation of 360° in a time interval equal to the period of the DDD (namely T_{DDD}).

The combination of the two phasors at the receiving antenna A_{RX} produces a resultant signal that fades at a faster rate than the signal without DDD, due to the alternation of constructive (phasors recombine in phase) and destructive combination (phasors recombine with opposite phases). The average amplitude ratio of the two phasors is directly proportional to the power imbalance Δ set at the transmitter in the DDD processor. As a consequence, the amplitude depth of the fades induced by the DDD can be progressively reduced by means of the power imbalance.

The alternation of constructive and destructive combining reduces the length of the error bursts and thus improves the effectiveness of the transmission modes that use channel coding. The DDD technique thus affects the error statistics at the input of the channel decoder by making the error distribution more uniform over the received data stream (i.e. the error statistic becomes less bursty). The effectiveness of the channel decoding algorithms is then improved with a consequent reduction of the BLER after the decoding operation.

On the other hand, in the case of uncoded (e.g. EDGE mode MCS-9) or near-to-uncoded transmission the distribution of the errors over the received data stream may cause an increase of the BLER and thus a reduction of the user data rate. The power imbalance technique described herein provides an effective solution to this problem.

The effect of the DDD technique is shown in the diagrams of figure 10. Specifically, these diagrams provide a measure of the received signal power (ordinate scale) as a function of time (abscissa scale) in a system without DDD (diagram I) and in systems that use a DDD processor 10 at the transmitter (diagrams II and III). In this case the user speed is set equal to v = 3 km/h and the configuration parameters of the DDD processor are Δ = 0 dB (balanced transmission - diagram II) or Δ = 6 dB (unbalanced transmission - diagram III) and DDD period equal to T_{DDD} = 13 ms.

Figure 10 shows that the amplitude depth of the fades caused by the DDD is reduced by transmitting two signals with different powers. A lower amplitude depth of the induced fades reduces the probability that a block of unencoded bits is received with errors and therefore avoids any BLER degradation for the unencoded transmission modes.

This result is confirmed by experiments documented in the following. A second remarkable advantage of the unbalanced configuration is the simplification of the time variable delay line design, since the power associated to the second antenna can be significantly reduced.

The effect of the power imbalance can be measured by means of a parameter that characterizes the fade occurrence on the received signal. This parameter is the fade rate or Level Crossing Rate (LCR). The LCR is dependent on the environment characteristics (e.g. position and structure of the scattering objects) and on the relative speed between transmitter and receiver. The natural value of LCR in a given environment (e.g. indoor) can be modified by means of the DDD technique in order to improve the link level performance of the communication system. In particular, LCR can be finely tuned by properly selecting the power imbalance Δ (line/input C of figures 5 and 6) of the DDD processor in order to get optimal link performance with systems that use multiple transmission modes.

LCR is defined as the average rate at which the received signal envelope crosses a specified amplitude threshold A in a positive direction. The LCR is measured in number of fades per second, where the term fade means that the envelope crosses the threshold A. In case of a single path Rayleigh channel with classic

Doppler spectrum the LCR can be calculated analytically, as demonstrated in "CDMA systems engineering handbook", J. Lee, L. Miller, pag. 256-262. In this particular case the theoretical expression of the LCR is equal to

$$LCR = f_d \cdot \rho \cdot \sqrt{2\pi} \cdot e^{-\rho^2} \quad \text{[fades/s]} \qquad (3)$$

where ρ is the fade-depth parameter defined as the ratio between the signal envelope threshold A and the local RMS (Root Mean Square) signal level

$$\rho = \frac{\mathrm{A}}{\mathrm{A}_{\mathrm{rms}}} \qquad (4)$$

and f_d is the maximum Doppler spread given by

$$f_d = f_0 \cdot \frac{v}{c} \quad \text{[Hz]} \qquad (5)$$

with f_0 indicating the carrier frequency, v the relative speed between transmitter and receiver and c the light speed. By substituting the equation (5) in the equation (3) we notice that, as expected, the LCR is proportional to the speed v. For example, by considering a received power threshold of 10 dB below the average signal power received, the fade depth parameter ρ is equal to

$$\rho = \sqrt{0.1} = 0.316 \qquad (6)$$

resulting, for a mobile speed v of 3 km/h and a carrier frequency f_0 of 2 GHz, in a LCR equal to

$$LCR = f_0 \cdot \frac{v}{c} \cdot \rho \cdot \sqrt{2\pi} \cdot e^{-\rho^2} = 3.9 \text{ fades/s} \qquad (7)$$

In a wireless system using the DDD TX processor of Figure 5 or Figure 6 the LCR can be evaluated by simulation as shown in Figure 11, where the LCR (ordinate scale) is given as a function of the fade depth parameter $10 \cdot \log_{10}(\rho^2)$ - abscissa scale, referred to the received power in decibel. The results indicate that the LCR reduces as the power imbalance increases (0dB, 3dB, 6dB, 9dB). A lower LCR corresponds to a lower amplitude depth of the induced fades and that reduces the probability that a block of uncoded bits is received with errors. With an accurate choice of the power imbalance is then possible to avoid the BLER degradation for the uncoded transmission modes.

The application of the DDD processor in systems that use multiple transmission modes with different coding rates requires an accurate optimisation of the DDD parameters. The experimental measurements have shown that optimum link performance can be obtained with a period of the DDD of the same order of the interleaving period used in the communication system. This choice maximizes the effectiveness of channel coding and therefore the link performance gain for the transmission modes that use channel coding (indicatively with rates $r \leq 1/2$). The power imbalance Δ is instead optimised by considering the uncoded transmission modes or the transmission modes with the highest coding rates.

The diagrams of Figures 12, 13 and 14 provide some experimental measurement results obtained with an EDGE test-bed and using the DDD TX processor of figure 5. In particular the figures show the effect of the power imbalance on the link performance. The link performance is given in terms of BLER (ordinate scale) after channel decoding as a function of C/I (Signal to Interference plus Noise Ratio - abscissa scale) for the MCS-1, MCS-5 and MCS-9 transmission mode, respectively.

The period of the DDD is set equal to 36 ms as it provides a good performance gain for the coded transmission modes, which use in the physical layer a block interleaving of 20 ms.

From the Figures one notices that, with a power imbalance Δ = 6 dB, the arrangement described herein:

- provides an appreciable performance improvement for the transmission modes MCS-1 and MCS-5 that use channel coding, and

- ensures essentially the same performance of a system without DDD for the unencoded mode MCS-9.

This is in contrast to a system without imbalance, where the use of DDD would result in at least a certain degree of performance impairment for unencoded modes (such as MCS-9) or near-to-unencoded modes, i.e. modes having a coding rate near to unity.

In particular a C/I gain of about 0.8 and 1 dB is measured for the MCS-1 and MCS-5 transmission modes at a target BLER of 10%, with respect to a system without DDD. Performance of the transmission mode MCS-9 with a power imbalance of 6 dB is the same of the conventional system without DDD, for a target BLER of 30%. The BLER targets of 10% and 30% considered are normally taken as reference working points in the deployment of the EDGE networks. The application of the DDD technique with power imbalance thus improves the overall spectral efficiency of the wireless communication system, even when multiple transmission modes with different coding rates are used.

In general, the degree of imbalance Δ will be increased as a function of the channel coding rate, which means that higher imbalance values (e.g. 6 dB) will be used for uncoded (e.g. MCS-9) or near-to-uncoded modes, so that the value of imbalance will approximately be proportional to the coding rate.

Stated otherwise, the level imbalance value Δ is selected as a function of the transmission mode by selecting increasing (i.e. higher) level imbalance values for increasing (i.e. higher) coding rates. In practice, the specific values for Δ can be properly identified via numerical simulation or experimental testing.

Experiments carried out heretofore by the applicant show that power imbalance values of 3 to 10 dB ensure that no performance degradation is caused to the uncoded or near-to-uncoded transmission modes and thus the same BLER performance of a system without DDD is obtained. With this design choice, the application of the DDD technique improves the overall spectral efficiency of the wireless communication system even when multiple transmission modes are used. Clearly, different tradeoffs between the performance of the coded and unencoded transmission modes are possible with different choices of the DDD parameters.

The following description relates to figures 15 to 27. These figures illustrate a number of possible developments of the basic DDD processing schemes described in connection with figures 5 and 6. While a corresponding description is not re-iterated for the sake of brevity, it will be appreciated that all the possible variants now described lend themselves to be implemented with selectively varying splitting/combination coefficients α_1 and α_2. Again, these coefficients may be possibly varied via a line/input C as shown in figures 5 and 6. This may either be in the form of a "*una tantum*" trimming of the system or in the form of automatic adjustment under the control of a block 19 sensitive to the current transmission mode used (e.g. any of the modes MCS-1 to MCS-9 or 1 to 22 contemplated in figures 1 and 2).

A preferred common feature to the various embodiments described herein lies in that, as the at least two signal replicas considered have respectively higher and lower power levels (i.e. the power level of the first replica is higher than the power level of the second replica, so that the power level of the second replica is lower than the power level of the first replica), the DDD arrangement described herein provides for the time variable delay being preferably applied to the replica having a lower power level. As indicated this is advantageous as it facilitates the use of low power handling components for the delay element(s).

It will be further appreciated that while - for the sake of simplicity - only arrangements including two diversity antennas 1, 2 are described herein and shown in the figures 3a, 3b, 5, 6, and 15 to 29, the invention is adapted to be applied to arrangements including any of a plural number of diversity antennas, namely three diversity antennas or more.

As a first example of an alternative embodiment, the DDD technique can be also used at the receiver side to improve the radio link performance of wireless systems even if not designed to support the receiver diversity.

In this case (see e.g. figures 15 and 16) a conventional receiver 22 is equipped with a single radio chain and thus only one RF signal can be demodulated. The DDD RX processor 20 is an add-on RF module connected between the receiving antennas 1,2 and the conventional receiver 22.

Specifically, the scheme of a DDD RX processor 20 suitable for conventional receivers that do not support antenna diversity is shown in Figure 15. The processor 20 includes an asymmetric combiner 24 and a time variant delay line 26. The asymmetric combiner 24 combines (i.e. adds) the two RF signals so that the power ratio of the two combined signals is equal to

$$\Delta = 10 \cdot \log_{10}\left(\frac{P_1}{P_2}\right) \qquad [dB] \qquad (8)$$

where P_1 and P_2 are the powers of the first and second received signals before the combination. In the scheme of Figure 15, the signal received from the first antenna 1 is provided to the first input of the asymmetric combiner 24 while a second antenna 2 is added and this received signal is subject to the time variant delay 26 and then provided to the second input of the combiner. The combined signal is then provided to the conventional receiver 22 for the subsequent demodulation.

By denoting with $r_1(t)$ and $r_2(t)$ the signals received at the two antennas 1 and 2, the signal $z(t)$ at the output of the DDD processor can be expressed as follows

$$z(t) = \alpha_1 \cdot r_1(t) + \alpha_2 \cdot r_2(t - \tau_1(t)) \qquad (9)$$

where α_1 and α_2 are the combining coefficients introduced by the asymmetric combiner. If we suppose that the two received signals $r_1(t)$ and $r_2(t)$ have the same average power, the imbalance can then be expressed as follows

$$\Delta = 10 \cdot \log_{10}\left(\frac{\alpha_1}{\alpha_2}\right)^2 \qquad (10)$$

The DDD RX processor 20 can also be realized according to the second architecture shown in Figure 16. The signals received from the antennas 1, 2 are amplified by two Low Noise Amplifiers (LNAs) 24a and 24b with different gains G_1 and G_2. The signal received from the first antenna 1 is provided to a symmetric RF combiner 24 while the signal from the second antenna 2 is subject to the time variant delay. After the insertion of the delay 26, the second signal is then provided to the other input of the symmetric combiner. The symmetric combiner adds the two input signals maintaining the power imbalance Δ of the signals at its inputs. The gains G_1 and G_2 of the LNAs 24a and 24b are set in order to obtain the desired power imbalance between the received signals prior to the RF combination.

The effect of the power imbalance, in the case of the DDD technique is applied at the receiver side, is similar to that described in connection with figure 9 with reference to transmission of a single frequency component. Again, the signals received at the antennas may be represented as two phasors, whose amplitude and phase change according to the channel characteristic. In low mobility environments these variations can be very slow thus causing prolonged signal fades. The insertion of the time variant delay on one of the received signals and the subsequent combination cause the alternation of constructive and destructive combining, which reduces the length of the error bursts and thus improves the effectiveness of the transmission modes that use channel coding. However, the alternation of constructive and destructive combining may negatively affect the Block Error Rate of the uncoded transmission modes. By introducing the power imbalance it is possible to reduce the depth of the fades induced by the DDD and thus avoid any performance degradation of the uncoded transmission modes.

The DDD processors can be also applied to improve the performance of conventional transmitters and receivers that support some kind of transmission or receive antenna diversity.

A block diagram of such a DDD TX processor is shown in Figure 17. The signals $INPUT_1$, $INPUT_2$ at the outputs of the conventional transmitter 12 feed two asymmetric splitters 141, 142. Each splitter divides the input signal in two replicas with different powers. Two of the four signals obtained after RF splitting are directly recombined in a first (symmetric) combiner 171, while the other two signals are subject to time variant delays in two delay elements 161 and 162 and then recombined in a second (symmetric) combiner 172. The signals after recombination feed the transmitting antennas 1, 2.

The power asymmetry of the splitters is designed in order to obtain the desired imbalance Δ (see equation 1) between the powers P_1 and P_2 radiated by the two antennas 1, 2. By denoting with $x_1(t)$ and $x_2(t)$ the signals at the output of the conventional transmitter, the two transmitted signals $y_1(t)$ and $y_2(t)$ can be expressed as follows

$$\begin{aligned} y_1(t) &= \alpha_1 \cdot x_1(t) + \alpha_3 \cdot x_2(t) \\ y_2(t) &= \alpha_2 \cdot x_1(t-\tau_1(t)) + \alpha_4 \cdot x_2(t-\tau_2(t)) \end{aligned} \qquad (11)$$

where α_1 and α_2 are the amplitude coefficients introduced by the first asymmetric splitter, while α_3

and α_4 are the amplitude coefficients introduced by the second asymmetric splitter. In the typical configuration of the DDD TX processor, the two asymmetric splitter are identical so that we may assume $\alpha_1 = \alpha_3$ and $\alpha_2 = \alpha_4$.

As demonstrated in detail in PCT/EP2005/010799, the arrangement illustrated in figure 17 corresponds to a specific, simplified implementation of a more general layout where time variable delay lines are associated to all of the four signal propagation paths that connect the inputs $INPUT_1$ and $INPUT_2$ to the antennas 1 and 2 via the splitters 141, 142 and the combiners 171, 172.

With a proper choice of the delay functions (e.g. the two delay functions $\tau_1(t)$ and $\tau_2(t)$ of figure 17) the DDD TX processor 10 works as a signal decorrelator by providing two output signals that have a lower cross-correlation coefficient than the cross-correlation coefficient of the two input signals $INPUT_1$ and $INPUT_2$. In particular, in the embodiment illustrated in figure 17, the DDD TX processor 10 operates as a signal decorrelator by using two delay functions $\tau_1(t)$ and $\tau_2(t)$ that satisfy the following condition

$$\tau_2(t) = \tau_1(t) + \frac{T_0}{2} \tag{12}$$

where T_0 is the carrier period of the (RF or IF) input signals $INPUT_1$ and $INPUT_2$.

By taking into account the formula (12) the structure of the DDD TX processor of figure 17 can be simplified as illustrated in figure 18. There, the two time variant delay lines 161, 162 of figure 17 are replaced by:

- a single variable delay element (delay line) 161 inserted after the combiner 172, i.e. on a common portion of the propagation paths of the signals $INPUT_1$ and $INPUT_2$ towards the antenna 2; and

- a fixed delay element 1601 with a delay equal to $T_0/2$ inserted between the splitter 142 and the combiner 172, i.e. on those portions of the propagation paths of the signals $INPUT_1$ and $INPUT_2$ towards the antenna 2 that are distinct from each other.

Along the same lines of the arrangements of figures 6 and 16, the asymmetric/imbalanced arrangements of DDD TX processors of figures 17 and 18 can be also implemented by using symmetric splitters 141, 142 and cascading to the combiners 171, 172 two power amplifiers with different gains G_1 and G_2.

Figure 19 shows two such power amplifiers 14a, 14b with different gains G_1 and G_2 inserted prior to the antennas 1, 2 within the processor layout illustrated in figure 18 (the extension to the processor layout of figure 17 is straightforward and is not illustrated in detail).

The gains of the power amplifiers 14a, 14b are determined in order to obtain the desired transmission power imbalance Δ. This architecture has the advantage that the DDD processor can be realized with low power components. The application of this architecture is suitable for communication networks that use Remote Radio Head (RRH) units.

The same DDD processor concept can be also employed at the receiver side in order to improve the performance of conventional receivers that support antenna diversity. The DDD RX processor is inserted between the antenna subsystem and the two RF inputs of a conventional receiver 22.

A first architecture of such a DDD RX processor 20 is shown in Figure 20. The received signals at the antennas are provided to two splitters 241, 242. Each splitter divides the input signal in two replicas with the same power. Two of the four signals obtained after RF splitting are directly recombined by means of an asymmetric combiner 271. The other two signals are subject to time variant delays 261, 262 and then asymmetrically recombined in a combiner 272. The signals after recombination then feed the conventional receiver.

The asymmetry of the combiners 271, 272 is designed in order to obtain the desired imbalance Δ between the powers of the recombined signals.

By denoting with $r_1(t)$ and $r_2(t)$ the signals received at the two antennas, the signals $z_1(t)$ and $z_2(t)$ at the output of the DDD processor can be expressed as follows

$$\begin{aligned} z_1(t) &= \alpha_1 \cdot r_1(t) + \alpha_2 \cdot r_2(t - \tau_1(t)) \\ z_2(t) &= \alpha_3 \cdot r_1(t) + \alpha_4 \cdot r_2(t - \tau_2(t)) \end{aligned} \tag{13}$$

where α_1 and α_2 are the combining coefficients introduced by the first asymmetric combiner and α_3 and α_4 are the combining coefficients introduced by the second asymmetric combiner. By assuming that the two signals received $r_1(t)$ and $r_2(t)$ have the same average power, the power imbalance for the first output signal $z_1(t)$ can be expressed as follows

$$\Delta_1 = 10 \cdot \log_{10}\left(\frac{\alpha_1}{\alpha_2}\right)^2 \tag{14}$$

while the power imbalance for the second output signal $z_2(t)$ is equal to

$$\Delta_2 = 10 \cdot \log_{10}\left(\frac{\alpha_3}{\alpha_4}\right)^2 \tag{15}$$

In the typical configuration of the DDD RX processor, the power imbalance on the two branches are set equal (namely $\Delta_1 = \Delta_2$), which can be obtained by setting $\alpha_1 = \alpha_3$ and $\alpha_2 = \alpha_4$ or using two identical asymmetric combiners.

Again as demonstrated in detail in PCT/EP2005/010799, the arrangement illustrated in figure 20 corresponds to a specific, simplified implementation of a more general layout where time variable delay lines are associated to all of the four signal propagation paths that connect the antennas 1 and 2 to the outputs $OUTPUT_1$ and $OUTPUT_2$ via the splitters 241, 242 and the combiners 271, 272.

With a proper choice of the delay functions (e.g. the two delay functions $\tau_1(t)$ and $\tau_2(t)$ of figure 20) the DDD RX processor operates as a signal decorrelator by providing two output signals that have a lower cross-correlation coefficient than the cross-correlation coefficient of the two input signals.

By taking into account the formula (12), which - mutatis mutandis - also applies to DDD RX processing, the processor of Figure 20 can be simplified as illustrated in figure 21. There, the two time variant delay lines 261, 262 of figure 20 are replaced by:

- a single variable delay element (delay line) 261 inserted before the splitter 242, i.e. on the common portion of the signal propagation paths from the antenna 2 towards the outputs $OUTPUT_1$ and $OUTPUT_2$; and

- a fixed delay element 2601 with a delay equal to $T_0/2$ (where T_0 is the carrier period) inserted between the splitter 242 and the combiner 272, i.e. on those portions of the signal propagation paths from the antenna 2 to the outputs $OUTPUT_1$ and $OUTPUT_2$ that are distinct from each other.

Along the same lines of the arrangements of figures 6, 16, and 19 the asymmetric/imbalanced arrangements of DDD RX processors of figures 20 and 21 can be also implemented by using symmetric combiners 271, 272 and placing upstream of the splitters 241, 242 two low noise amplifiers (LNAs) with different gains G_1 and G_2.

Figure 22 shows the arrangement resulting from the use of two such amplifiers 24a, 24b inserted at the outputs of the receiving antennas 1, 2. In this case two symmetric combiners 271, 272 are used, while the gains of the LNAs 24a, 24b are designed in order to obtain the desired imbalance between the powers of the recombined signals. The application of this architecture (which can be applied also to the receiver layout of figure 20) is suitable for communication networks that use Remote Radio Head (RRH) units.

The DDD processors described up to now are unidirectional devices that can be used separately for transmission (TX) or reception (RX). Comparison of e.g. the architectures of Figure 5 (DDD TX processor) and Figure 15 (DDD RX processor) shows that the two circuits are inherently symmetrical.

As a consequence, a single DDD TX/RX processor, implemented with reciprocal components, can be used simultaneously both for transmission and reception. The same consideration holds for the architectures shown in figure 18 and figure 21, used together with conventional transceivers that support transmit and receive diversity.

Figure 23 and figure 24 show the architectures of DDD TX/RX processors 1020 realized with reciprocal components that can be used simultaneously for transmission and reception. The separation of transmit and receive paths is realized within the transceiver by means of duplexer elements.

The "transceiver" block 1222 in Figure 23 and 24 represents a unit that includes the functionalities of both the conventional transmitter and conventional receiver as shown in figures 3a and 3b, respectively.

The block 1424 of figure 23 is a reciprocal module adapted to operate as an asymmetric splitter on the signal being transmitted from the TX section of the transceiver 1222 via the antennas 1, 2 and as an asymmetric combiner on the signals being received via the antennas 1, 2 and forwarded to the RX section of the transceiver 1222.

In the system of figure 24 two signals are both transmitted and received by means of the diversity antennas.

From the functional viewpoint, the system of figure 24 thus includes:

- two first splitters for splitting the two signals transmitted to produce two respective replicas transmitted over respective transmission paths towards different ones of the diversity antennas 1, 2,
- two second splitters for splitting the two signals received via the antennas 1, 2 to produce two respective replicas received over respective transmission paths from each diversity antenna 1, 2,
- two first combiners for combining the replicas received over respective transmission paths from different ones of the diversity antennas 1, 2, and
- two second combiners for combining at each diversity antenna 1, 2 respective replicas of each of

the signals transmitted.

The system being "reciprocal" leads however the first splitters and the first combiners to be in fact comprised of a first pair of reciprocal elements 14241, 14242. Similarly, the second splitters and the second combiners are in fact comprised of a second pair of reciprocal elements 17271, 17272.

Those of skill in the art will promptly appreciate that the details of the various implementations of DDD processors previously described are not unique to the implementation in respect of which they have been described and can be applied also to other implementations. Similarly, various of these details lend themselves to be substituted by equivalent arrangements.

For instance, the arrangement illustrated in figure 24 can be alternatively implemented by using two (reciprocal) time variable delay elements playing the role of the transmission delay elements 161, 162 of figure 17 and the reception delay elements 261, 262 of figure 20.

As a further example, the location of the power and low-noise amplifiers described and shown in connection with several embodiments disclosed in the foregoing represents the presently preferred design choice, but is in no way mandatory; the skilled designer may in fact easily devise different equivalent arrangements for these power and low-noise amplifiers while preserving their function of producing the power imbalance/difference underlying operation of the invention.

Similarly, those of skill in the art will appreciate that the various implementations of DDD processors previously described can be combined in order to obtain different system architectures, where the DDD processing is introduced both in transmission and reception.

For instance, figure 25 shows a first system architecture based on non-reciprocal DDD transmit and receive processors 10, 20. This architecture is suitable for conventional transceivers that do not support any form of transmit and receive antenna diversity. The internal structures of the DDD TX and RX processors 10, 20 can be e.g. those disclosed in the Figures 5 and 6 or Figures 15 and 16 for the TX and RX parts, respectively. A first duplexer element 101 separates the transmission and reception paths on the TX/RX side, and the separation between transmit and receive paths at the antennas 1, 2 is obtained by means of two further duplexer elements 102, 103.

Figure 26 illustrates another system architecture, realized with non-reciprocal processors, that is suitable for conventional transceivers that support only receive antenna diversity. The first duplexer element 101 here separates the transmission and reception paths TX_1/RX_1 at the port supporting the single transmission channel and one of the diversity reception channels, and the separation between transmit and receive paths at the antennas 1, 2 is again obtained by means of two further duplexer elements 102, 103. The DDD TX processor 10 can be implemented e.g. according to any of the structures shown in Figure 5 or 6, while the DDD RX processor 20 can be implemented e.g. according to any of the schemes described in figures 20, 21 or 22.

Figure 27 illustrates still another system architecture, realized with non-reciprocal processors, which is suitable for conventional transceivers that support both transmit and receive antenna diversity. Two first duplexer elements 1011 and 1012 here separate the transmission and reception paths TX_1/RX_1 and TX_2/RX_2 at the two ports supporting the diversity transmission and reception channels. The separation between transmit and receive paths at the antennas 1, 2 is again obtained by means of two further duplexer elements 102, 103. The DDD TX processor 10 can be implemented e.g. according to any of the structures shown in figures 17, 18 or 19, while the DDD RX processor can be implemented e.g. according to any of the schemes described in figures 20, 21 or 22.

The exemplary embodiments of the invention presented in the foregoing refer to the transmission/reception of signals selected out of radiofrequency (RF) signals and intermediate frequency (IF) signals. Those of skill in the art will however appreciate that the invention can also be applied to baseband signals, in which case the effect of time variable delays may be obtained by subjecting the baseband signal(s) to multiplication by a complex signal.

Consequently, without prejudice to the underlying principles of the invention, the details and the embodiments may vary, even appreciably, with reference to what has been described by way of example only, without departing from the scope of the invention as defined by the annexed claims.

CLAIMS

1. A method of diversity processing at least one signal (INPUT; $INPUT_1$, $INPUT_2$) propagated via at least two diversity antennas (1, 2), the method including the steps of:

- propagating at least two replicas of said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) over respective propagation paths coupled to said at least two diversity antennas (1, 2), whereby said replicas are propagated via different antennas (1, 2);

- subjecting at least one of said replicas to a time variable delay (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261); and

- adjusting (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) the power levels of said at least two replicas to produce a level imbalance (Δ) therebetween.

2. The method of claim 1, characterised in that said at least two replicas include replicas having respectively higher and lower power levels, and in that the method includes the step of subjecting to said time variable delay (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261) said replica having a lower power level.

3. The method of either of claims 1 or 2, characterised in that it includes the step of selecting said level imbalance (Δ) in the range of 3 to 10 dB.

4. The method of any of claims 1 to 3, characterised in that it includes the steps of :

- selectively using one of a plurality of transmission modes (MCS-1 to MCS-9; 1 to 22) for said at least one signal, and

- selecting said level imbalance (Δ) as a function of the transmission mode used.

5. The method of claim 4, characterised in that said plurality of transmission modes (MCS-1 to MCS-9; 1 to 22) have respective coding rates (CR), and the method includes the step of selecting said level imbalance (Δ) as a function of said coding rates, wherein higher level imbalance values are selected for higher coding rates.

6. The method of either of claims 4 or 5, characterised in that it includes the steps of:

- selectively varying the transmission mode (MCS-1 to MCS-9; 1 to 22) used, and

- adaptively varying (19, C) said level imbalance (Δ) as a function of the current transmission mode used.

7. The method of any of the previous claims, characterised in that it includes the step of subjecting to time variable delays the replicas propagating over all of said respective propagation paths.

8. The method of any of the previous claims 1 to 6, characterised in that it includes the step of subjecting to time variable delays (161, 162; 161, 1601; 261, 262; 261, 2601) two of said replicas propagating over propagation paths associated with the same (2) of said diversity antennas (1, 2).

9. The method of claim 8, characterised in that it includes the step of subjecting to time variable delays

the replicas propagating over at least two of said propagation paths by:

- providing, in the propagation paths for said at least two replicas associated with the same (2) of said diversity antennas (1, 2), respective distinct propagation portions and a combined propagation portion for said at least two replicas,

- subjecting said at least two replicas to a time variable delay (161, 261; 1261) over the common portion of said propagation paths, and

- subjecting one of said at least two replicas to a fixed delay (1601; 2601; 12601) over the respective distinct portion of said propagation paths.

10. The method of claim 9, wherein said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) has a carrier frequency with a given period (T_0), characterised in that said fixed delay (1601; 2601; 12601) is equal to half said given period ($T_0/2$).

11. The method of any of the previous claims, applied to at least one signal (INPUT; $INPUT_1$, $INPUT_2$) transmitted in the form of at least two replicas propagated over respective propagation paths towards said at least two diversity antennas (1, 2), characterised in that it includes the step of splitting (14; 141, 142; 1424; 14241; 14242) said at least one signal transmitted (INPUT; $INPUT_1$, $INPUT_2$) to produce said at least two replicas of said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) propagated over respective propagation paths coupled to said at least two diversity antennas (1, 2).

12. The method of claim 11, characterised in that said splitting (14; 141, 142; 1424; 14241; 14242) is an

asymmetric splitting producing said level imbalance (Δ) between said replicas.

13. The method of claim 11, characterised in that said splitting (14; 141, 142; 1424; 14241; 14242) is a symmetric splitting, the method further including the steps of applying different gains (14a, 14b) over said respective propagation paths coupled to said at least two diversity antennas (1, 2) to produce said level imbalance (Δ) between said replicas.

14. The method of any of claims 11 to 13, applied to at least two signals ($INPUT_1$, $INPUT_2$) transmitted by means of said at least two diversity antennas (1, 2), characterised in that it includes the step of combining (171, 172; 17271, 17272) at each of said diversity antennas (1, 2) respective replicas of said at least two signals transmitted.

15. The method of any of the previous claims, applied to at least one signal (INPUT; $INPUT_1$, $INPUT_2$) received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2), characterised in that it includes the step of combining (24; 271, 272; 1424; 14241; 14242) said at least two replicas to produce said at least one signal received (OUTPUT; $OUTPUT_1$, $OUTPUT_2$).

16. The method of claim 15, characterised in that said combining (24; 271, 272; 1424; 14241; 14242) is an asymmetric combining producing said level imbalance (Δ) between said replicas.

17. The method of claim 15, characterised in that

said combining (24; 271, 272; 1424; 14241; 14242) is a symmetric combining, the method further including the steps of applying different gains (24a, 24b) to said respective propagation paths of said replicas from said at least two diversity antennas (1, 2) to produce said level imbalance (Δ) between said replicas.

18. The method of any of claims 15 to 17, applied to at least two signals ($INPUT_1$, $INPUT_2$) received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2), characterised in that it includes the step of splitting (241, 242; 17271, 17272) at each of said diversity antennas (1, 2) the respective propagation paths of said at least two signals received.

19. The method of any of the previous claims, applied to at least one signal (INPUT) transmitted and received by means of said at least two diversity antennas (1, 2), characterised in that it includes the steps of:

- splitting (1424) said at least one signal transmitted (INPUT) to produce at least two replicas transmitted over respective transmission paths towards said diversity antennas (1, 2),
- combining (1424) said at least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2), to produce said at least one signal received (INPUT),
- wherein said steps of splitting and combining are performed by means of at least one reciprocal elements (1424).

20. The method of claim 19, applied to at least

two signals ($INPUT_1$, $INPUT_2$) transmitted and received by means of said at least two diversity antennas (1, 2), characterised in that it includes the steps of:

- a) splitting (14241, 14242) each said at least two signals ($INPUT_1$, $INPUT_2$) transmitted to produce at least two respective replicas transmitted over respective transmission paths towards different ones of said diversity antennas (1, 2),

- b) splitting (17271, 17272) each said at least two signals ($INPUT_1$, $INPUT_2$) received to produce at least two respective replicas received over respective transmission paths from each said diversity antennas (1, 2),

- c) combining (14241, 14242) replicas received over respective transmission paths from different ones of said diversity antennas (1, 2), and

- d) combining (17271, 17272) at each of said diversity antennas (1, 2) respective replicas of each said at least two signals ($INPUT_1$, $INPUT_2$) transmitted

- wherein said splitting and combining steps a) and c), and said splitting and combining steps b) and d), respectively, are performed by means of at least one reciprocal elements (14241, 14242; 17271, 17272).

21. The method of any of the previous claims, characterised in that said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) is selected out of radiofrequency (RF) signals and intermediate frequency (IF) signals.

22. The method of any of the previous claims 1 to 20, characterised in that said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) is a baseband signal, and said time variable delay is applied to said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) by subjecting said baseband signal to multiplication by a complex signal.

23. A system for diversity processing at least one signal (INPUT; $INPUT_1$, $INPUT_2$) propagated via at least two diversity antennas (1, 2), the system including:

- respective propagation paths for propagating at least two replicas of said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) said respective propagation paths being coupled to said at least two diversity antennas (1, 2), whereby said replicas are propagated via different antennas (1, 2);

- at least one time variable delay element (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261) for subjecting at least one of said replicas to a time variable delay; and

- level adjusting elements (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) arranged on said respective propagation paths to produce a level imbalance (Δ) between the power levels of said at least two replicas.

24. The system of claim 23, characterised in that it includes respective propagation paths for at least two said replicas having respectively higher and lower power levels, and in that said at least one time variable delay element (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261) is arranged on the propagation path of said replica having a lower power level.

25. The system of either of claims 23 or 24, characterised in that said level adjusting elements (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) are configured to produce a level imbalance (Δ) in the range of 3 to 10 dB.

26. The system of any of claims 23 to 25, wherein said at least one signal admits a plurality of transmission modes (MCS-1 to MCS-9; 1 to 22), characterised in that said level adjusting elements (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) are configured (C) for selecting said level imbalance (Δ) as a function of the transmission mode used.

27. The method of claim 26, wherein said plurality of transmission modes (MCS-1 to MCS-9; 1 to 22) have respective coding rates (CR), characterised in that said level adjusting elements (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) are configured (C) for selecting said level imbalance (Δ) as a function of said coding rates, wherein higher level imbalance values are selected for higher coding rates.

28. The system of either of claims 26 or 27, characterised in that it includes at least one module (19) sensitive to the current transmission mode used and configured for acting (C) on said level adjusting elements (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) to adaptively vary said level imbalance (Δ) as a function of the current transmission mode used.

29. The system of any of the previous claims 23 to 28, characterised in that it includes variable delay elements (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261) for subjecting to time variable delays the replicas propagating over all of said respective propagation paths.

30. The system of any of the previous claims 23 to 28, characterised in that it includes variable delay elements (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261) for subjecting to time variable delays two said replicas propagating over propagation paths associated with the same (2) of said diversity antennas (1, 2).

31. The system of claim 30, characterised in that it includes:

- in the propagation paths for said at least two replicas associated with the same (2) of said diversity antennas (1, 2), respective distinct propagation portions and a combined propagation portion for said at least two replicas,

- a time variable delay element (161, 261; 1261) arranged over the common portion of said propagation paths for subjecting said at least two replicas to a time variable delay, and

- a fixed delay (1601; 2601; 12601) arranged over said respective distinct portions of said propagation paths for subjecting one of said at least two replicas to a fixed delay (1601; 2601; 12601).

32. The system of claim 31, wherein said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) has a carrier frequency with a given period (T_0), characterised in that said fixed delay (1601; 2601; 12601) is equal to half said given period ($T_0/2$).

33. The system of any of the previous claims 23 to 32, wherein said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) is transmitted in the form of at least two replicas propagated over respective propagation paths

towards said at least two diversity antennas (1, 2), characterised in that the system includes at least one splitter (14; 141, 142; 1424; 14241; 14242) for splitting said at least one signal transmitted (INPUT; $INPUT_1$, $INPUT_2$) to produce said at least two replicas of said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) propagated over respective propagation paths coupled to said at least two diversity antennas (1, 2).

34. The system of claim 33, characterised in that said at least one splitter (14; 141, 142; 1424; 14241; 14242) is an asymmetric splitter producing said level imbalance (Δ) between said replicas.

35. The system of claim 33, characterised in that said at least one splitter (14; 141, 142; 1424; 14241; 14242) is a symmetric splitting, the system further including gain elements (14a, 14b) to apply different gains to respective propagation paths coupled to said at least two diversity antennas (1, 2) to produce said level imbalance (Δ) between said replicas.

36. The system of any of claims 33 to 35, wherein at least two signals ($INPUT_1$, $INPUT_2$) are transmitted by means of said at least two diversity antennas (1, 2), characterised in that the system includes at least one combiner (171, 172; 17271, 17272) for combining at each of said diversity antennas (1, 2) respective replicas of said at least two signals transmitted.

37. The system of any of the previous claims 23 to 36, wherein said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) is received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2),

characterised in that the system includes at least one combiner (24; 271, 272; 1424; 14241; 14242) for cimbining said at least two replicas to produce said at least one signal received (INPUT; $INPUT_1$, $INPUT_2$).

38. The system of claim 37, characterised in that said at least one combiner (24; 271, 272; 1424; 14241; 14242) is an asymmetric combiner producing said level imbalance (Δ) between said replicas.

39. The system of claim 37, characterised in that said at least one combiner (24; 271, 272; 1424; 14241; 14242) is a symmetric combiner, the system further including gain elements (24a, 24b) for applying different gains to said respective propagation paths of said replicas from said at least two diversity antennas (1, 2) of said replicas to produce said level imbalance (Δ) between said replicas.

40. The system of any of claims 37 to 39, wherein at least two signals ($INPUT_1$, $INPUT_2$) are received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2), characterised in that the system includes includes at least one splitter (241, 242; 17271, 17272) for splitting at each of said diversity antennas (1, 2) respective propagation paths for replicas of said at least two signals received.

41. The system of any of the previous claims 23 to 40, wherein said at least one signal (INPUT) is transmitted and received by means of said at least two diversity antennas (1, 2), characterised in that the system includes:

- at least one splitter (1424) for splitting said at least one signal transmitted (INPUT) to produce at least two replicas transmitted over respective transmission paths towards said diversity antennas (1, 2),

- at least one combiner (1424) for combining said least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2), to produce said at least one signal received (INPUT),

- wherein said at least one splitter and combiner are comprised of at least one reciprocal element (1424).

42. The system of claim 41, wherein at least two signals ($INPUT_1$, $INPUT_2$) are transmitted and received by means of said at least two diversity antennas (1, 2), characterised in that it includes:

- a) at least one first splitter (14241, 14242) for splitting each said at least two signals ($INPUT_1$, $INPUT_2$) transmitted to produce at least two respective replicas transmitted over respective transmission paths towards different ones of said diversity antennas (1, 2),

- b) at least one second splitter (17271, 17272) for splitting each said at least two signals ($INPUT_1$, $INPUT_2$) received to produce at least two respective replicas received over respective transmission paths from each said diversity antennas (1, 2),

- c) at least one first combiner (14241, 14242) for combining replicas received over respective transmission paths from different ones of said diversity antennas (1, 2), and

- d) at least one second combiner (17271, 17272) for combining at each of said diversity antennas (1, 2) respective replicas of each said at least two signals

($INPUT_1$, $INPUT_2$) transmitted,

- wherein said at least one first splitter and said at least one first combiner are comprised of at least one first reciprocal element (14241, 14242), and said at least one second splitter and said at least one second combiner are comprised of at least one second reciprocal element (17271, 17272).

43. The system of any of the previous claims 23 to 42, wherein said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) is a baseband signal, and said time variable delay is applied to said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) by subjecting said baseband signal to multiplication by a complex signal.

44. A wireless communication apparatus including the system of any of claims 23 to 43.

45. A computer program product, loadable into the memory of at least one computer and including software code portions for performing the method of any of claims 1 to 22.

Fig. 1

TM MOD MT CR

Transmission mode	Modulation	Maximum Throughput [kbps]	Coding Rate
MCS-9	8 PSK	59.2	1
MCS-8		54.5	0.92
MCS-7		44.8	0.76
MCS-6		29.6	0.49
MCS-5		22.4	0.37
MCS-4	GMSK	17.6	1
MCS-3		14.8	0.8
MCS-2		11.2	0.66
MCS-1		8.8	0.53

Fig. 2

TM NC MOD MT CR

Transmission mode	Number of HS-PDSCH codes	Modulation	Maximum Throughput [kbps]	Coding Rate
1	1	QPSK	68.5	0.14
2	1	QPSK	86.5	0.18
3	1	QPSK	116.5	0.24
4	1	QPSK	158.5	0.33
5	1	QPSK	188.5	0.39
6	1	QPSK	230.5	0.48
7	2	QPSK	325	0.34
8	2	QPSK	396	0.41
9	2	QPSK	465.5	0.48
10	3	QPSK	631	0.44
11	3	QPSK	741.5	0.51
12	3	QPSK	871	0.60
13	4	QPSK	1139.5	0.59
14	4	QPSK	1291.5	0.67
15	5	QPSK	1659.5	0.69
16	5	16-QAM	1782.5	0.37
17	5	16-QAM	2094.5	0.44
18	5	16-QAM	2332	0.49
19	5	16-QAM	2643.5	0.55
20	5	16-QAM	2943.5	0.61
21	5	16-QAM	3277	0.68
22	5	16-QAM	3584	0.75

Fig. 3a

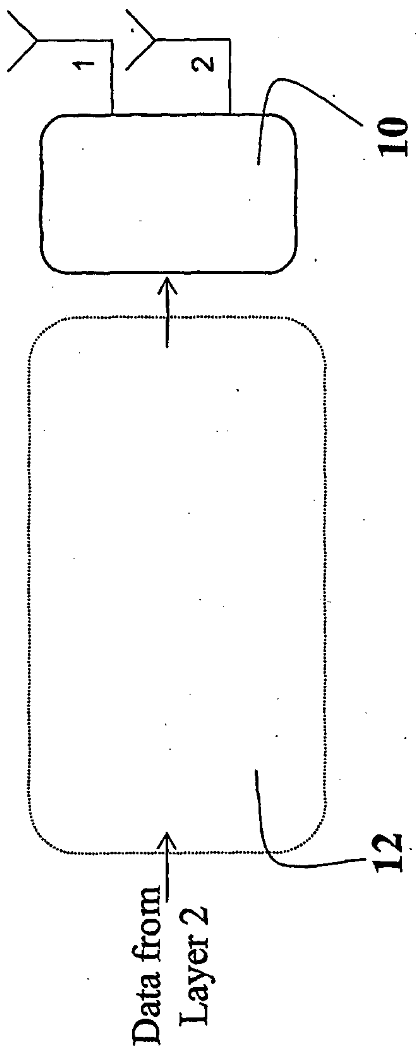


Fig. 3b

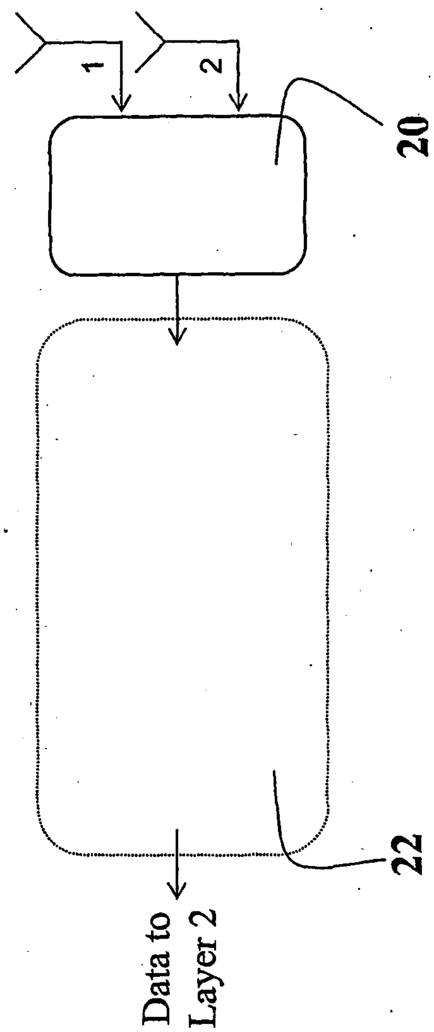


Fig. 4a

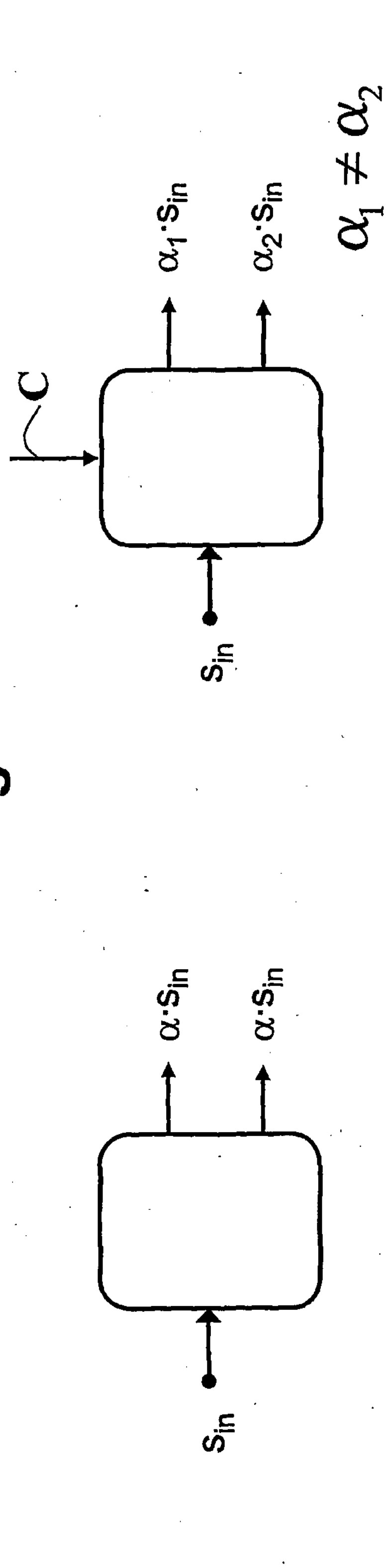

C
s_{in}
$\alpha_1 \cdot s_{in}$
$\alpha_2 \cdot s_{in}$
$\alpha_1 \neq \alpha_2$
s_{in}
$\alpha \cdot s_{in}$
$\alpha \cdot s_{in}$

Fig. 4b

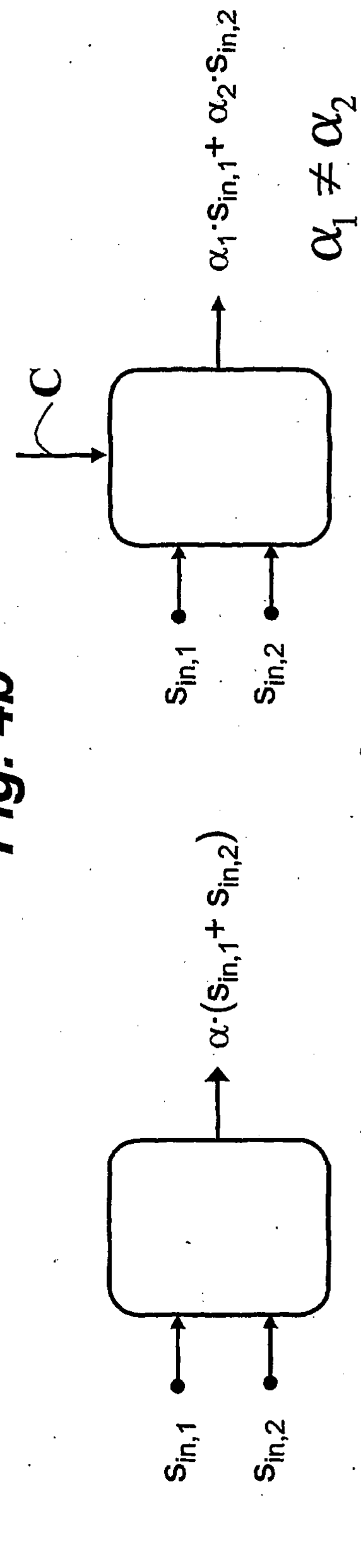
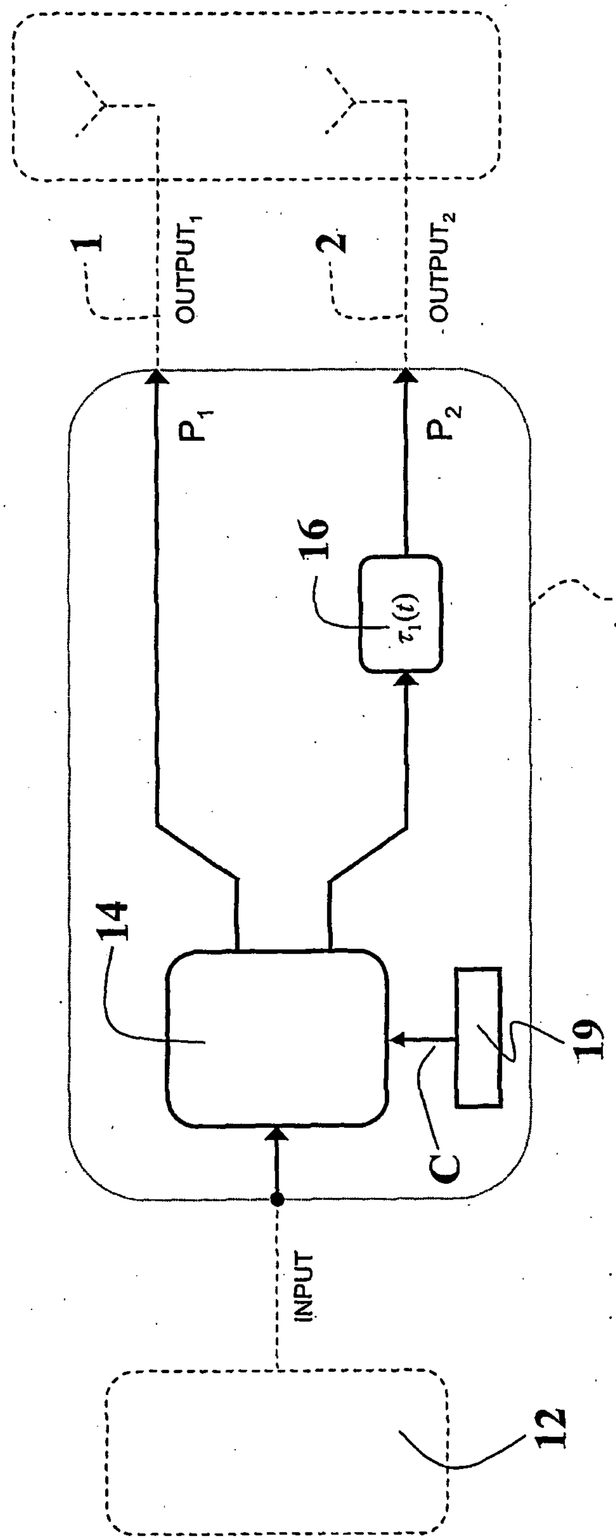

C
$s_{in,1}$
$s_{in,2}$
$\alpha_1 \cdot s_{in,1} + \alpha_2 \cdot s_{in,2}$
$\alpha_1 \neq \alpha_2$
$s_{in,1}$
$s_{in,2}$
$\alpha \cdot (s_{in,1} + s_{in,2})$

Fig. 5



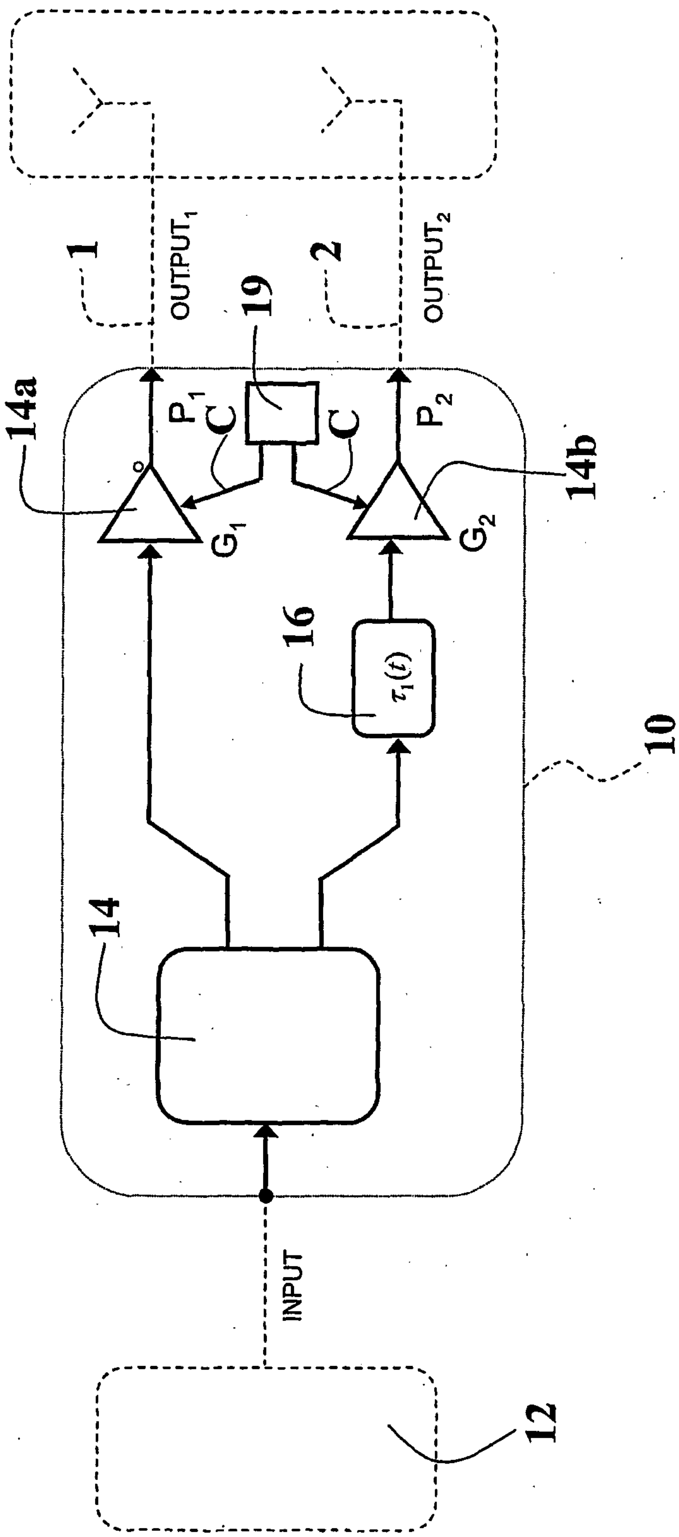

OUTPUT$_1$
OUTPUT$_2$
1
2
19
14a
14b
P$_1$
P$_2$
C
C
G$_1$
G$_2$
16
$\tau_1(t)$
10
14
INPUT
12

Fig. 6

Fig. 7a

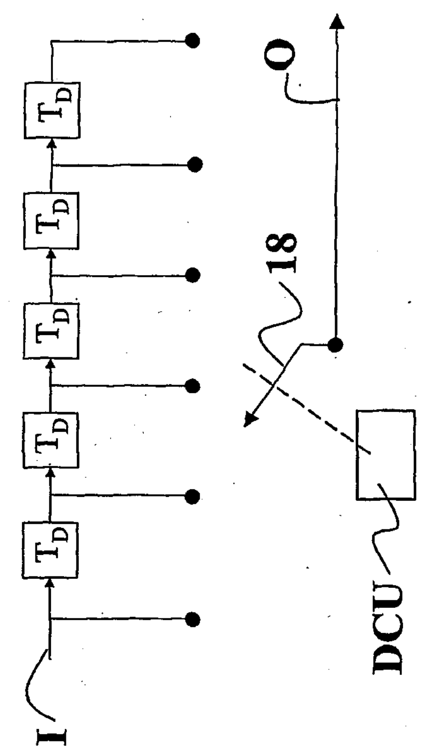


Fig. 7b

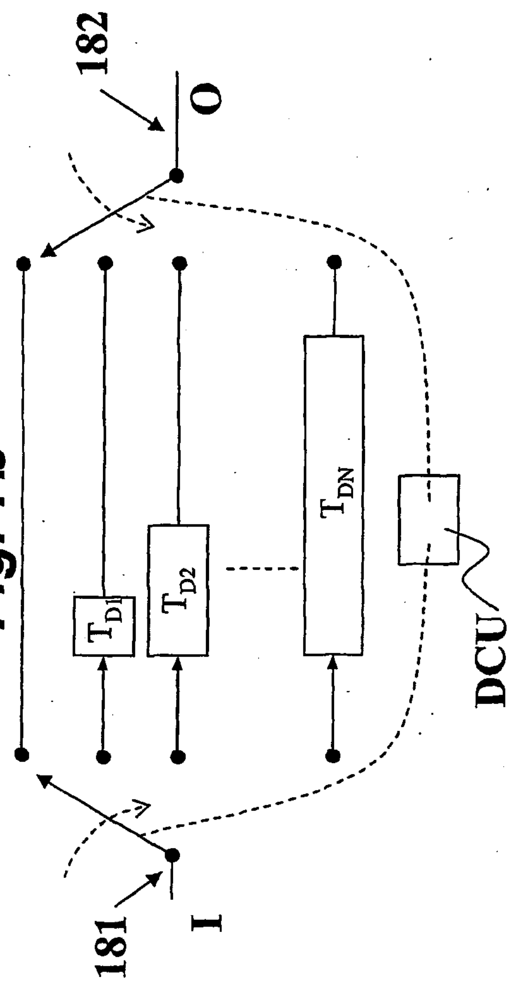


Fig. 8

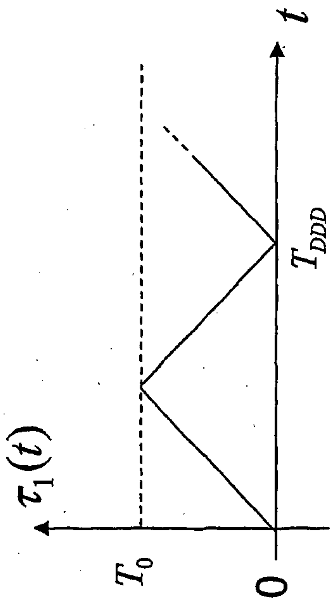
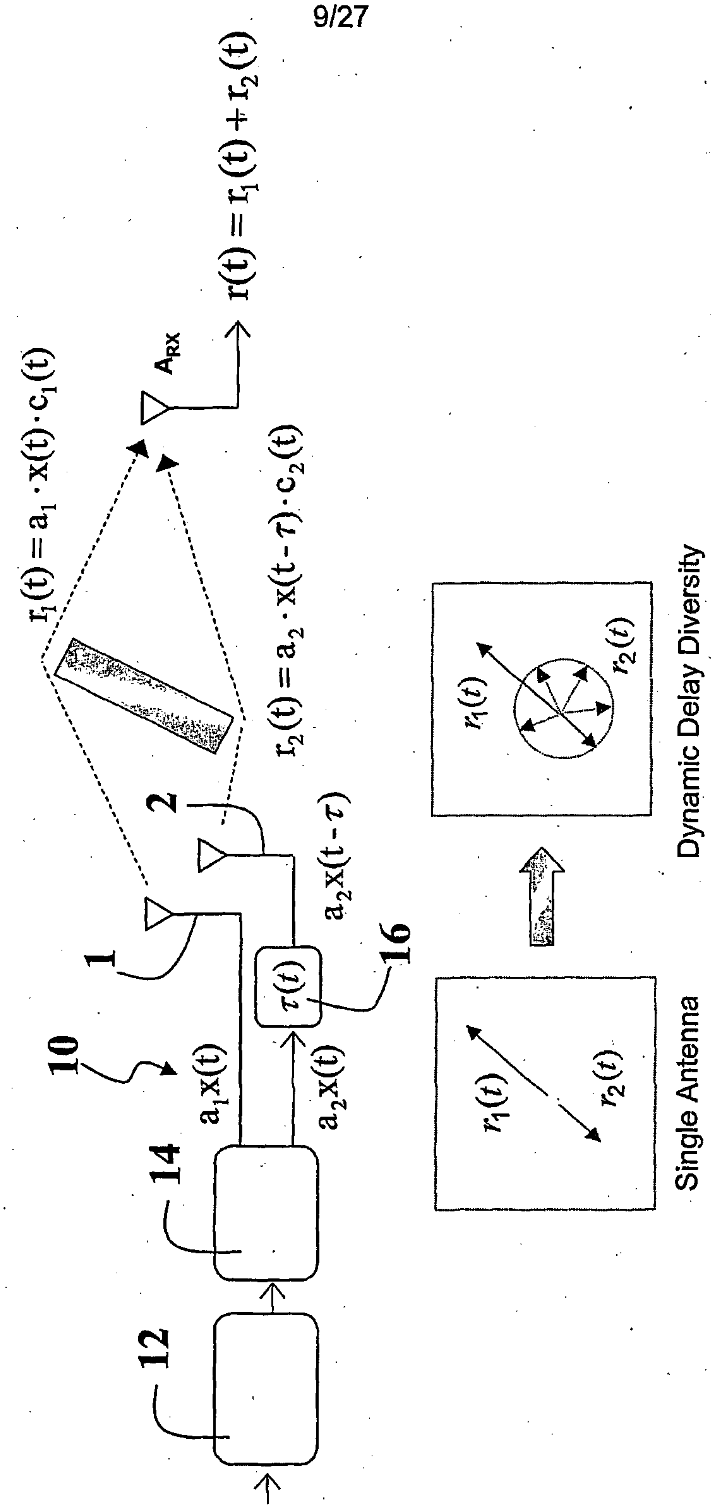


Fig. 9


10
12
14
16
1
2
$a_1x(t)$
$a_2x(t)$
$\tau(t)$
$a_2x(t-\tau)$
$r_1(t) = a_1 \cdot x(t) \cdot c_1(t)$
$r_2(t) = a_2 \cdot x(t-\tau) \cdot c_2(t)$
A_{RX}
$r(t) = r_1(t) + r_2(t)$
$r_1(t)$
$r_2(t)$
Single Antenna
$r_1(t)$
$r_2(t)$
Dynamic Delay Diversity

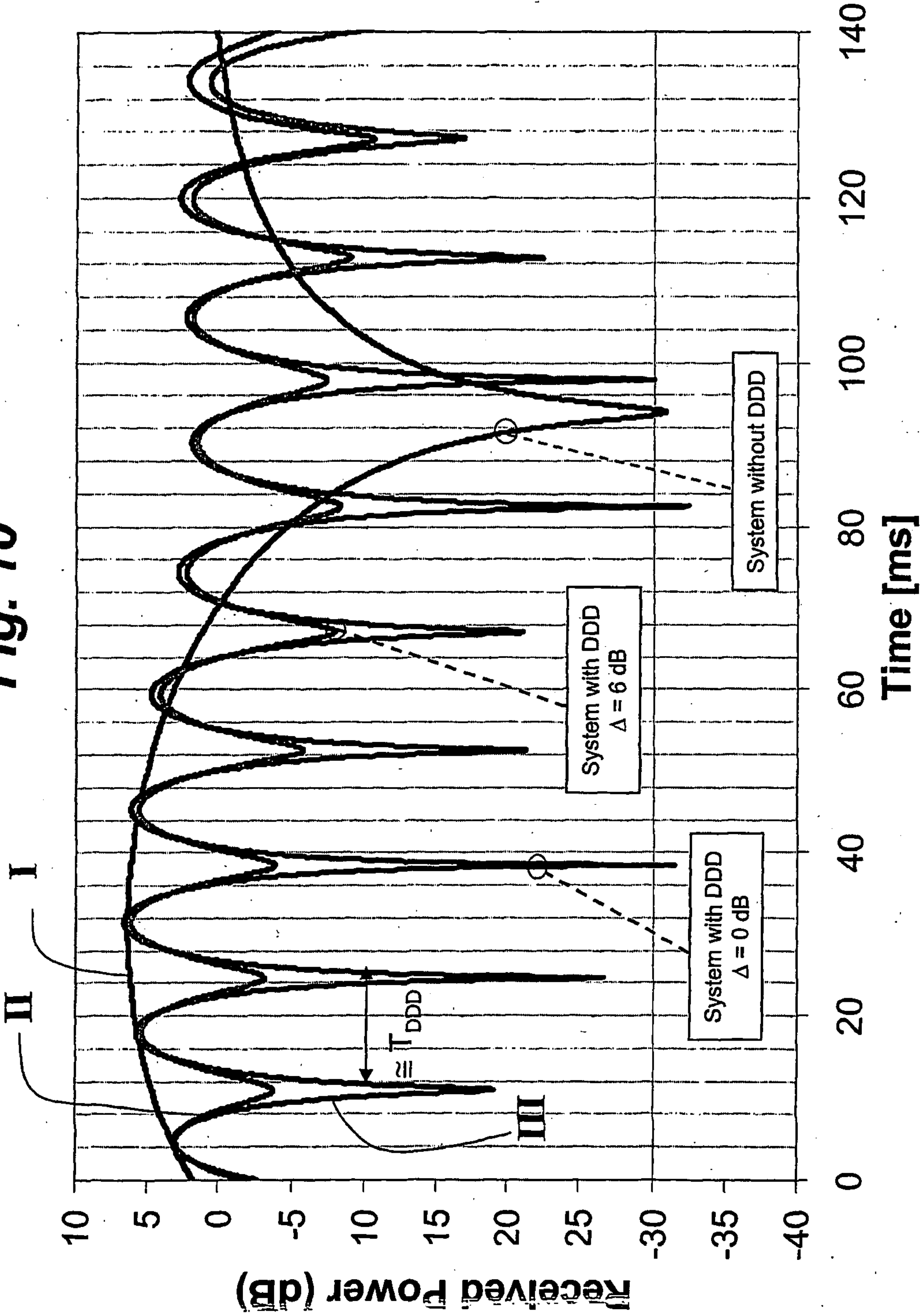

II
I
III
≅ T_{DDD}
System with DDD
Δ = 0 dB
System with DDD
Δ = 6 dB
System without DDD
Received Power (dB)
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
20
40
60
80
100
120
140
Time [ms]

Fig. 10

Fig. 11

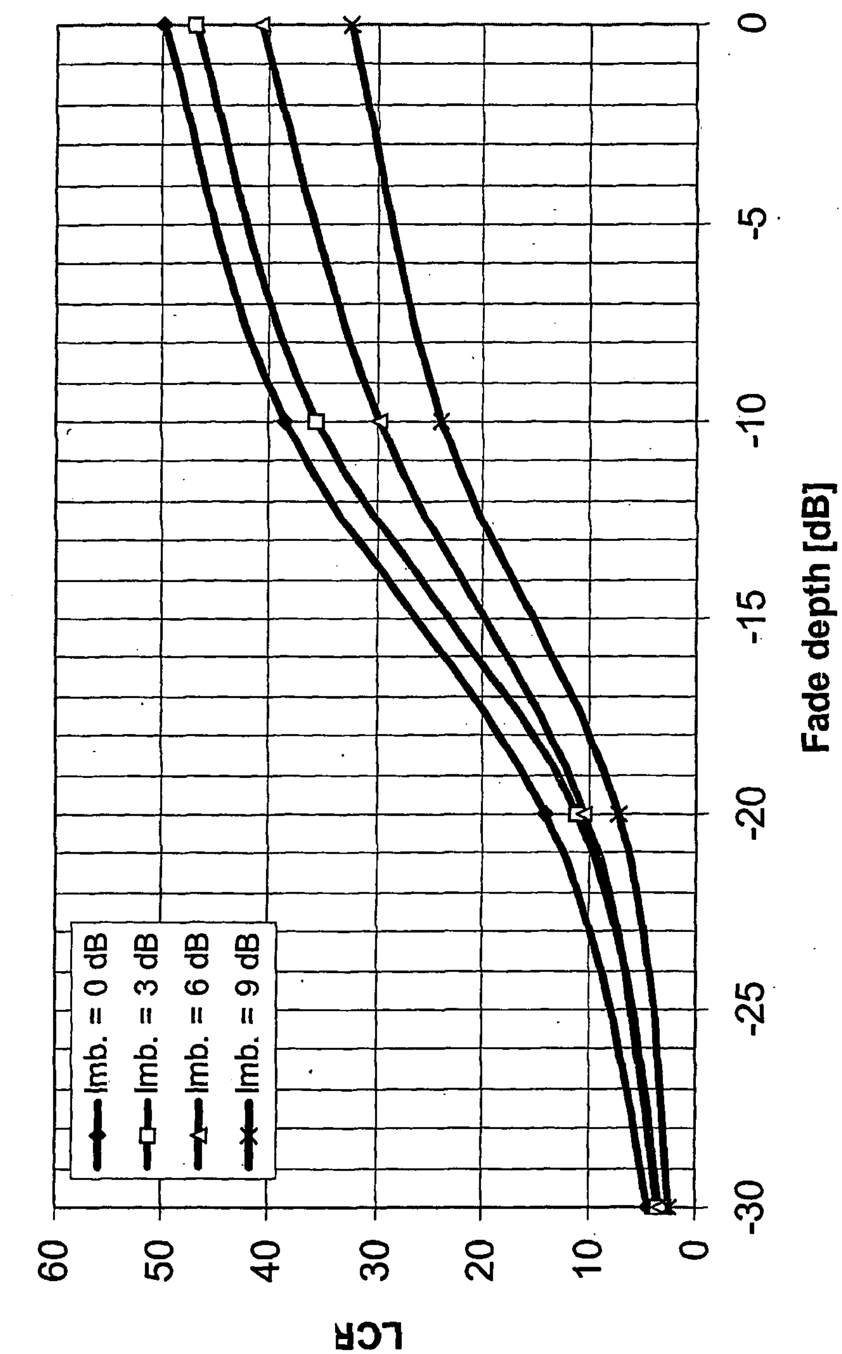

Imb. = 0 dB
Imb. = 3 dB
Imb. = 6 dB
Imb. = 9 dB
LCR
60
50
40
30
20
10
0
-30
-25
-20
-15
-10
-5
0
Fade depth [dB]

Fig. 12

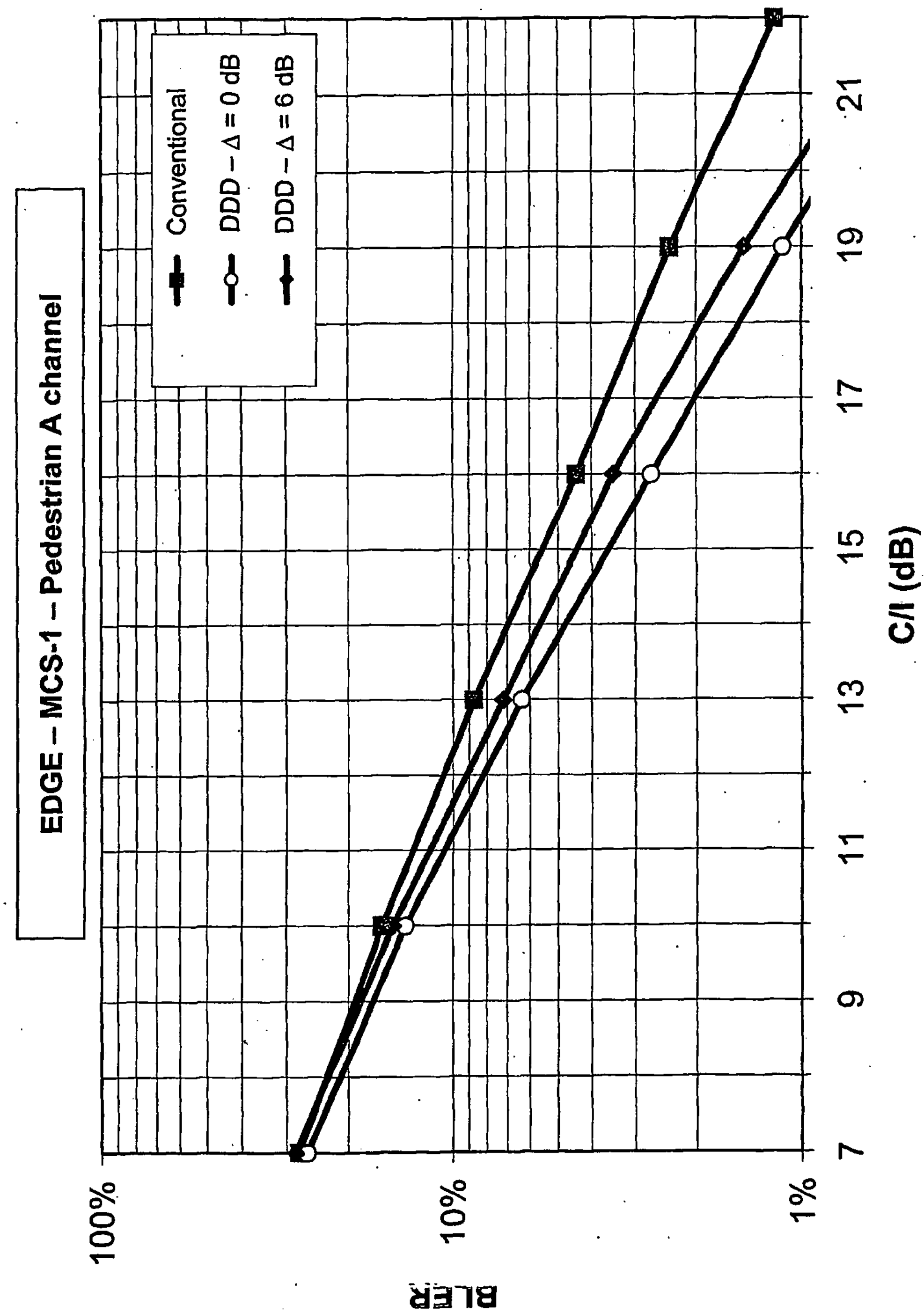

EDGE – MCS-1 – Pedestrian A channel
Conventional
DDD – Δ = 0 dB
DDD – Δ = 6 dB
100%
10%
1%
BLER
7
9
11
13
15
17
19
21
C/I (dB)

Fig. 13

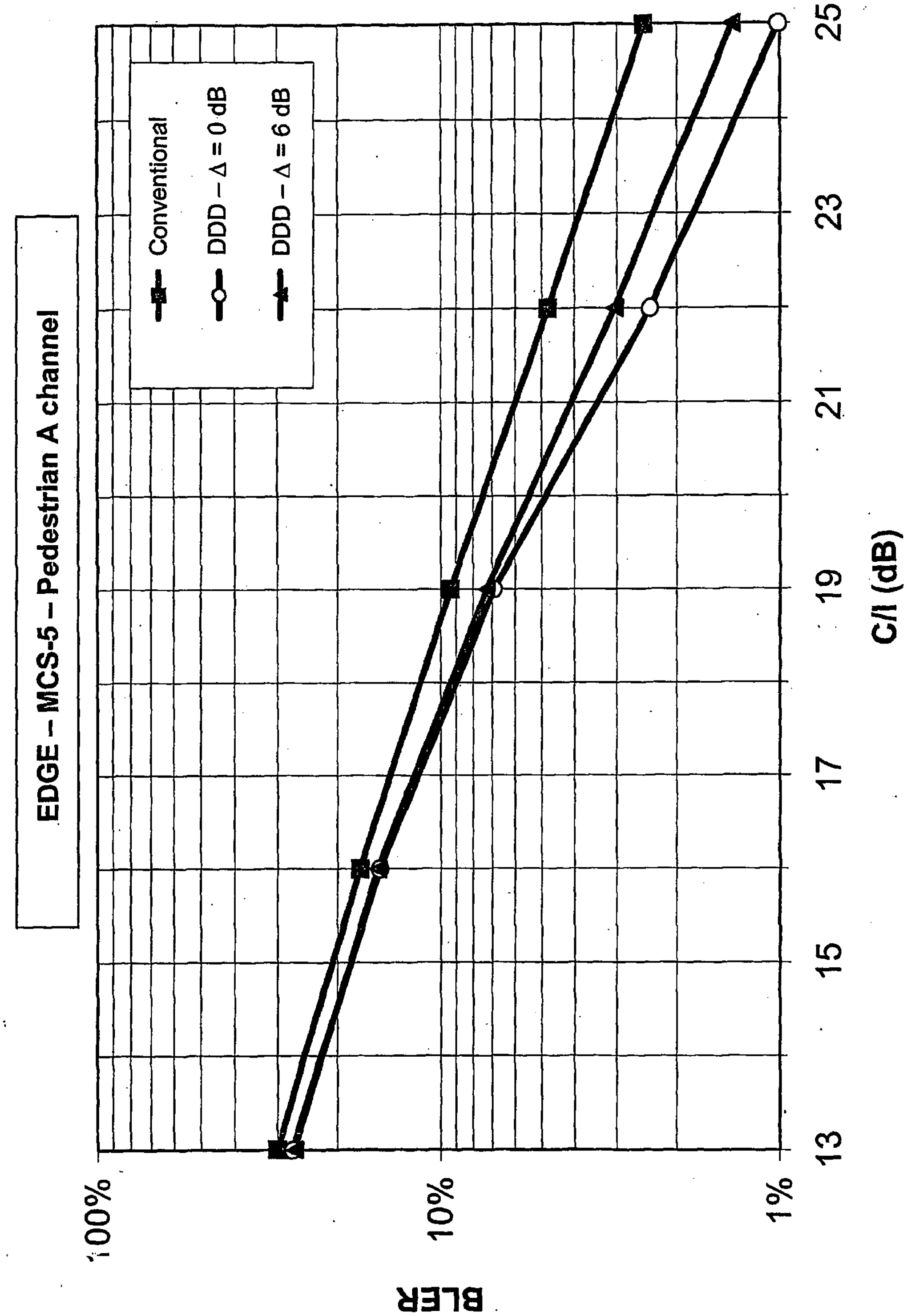
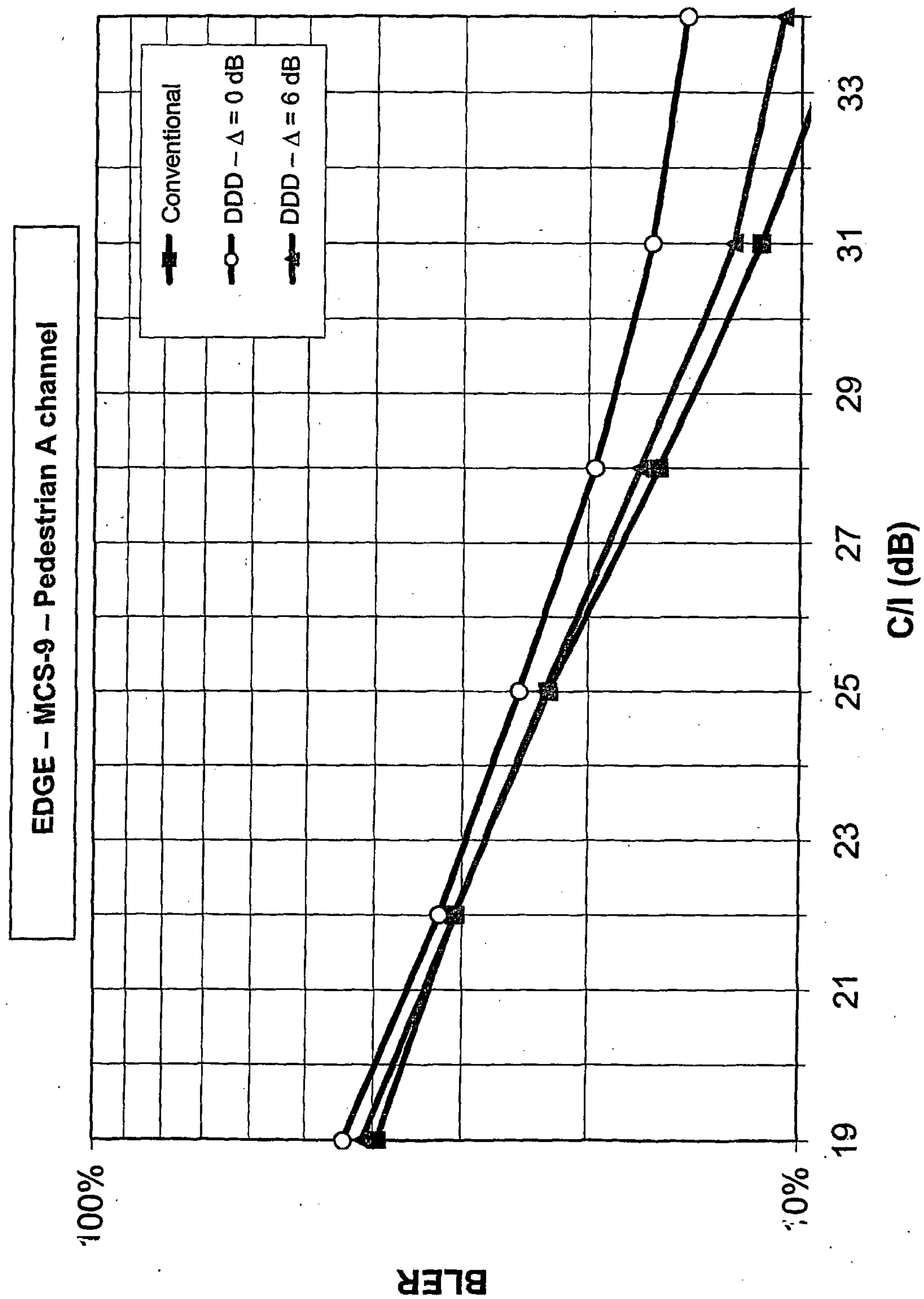

EDGE – MCS-5 – Pedestrian A channel
Conventional
DDD – Δ = 0 dB
DDD – Δ = 6 dB
100%
10%
1%
BLER
13
15
17
19
21
23
25
C/I (dB)

Fig. 14


EDGE – MCS-9 – Pedestrian A channel
Conventional
DDD – Δ = 0 dB
DDD – Δ = 6 dB
BLER
100%
0%
19
21
23
25
27
29
31
33
C/I (dB)

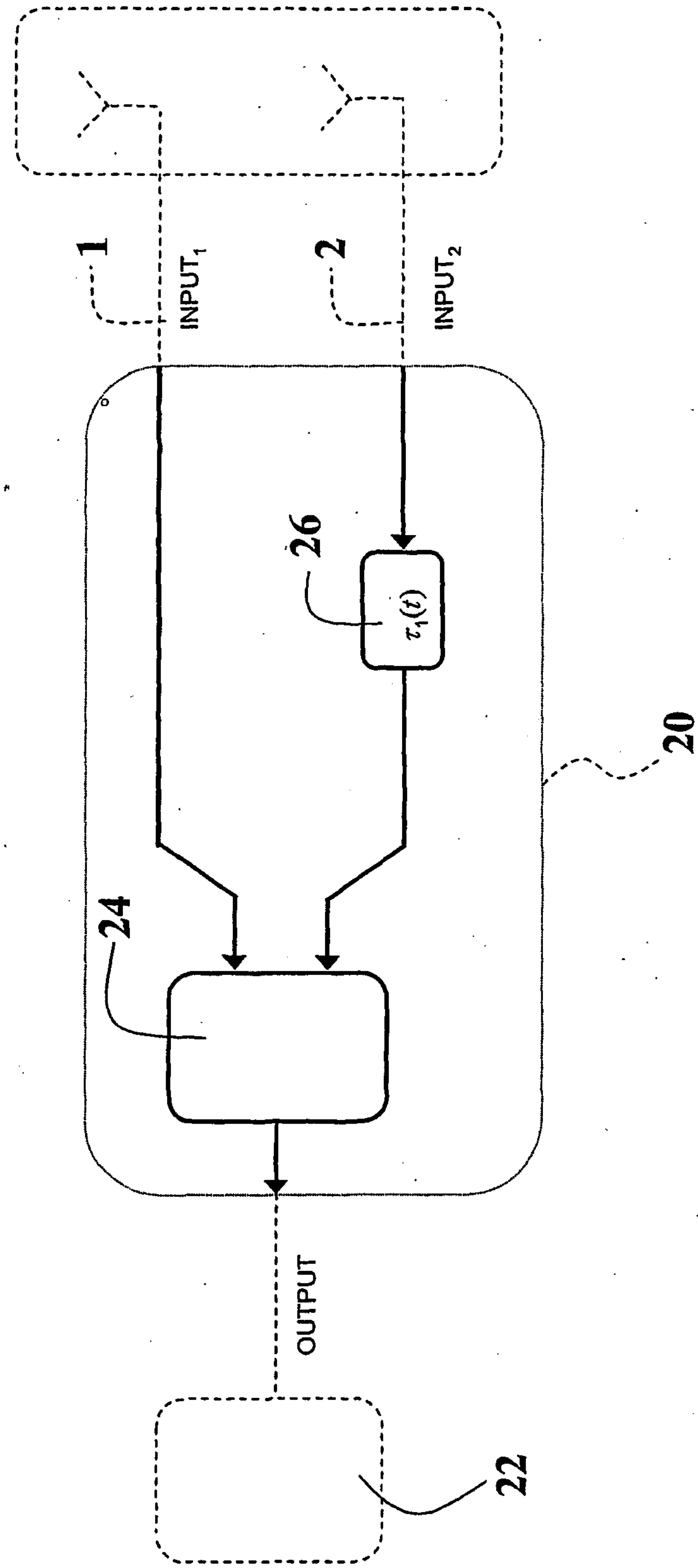


Fig. 15

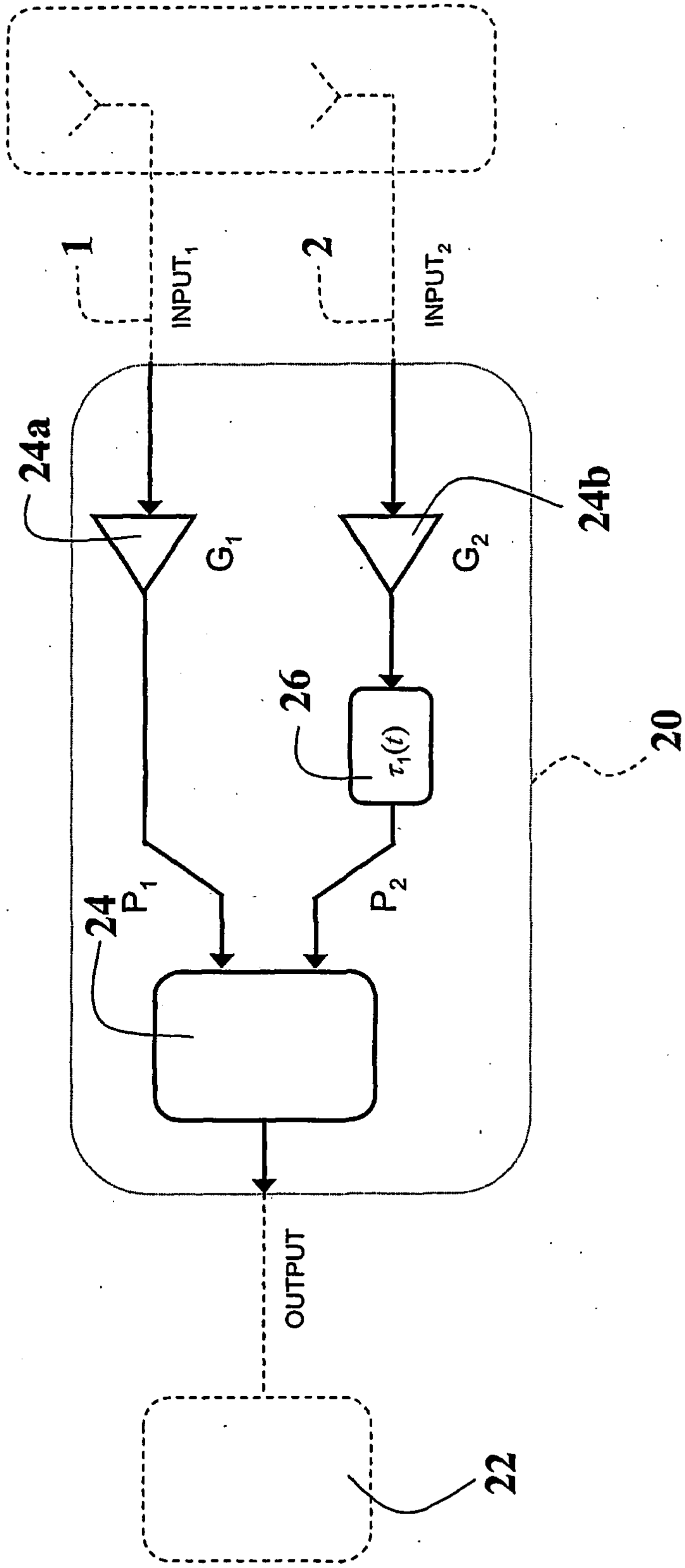


Fig. 16

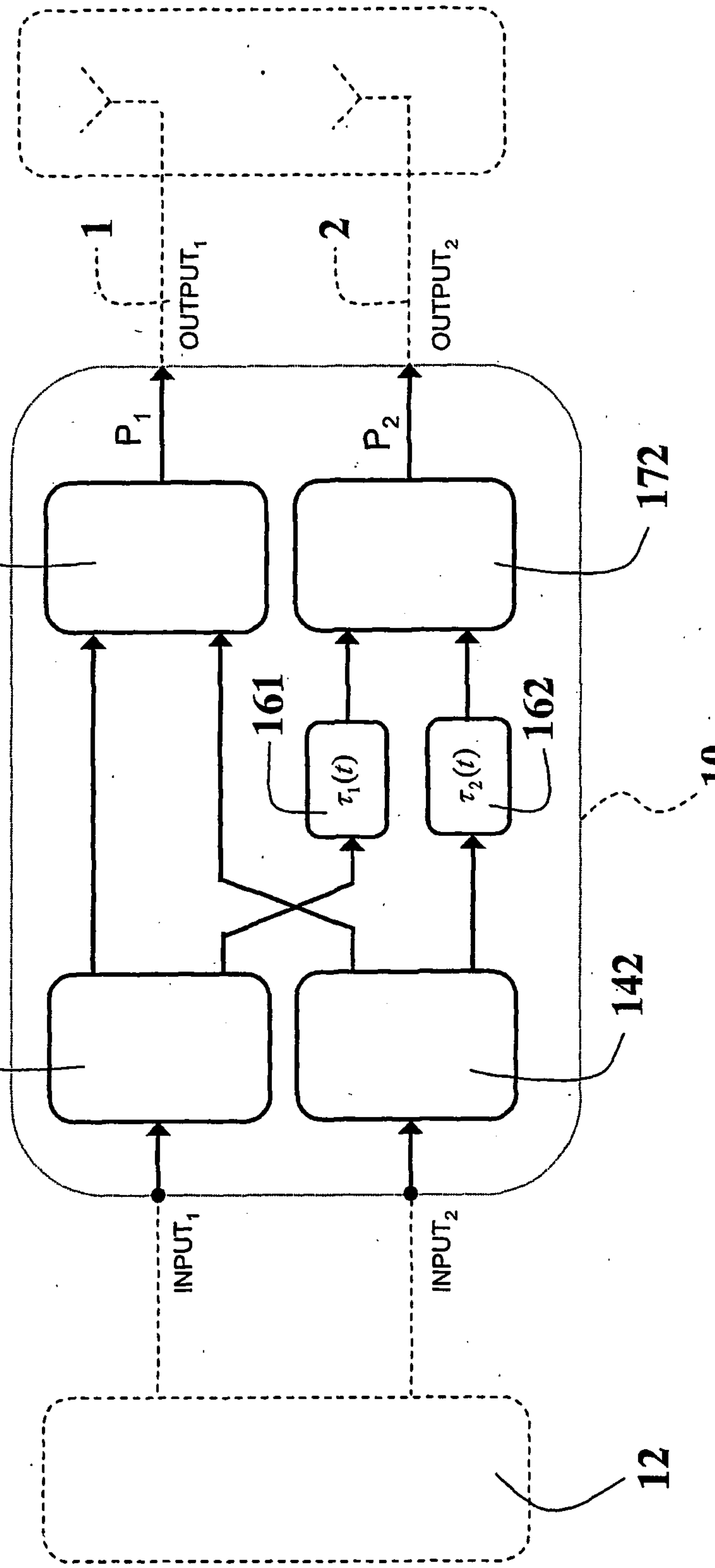

1
2
OUTPUT1
OUTPUT2
P1
P2
171
172
161
162
τ1(t)
τ2(t)
141
142
10
INPUT1
INPUT2
12

Fig. 17

Fig. 18

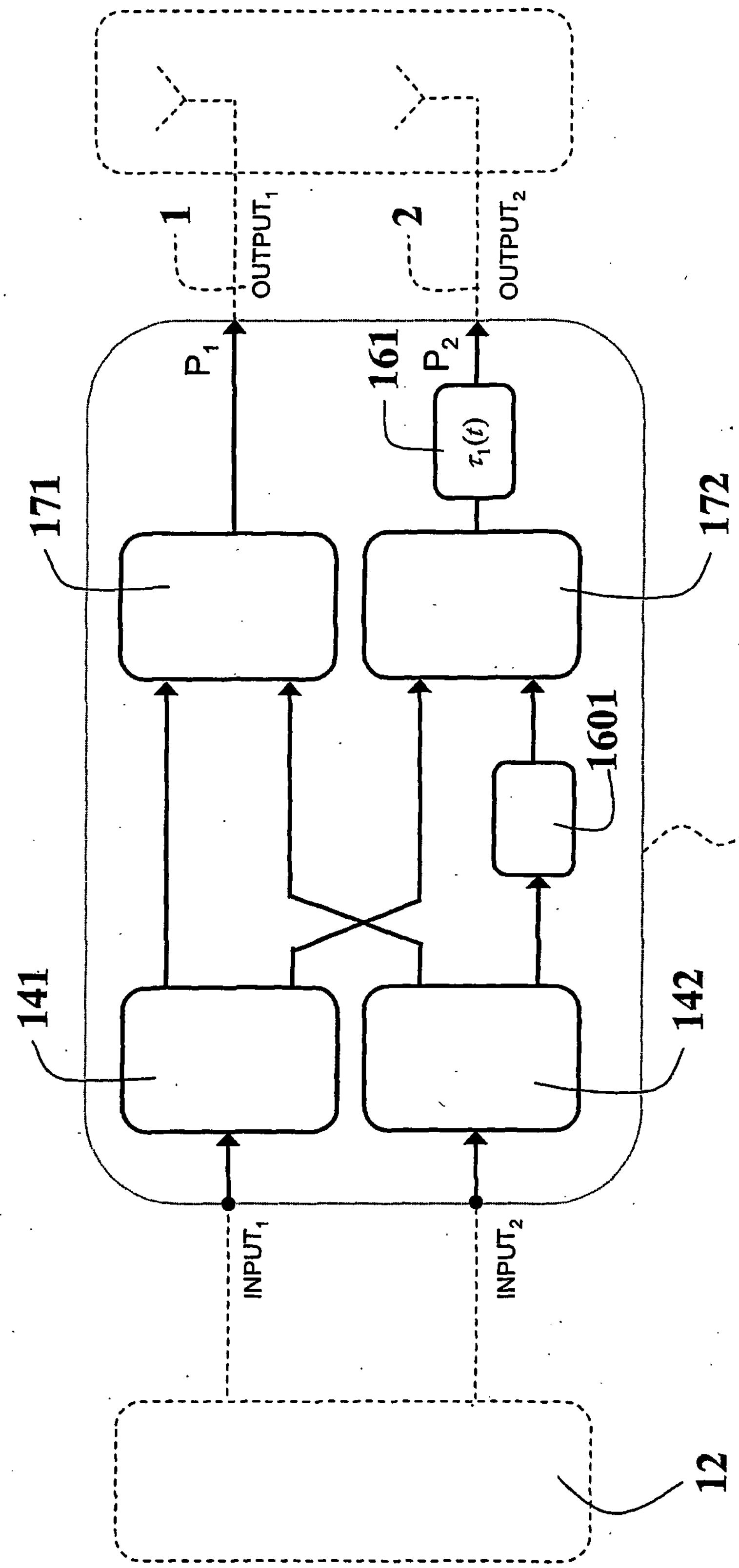
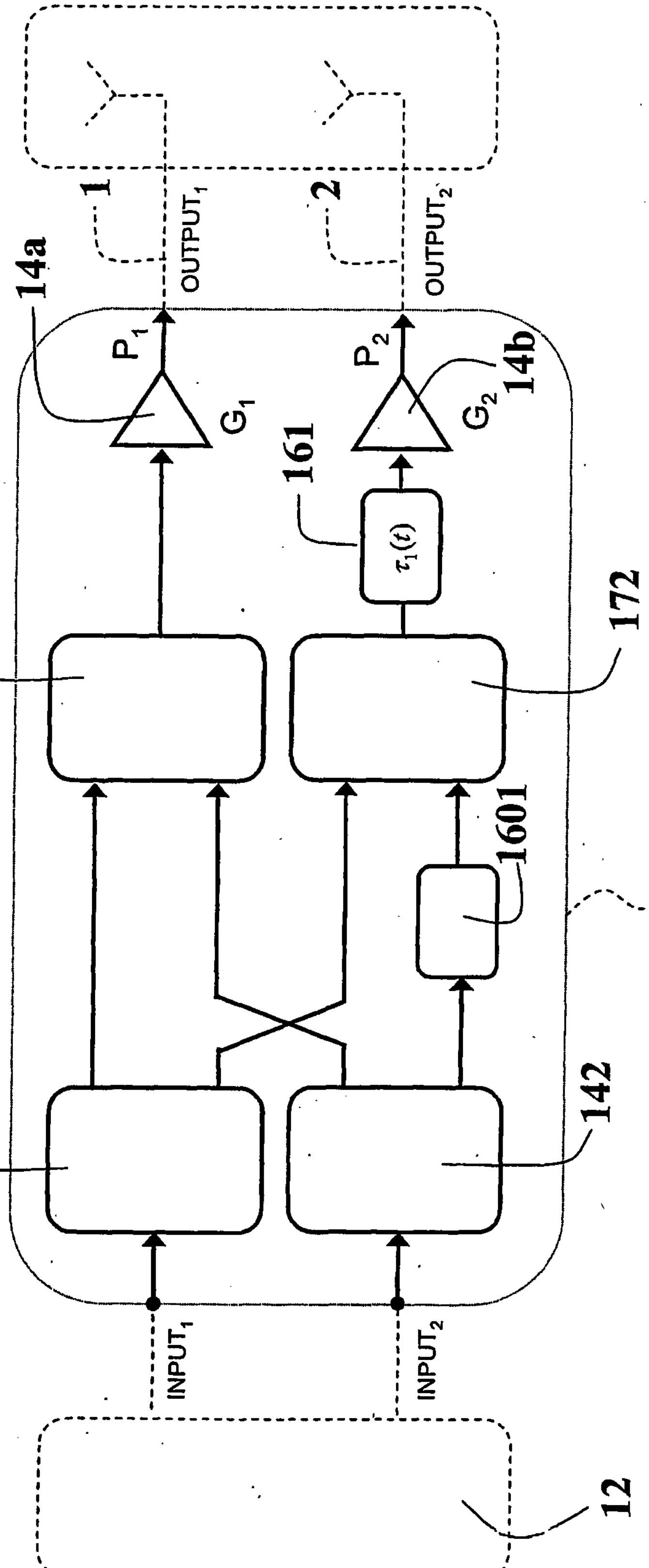

1
OUTPUT$_1$
2
OUTPUT$_2$
P$_1$
161
P$_2$
$\tau_1(t)$
171
172
1601
10
141
142
INPUT$_1$
INPUT$_2$
12

Fig. 19


1
2
OUTPUT1
OUTPUT2
14a
P1
P2
G1
G2
14b
161
τ1(t)
171
172
1601
10
141
142
INPUT1
INPUT2
12

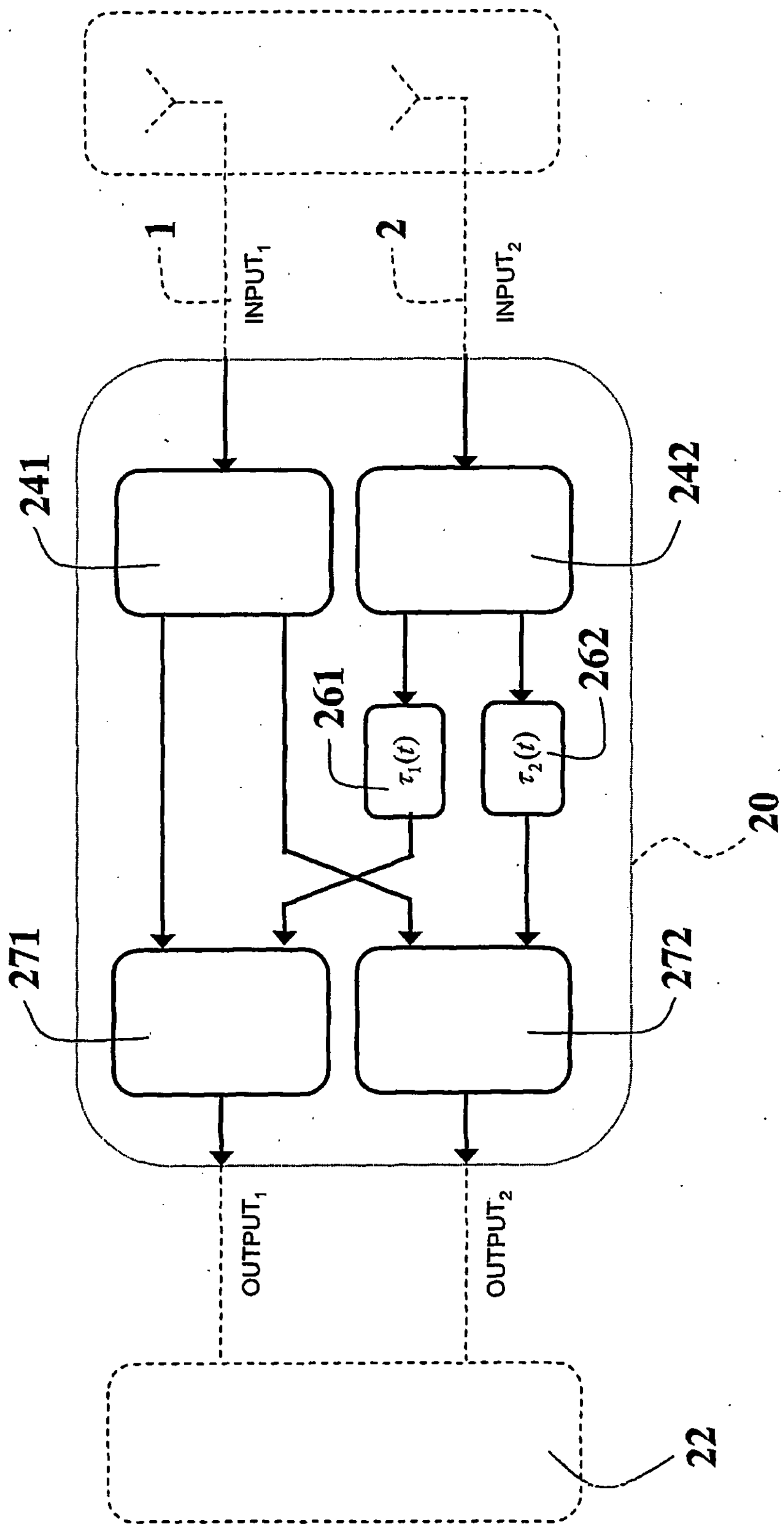

1
2
INPUT$_1$
INPUT$_2$
241
242
261
262
$\tau_1(t)$
$\tau_2(t)$
20
271
272
OUTPUT$_1$
OUTPUT$_2$
22

Fig. 20

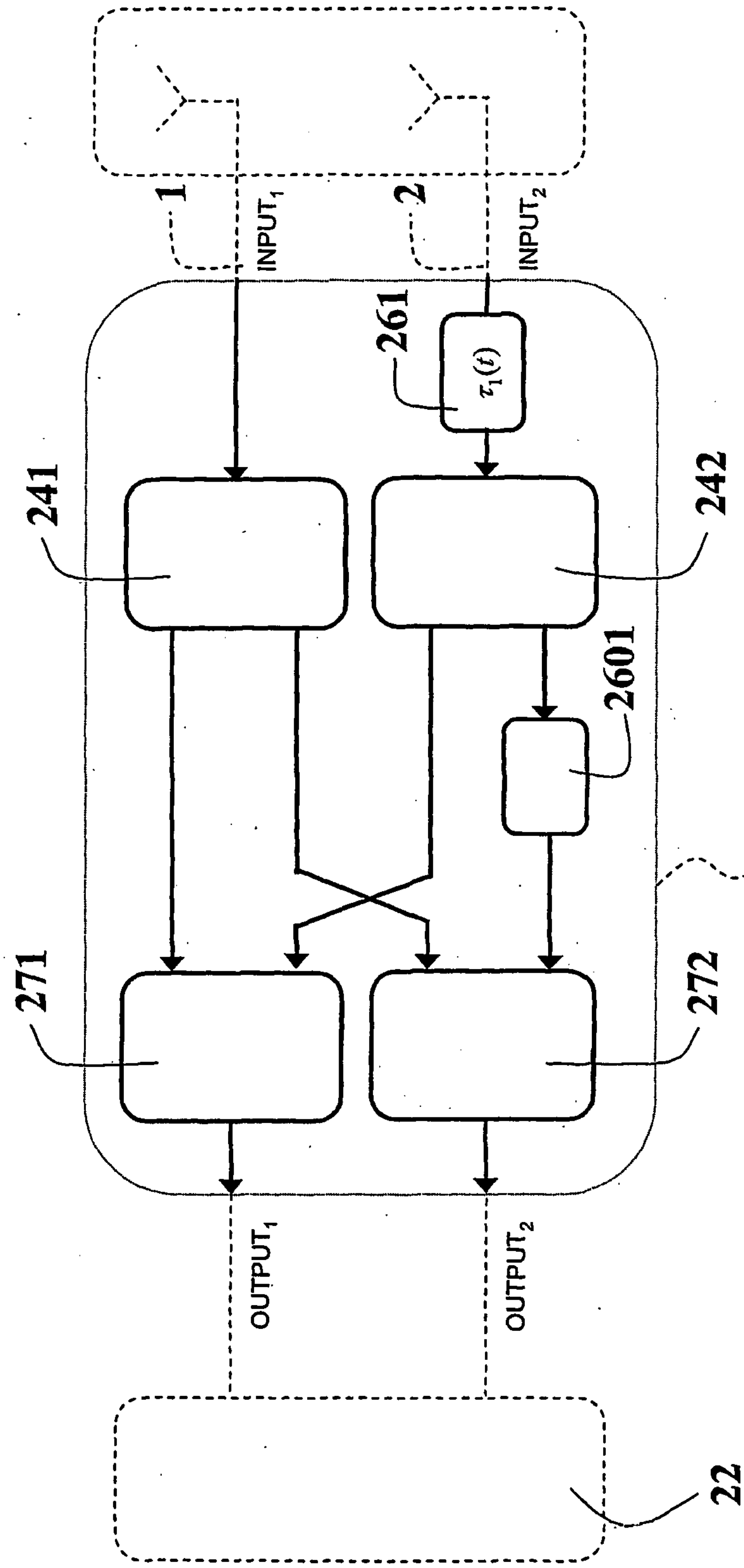

1
2
INPUT$_1$
INPUT$_2$
261
$\tau_1(t)$
241
242
2601
20
271
272
OUTPUT$_1$
OUTPUT$_2$
22

Fig. 21

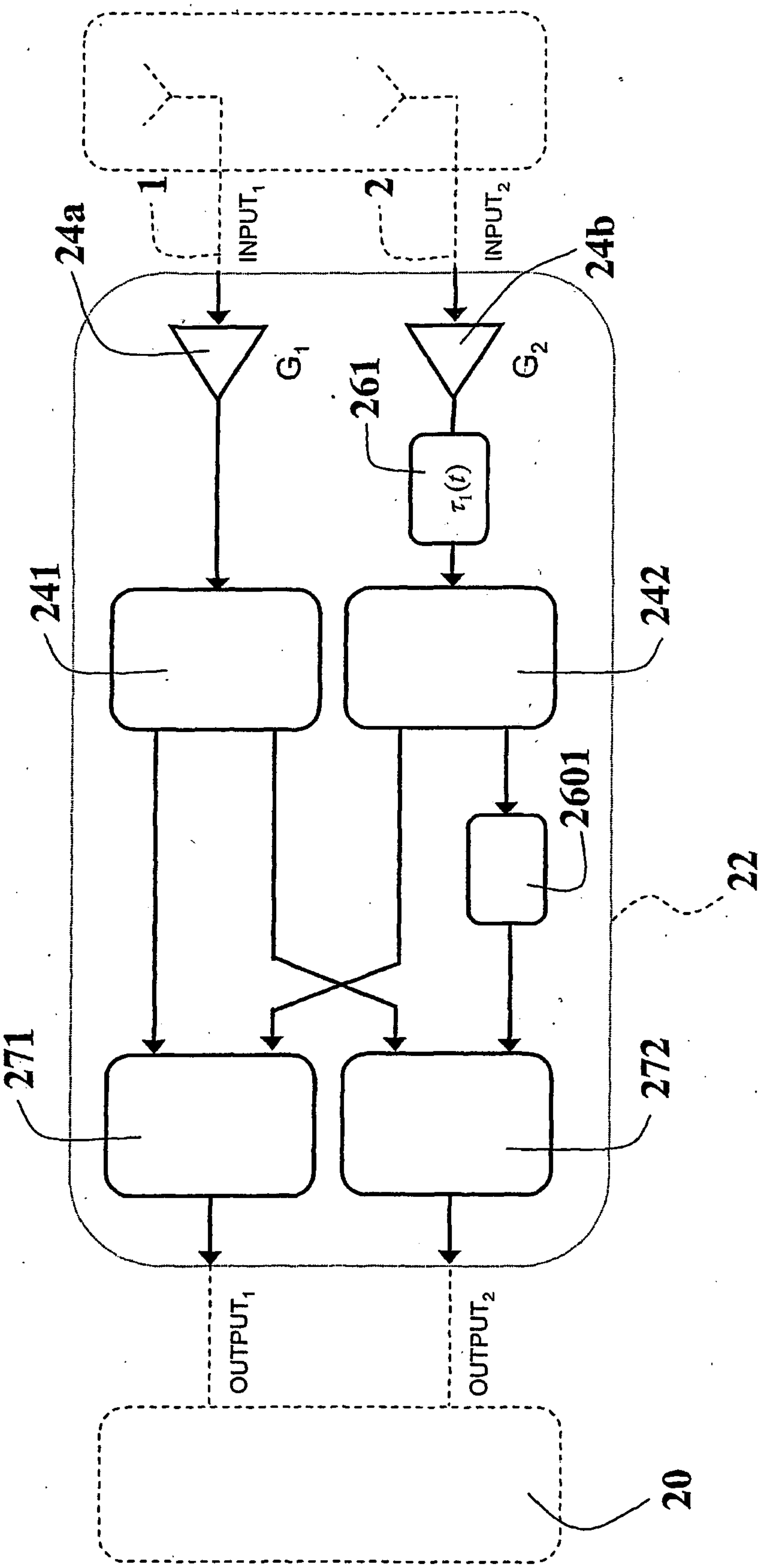
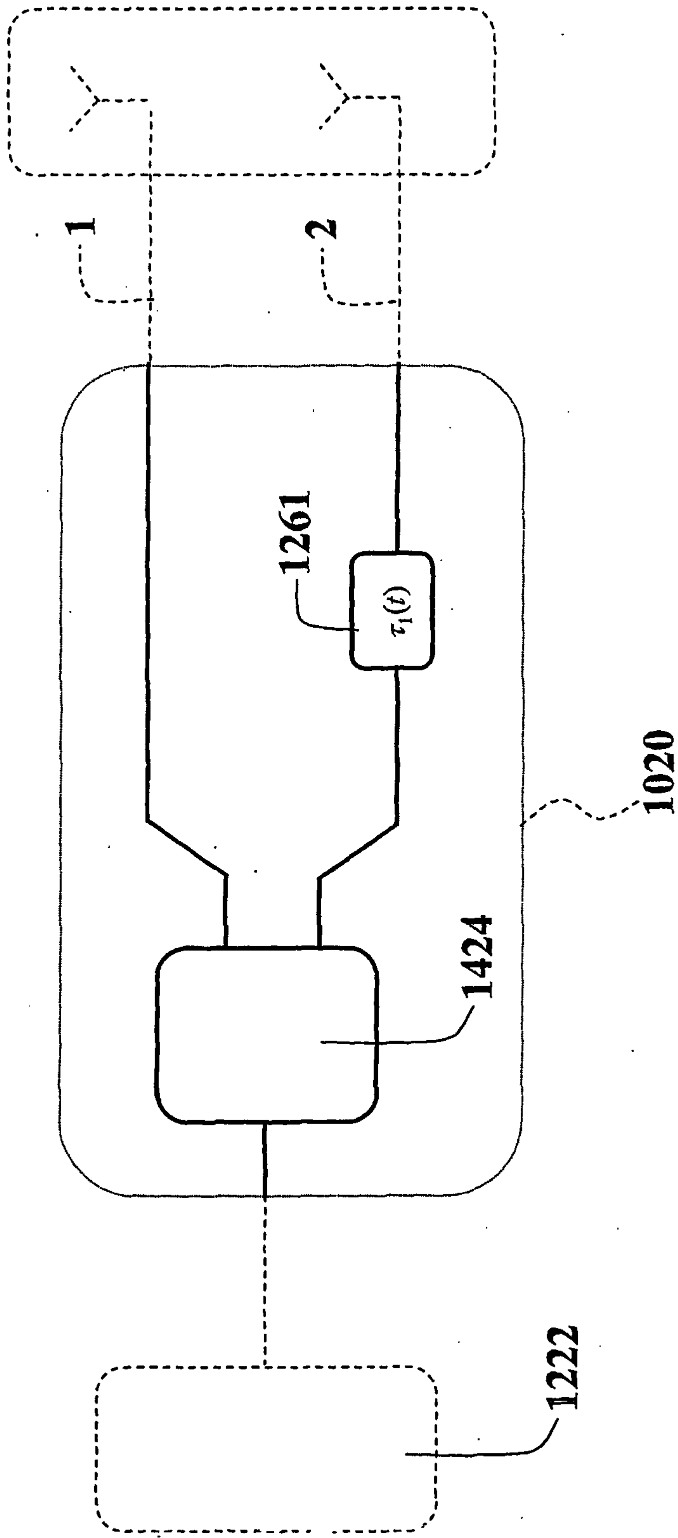

1
2
INPUT$_1$
INPUT$_2$
24a
24b
G$_1$
G$_2$
261
$\tau_1(t)$
241
242
2601
22
271
272
OUTPUT$_1$
OUTPUT$_2$
20

Fig. 22

Fig. 23



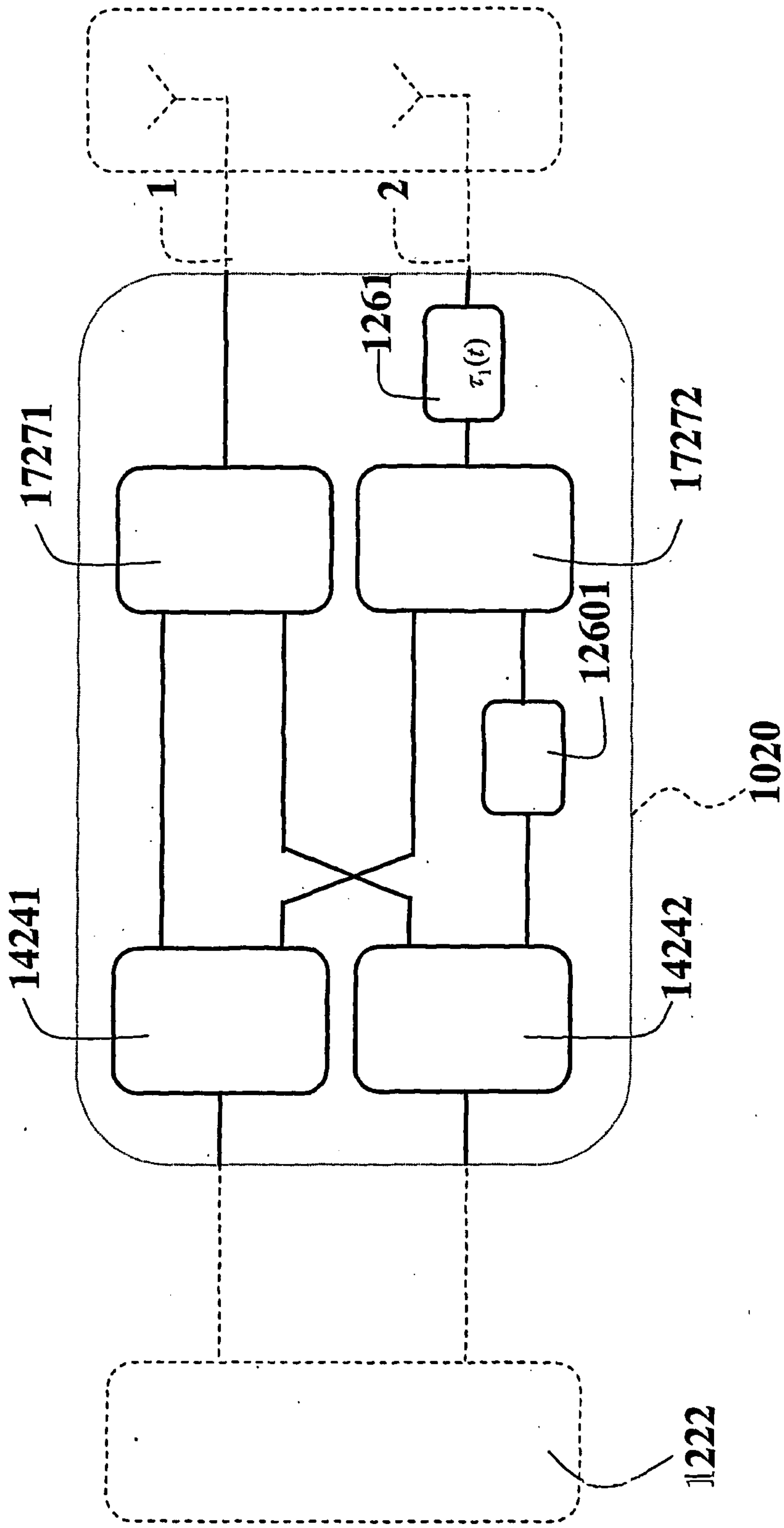


Fig. 24

Fig. 25

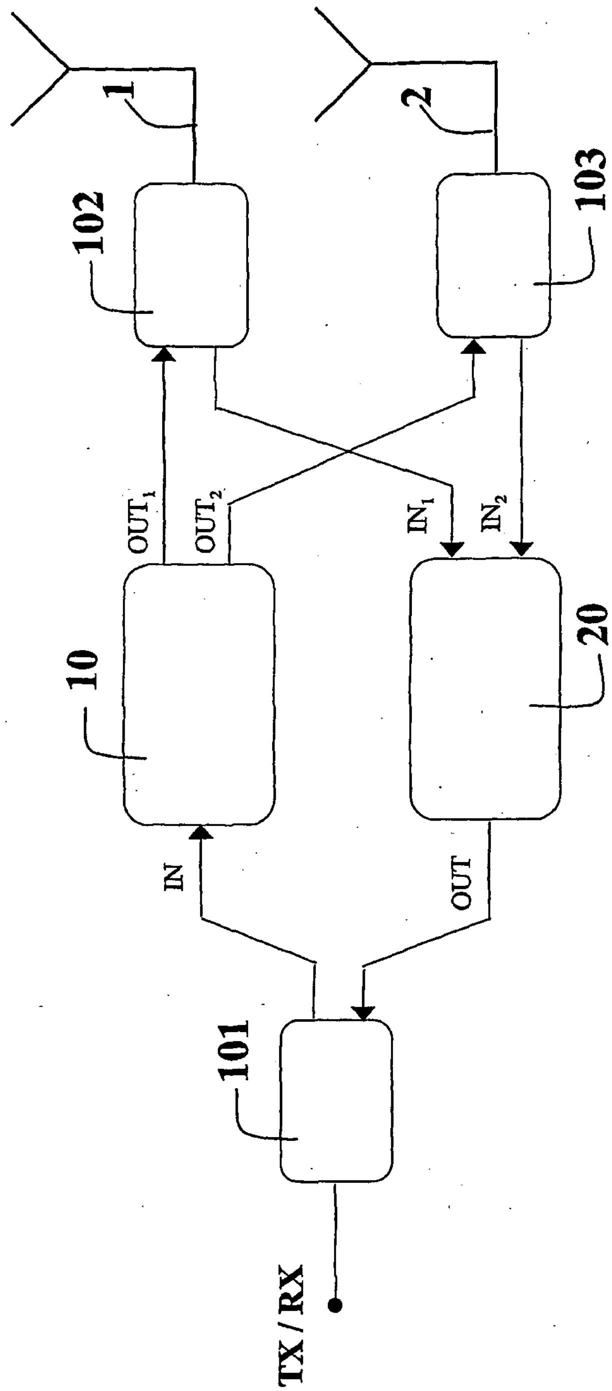


Fig. 26

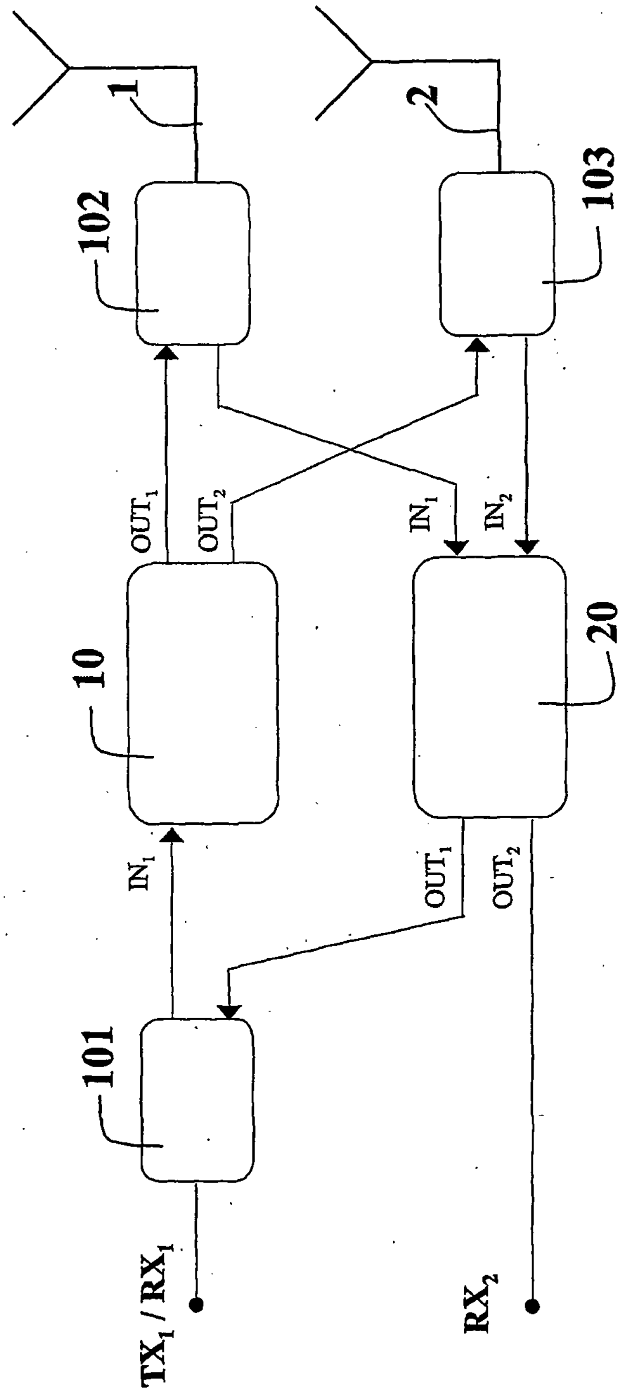
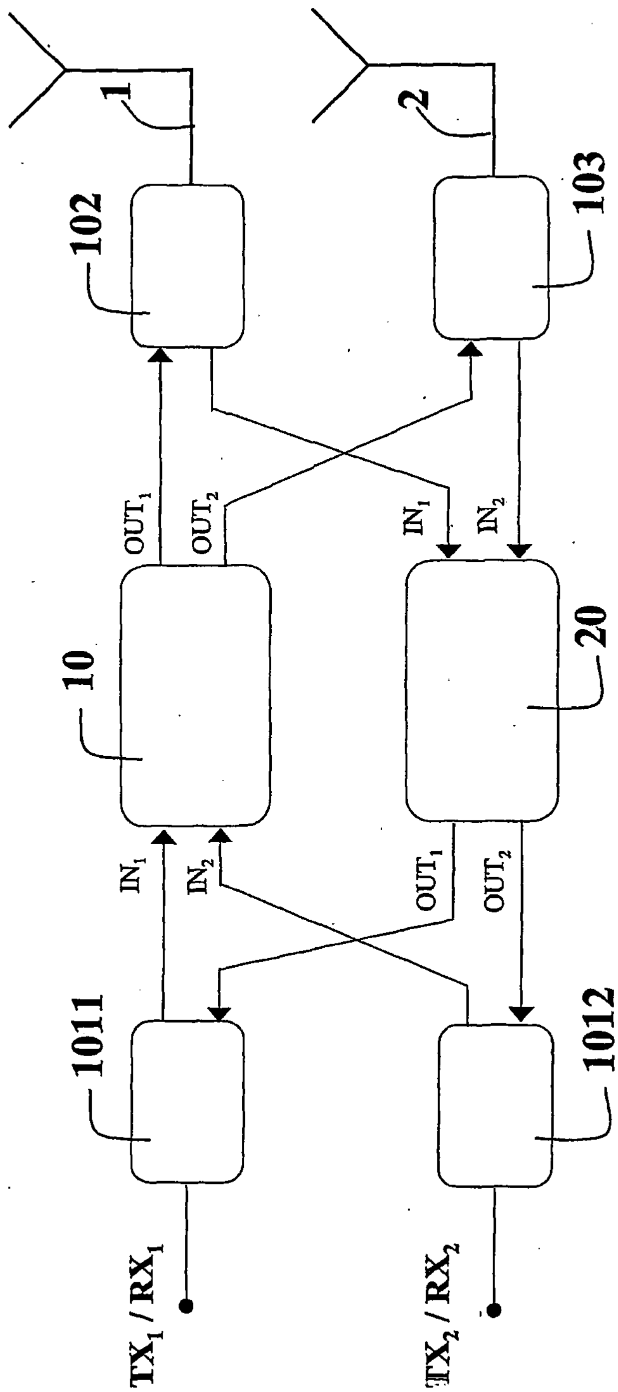


Fig. 27


1
2
102
103
OUT1
OUT2
IN1
IN2
10
20
IN1
IN2
OUT1
OUT2
1011
1012
TX1 / RX1
TX2 / RX2

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

U.S. National Phase Application of International Application No.:	Group Art Unit: Not Yet Assigned
PCT/EP2005/011529	Examiner: Not Yet Assigned
Inventors.: Bruno MELIS, et al.	
Serial No.: Not Yet Assigned	
Filed: April 25, 2008	
Title: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT	

MAIL STOP PCT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

PRELIMINARY AMENDMENT

Before examining this application, please amend the application as follows:

Amendments to the Specification begin on page 2 of this amendment.

Amendments to the Claims are reflected in the listing of claims which begin on page 3 of this amendment.

An abstract is provided on page 8 of this amendment and as a separate page enclosed herewith.

Remarks begin on page 9 of this amendment.

IN THE SPECIFICATION:

And a new heading and paragraph at page 1, after the title as follows:

CROSS REFERENCE TO RELATED APPLICATION

This application is a national phase application based on PCT/EP2005/011529, filed October 27, 2005, the content of which is incorporated herein by reference.

IN THE CLAIMS:

Please cancel claims 1-45 without prejudice or disclaimer, and substitute new claims 46-68 therefor as follows:

Claims 1-45 (Cancelled).

46. (New) A method of diversity processing at least one signal propagated via at least two diversity antennas comprising the steps of:

propagating at least two replicas of said at least one signal over respective propagation paths coupled to said at least to diversity antennas, whereby said replicas are propagated via different antennas;

subjecting at least one of said replicas to a time variable delay; and

adjusting the power levels of said at least two replicas to produce a level imbalance therebetween.

47. (New) The method of claim 46, wherein said at least two replicas comprise replicas having respectively higher and lower power levels, and wherein the method comprises the step of subjecting to said time variable delay, said replica having a lower power level.

48. (New) The method of claim 46, comprising the step of selecting said level imbalance in the range of 3 to 10 dB.

49. (New) The method of claim 46, comprising the steps of:

selectively using one of a plurality of transmission modes for said at least one signal; and

selecting said level imbalance as a function of a selected transmission mode.

50. (New) The method of claim 49, wherein said plurality of transmission modes have respective coding rates and comprises the step of selecting said level imbalance as a function of said coding rates, wherein higher level imbalance values are selected for higher coding rates.

51. (New) The method of claim 49, comprising the steps of:

selectively varying the transmission mode used; and

adaptively varying said level imbalance as a function of the selected current transmission mode.

52. (New) The method of claim 46, comprising the step of subjecting to time variable delays two of said replicas propagating over propagation paths associated with the same of said diversity antennas.

53. (New) The method of claim 52, comprising the step of subjecting to time variable delays the replicas propagating over at least two of said propagation paths by:

providing, in the propagation paths for said at least two replicas associated with the same of said diversity antennas, respective distinct propagation portions and a combined propagation portion for said at least two replicas;

subjecting said at least two replicas to a time variable delay over the common portion of said propagation paths; and

subjecting one of said at least two replicas to a fixed delay over a respective distinct portion of said propagation paths.

54. (New) The method of claim 46, applied to at least one signal transmitted in the form of at least two replicas propagated over respective propagation paths toward said at least two diversity antennas, comprising the step of splitting said at least one

signal transmitted to produce said at least two replicas of said at least one signal propagated over respective propagation paths coupled to said at least two diversity antennas.

55. (New) The method of claim 54, wherein said splitting is an asymmetric splitting producing said level imbalance between said replicas.

56. (New) The method of claim 55, wherein said splitting is a symmetric splitting, and further comprising the step of applying different gains over said respective propagation paths coupled to said at least two diversity antennas to produce said level imbalance between said replicas.

57. (New) The method of claim 46, applied to at least one signal received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas, comprising the step of combining said at least two replicas to produce said at least one signal received.

58. (New) The method of claim 57, wherein said combining is an asymmetric combining producing said level imbalance between said replicas.

59. (New) The method of claim 57, wherein said combining is a symmetric combining, and further comprising the steps of applying different gains to said respective propagation paths of said replicas from said at least two diversity antennas to produce said level imbalance between said replicas.

60. (New) The method of claim 57, applied to at least two signals received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas, comprising the step of splitting at each of said diversity antennas the respective propagation paths of said at least two signals received.

61. (New) A system for diversity processing at least one signal propagated via at least two diversity antennas by means of the method of claim 46, comprising:

respective propagation paths for propagating at least two replicas of said at least one signal, said respective propagation paths being coupled to said at least two diversity antennas, whereby said replicas are propagated via different antennas;

at least one time variable delay element for subjecting at least one of said replicas to a time variable delay; and

level adjusting elements arranged on said respective propagation paths to produce a level imbalance between the power levels of said at least two replicas.

62. (New) The system of claim 61, comprising respective propagation paths for at least two said replicas having respectively higher and lower power levels, said at least one time variable delay element being arranged on the propagation path of said replica having a lower power level.

63. (New) The system of claim 61, wherein said at least one signal is received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas, comprising at least one combiner for combining said at least two replicas to produce said at least one signal received.

64. (New) The system of claim 63, wherein said at least one combiner is an asymmetric combiner producing said level imbalance between said replicas.

65. (New) The system of claim 63, wherein said at least one combiner is a symmetric combiner, and further comprising gain elements for applying different gains to said respective propagation paths of said replicas from said at least two diversity antennas of said replicas to produce said level imbalance between said replicas.

66. (New) The system of claim 61, wherein said at least one signal transmitted and received by means of said at least two diversity antennas, comprises:

at least one splitter for splitting said at least one signal transmitted to produce at least two replicas transmitted over respective transmission paths toward said diversity antennas; and

at least one combiner for combining said at least two replicas propagated over respective propagation paths from said at least two diversity antennas to produce said at least one signal received,

wherein said at least one splitter and combiner comprise at least one reciprocal element.

67. (New) A wireless communication apparatus comprising the system of claim 61.

68. (New) A computer program product, loadable into the memory of at least one computer and comprising software code portions capable of performing the method of claim 46.

IN THE ABSTRACT:

Replace the abstract originally provided on the cover sheet of the PCT application with the following new abstract. A new abstract numbered page 53 is enclosed for the last page of the application following the claims.

ABSTRACT OF THE DISCLOSURE

A system for diversity processing a signal propagated via two diversity antennas includes: respective propagation paths for propagating two replicas of the signal, these propagation paths being coupled to the two diversity antennas so that the replicas are propagated via different antennas; a time variable delay element for subjecting at least one of the replicas to a time variable delay; and a level adjusting element, such as an asymmetric splitter, to produce a level imbalance between the power levels of the replicas propagated via the two diversity antennas.

REMARKS

By this amendment, an Abstract of the Disclosure has been added as the last page of the application (page no. 53). The separate page for the Abstract of the Disclosure is enclosed herewith.

An amendment to the specification is also made to incorporate related application information.

Claims 46-68 are currently pending. The claims have been amended in order to conform them to U.S. practice. No new matter has been introduced by this amendment.

The examiner is respectfully requested to consider the above preliminary amendment prior to examination of the application.

If there is any fee due in connection with the filing of this Preliminary Amendment, please charge the fee to our Deposit Account No. 06-0916. If a fee is required for an extension of time under 37 C.F.R. §1.136 not accounted for above, such an extension is requested and the fee should be charged to our deposit account.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: April 25, 2008

By: ______________________
Ernest F. Chapman
Reg. No. 25,961

Attachments: Abstract of the Disclosure.

ABSTRACT OF THE DISCLOSURE

A system for diversity processing a signal propagated via two diversity antennas includes: respective propagation paths for propagating two replicas of the signal, these propagation paths being coupled to the two diversity antennas so that the replicas are propagated via different antennas; a time variable delay element for subjecting at least one of the replicas to a time variable delay; and a level adjusting element, such as an asymmetric splitter, to produce a level imbalance between the power levels of the replicas propagated via the two diversity antennas.

IAP02Rec'd PCT 25 APR 2008
12/084134
Customer No. 22,852
Attorney Docket No. 09952.0468-00000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re U.S. National Phase Application of International Application No.:	)
PCT/EP2005/011529	)
Inventors: Bruno MELIS et al.	) Group Art Unit: Not Yet Assigned
Application No.: Not Yet Assigned	) Examiner: Not Yet Assigned
Filed: April 25, 2008	)
For: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT	)

MAIL STOP PCT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

INFORMATION DISCLOSURE STATEMENT UNDER 37 C.F.R. § 1.97(b)

Pursuant to 37 C.F.R. §§1.56 and 1.97(b), Applicant brings to the Examiner's attention the documents listed on attached Form PTO/SB/08 and cited in the international search report. Copies of the listed foreign patent documents are attached. Applicant respectfully requests that the Examiner consider the documents listed on attached Form PTO/SB/08 and indicate that they were considered by making an appropriate notation on this form.

IAP02Rec'd PCT 25 APR 2008

Customer No. 22,852
Attorney Docket No. 09952.0468-00000

12/084134

This Information Disclosure Statement is being filed with the above-referenced application.

This submission does not represent that a search has been made or that no better art exists and does not constitute an admission that each or all of the listed documents are material or constitute "prior art." If the Examiner applies any of the documents as prior art against any claim in the application and Applicant determines that the cited documents do not constitute "prior art" under United States law, Applicant reserves the right to present to the Office the relevant facts and law regarding the appropriate status of such documents. Applicant further reserves the right to take appropriate action to establish the patentability of the disclosed invention over the listed documents, should one or more of the documents be applied against the claims of the present application.

If there is any fee due in connection with the filing of this Statement, please charge the fee to our Deposit Account No. 06-0916.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: April 25, 2008

By: ____________________
Ernest F. Chapman
Reg. No. 25,961

Enclosures
EFC/FPD/acd

IAP02Rec'd PCT 25 APR 2008

IDS Form PTO/SB/08: Substitute for form 1449A/PTO				*Complete if Known*	
INFORMATION DISCLOSURE STATEMENT BY APPLICANT				*Application Number*	Not Yet Assigned 12/084134
				Filing Date	April 25, 2008
				First Named Inventor	Bruno MELIS
				Art Unit	Not Yet Assigned
(Use as many sheets as necessary)				*Examiner Name*	Not Yet Assigned
Sheet	1	of	1	*Attorney Docket Number*	09952.0468-00000

U.S. PATENTS AND PUBLISHED U.S. PATENT APPLICATIONS

Examiner Initials*	Cite No.[1]	Document Number Number-Kind Code[2] (if known)	Issue or Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
		US 2004/0087294 A1	05-06-2004	Wang	
		US 5,930,293	07-27-1999	Light et al.	

Note: Copies of the U.S. Patent Documents are not Required in IDS filed after October 21, 2004

FOREIGN PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	Foreign Patent Document Country Code[3] Number[4] Kind Code[5] (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear	Translation[6]
		EP 1 164 718 A2	12-19-2001	NEC Corporation		
		EP 1 487 134 A1	12-15-2004	Nokia Corporation		
		WO 2003/055097 A3	07-03-2003	Motorola, Inc.		
		WO 2006/037364 A1	04-13-2006	Telecom Italia S.p.A.		
		WO 2007/038969 A1	04-12-2007	Telecom Italia S.p.A. et al.		

NON PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No.[1]	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	Translation[6]

Examiner Signature		Date Considered	

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

FPD/acd

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2005/011529

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/06 H04B7/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 1 164 718 A (NEC CORPORATION) 19 December 2001 (2001-12-19) abstract paragraphs [0007], [0008]	1,23,44, 45
A	EP 1 487 134 A (NOKIA CORPORATION) 15 December 2004 (2004-12-15) abstract paragraphs [0009] - [0012]	1,23,44, 45
A	US 2004/087294 A1 (WANG JAMES JUNE-MING) 6 May 2004 (2004-05-06) abstract paragraphs [0064], [0065] figure 5B1	1,23,44, 45

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 May 2006	17/05/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lustrini, D

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2005/011529

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 1164718	A	19-12-2001	JP	3402363	B2	06-05-2003
			JP	2001358623	A	26-12-2001
			SG	100723	A1	26-12-2003
			US	2001050963	A1	13-12-2001
EP 1487134	A	15-12-2004	EP	1489756	A1	22-12-2004
US 2004087294	A1	06-05-2004	NONE			

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 164 718 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
19.12.2001 Bulletin 2001/51

(51) Int Cl.7: H04B 7/06

(21) Application number: 01113922.7

(22) Date of filing: 07.06.2001

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 13.06.2000 JP 2000177110

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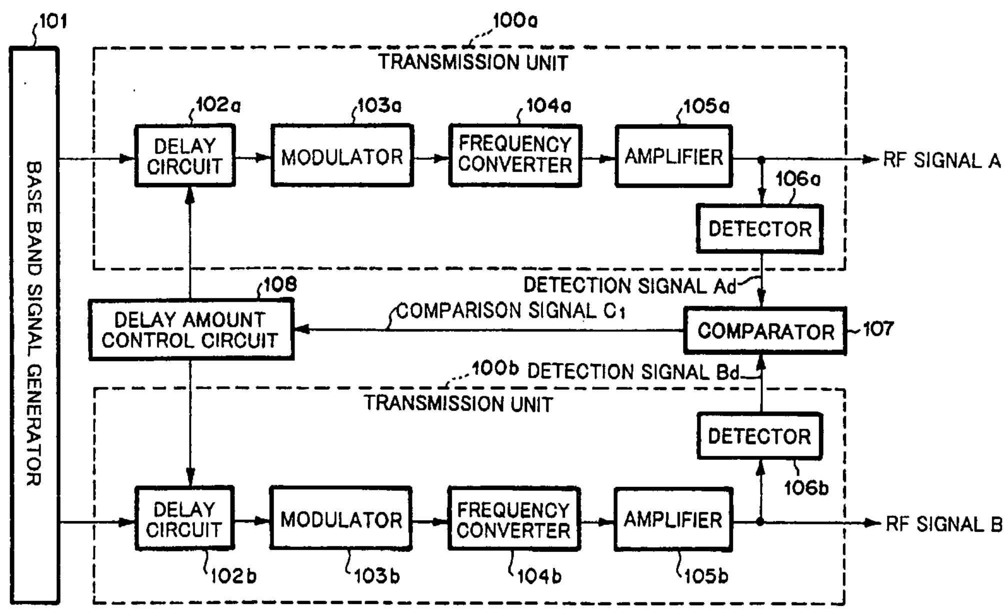
(54) **Delay control in time diversity transmitter**

(57) Detectors 106a, 106b detect RF output signals of transmission units 100a, 100b, and output detection signals. A comparator 107 compares the detection signals output from the detectors 106a, 106b and outputs a comparison signal. On the basis of the comparison signal output from the comparator 107, a delay amount control circuit 108 controls delay circuits 102a, 102b so that the modulation timing is coincident at the transmission output terminal.

FIG.2



EP 1 164 718 A2

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a diversity type transmitter used for mobile communication and particularly, to a diversity type transmitter having a delay time control system for controlling the delay time of each of plural transmission units so that the difference in delay time among the transmission units is within a permissible value range.

2. Description of the Related Art

[0002] In a transmission diversity system in which the same modulation waves are transmitted from plural transmission units at the same time and the modulation timing is made coincident among these modulation waves at a reception point to thereby achieve a diversity gain, it is required that the modulation timing at the transmission output terminal is within a permissible value range (coincident desirably). Accordingly, it is required that plural diversity type transmission units reduce the difference in delay timing of modulated data thereof so that the difference is within a permissible value range.

[0003] Dispersion in delay time among circuit parts is considered as a factor of inducing the difference in delay time among the transmission units. Particularly, the effect of the dispersion in delay amount among IF filters to be mounted for an intermediate frequency (IF) before it is converted to RF frequency is large. Further, the effect degree of the dispersion in delay time among these IF filters is increased as the transmission rate of the modulated data (chip rate) increases. Therefore, a CDMA (Code Division Multiple Access) type mobile communication system for carrying out high-speed data transmission or the like need the control of the delay time in each transmission unit in order to implement a diversity type transmitter.

[0004] Fig. 1 is a diagram showing a transmitter used a conventional delay time control system.

[0005] According to the transmitter shown in Fig. 1, signals generated by base band signal generator 101 are delayed by delay circuits 102a and 102b of transmission units 100a and 100b, passed through modulators 103a and 103b, frequency converters 104a and 104b and amplifiers 105a and 105b, and then finally output as RF (Radio Frequency) signals A and B. In order to control the delay amount of the signals, delay amount control circuit 108 controls the delay amount with delay amount set value 109 which is calculated in advance. The delay amount set value 109 is calculated by measuring the delay amounts of the transmission units 100a and 100b which are actually used.

[0006] In the transmitter described above, the delay amounts of the transmission units must be actually measured in order to achieve the delay amount set value 109, and thus the productive efficiency is low. The delay amount set value 109 is set only at the time when a diversity type transmitter is produced. Therefore, when the difference in delay amount is varied due to a temperature variation or a secular change under operation, an expected diversity gain may not be obtained.

SUMMARY OF THE INVENTION

[0007] An object of the present invention is to provide a transmitter which can improve the productive efficiency and achieve an expected diversity gain even when a temperature variation or a secular change under operation occurs.

[0008] In order to attain the above object, according to the present invention, a transmission diversity type transmitter in which the same modulation waves are transmitted from plural transmission units at the same time by delaying a base band signal with delay circuits, and the modulation timing is made coincident among the modulation waves at a reception point to achieve a diversity gain, the transmitter comprising:

a detector for detecting an RF signal of each transmission unit and outputting a detection signal,
a comparator for comparing the detection signals output from the two detectors of two transmission units in the plural transmission units and outputting a comparison signal, and
a delay amount control circuit for controlling the delay circuits of the two transmission units on the basis of the comparison signal output from the comparator so that the modulation timing is coincident at the transmission output terminals of the two transmission units.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

Fig. 1 is a block diagram showing a transmitter having a conventional delay time control system;
Fig. 2 is a block diagram showing a first embodiment of a transmitter according to the present invention;
Fig. 3 is a graph showing examples of detection signals of detectors 106a and 106b of Fig. 2;
Fig. 4 is a graph showing another examples of the detection signals of the detectors 106a and 106b of Fig. 2;
Fig. 5 is a graph showing another examples of the detection signals of the detectors 106a and 106b of Fig. 2;
Fig. 6 is a flowchart showing the operation of a delay amount control circuit 108 of Fig. 2; and
Fig. 7 is a block diagram showing a second embodiment of the transmitter according to the present in-

vention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010] Preferred embodiments according to the present invention will be described hereunder with reference to the accompanying drawings.

(First Embodiment)

[0011] Fig. 2 is a block diagram showing a first embodiment of a transmitter according to the present invention.

[0012] Fig. 2 shows a diversity type transmitter comprising two transmission units, and the same parts as shown in Fig. 1 are represented by the same reference numerals.

[0013] In Fig. 2, a base band signal generated in a base band signal generator 101 is input to two transmission units 100a and 100b. The base band signals input to the transmission units 100a and 100b are passed through delay circuits 102a and 102b, and then input to modulators 103a and 103b. The modulator 103a and 103b generate modulation waves from the base band signals input thereto. The modulation waves are converted to RF signals in frequency converters 104a and 104b, amplified by amplifiers 105a and 105b so as to have predetermined power, and then output as RF (Radio Frequency) signals A and B from the transmission units 100a and 100b.

[0014] The detectors 106a and 106b detect the RF output signals A and B of the transmission units 100a and 100b thereof, and output detection signals Ad and Bd. In comparator 107, the detection signals Ad and Bd of the detectors 106a and 106b are compared with each other to output a comparison signal C_1. In delay amount control circuit 108, the delay amounts of the delay circuits 102a and 102b of the respective transmission units are controlled on the basis of the comparison signal C_1 as information. The control is automatically carried out so that the difference in delay time between the transmission units 100a and 100b is converged to a permissible value range. It is judged on the basis of the comparison signal C_1 from the comparator 107 whether the difference in delay time between the transmission units 100a and 100b is within the permissible value range.

[0015] A dispersion in delay time between circuit parts is considered as a factor inducing the difference in delay time between the transmission units. Particularly, the effect of the dispersion in delay amount among IF filters to be mounted for an intermediate frequency (IF) before it is converted to RF frequency is large. Further, the effect degree of the dispersion in delay time among these IF filters is increased as the transmission rate of the modulated data (chip rate) increases. Therefore, a CDMA type mobile communication system for carrying out high-speed data transmission or the like need the control of the delay time in each transmission unit in order to implement a diversity type transmitter.

[0016] Next, the operation will be described.

[0017] Since the RF signal is a modulation wave, the output power thereof is instantaneously varied at a rate proportional to the transmission rate of the modulation data (base band signal). Each of the detectors 106a and 106b outputs the instantaneous power variation of the RF signal as a detection voltage.

[0018] Figs. 3 to 5 show detection signals Ad and Bd of the detectors 106a and 106b of the respective transmission units. Comparison signal C_1 is the difference signal between the detection signals Ad and Bd. The ordinate represents the detection voltage and the abscissa represents the time normalized on the basis of the transmission rate unit (chip). One scale of the abscissa represents the time of one chip.

[0019] Fig. 3 is a graph showing the detection signals Ad and Bd when the difference in delay time between the transmission unit 100a and the transmission unit 100b is equal to zero. Since no difference occurs in delay time, the same amplitude variation occurs at the same time. Therefore, the detection signal Ad corresponding to the output signal of the detector 106a and the detection signal Bd corresponding to the output signal of the detector 106b are overlapped with each other.

[0020] Figs. 4 and 5 show the detection signals Ad and Bd when there occurs a difference in delay time between the transmission unit 100a and the transmission unit 100b. Fig. 4 shows a case where the transmission unit 100a is delayed by 1/8 chip to the transmission unit 100b, and Fig. 5 shows a case where the transmission unit 100a is delayed by 4/8 chip to the transmission unit 100b.

[0021] Next, the comparison signal output from the comparator 107 will be described.

[0022] The comparator 107 compares the detection signal Ad and the detection signal Bd with each other, and outputs the difference between the detection signals Ad and Bd (detection signal Ad — detection signal Bd). Figs. 3 to 5 show the comparison signal C_1 as the difference between the detection signals Ad and Bd.

[0023] In Fig. 3, the detection signal Ad and the detection signal Bd take the same value as the same time because no difference exists in delay time between the transmission units. Therefore, the comparison signal C_1 is equal to zero. On the other hand, as shown in Figs. 4 and 5, when there occurs a difference in delay time between the transmission units, the comparison signal C_1 is not equal to zero. As the difference in delay time is increased, the amplitude variation of the comparison signal is intensified.

[0024] The comparison signal C_1 obtained by the comparator 107 is input to the delay amount control circuit 108 to control the delay amounts of the delay circuits 102a and 102b provided to the transmission unit 100a and 100b.

[0025] Next, the operation of the delay amount control circuit 108 will be described with the flowchart of Fig. 6.

[0026] Fig. 6 is a flowchart showing the operation of the delay amount control circuit 108.

[0027] The delay amount control circuit 108 calculates the average amplitude Vn of the comparison signal input from the comparator 107 (step S1), and compares the average amplitude Vn with a predetermined threshold value (step S2). When the average amplitude Vn of the comparison signal is smaller than the threshold value, no control is carried out, and the processing returns to the step S1 to calculate the average amplitude of the comparison signal again. Accordingly, if the average amplitude Vn is not larger than the threshold value, the average amplitude of the comparison signal is re-calculated.

[0028] The threshold value is preset as follows. When the difference in delay time between the transmission units is large, the transmission diversity characteristic is deteriorated. Therefore, the permissible difference in delay time between the transmission units is set. As shown in Figs. 3 to 5, the amplitude variation of the comparison signal output from the comparator 107 is proportional to the difference in delay time. Accordingly, the permissible difference in delay time can be replaced by the value of the average amplitude of the comparison signal, and the value can be set as the threshold value.

[0029] On the other hand, if the average amplitude Vn of the comparison signal is larger than the threshold value, the delay amount of the transmission unit 100a is increased by one step (step S3). Here, as shown in Figs. 4 and 5, as the transmission unit 100a has a delay time larger than the transmission unit 100b, the delay time is further increased, and the average amplitude Vn of the comparison signal is also larger. Therefore, after the delay amount of the transmission unit 100a is increased by one step, the average amplitude Vn of the comparison signal is calculated again, and it is judged whether the average amplitude Vn is reduced (step S5). If the average amplitude Vn is reduced, the processing returns to the step S2 to judge again whether the value of Vn is smaller than the threshold value. On the other hand, if the average amplitude Vn is increased, the delay amount of the transmission unit 100b is increased by one step (step S6), the average amplitude Vn of the comparison signal is calculated again (step S7) and then it is judged whether the average amplitude Vn is smaller than the threshold value (step S8).

[0030] Subsequently, the control is repetitively carried out until the average amplitude Vn is equal to or smaller than the threshold value. As a result, the control is automatically carried out so that the difference in delay time between the transmission units is equal to a permissible value or less.

[0031] As described above, according to the present invention, the control is automatically carried out so that the difference in delay time between the diversity type transmitters is equal to a permissible value or less. Accordingly, an expected transmission diversity characteristic can be achieved at all times.

[0032] Further, according to the present invention, the dispersion of circuit parts used in the respective transmission units can be automatically corrected. In addition, the deterioration of the transmission diversity characteristic due to the temperature variation and the secular change under operation can be prevented.

(Second Embodiment)

[0033] Fig. 7 is a block diagram showing a second embodiment of the transmitter according to the present invention.

[0034] The transmitter of Fig. 7 includes three transmission units 100a, 100b and 100c, and each transmission unit is designed in a similar construction to that of Fig. 2.

[0035] In Fig. 7, a base band signal generated in a base band signal generator 101 is input to two transmission units 100a, 100b and 100c. The base band signals input to the transmission units 100a, 100b and 100c are passed through delay circuits 102a, 102b and 102c, and then input to modulators 103a, 103b and 103c. The modulator 103a, 103b and 103c generate modulation waves from the base band signals input thereto. The modulation waves are converted to RF signals in frequency converters 104a, 104b and 104c, amplified by amplifiers 105a, 105b and 105c so as to have predetermined power, and then output as RF (Radio Frequency) signals A, B and C from the transmission units 100a, 100b and 100c.

[0036] The detectors 106a and 106b detect the RF output signals A and B of the transmission units 100a and 100b, and output detection signals Ad and Bd. In comparator 107_1, the detection signals Ad and Bd of the detectors 106a and 106b are compared with each other to output comparison signal C_1. In delay amount control circuit 108_1, the delay amounts of the delay circuits 102a and 102b of the respective transmission units are controlled on the basis of the comparison signal C_1 as information.

[0037] Further, detector 106c detects the RF output signal C of transmission unit 100c, and output detection signal Cd. In comparator 107_2, the detection signals Bd and Cd of the detectors 106b and 106c are compared with each other to output comparison signal C_2. In delay amount control circuit 108_2, the delay amounts of the delay circuits 102b and 102c of the respective transmission units are controlled on the basis of the comparison signal C_2 as information.

[0038] Consequently, the RF signal A and the RF signal B are compared in delay time by a comparator 107_1 while the RF signal B and the RF signal C are compared in delay time by comparator 107_2, and delay control circuits 108_1 and 108_2 control the delay circuits 102a and 102b and the delay circuits 102b and 102c so that the difference in delay time is suppressed to each predetermined threshold value or less.

(Other Embodiments)

[0039] The second embodiment relates to the transmitter including three transmission units. However, even when a diversity transmitter includes four or more transmission units, the delay amounts of respective two transmission units are compared with each other (when n is an integer larger than 1, the number of the transmission units is equal to n, and the number of the comparators and the number of the delay amount control circuits are equal to n-1, respectively), whereby the difference in delay amount between the respective transmission units can be suppressed to each threshold value or less.

[0040] Further, in the above embodiments, the delay circuit is disposed in front of the modulator (that is, at the end to which the base band signal is input), however, the delay circuit may be disposed at the output side of the amplifier to control the delay amount. Also, the delay circuit may be disposed between the modulator and the frequency converter or between the frequency converter and the amplifier to control the delay amount. The detector is disposed in the transmission unit, however, the detector may be disposed out the transmission unit.

[0041] Further, the same control operation can be performed even when the base band signal is transmitted while being subjected to ON/OFF control, and a method of comparing the rise-up timing and the falling timing of the detection output at the ON/OFF-control time by the comparator and controlling the delay circuits by the delay amount control circuit so that the difference therebetween can be converged to a permissible time range can be used.

[0042] As described above, according to the present invention, the detection signals output from the detectors of the two transmission units are compared with each other to control the delay amount, whereby the control can be automatically performed so that the difference in delay time between the diversity type transmission units can be reduced to a permissible value or less. Therefore, an expected transmission diversity characteristic can be achieved.

[0043] Further, the dispersion of circuit parts used for the respective transmission units can be automatically corrected, and the deterioration of the transmission diversity characteristic due to the temperature variation and the secular change under operation can be prevented.

Claims

1. A transmission diversity type transmitter in which the same modulation waves are transmitted from plural transmission units at the same time by delaying a base band signal with delay circuits, and the modulation timing is made coincident among the modulation waves at a reception point to achieve a diversity gain, the transmitter comprising:

    a detector for detecting an RF signal of each transmission unit and outputting a detection signal,
    a comparator for comparing the detection signals output from the two detectors of two transmission units in said plural transmission units and outputting a comparison signal, and
    a delay amount control circuit for controlling the delay circuits of said two transmission units on the basis of the comparison signal output from said comparator so that the modulation timing is coincident at the transmission output terminals of said two transmission units.

2. The transmitter as claimed in claim 1, wherein each transmission unit contains said detector.

3. The transmitter as claimed in claim 1 or 2, wherein said delay amount control circuit calculates the average amplitude of the comparison signal output from said comparator, and controls said delay circuits so that the average amplitude is equal to or lower than a threshold value, whereby the difference in delay time between said two transmission units is converged to a permissible value range.

4. The transmitter as claimed in claim 1, 2 or 3, wherein, when n is an integer larger than 1, the number of said plural transmission units is equal to n, and the number of said comparators and the number of said delay amount control circuits are equal to n-1, respectively.

5. The transmitter as claimed in one of claims 1 to 4, wherein each of said transmission units comprises a delay circuit, a modulator, a frequency converter and an amplifier, and said delay circuit is provided at the end to which the base band signal is input.

6. The transmitter as claimed in one of claims 1 to 4, wherein each of said transmission units comprises a delay circuit, a modulator, a frequency converter and an amplifier, and said delay circuit is provided between said modulator and said frequency converter.

7. The transmitter as claimed in one of claims 1 to 4, wherein each of said transmission units comprises a delay circuit, a modulator, a frequency converter and an amplifier, and said delay circuit is provided between said frequency converter and said amplifier.

8. The transmitter as claimed in one of claims 1 to 4, wherein each of said transmission units comprises a delay circuit, a modulator, a frequency converter

and an amplifier, and said delay circuit is provided at the output side of said amplifier.

9. The transmitter as claimed in one of claims 1 to 8, wherein the base band signal is subjected to ON/OFF control, the rising timing and falling timing of the detection output when the ON/OFF control is carried out are compared with each other by said comparator, and said delay circuits are controlled by said delay amount control circuit so that the difference between the rising timing and the falling timing is within a permissible time range.

FIG. 1

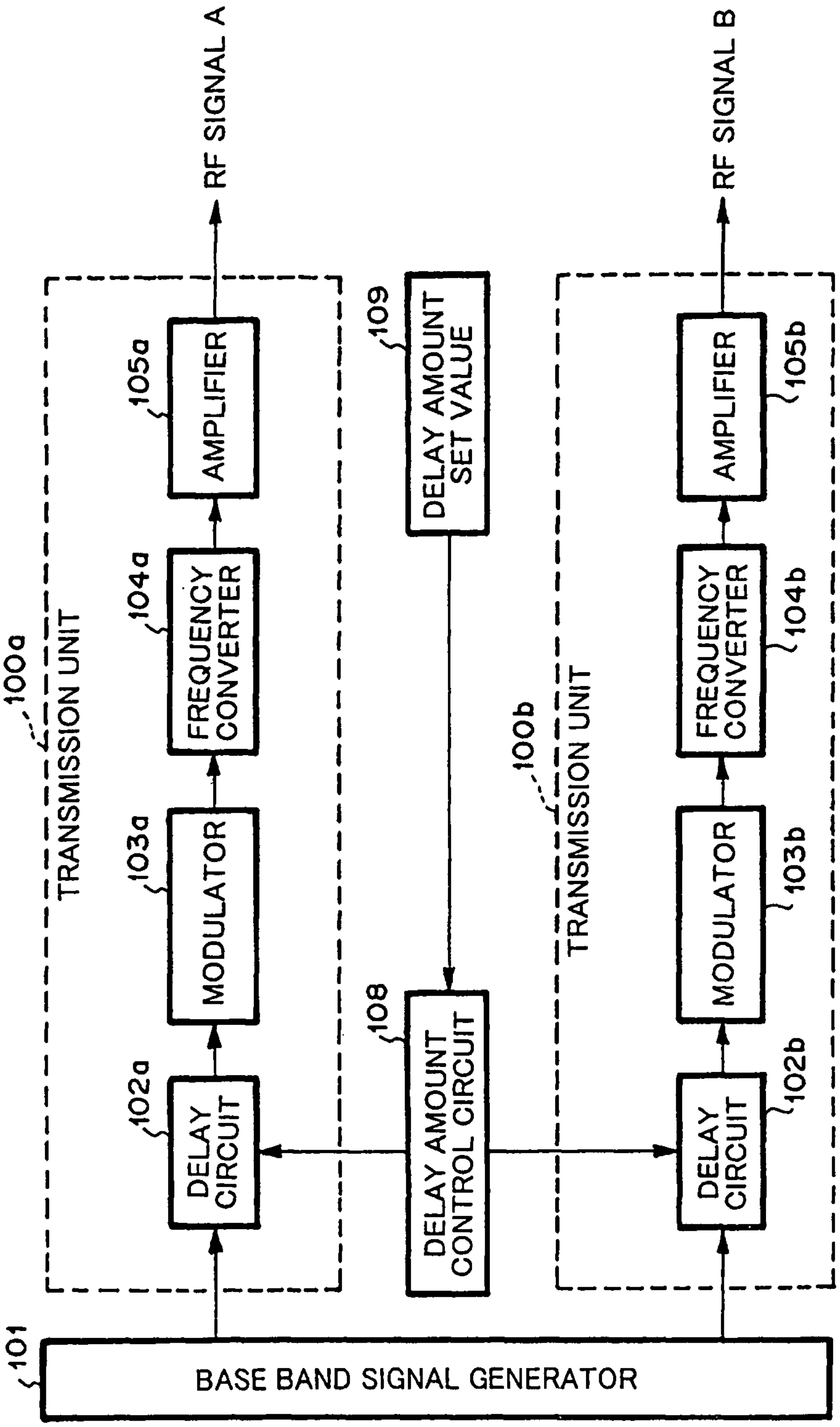

BASE BAND SIGNAL GENERATOR
101
TRANSMISSION UNIT
100a
DELAY CIRCUIT
102a
MODULATOR
103a
FREQUENCY CONVERTER
104a
AMPLIFIER
105a
RF SIGNAL A
DELAY AMOUNT CONTROL CIRCUIT
108
DELAY AMOUNT SET VALUE
109
TRANSMISSION UNIT
100b
DELAY CIRCUIT
102b
MODULATOR
103b
FREQUENCY CONVERTER
104b
AMPLIFIER
105b
RF SIGNAL B

FIG.2

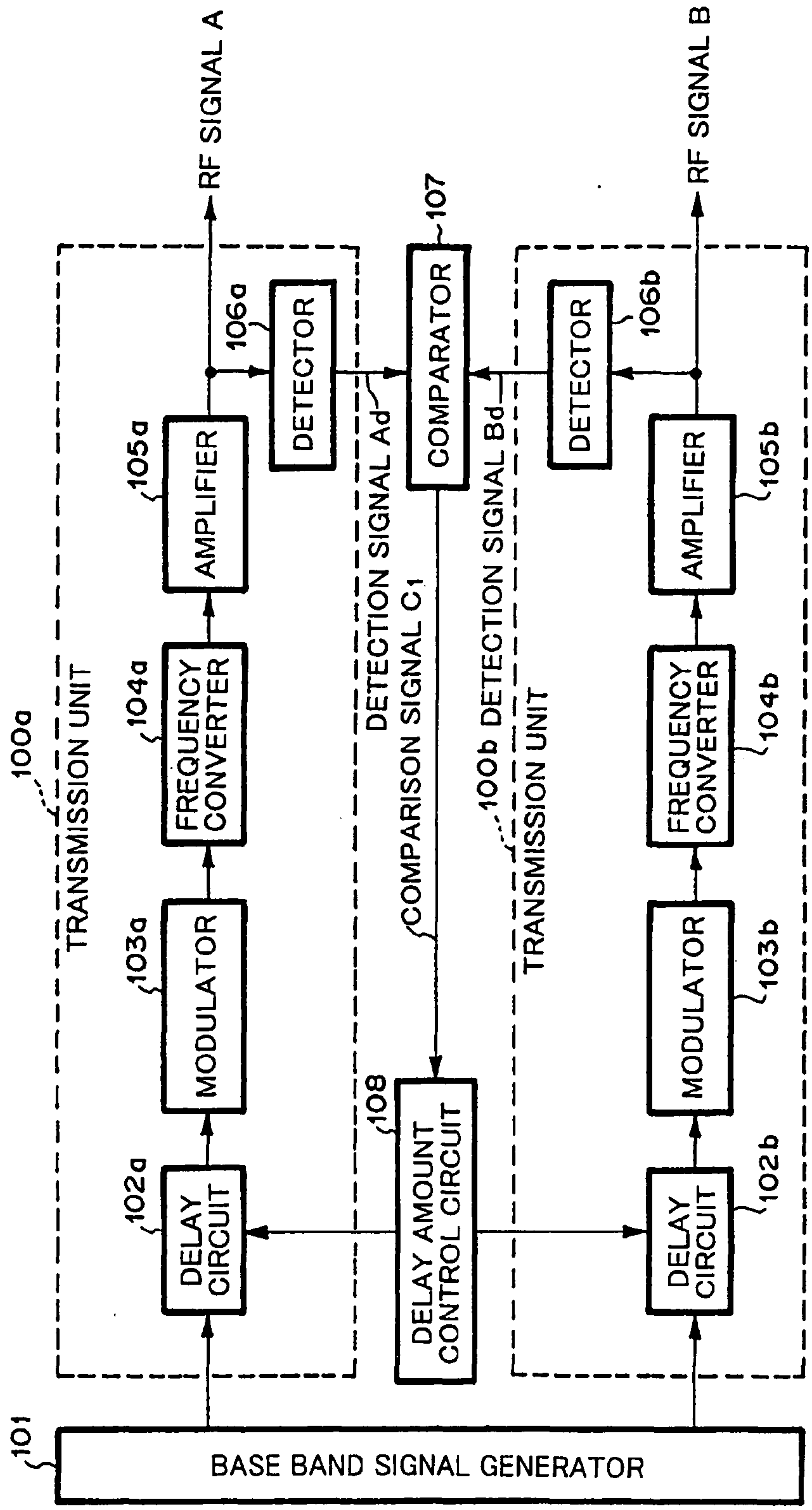

RF SIGNAL A
RF SIGNAL B
100a
TRANSMISSION UNIT
100b
TRANSMISSION UNIT
101
BASE BAND SIGNAL GENERATOR
102a
DELAY CIRCUIT
103a
MODULATOR
104a
FREQUENCY CONVERTER
105a
AMPLIFIER
106a
DETECTOR
102b
DELAY CIRCUIT
103b
MODULATOR
104b
FREQUENCY CONVERTER
105b
AMPLIFIER
106b
DETECTOR
107
COMPARATOR
108
DELAY AMOUNT CONTROL CIRCUIT
DETECTION SIGNAL Ad
DETECTION SIGNAL Bd
COMPARISON SIGNAL C1

FIG.3

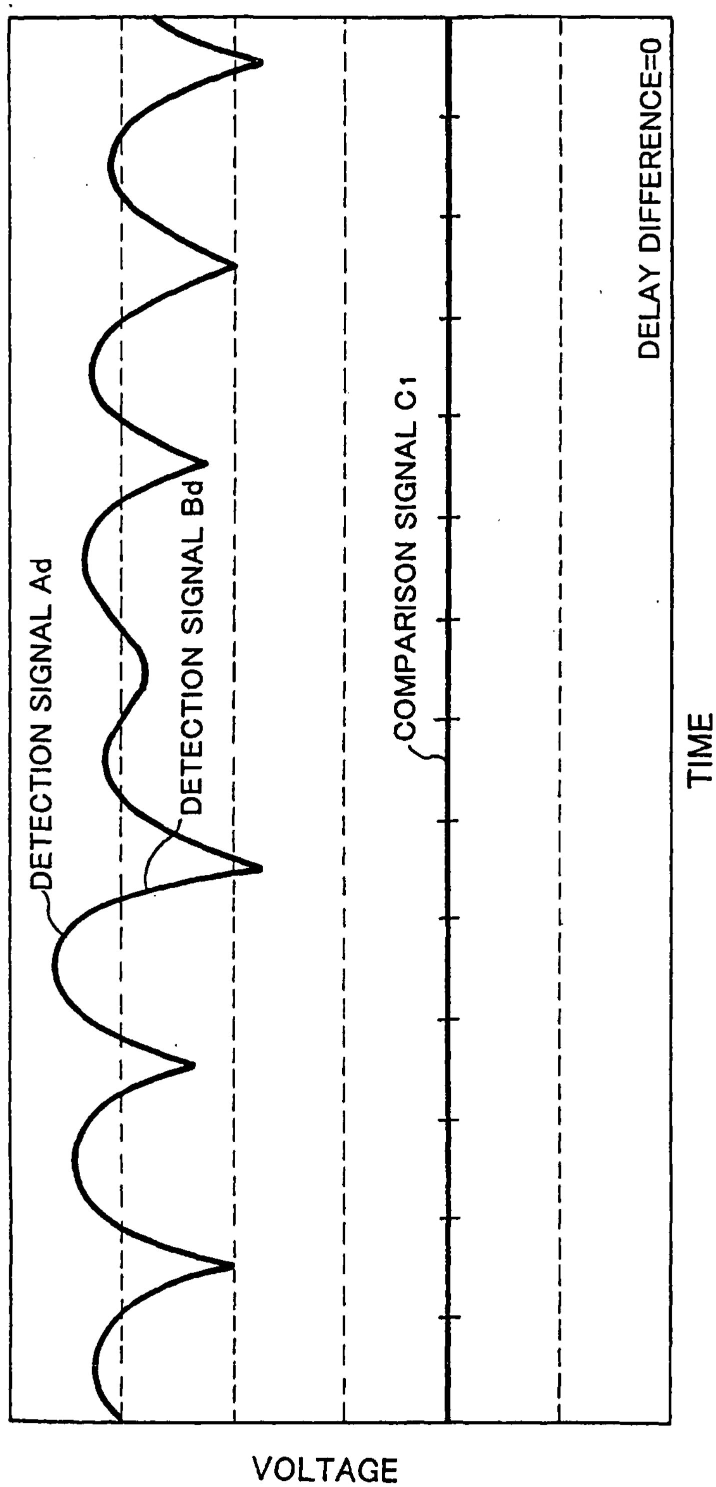

DETECTION SIGNAL Ad
DETECTION SIGNAL Bd
COMPARISON SIGNAL C1
DELAY DIFFERENCE=0
TIME
VOLTAGE

FIG. 4

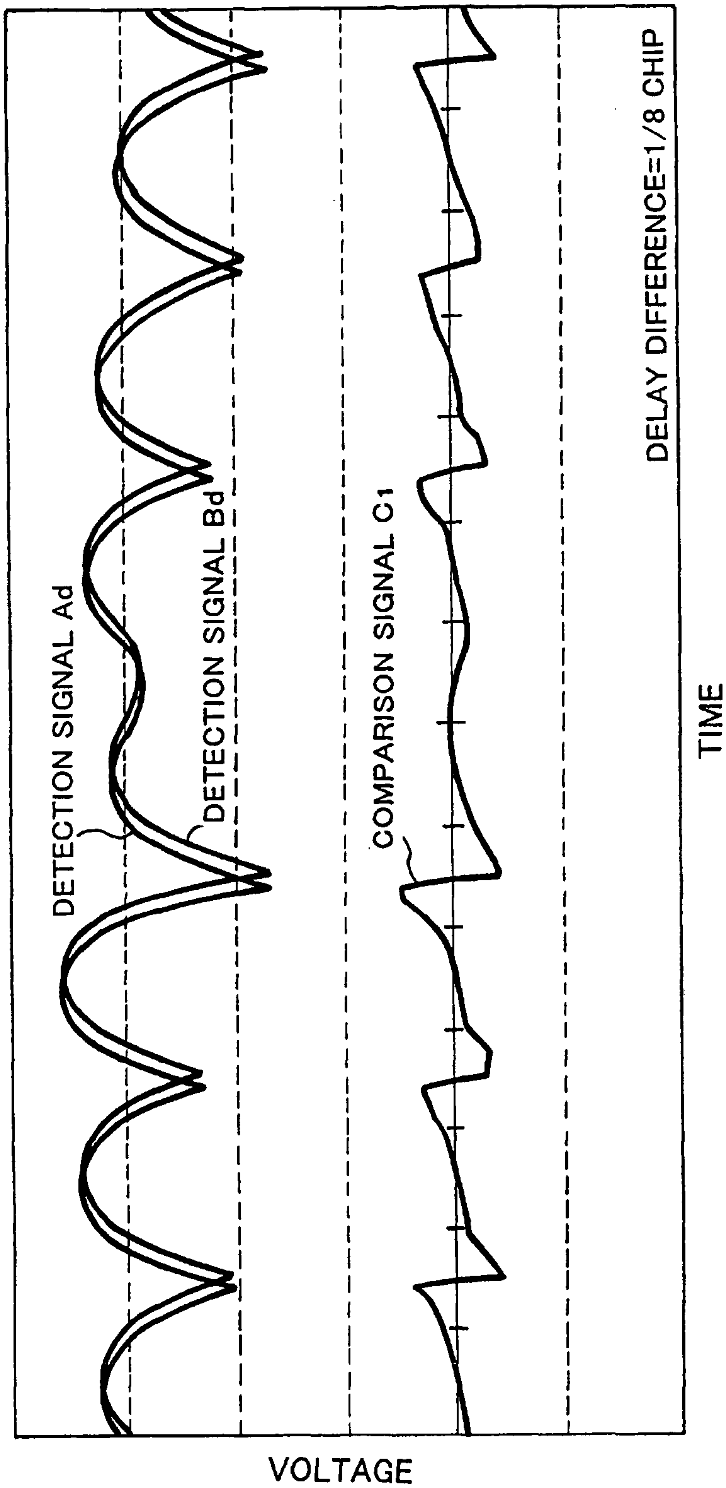

DETECTION SIGNAL Ad
DETECTION SIGNAL Bd
COMPARISON SIGNAL C1
DELAY DIFFERENCE=1/8 CHIP
TIME
VOLTAGE

FIG.5

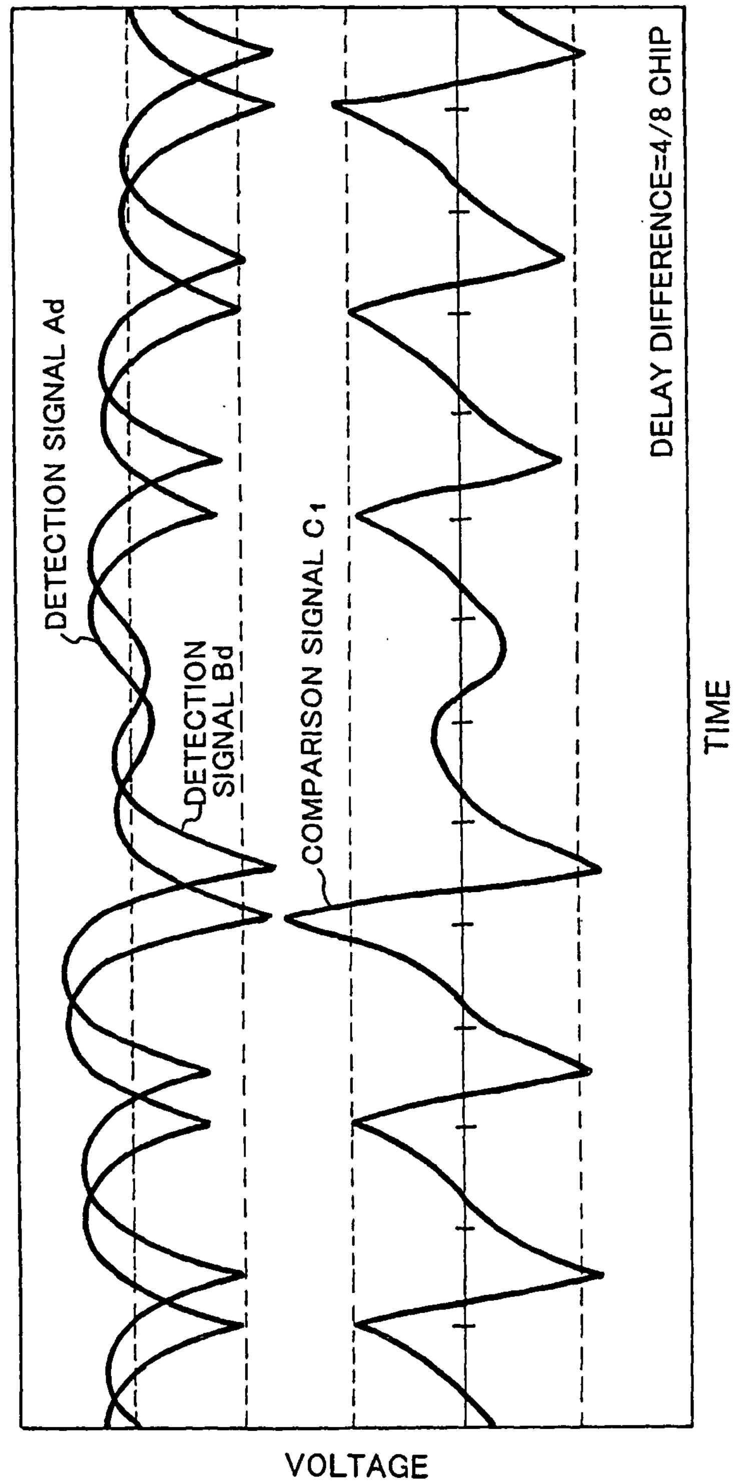

DETECTION SIGNAL Ad
DETECTION SIGNAL Bd
COMPARISON SIGNAL C_1
DELAY DIFFERENCE=4/8 CHIP
TIME
VOLTAGE

FIG.6

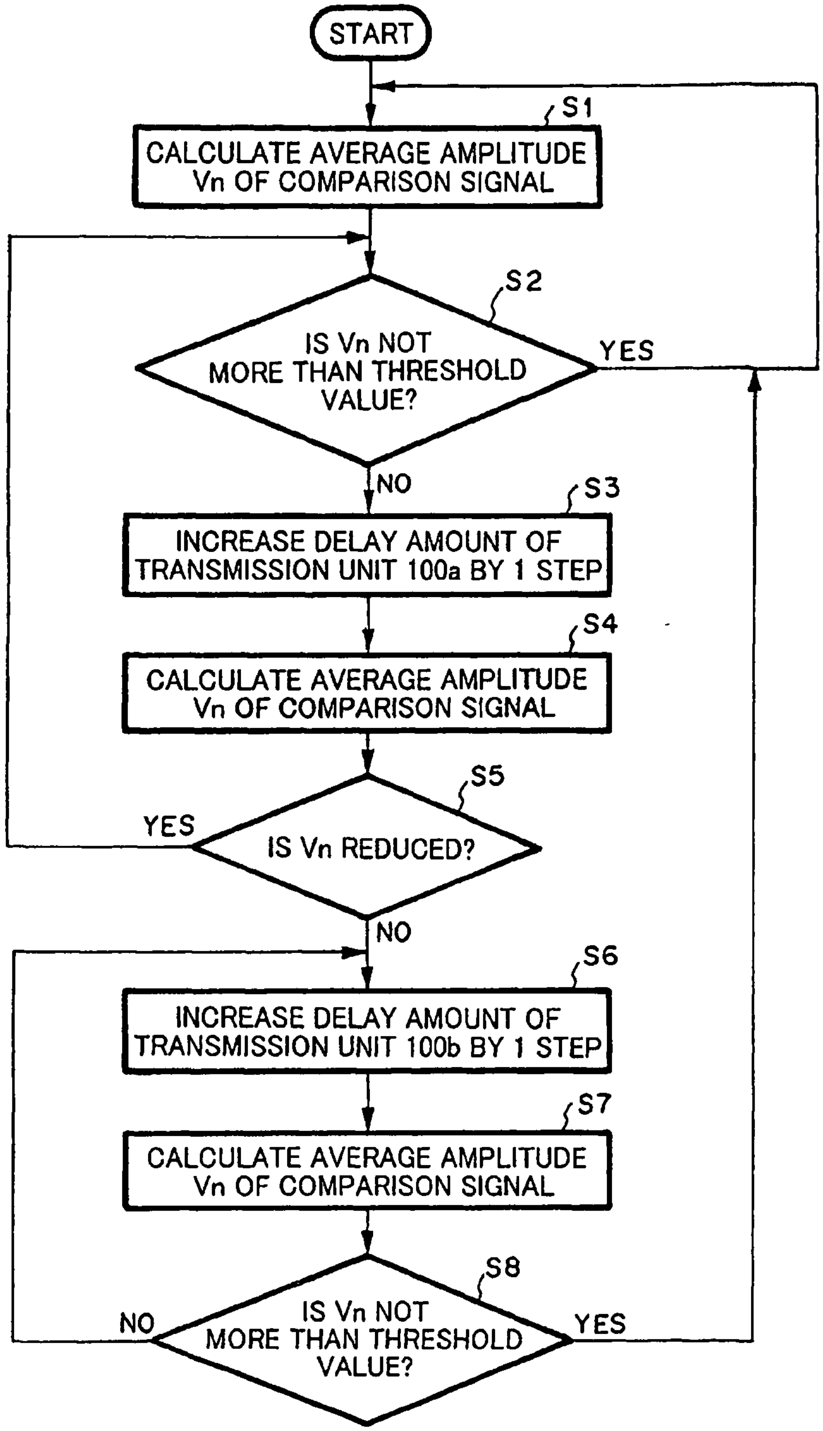
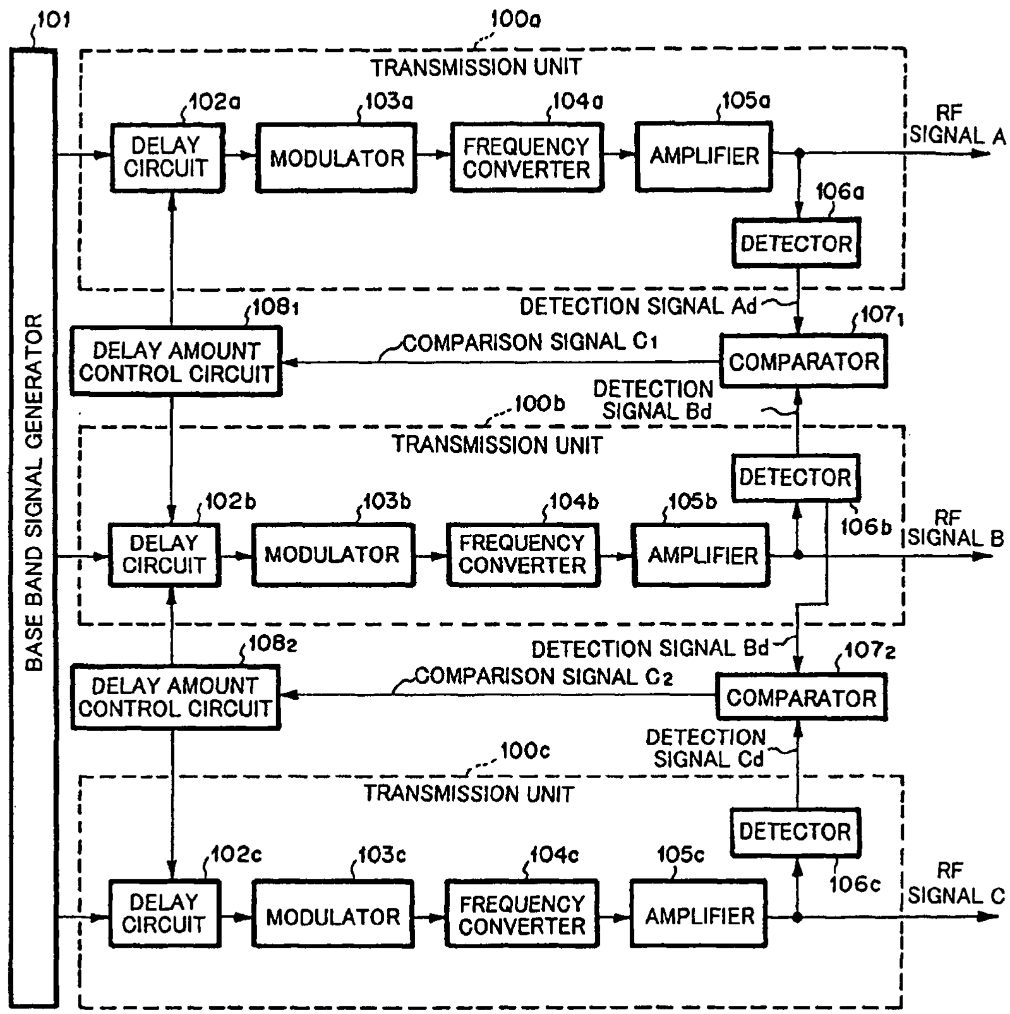

START
S1
CALCULATE AVERAGE AMPLITUDE Vn OF COMPARISON SIGNAL
S2
IS Vn NOT MORE THAN THRESHOLD VALUE?
YES
NO
S3
INCREASE DELAY AMOUNT OF TRANSMISSION UNIT 100a BY 1 STEP
S4
CALCULATE AVERAGE AMPLITUDE Vn OF COMPARISON SIGNAL
S5
IS Vn REDUCED?
YES
NO
S6
INCREASE DELAY AMOUNT OF TRANSMISSION UNIT 100b BY 1 STEP
S7
CALCULATE AVERAGE AMPLITUDE Vn OF COMPARISON SIGNAL
S8
IS Vn NOT MORE THAN THRESHOLD VALUE?
NO
YES

FIG.7


101
100a
TRANSMISSION UNIT
102a
103a
104a
105a
DELAY CIRCUIT
MODULATOR
FREQUENCY CONVERTER
AMPLIFIER
RF SIGNAL A
106a
DETECTOR
DETECTION SIGNAL Ad
108₁
107₁
DELAY AMOUNT CONTROL CIRCUIT
COMPARISON SIGNAL C1
COMPARATOR
100b
DETECTION SIGNAL Bd
TRANSMISSION UNIT
DETECTOR
102b
103b
104b
105b
106b
DELAY CIRCUIT
MODULATOR
FREQUENCY CONVERTER
AMPLIFIER
RF SIGNAL B
BASE BAND SIGNAL GENERATOR
108₂
DETECTION SIGNAL Bd
107₂
DELAY AMOUNT CONTROL CIRCUIT
COMPARISON SIGNAL C2
COMPARATOR
100c
DETECTION SIGNAL Cd
TRANSMISSION UNIT
DETECTOR
102c
103c
104c
105c
106c
DELAY CIRCUIT
MODULATOR
FREQUENCY CONVERTER
AMPLIFIER
RF SIGNAL C

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 487 134 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
15.12.2004 Bulletin 2004/51

(51) Int Cl.7: **H04B 7/06**, H04B 7/04

(21) Application number: **04020209.5**

(22) Date of filing: **01.06.2001**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR

(30) Priority: **02.06.2000 US 586561**

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
01934236.9 / 1 287 627

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Remarks:
This application was filed on 26 - 08 - 2004 as a divisional application to the application mentioned under INID code 62.

(54) Closed loop feedback system for improved down link performance

(57) A method includes selecting at least two beams of plural beams formed by a multi-beam antenna array associated with a first station for transmission of a corresponding at least two space-time coded signals produced by a space-time encoder, determining a time delay associated with each of the at least two space-time coded signals as received in each respective beam, and setting into a variable delay line the time delay corresponding to each beam, each variable delay line being coupled between the multi-beam antenna array the space-time encoder.

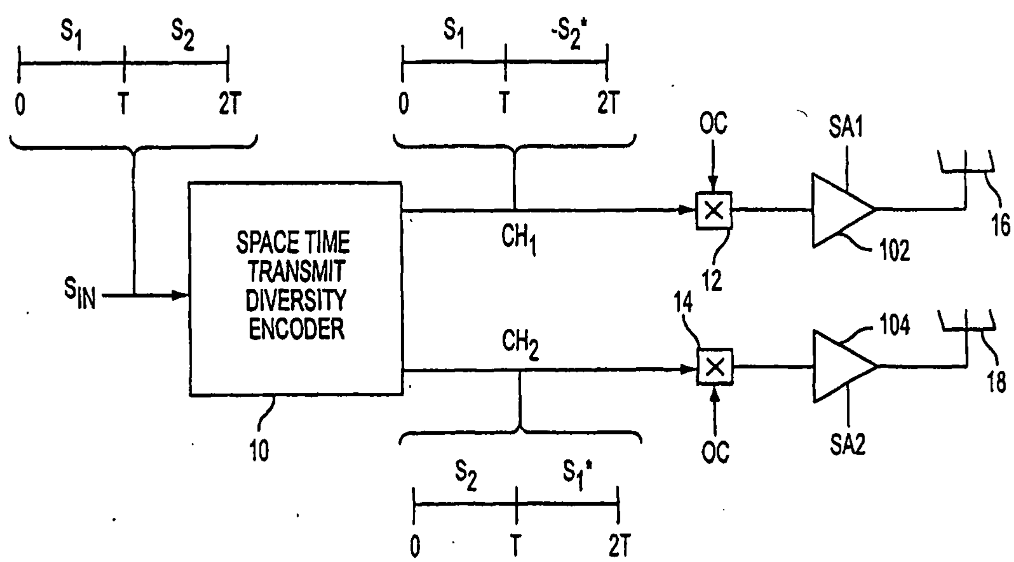

FIG. 4

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a system to control down link signal transmission from a base station of a cellular radio system to a remote station. In particular, the invention relates to a closed loop phase and amplitude control system to adjust the phase and amplitude of down link transmitted signals.

Description Of Related Art

[0002] Cellular telephone systems are operated in environments that give rise to multi-path or reflections of the their signals, particularly in urban environments. In FIG. 1, base station transmitter 1 broadcasts its signal to remote station 2 (often mobile) along direct path 3. However, owing to the presence of tall building 4, transmitter 1 also broadcasts its signal to remote station 2 along indirect path 5, thus, giving rise to angular spread AS between the direction of arrival of direct path 3 at remote station 2 and the direction of arrival of indirect path 5 at remote station 2. Direct path 3 and indirect path 5 are recombined at remote station 2 where constructive and destructive superimposed signals cause random or what appears to be random fading and black out zones.

[0003] To reduce the effects of multi-path, known systems employ space time transmit diversity techniques. In FIG. 2, a known transmitter includes space time transmit diversity encoder 10, complex multipliers 12 and 14, and antennas 16 and 18. Space time transmit diversity encoder 10 processes input signal S_{IN} into two channel signals CH_1 and CH_2. Multipliers 12 and 14 may impart a same orthogonalizing code OC on the two channel signals CH_1 and CH_2 to identify the two channels as containing information about input signal S_{IN}; however, different orthogonal identifiers (e.g., pilot sequences or training sequences) are applied to the different antenna signals so that the remote station can separately identify the signals from the two antennas. The multiplied channel signals are transmitted on respective antennas 16 and 18 substantially spaced apart by a distance (e.g., 20 wavelengths). Such spaced apart antennas are referred to as diversity antennas. In multi-path environments severe fading results when different propagation paths sum destructively at the receiving antenna. Using diversity antennas, the probability that both signals CH_1 and CH_2 will be in deep fade is low since the two signals are likely to propagate over different paths such as the multi-paths 3 and 5. Diversity antennas may be omni-directional antennas or antennas directed at antenna sectors with overlayed sectors. When diversity antennas are sufficiently separated in space, they can be regarded as orthogonal since they propagate signals in non-correlated channels (i.e., paths).

[0004] Input signal S_{IN} carries two symbols, S_1 and S_2, in time succession, the first symbol in symbol slot between 0 and T, and the second symbol in symbol slot between T and 2T. In FIG. 3, exemplary encoder 10 uses a QPSK modulation technique and includes time align register 20 and hold registers 22 to hold the two symbols. Base band carrier signal SBBC is inverted in inverter 24 to produce negative base band carrier - SBBC. QPSK modulator 26 encodes symbol S_1 onto base band carrier signal SBBC to produce a modulated first symbol, and QPSK modulator 28 encodes symbol S_1 onto negative base band carrier signal -SBBC to produce a modulated conjugate of the first symbol. QPSK modulator 30 encodes symbol S_2 onto base band carrier signal SBBC to produce a modulated second symbol, and QPSK modulator 32 encodes symbol S_2 onto negative base band carrier signal -SBBC to produce a modulated conjugate of the second symbol. The modulated conjugate of the second symbol is inverted in inverter 34 to produce a negative modulated conjugate of the second symbol. Analog multiplexer 36 switches the modulated first symbol into the first channel signal during the first symbol time slot (i.e., 0 to T, FIG. 2) and switches the negative modulated conjugate of the second symbol into the first channel signal during the second symbol time slot (i.e., T to 2T, FIG. 2) so that the signal on CH1 is $[S_1, - S_2^*]$. Analog multiplexer 38 switches the modulated second symbol into the second channel signal during the first symbol time slot (i.e., 0 to T, FIG. 2) and switches the modulated conjugate of the first symbol into the second channel signal during the second symbol time slot (i.e., T to 2T, FIG. 2) so that the signal on CH2 is $[S_2, S_1^*]$.

[0005] In FIG. 2, code OC consists of one code applied to both multipliers 12, 14 that is used as a CDMA spreading function to isolate the two signals transmitted from antennas 16 and 18 from other signals that may generate co-channel interference. Multipliers 12 and 14, multiply the first and second channel signals before being transmitted through antennas 16 and 18. RF up converters are not shown for simplicity.

[0006] At remote station 2, a receiver receives signals from both antennas 16 and 18 on a single antenna, down-converts the signals, despreads the signals using code OC, and recovers a composite of channels CH1 and CH2 as transmitted from antennas 16 and 18, respectively. In the first symbol time slot between 0 and T, the composite QPSK modulated signal R_1 is received (where $R_1 = k_{11}S_1 + k_{12}S_2$), and in the second symbol time slot between T and 2T, the composite QPSK modulated signal R_2 is received (where $R_2 = -k_{21}S_2^* + k_{22}S_1^*$ and the asterisk refers to a complex conjugate). Constant k_{11} is a transmission path constant from first antenna 16 to remote station 2 during the first time slot, constant k_{12} is a transmission path constant from second antenna 18 to remote station 2 during the first time slot, constant k_{21} is a transmission path constant from first antenna 16 to remote station 2 during the second time slot, and constant k_{22} is a transmission path constant from second antenna 18 to remote station 2 during the second time slot. The receiver derotates the channel to recover soft symbols S_1' and S_2', where

$$S_1' = k_{11}R_1 + k_{12}R_2 \text{ and } S_2' = k_{21}R_2^* + k_{22}R_1^*.$$

[0007] In this time space encoder technique, the first and second symbols are redundantly transmitted from separate antennas. The first symbol is encoded to be transmitted in both the first and second symbol time slots, and the second symbol is also encoded to be transmitted in both the first and second symbol time slots. The effect of this symbol recovery technique is that fading or drop out regions that may appear during one symbol time slot are less likely to appear during both symbol time slots when interleaving is also exploited. Interleaving is used before space-time coding to make adjacent bits less correlated in time. Since the received symbols are recovered from received signals during both time slots, R_1 and R_2, the effect of fading is diminished.

[0008] However, the prior art does not exploit advantages provided by independent power and phase management of individual beams transmitted by different diversity type antennas to achieve greater spectral efficiency at the base station while minimizing co-channel interference. The prior art does not exploit advantages provided by spatial power management of independently directed beams to achieve greater spectral efficiency at the base station while minimizing co-channel interference.

SUMMARY OF THE INVENTION

[0009] It is an object to the present invention to improve the down link performance of a cellular radio system. It is another object to minimize undesired effects of fading and drop out.

[0010] These and other objects are achieved with a method that includes receiving at least two space-time coded signals from an antenna system associated with a first station, determining complex channel state information based on the received space-time coded signals, and sending the complex channel state information to the first station.

[0011] These and other objects are achieved with an alternative embodiment where the method includes transmitting at least two space-time coded signals in respective beams of a multi-beam antenna array, measuring a channel impulse response for each space-time coded signal at a second station, and sending an indicia of a selected set of least attenuated signals from the second station to the first station. The multi-beam antenna array is associated with a first station. The beams transmit a signature code embedded in each respective space-time coded signal, and the signature codes are orthogonal so that the second station can separate and measure the channel impulse response corresponding to each space-time coded signal. The space-time coded signals include the selected set of least attenuated signals and a remaining set of most attenuated signals.

[0012] These and other objects are achieved with an alternative embodiment where the method includes selecting at least two beams of plural beams formed by a multi-beam antenna array associated with a first station for transmission of a corresponding at least two space-time coded signals produced by a space-time encoder, determining a time delay associated with each of the at least two space-time coded signals as received in each respective beam, and setting into a variable delay line the time delay corresponding to each beam, each variable delay line being coupled between the multi-beam antenna array and the space-time encoder.

BRIEF DESCRIPTION OF DRAWINGS

[0013] The invention will be described in detail in the following description of preferred embodiments with reference to the following figures wherein:

FIG. 1 is a schematic view of the radio environment in which the present invention is employed;
FIG. 2 is a block diagram of a known base station;
FIG. 3 is a block diagram of a known space time encoder;
FIG. 4 is a block diagram of a base station apparatus according to an embodiment of the present invention;
FIG. 5 is a block diagram of a base station apparatus according to another embodiment of the present invention;
FIG. 6 is a schematic diagram of a known hex comer reflector antenna system;
FIG. 7 is a schematic diagram of a known phase array antenna;
FIG. 8 is a schematic diagram in plan view of an exemplary three sector antenna system;
FIG. 9 is a schematic diagram of a known "Butler matrix" antenna;

FIG. 10 is a schematic diagram of a dual beam phase array antenna;
FIG. 11 is a block diagram of a base station apparatus according to another embodiment of the present invention;
FIG. 12 is a block diagram of a TDMA base station apparatus according to another embodiment of the present invention;
FIG. 13 is a block diagram of a closed loop beam power management system according to the present invention;
FIG. 14 is a block diagram of a radio system according the present invention;
FIGS. 15-17 are flow charts of methods of determining the angular power spectrum according to the present invention;
FIG. 18 is a graph of an angular power spectrum as received and/or computed by the present invention;
FIG. 19 is a block diagram of an embodiment of the present invention;
FIG. 20 is a flow chart of a method of feedback control according to the present invention;
FIG. 21 is a schematic view that illustrates the multi-path signal processed by the invention with a sector coverage antenna;
FIG. 22 is a graph showing the direct and multi-path signal of FIG. 21 that is received by a remote station;
FIG. 23 is a schematic view that illustrates the multi-path signal processed by the invention with a multi-beam antenna covering a sector;
FIG. 24 is a graph showing the direct signal and a delayed replica of the direct signal of FIG. 21 or 23 that is received by a remote station;
FIG. 25 is a graph showing the multi-path signal of FIG. 21 or 23 that is received by a remote station;
FIG. 26 is a block diagram of a base station apparatus with a programmable delay line according to an embodiment of the present invention;
FIG. 27 is a graph depicting a delay distribution profile according to the invention;
FIG. 28 is a flow chart of a set up method according to the present invention;
FIG. 29 is a flow chart of a time align method according to the present invention; and
FIG. 30 is a flow chart of a method of feedback according to the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0014] To achieve greater spectral efficiency of transmissions from the base station while minimizing co-channel interference, independent power management of individual beams transmitted by different antennas of the diversity antennas has been developed, and beamspace time encoder techniques has been developed to exploit angle of arrival diversity and exploit spatial power management of independently directed beams. Beamspace time techniques differ from known space time encoder techniques by its use of two or more independently directed orthogonal beams to exploit power and beam width management and angle of arrival diversity. Orthogonal beams are separately identifiable to the receiver by using perpendicular polarization (two beam case), by using a different pilot code for each beam in a CDMA system in addition to the CDMA spread spectrum code that is common to all beams, by using a different spread spectrum code for each beam in a CDMA system without pilot codes, by using a different training sequence (e.g., pilot code) multiplexed into each.beam in a TDMA system. Persons skilled in the art will appreciate that there are other orthogonal beam techniques not listed above or techniques that use different combinations of the above techniques that are equivalent for providing a means for the receiver at the remote station to separately identify the individual beams and recover the signals they carry.

[0015] Power management techniques to transmit different powers in different orthogonal beams improve spectral efficiency at the base station on a system wide basis by minimizing co-channel interference even when this power management control is applied to overlaid sector directed beams or omni directional beams of diversity antennas. However, with orthogonally coded beams that are directed differently, spatial power management of independently directed beams provides even further improvements. The relatively poor downlink performance of radio environments with large angular spreads is significantly improved by applying the beamspace time encoder techniques described herein.

[0016] In FIG. 4, a first embodiment of an improved transmitter 100 (referred to as power management of diversity antennas) includes known space time transmit diversity encoder 10 and complex multipliers 12 and 14. Improved transmitter 100 further includes scaling amplifiers 102 and 104 and diverse antennas 16 and 18. In a CDMA system, multipliers 12, 14 impart different spread spectrum codes to different beams so that a receiver at remote station 2 can discern the beams separately.

[0017] Although separate distinguishable spreading codes in a CDMA system are applied to multipliers 12, 14 as described here to create the orthogonal beams, it will be appreciated that any means to create orthogonal beams enable the separate power management of the transmissions from the diversity antennas (i.e., overlaid coverage), or from controllable directional antennas for that matter. For example, in a CDMA system where the multipliers 12 and 14 are provided with the same spreading codes, another set of multipliers 12' and 14' (not shown) may be used for imparting pilot codes to the channel signals. Multipliers 12' and 14' are then provided with orthogonal pilot codes so the receiver in remote station 2 can separately discern the beams. In another variant, antennas 16 and 18 are constituted by a single antenna with two exciter elements arranged to generate two beams that are orthogonally polarized (e.g., polarized at a +/-45 degree slant to the vertical or some other reference), but otherwise cover the same sector. Such beams are orthogonal, and transmissions over the respective signal paths experience uncorrelated fading.

[0018] Scaling control signals SA1 and SA2 separately control the amplification or attenuation achieved by separate scaling amplifiers 102 and 104, respectively. Scaling control signals SA1 and SA2 may be real to scale amplitudes, or imaginary to shift phases or complex with both real and imaginary components to both scale amplitudes and shift phases. It will be appreciated that the amplification may be applied at the output of encoder 10, before multipliers 12 and 14, after multipliers 12 and 14 or in antennas 16 and 18.

[0019] Antennas 16, 18 are diversity antennas that cover overlaid sectors or are omni-directional. This first embodiment differs from known space-time coded systems in that the power transmitted in each beam is separately controlled by SA1 and SA2.

[0020] In FIG. 5, a second embodiment of an improved transmitter 100 (referred to as angular spectral power management) includes known space time transmit diversity encoder 10 and complex multipliers 12 and 14. Improved transmitter 100 further includes scaling amplifiers 102 and 104 and controlled directional antennas 106 and 108. Unlike antennas 16 and 18 of FIG. 2, directional antennas 106 and 108 are directed toward direct path 3 and indirect path 5 (FIG. 1) or some other direction to cover angular spread AS or that portion of the angular power spectrum that exceeds a threshold as described herein. In a CDMA system, multipliers 12, 14 impart different spread spectrum codes to different beams or use other means so that a receiver at remote station 2 can discern the beams separately as described for the first embodiment using diversity antennas. Scaling control signals SA1 and SA2 separately control the amplification or attenuation achieved by separate scaling amplifiers 102 and 104, respectively. Scaling control signals SA1 and SA2 may be real to scale amplitudes, or imaginary to shift phases or complex with both real and imaginary components to both scale amplitudes and shift phases. It will be appreciated that the amplification may be applied at the output of encoder 10, before multipliers 12 and 14, after multipliers 12 and 14 or in antennas 106 and 108. Although separate spreading codes in a CDMA system are applied to multipliers 12, 14 as described here to create the orthogonal beams, it will be appreciated that any means to create orthogonal beams enable the separate power management of the transmissions from the controlled directional antennas (i.e., directions selected as described herein).

[0021] In a third embodiment (referred to as directional diversity and not separately shown), amplifiers 102 and 104 of FIG. 5 are removed from transmitter 100 so that no differential amplification is achieved, and both channels CH1 and CH2 have balanced and equal amplification, but their signals are transmitted directionally through controlled directional antennas 106 and 108.

[0022] There are several means to implement controlled directional antennas. In FIG. 6, known hex controlled directional antenna system 6 includes six co-sited comer reflector antennas, such as comer reflector antenna 8, arranged in a circle and all depicted in plan view. Each comer reflector antenna 8 includes a single half wave dipole 12 as an exciter element and comer reflectors 14. Each comer reflector antenna 8 illuminates a 60 degree beam width in plan view. Hex diversity antenna system 6 has been shown to provide angle location information that gives the bearing angle from a base station to the remote station based on received signal strength at 820 MHz (Rhee, Sang-Bin, "Vehicle Location In Angular Sectors Based On Signal Strength", IEEE Trans. Veh. Technol., vol. VT-27, pp 244-258, Nov. 1978). Such co-sited corner reflector antennas could divide a 360 degree coverage into three sectors (120 degree antennas), four sectors (90 degree antennas), five sectors (72 degree antennas), eight sectors (45 degree antennas), or any convenient number of sectors that may be realizable.

[0023] In the second and third embodiments of the present invention, a controlled directional antenna system is used for cellular radio transmitter 1 (FIG. 1). A controlled directional antenna system is defined as being capable of providing two or more distinguishable and separately controllable beams. It may be a single antenna with two or more exciter elements arranged to generate two or more beams (e.g., arranged to generate two discernable beams respectively polarized at a +/- 45 degree slant to the vertical, but otherwise cover the same sector). It may be a multi-antenna system to generate beams that cover different sectors. For example, the controlled directional antenna system may advantageously be a hex comer reflector system, such as the antenna system depicted in FIG. 6. The controlled directional antenna system is used in a receive mode to determine the angle location of remote station 2 based on a signal transmitted from remote station 2. The two sectors with the strongest received signals are identified as the likely direction of arrival of direct path 3 and indirect path 5 (see FIG. 1). The antennas illuminating these two sectors are selected to be directional antennas 106 and 108 of the second and third embodiments of the present invention (FIGS. 4 and 5). Alternatively, the respective directions of arrival may be determined based on a calculation of the angular power spectrum as discussed below.

[0024] In FIG. 7, known stearable beam phased array antenna 20 includes an array of exciter elements 22 (e.g., halfwave dipole) disposed to be spaced from ground plane or reflector plane 24. FIG. 7 depicts eight radiating elements, but more or fewer elements may be used. Each exciter element 22 is fed with a signal from a corresponding phase shifter 26. Each phase shifter 26 alters the phase and attenuates (or amplifies) the amplitude of signal S according to a corresponding individual control portion of control signal C. For example, control signal C includes 8 phase shift parameters and 8 attenuation parameters. Each phase and amplitude parameter individually controls the phase and amplitude radiated from a corresponding element of the eight exciter elements of antenna 20. The angular beam width of such an antenna is limited by the ratio of the wavelength of the signal being radiated divided by the aperture dimension D; however, by controlling signal amplitudes on exciter elements 22 as distributed across the antenna with what is called a weighting function, the beam may be shaped to broaden the beam, flatten the center of the beam and/or suppress side lobes. By controlling the gradient of the phase at the exciter elements across the antenna, the beam may be electronically directed to point in a controlled direction.

[0025] In a variant of the second and third embodiments, the antenna system for transmitter I (FTG. 1) includes plural phased array antennas 20 organized in a multi-antenna system. In FIG. 8, an exemplary multi-antenna system may include three antennas (taken to be phased array antennas 20) arranged to point outward in equally spaced angular direction so that the three phased array antennas 20 are formed into the antenna system at the base station. Each antenna 20 is designed to cover a 120 degree sector. The base station locates the remote station by electronically scanning antenna 20. Amplitude weights for each radiating element are preferably set to a maximum and are all equal so that the antenna provides its narrowest beam (most directional beam). The receive beam is scanned in steps by first computing the phase parameters for control signal C that represent a gradient in phase across the antenna to achieve a desired beam point, and then controlling antenna 20 to point in the desired direction. Second, a receiver at transmitter I (FIG. 1) detects any received signal strength. The steps of pointing a receive beam and detecting a signal strength are repeated at each of several beam positions until the entire sector covered by antenna 20 has been scanned. In this way, the angle location of remote station 2 is determined to a precision limited only by the narrowest achievable beam width of antenna 20. Once the location of direct path 3 and indirect path 5 are determined to be in different sectors (e.g., 120 degree sectors), antennas 106 and 108 (FIG. 5) are selected from the plural antennas 20 of the antenna system that are closest to direct path 3 and indirect path 5, and within the sector covered by each selected antenna 20, the phase gradients that define beams pointing at the angle locations for direct path 3 and for indirect path 5 are determined. Alternatively, when paths 3 and 5 lie in a single sector, two transmitting beams can be formed within the single sector to be directed along paths 3 and 5 if the antenna system is capable of forming the two beams in the single sector (see discussion below with respect to FIG. 10).

[0026] In FIG. 9, antenna system 30 includes four radiating elements 32 disposed to be spaced from ground plane or reflector plane 34. Each radiation or exciter element 32 is fed with a signal from known Butler matrix 36. The Butler matrix provides phase shifting and combination functions that operate on signals S1, S2, S3 and S4 so that the radiation from the four exciter elements 32 combine to generate four fixed angularly directed and orthogonal beams B1, B2, B3 and B4. In general, a Butler matrix performs a Fourier processing function to feed M radiating elements so as to form M fixed and orthogonal beams ("angular bins"). For example, in antenna system 30, signal S1 is transmitted only in first beam B1, signal S2 is transmitted only in second beam B2, signal S3 is transmitted only in third beam B4, and signal S4 is transmitted only in fourth beam B4. A switching matrix may be used to direct desired signals (e.g., the signals CH1 and CH2 of FIG. 5) onto any of the lines for signals S1, S2, S3, and S4 and from there into respective beams B1, B2, B3 and B4.

[0027] In a variant of the second and third embodiments, the antenna system for transmitter 1 (FIG. 1) includes plural "Butler matrix" antennas 30 organized in a multi-antenna system. In FIG. 8, an exemplary multi-antenna system includes three antennas (taken here to be "Butler matrix" antennas 30) arranged to point outward in equally spaced angular direction so that the three "Butler matrix" antennas 30 are formed into the antenna system at the base station. Each antenna 30 is designed to cover a 120 degree sector with, for example, four beams. The base station locates the remote station by electronically switching between the four beams (each 30 degrees) of each of the three antennas 30 and detecting the signal strength received. In this way, the angle location of remote station 2 is determined to a precision of one beam width of antenna 30. Once the locations of direct path 3 and indirect path 5 are determined, antennas 106 and 108 (FIG. 5) are selected from the two different "Butler matrix" antennas 30 that make up the antenna system for transmitter 1 (FIG. 1) if direct path 3 and indirect path 5 lie in different sectors. The two particular "Butler matrix" antennas 30 are selected to cover the sectors that are closest to direct path 3 and indirect path 5, and from there, a particular beam within each selected antenna 30 is selected that most closely aligns with the path. Alternatively, antennas 106 and 108 may be selected to be different beams of the same "Butler matrix" antenna 30. Within the sector covered by each antenna 30, the beam pointing at the angle location for each of direct path 3 and indirect path 5 is selected by a switch matrix (not shown).

[0028] In FIG. 10, antenna 40 is a modified version of phased array antenna 20 to provide two independently steerable and shapable beams. Antenna 40 includes an array of exciter elements 42 (e.g., half wave dipole) disposed to be spaced from ground plane or reflector plane 44. FIG. 10 depicts eight radiating elements, but more or fewer elements may be used. However, unlike antenna 20, each exciter element in antenna 40 is fed by a signal from a corresponding summer 48. Each summer 48 superimposes (e.g., adds) signals from two corresponding phase shifters 46-1 and 46-2.

All phase shifters 46-1 form a first bank of phase shifters, and all phase shifters 46-2 form a second bank of phase shifters. Each phase shiner 46-1 in the first bank alters the phase and attenuates (or amplifies) the amplitude of signal S1 according to a corresponding individual control portion of control signal C1. For example, control signal C1 includes 8 phase shift parameters and 8 attenuation parameters to individually control the phase and amplitude output from the corresponding phase shiner 46-1. Correspondingly, each phase shifter 46-2 in the second bank alters the phase and attenuates (or amplifies) the amplitude of signal S2 according to a corresponding individual control portion of control signal C2. For example, control signal C2 includes 8 phase shift parameters and 8 attenuation parameters to individually control the phase and amplitude output from the corresponding phase shifter 46-2. Summers 48 combine the outputs of respective phase shiners 46-1 and 46-2 and provide the combined signal to radiating elements 42. In this way, control signal C1 controls a first beam that radiates signal S1, and control signal C2 simultaneously controls a second beam that radiates signal S2.

[0029] In a variant of the second and third embodiments, the antenna system for transmitter 1 (FIG. 1) includes plural phased array antennas 40 organized in a multi-antenna system. In FIG. 8, an exemplary multi-antenna system includes three antennas (taken here to be phased array antennas 40) arranged to point outward in equally spaced angular direction so that the three phased array antennas 40 are formed into the antenna system at the base station. Each antenna 40 is designed to cover a 120 degree sector with two independently shapable and steerable beams. The base station locates the remote station by electronically scanning a beam of antenna 40 as discussed above with respect to antenna 20 (FIG. 7). Once the location of direct path 3 and indirect path 5 are determined, antennas 106 and 108 (FIG. 5) are selected from the plural antennas 40 of the antenna system that are closest to direct path 3 and indirect path 5, and within the sector covered by each selected antenna 40, the phase gradients that define beams pointing at the angle location for direct path 3 and for indirect path 5 are determined.

[0030] Alternatively, antennas 106 and 108 may be selected to be different beams of the same dual beam antenna 40. In FIG. 11, antennas 106 and 108 (FIG. 5) are implemented in separate beams (i.e., beams 1 and 2) of dual beam antenna 40, and scaling amplifiers 102 and 104 (of FIG. 5) are not needed since the scaling function may be achieved by scaling the amplitude coefficients of control signals C1 and C2 (FIG. 10).

[0031] In a fourth embodiment, the base station uses a time division multiple access (TDMA) transmitter instead of a spread spectrum CDMA transmitter. In FIG. 12, training sequence TS1 is modulated in QPSK modulator 101 and from there fed to a first input of multiplexer 105, and training sequence TS2 is modulated in QPSK modulator 103 and from there fed to a first input of multiplexer 107. Training sequences TS 1 and TS2 are orthogonal and provide the means by which remote station 2 can discern between the beams in much the same was as pilot codes help distinguish beams in a CDMA system. In the TDMA system, multipliers 12 and 14 (of FIGS. 4, 5 and 11) are omitted and channel signals CH1 and CH2 are fed to second inputs to multiplexers 105 and 107, respectively. In this fourth embodiment amplifiers 102 and 104 independently amplify or attenuate the outputs of respective multiplexers 105 and 107. The outputs of amplifiers 102 and 104 are fed to the antenna system (through up converters, etc., not shown). The antenna system may provide the overlaid coverage of diversity antennas 16, 18 (FIG. 4) as in the first embodiment or may provide controlled directional coverage of directional antennas 106, 108 (FIGS. 5 and 11) as in the second and third embodiments. Moreover, in the case of controlled directional coverage, a variant may be to forego power management and omit amplifiers 102, 104 and rely on angle (beam) diversity by steering beams from directional antennas 106,108. A data slot in a time division system may include, for example, 58 data bits followed by 26 bits of a training sequence followed by 58 data bits as in a GSM system. The training sequence identifies the source of signal S_{IN} and the individual beam to remote station 2 so that the remote station can separately discern the beams. In this way, remote station 2 can separately receive the two beams using the training sequences, instead of using orthogonal spreading codes OC as in a CDMA system.

[0032] Although two beams are discussed, extensions to higher order coding techniques with more beams are straightforward. For example, four symbols (S_1, S_2, S_3, S_4) encoded into four channel signals (CH1, CH2, CH3, CH4) in four symbol time slots so that the original symbols are recoverable from the encoded channel signals. The four channel signals are then transmitted from the base station in four beams, each beam corresponding to a channel signal of the channel signals CH1, CH2, CH3, and CH4. Although QPSK modulation techniques are discussed herein, extensions to other PSK modulation techniques are straightforward, and extensions to other modulation techniques (e.g., QAM) are equally useable.

[0033] In FIG. 13, a closed loop control system to manage transmit powers is depicted as process S10. In step S102, the base station selects the power level to be transmitted from each antenna. For example, in a two antenna system, the base station selects powers P1 and P2 based on the total power (i.e., P1 + P2) as defined by a conventional power control loop (e.g., a control loop typical to a CDMA system) and the relative powers (i.e., P1/P2) as defined by power control coefficients measured at remote station 2. In step S104, a value representing the selected transmit power level is sent to the remote station in a signaling channel. In step S106, the power level received at the remote station from each antenna radiation pattern is measured, and corresponding power control coefficients are determined. The power control coefficients for each antenna radiation pattern are determined at remote station 2 to be proportional to the received power at remote station 2 divided by the transmitted power as indicated by the power level value that is sent to the remote station in a signaling channel. In step 106 the power control coefficients are sent from the remote station to the base station in a signaling channel. In step S108, the power control coefficients from step S106 are compared for each antenna. In step S110, adjustments in transmit signal power are determined according to the comparision of step S108. The adjustments are made to increase transmit powers sent in channels that have favorable transmission qualities and reduce transmit powers in channels that have poor transmission qualities. Then, in step S102 at the begining of the cycle, the base station selects adjusted transmit powers to form the basis for the powers to be transmitted from the antennas during the next cycle of the closed loop beam power management. The loop cycle delay may be one time slot as in a third generation TDMA system.

[0034] Alternatively, the remote station may compare (in step S 108) the power control coefficients for each antenna from step S106 and then compute power coefficient indicator information to be sent from the remote station to the base station in an up link signaling channel. For example, a ratio of the power control coefficients (e.g., P1/P2 in a two antenna case) may be advantageously computed as the power coefficient indicator information and transmitted in the up link direction. Or the power coefficient indicator information may be quantized value of the ratio (e.g., a single bit indicating whether P1 > P2 or not).

[0035] Alternatively, in step S104, the selected transmit power is saved for a cycle time of the closed loop control system. For example, in a two antenna system, the base station selects powers P1 and P2 based on the total power (i.e., P1 + P2) as defined by a conventional power control loop (e.g., a control loop typical to a CDMA system) and the relative powers (i.e., P1/P2) as defined by power control coefficients measured at remote station 2. In step S106, the power levels received at the remote station from each antenna radiation pattern are measured at remote station 2 and sent as power control coefficients in an up link signaling channel from remote station 2 to base station 1. The power control coefficients are normalized to their respective transmit powers as saved in step S104. In step S108, the normalized power control coefficients from step S106 are compared at the base station for each antenna. In step S110, adjustments in transmit signal power are determined according to the comparison of step S108. Then, in step S102 at the beginning of the cycle, the base station selects adjusted transmit powers to form the basis for the powers to be transmitted from the antennas during the next cycle of the closed loop beam power management.

[0036] In FIG. 14, a cellular radio system with closed loop beam power management controls includes base station 210 and remote station 230. Base station 210 includes space-time encoders 212 to encode a stream of symbols into first and second space-time coded signals, antenna system 216, transmitter 214 to transmit the first and second space-time coded signals at respective first and second initial transmit powers from the antenna system so as to form respective first and second radiation patterns, base station receiver 220 to receive power coefficient indicator information from the remote station, and power management controller 222 to determine first and second adjusted transmit powers based on the respective first and second initial transmit powers and the power coefficient indicator information.

[0037] Antenna system 216 may include plural antennas where each antenna is an antenna that generates either a substantially omni-directional radiation pattern or a radiation pattern directed to a sector. Omni-directional antennas are advantageously spaced apart. Antenna system 216 may form the first and second radiation patterns as orthogonal radiation patterns capable of being separately received at the remote station. Alternatively, transmitter 214 includes a circuit to process the first and second space-time coded signals so that the signals transmitted from the antenna system are orthogonal and can be separately received at the remote station.

[0038] Antenna system 216 is capable of generating plural beams (i.e., a multi-beam antenna) and the base station include antenna control 218 to control the multi-beam antenna to form the plural beams. In one embodiment, the multi-beam antenna may be a multi-port Butler matrix antenna, and in this case, transmitter 214 will include amplifiers to scale the first and second space-time coded signals to form respective first and second scaled space-time coded signals based on the respective first and second adjusted transmit powers, and antenna control 218 will include a switch to couple the first and second scaled space-time coded signals into respective first and second input ports of the Butler matrix antenna to form the respective first and second beams.

[0039] Alternatively, the multi-beam antenna includes a phased array antenna system, and antenna control 218 includes a beam steering controller to form first and second weighting functions. The beam steering controller includes logic to input the first and second weighting functions into the phased array antenna system to scale antenna gains of the respective first and second beams based on the respective first and second adjusted transmit powers without scaling amplifiers in transmitter 214. The phased array antenna system may include either a plural beam phased array antenna (e.g., 40 of FIG. 10) or plurality of phased array antennas (e.g., 20 of FIG. 7).

[0040] In some embodiments, the power coefficient indicator information includes first and second power control coefficients, and base station receiver 220 receives up link signaling information and detects values of the first and second power control coefficients in the up link signaling information.

[0041] Power management controller 222 includes a circuit (e.g., logic or a processor) to determine the first adjusted transmit power to be greater than the second adjusted transmit power when the indicated first path attenuation characteristic (or first power control coefficient) is less than the indicated second path attenuation characteristic (or second power control coefficient).

[0042] Remote station 230 includes remote station receiver 234, detector 236, power measurement circuit 238 and processor 240. Receiver 234, detector 236, power measurement circuit 238 and processor 240 constitute a circuit by which remote station 230 can determine an indicated path attenuation characteristic based on a power received from the first radiation pattern and measured in circuit 238 and an initial transmit power determined in detector 236. With this circuit, remote station 230 can determine an indicated first path attenuation characteristic for a first radiation pattern of antenna system 216 and an indicated second path attenuation characteristic for a second radiation pattern of system 216 since the two radiation patterns are separately receivable. Detector 236 determines the initial transmit power, power measurement circuit 238 measures the power received from the radiation pattern as received by receiver 234, and processor 240 determines a power control coefficient to be proportional to the power received divided by the value of the initial transmit power. Power measurement circuit 238 measures an instantaneous power received, or in an alternative embodiment, measures an averaged power received, or in an alternative embodiment measures both and forms a combination of the instantaneous power received and the average power received. Remote station 230 further includes transmitter 242 to send values the power coefficient indicator information or ofthe indicated first and second path attenuation characteristics to the base station.

[0043] In a variant, processor 240 forms the power coefficient indicator information as a ratio of the indicated first path attenuation characteristic divided by the indicated second path attenuation characteristic. In an alternative variant, processor 240 forms the power coefficient indicator information with a first value when the indicated first path attenuation characteristic is less than the indicated second path attenuation characteristic and to form the power coefficient indicator information with a second value when the indicated first path attenuation characteristic is greater than the indicated second path attenuation characteristic.

[0044] In an exemplary embodiment, the base station transmits a first signal at first predetermined signal power P1 from the first antenna, and a receiver in remote station 2 determines first power control coefficient PCC1 to be a power received from the first antenna at the remote station. The base station also transmits a second signal at second predetermined signal power P2 from the second antenna, and a receiver in remote station 2 determines second power control coefficient PCC2 to be a power received from the second antenna at the remote station.

[0045] Both the first and second signals are transmitted simultaneously from respective first and second antennas in ordinary operation at their respective predetermined power levels. The transmit powers are distinguishable at remote station 2 by use of different orthogonal codes OC in multipliers 12 and 14 (FIGS. 4, 5 and 11) or by use of orthogonal training sequences as may be used in a TDMA base station (FIG. 12). The receiver in remote station 2 determines the signal power received from each antenna and transmits a value representing these received signal powers to the base station in a portion of the up link signaling data as separate power control coefficients PCC1 and PCC2 or as a relative power control coefficient PCC1/PCC2.

[0046] In a preferred embodiment, the base station first transmits signals in ordinary operation from the plural antennas at selected powers that may be unequal (S102). In one variant, the base station sends the power levels selected to be transmitted from each of the plural antennas in a down link signaling channel. The remote station (1) receives the base station's selected power levels (S104), (2) determines the signal powers received from the antennas (S106), and (3) compares the power transmitted from the base station from each antenna to the powers received at the remote station to determine the relative attenuations in the down link paths (S108) as the ratio of the received power to the corresponding transmitted power. The remote station sends this ratio determined for each antenna as power control coefficients back to the base station in the up link signaling data. Then, the base station adjusts the power allowed to be transmitted from the base station from each antenna according to the determined relative attenuations for all further down link transmissions (S110).

[0047] In another variant, (1) the remote station determines power control coefficients to be the signal powers received from the antennas (S106), and (2) the remote station sends the power control coefficients back to the base station in the up link signaling data. Then, the base station (1) adjusts for closed loop time delays in its receipt of the power control coefficients from remote station 2 (S104), (2) compares the power transmitted from the base station from each antenna to the power control coefficients received at the remote station to determine the relative attenuations in the down link paths (S108), and (3) adjusts the power allowed to be transmitted from the base station from each antenna according to the determined relative attenuations for all further down link transmissions (S110).

[0048] In either variant, the power allowed to be transmitted from an antenna will be greater for antennas associated with paths determined to posses a lesser path attenuation. For example, an indicated path attenuation characteristic is advantageously determined to be the ratio of the power received at remote station 2 to the power transmitted from base station 1. In this way, little or no power is transmitted in a path that is not well received by remote station 2, while a greater power is transmitted in a path that is well received by remote station 2. In many multi-path environments, increasing power transmitted in a path that has too much attenuation does little to improve reception at remote station 2, but such increased power would contribute to co-channel interference experienced by other remote stations. To improve the overall cellular radio system, the paths with the least attenuation are permitted the greatest transmit beam powers. The base station adjusts the power transmitted from each antenna by control scaling signals SA1 and SA2 (FIGS. 4 and 5) or by controlling the overall antenna gain for each beam by adjusting the amplitude parameters in control signal C (of FIG. 6) or in signals C1 and C2 (of FIG. 9).

[0049] In an embodiment of this closed loop method of power control, the remote station determines which antenna (or beam) is associated with the least attenuation path. The remote station sends an indication of which antenna (or beam) is favored (i.e., least attenuation) back to the base station in an up link signaling path. To conserve the number of bits sent in this up link signaling path, the remote station preferably determines the favored antenna and indicates this by a single bit (i.e., a "0" means antenna 16 is favored and a "1" means antenna 18 is favored, see FIG. 4). The base station receives this single bit indicator and applies it to determine a predetermined relative power balance. For example, it has been determined that applying 80% of full power to antenna 16 (e.g., when this is the favored antenna) and 20% of full power to antenna 18 consistently provides better performance than applying 100% of full power to antenna 16 and no power to antenna 18. Thus, the base station receives the single bit relative power indicator and selects the relative power P1/P2 for antennas 16 and 18 to be 80%/20% for a "1" indicator bit and 20%/80% for a "0" indicator bit.

[0050] In slowly varying radio environments, the coefficients (or any related channel information) can be parsed into segments, and the segments (containing fewer bits than the entire coefficient) can be sent to the base station in the up link signaling data using more up link time slots. Within a segment (perhaps plural TDMA time slots), the most significant bits are preferably transferred first, and these course values are gradually updated to be more precise using consecutive bits. Conversely, in rapidly varying radio environments, a special reserved signaling symbol may indicate the use of one or more alternative compressed formats for the up link transmission of the coefficients where an average exponent of all of the coefficients is transmitted (or presumed according to the signaling symbol) in the up link, and then only the most significant bits of the coefficients are then transmitted (i.e., truncating the less significant bits). In the extreme, only one bit is transmitted in the up link direction indicating that the power control coefficient is 1 (e.g., 80% of full power transmission) when the down link channel is good, and indicating that the power control coefficient is 0 (e.g., only 20% of full power transmission) when the associated channel is not adequate.

[0051] This closed loop control over beam power management is self adapting. If power control coefficients are up linked to the base station that cause over compensation in beam power, this closed loop control system will correct for this during the next closed loop control cycle. Persons skilled in the art will appreciate that other data compression techniques may be employed in the up link signaling to adjust to rapidly varying radio environments. Similarly, persons skilled in the art will appreciate that the remote station, not the base station, may compute commands to the base station to increase, or decrease, the power in specific beams.

[0052] In an alternative variant suitable for slowly varying radio environments, the first and second beams may be sequentially transmitted at their respective predetermined power levels in a calibration mode. In such a variant, only one beam is transmitted at a time so that the remote station need not employ orthogonal codes OC or orthogonal pilot signals to determine from which beam the received signal strength (e.g., power control coefficient) has been received. Once the channel attenuation is determined, signal S_{IN} is sent using the beamspace time coding technique.

[0053] In addition to embodiments that rely on amplifiers 102 and 104 or beam gain in phase array antennas to control closed loop power management, another embodiment relies on angular diversity management and/or beam width management with the power management being omitted. Yet another embodiment relies on both the power management and either angular diversity management, beam width management, or both.

[0054] The performance of beamspace time coding techniques depends at least in part on angular spread AS that characterizes the radio environment and how the base station adapts the beams to match the angular spread. Down link performance is generally improved when the down link beams are directed at angles of arrival at which sharp peaks occur in an angular power spectrum of a signal from a remote station. The sharp peaks suggest good transmission along the indicated path (e.g., likely direction of paths 3 and 5). However, sharp peaks may not always be found. When the angular power spectrum is diffuse and sharp peaks cannot be found, an estimate of angular spread AS is made, and the plural beams used for down link transmissions are allocated to approximately cover the angular spread. In this way the down link transmission spatially matches the total channel as determined by the angular spread.

[0055] The circuit to measure the angular power spectrum includes receiver 220 (FIG. 14) and such signal and data processing circuitry as is required to determine the angular power spectrum and peaks therein as discussed below. When a peak in the angular power spectrum is detected, an angular position is defined by the peak. Then, to direct the beam direction toward an angular position as detected, antenna controller 218 computer an array steering vector to input into antenna system 216 (FIG. 14). When an excessive number of peaks are detected in the angular power spectrum, power management controller 222 (FIG. 14) selects the angular directions to be used to form beams. Power management controller 222 may select beams directions toward specific angle of arrival paths (i.e., peaks), or power management controller 222 may select beam directions, and possibly beam widths, so as to cover a detected angular spread. The selected directions are provided to antenna controller 218 to form the beam commands to the antenna system.

[0056] In systems using frequency division duplexing, the up link and down link transmissions take place at different frequencies. There is no guarantee that peaks measured in the up link power spectrum will occur at angle that correspond to angles with good transmission performance in the down link direction. However, by employing either angle diversity management or beam width management or both, there will be a greater likelihood of producing a good down link transmission.

[0057] Both angular diversity and beam width management require a measurement of the angular power spectrum in one form or another. The remote station broadcasts an up link signal in its normal operation (e.g., signaling operation), the antenna system at the base station receives the signal, and the base station determines an angular power spectrum (i.e., a received power as a function of bearing angle in a plan view). FIG. 18 is a graph depicting the angular location of signal power received from remote station 2. In FIG. 18, discrete power measurements at each of 12 angular locations are shown based on, for example, twelve fixed location antenna beams pointed at 30 degree intervals in the antenna system for base station 1. The exemplary 12 beam antenna system may include three Butler matrix antennas, triangularly arranged, to form the 12 beam antenna system where each Butler matrix antenna forms four beams. While a 12 beam antenna system is considered in this example, it will be appreciated that any number of beams in an antenna system may be applied to the present invention (e.g., 24 beams, etc).

[0058] Alternatively, the antenna system may include three phased array antennas, triangularly arranged, to form an antenna system capable of forming the 12 beam where each phased array antenna forms a steerable beam with a beam width of 30 degrees so as to permit scanning over four beam positions. The 12 beam antenna system may also include 12 antennas of any type that have a 30 degree beam width and are angularly disposed at 30 degree increments around a 360 degree sector. While a 12 beam antenna system is considered in this example, it will be appreciated that any number of beams in an antenna system may be applied to the present invention (e.g., 24 beams, etc).

[0059] An antenna system based on a phased array antenna provides an opportunity to generate a more interpolated angular power spectrum (e.g., G1 of FIG. 18) by steering the antenna beam to point at as many angular positions as desired to generate the angular power spectrum. Power management controller 222 (FIG. 14) generates the angular power spectrum in process S20 (FIG. 15) by looping on θ in steps S20A and S20B and determining the angular power in step S21. Given the angle θ, power management controller causes antenna controller 218 (FIG. 14) to computer an array steering vector and point the antenna (step S211 of FIG. 16). The phased array antenna then receives a signal in receiver 220 (FIG. 14) from remote station 2 in each radiating element of the phased array antenna to form a signal vector in step S212 of FIG. 16. Each radiating element is preferably spaced apart from an adjacent element by one-half of the wavelength. For example, if a phased array antenna were to include 12 radiating elements (only 8 radiating elements are shown in antenna 20 of FIG. 7), the signal received in each of the 12 radiating elements would be sampled to form a measured signal vector. The sampled signal is preferably a complex value having amplitude and phase information. The signals from each of the 12 radiating elements are formed into a 12 element received signal vector as column vector x. Next, the complex conjugate transpose of received signal vector x is formed as row vector x^H, and the spatial covariance matrix of the received signal, $R=xx^H$, is calculated in step S213 (FIG. 16). When received signal vector x is 12 elements long, then the spatial covariance matrix of the received signal, $R=xx^H$, will be a 12 by 12 matrix.

[0060] Array steering vector $\bar{a}(\theta)$ is a column vector with one vector element for each radiating element of the phased array antenna. For example, if the phased array antenna were to include 12 radiating elements (e.g., half dipoles), array steering vector $\bar{a}(\theta)$ would include 12 vector elements. Array steering vector $\bar{a}(\theta)$ is constant C of FIG. 7, and it is used to point the beam of the phased array antenna toward bearing angle θ. Each vector element is given by:

$$\bar{a}_m(\theta)=\exp(-j\times k\times m\times d\times \sin\theta),$$

where k is 2π divided by the wavelength, m is an index from 0 to M (e.g., from 0 to 11 for a 12 element antenna) defining a number associated with the radiating element of the phased array antenna, d is the separation between radiating elements of the phased array antenna (preferably one-half of the wavelength) and θ is the bearing angle of the antenna beam formed.

[0061] Each vector element of array steering vector $\bar{a}(\theta)$ is a corresponding vector element of constant C as depicted in FIG. 7 so that the full vector combines to define an angle of arrival θ of the received signal in the receive beam, where θ is an angle with respect to a convenient reference direction of the phased array antenna. The complex conjugate transpose of array steering vector $\bar{a}(\theta)$ is row vector $\bar{a}(\theta)^H$.

[0062] The product, $xx^H\bar{a}(\theta)$, is still a column vector with one vector element for each radiating element of the phased array antenna. The product, $\bar{a}(\theta)^H xx^H\bar{a}(\theta)$, is a single point, a scalar, determined at step S214 (FIG. 16) to give the value of the angular power spectrum P(θ) at the angle of arrival θ. Thus, the angular power spectrum P(θ) is depicted in FIG. 18 at G1 and is computed to be:

$$P(\theta)=\bar{a}(\theta)^{H}\hat{x}\hat{x}^{H}\bar{a}(\theta)$$

where $\bar{a}(\theta)$ is an array steering vector, $\hat{x}$ is the received signal vector, $\hat{x}\hat{x}^{H}$ is the spatial covariance matrix of the received signal, and H denotes the complex conjugate transpose.

[0063] The above described equation for computing the array steering vector assumes the half wavelength spaced radiating elements are arrayed linearly. However, it will be appreciated by persons skilled in the art how to compute an array steering vector for radiating elements arrayed long a curved path. Three slightly "bowed out" antenna arrays may advantageously be employed in the antenna system depicted in FIG. 8. In fact, the antenna arrays may be severely "bowed out" so as to form a circle (e.g., FIG. 6). It will be appreciated by persons skilled in the art that computation of an array steering vector for such severely curved arrays of radiating elements will advantageously employ amplitude control as well as phase control in the array steering vector.

[0064] To provide improved performance the angular power spectrum is determined by averaging repeated measurements. In FIG. 17, the array steering vector is prepared and the antenna beam is pointed in step S211. The plural measurements are made by looping in steps S215A and S215B. Within this loop, received signal vector x is repeatedly measured in step S216 and the covariance matrix R is repeatedly determined and saved in step S217. Then, an average covariance matrix is determined in step S218, and angular power spectrum P(θ) is determined in step S214. This averaging determination is repeated several times over a time interval for each predetermined direction θ. In this way, fast fading phenomena are averaged out. The time period must be short enough that a mobile remote station 2 will not change position sufficiently to change the beam in which it is located during the averaging period. This time period, is preferably larger than the channel coherence time to average out fast fading effects. While the channel coherence time is not rigorously and universally defined, it may be taken to be proportional to and approximately equal to an inverse of the Doppler spread.

[0065] The Doppler spread is more rigorously defined. Due to a relative velocity between the base station and a mobile remote station, there will be a physical shift in the received frequency with respect to the transmitted frequency. The Doppler spread is twice this frequency shift. For example, the Doppler frequency shift is the ratio of the relative velocity to the wavelength (in like units, meters/second divided by meters or feet/second divided by feet, etc.). If a mobile remote station is traveling 13.9 meters/second (about 50 km/h) and the wavelength is about 0.15 meters (e.g., 2,000 MHz signal with the speed of light equal to 300,000,000 meters per second), then the Doppler frequency shift is 92.7 Hz, the Doppler spread is 185 Hz, and the channel coherence time is about 5.4 milliseconds. It can be easily verified that at a relative velocity of 40 meters per second (about 144 km/h) the channel coherence time is about 1.9 milliseconds, and that at a relative velocity of 1 meter per second (about 3.6 km/h) the channel coherence time is about 75 milliseconds.

[0066] The averaging time interval is preferably set to be greater than an inverse of the Doppler spread and less than a time in which a mobile station moving at an expected angular speed moves one-half of a beam width of the base station antenna system. The base station knows the remote station's range or can infer the range from signal strength. The base station is designed to communicate with mobile stations that can move at speeds up to a predetermined speed. This speed divided by the range may be taken to be the angular speed if the mobile station is moving radially around the base station. Setting the averaging interval to be a half beam width divided by the angular speed provides an estimate of the time in which a mobile remote station 2 will not change position sufficiently to change the beam in which it is located during the averaging period.

[0067] The time period over which the power P(θ) is averaged is usually much greater than the channel coherence time. For example, in a wide band CDMA system operating in an environment with a high incidence of multi-path reflections (e.g., urban environment), the average period could be tens of time slots. For indoor environments with a high incidence of multi-path reflections, the mobile is much slower and the averaging period can be much longer.

[0068] The base station computes the angular power spectrum and determines whether or not sharp peaks are indicated in the power spectrum. When sharp peaks are indicated, the angle location of each peak is determined. When the power spectrum is diffuse and no sharp peaks are indicated, the base station determines angular spread AS by first determining the angles at which the received angular power spectrum exceeds a predetermined threshold (G2 in FIG. 18). The threshold may also be adaptable based on the radio environment (e.g., signal density) detected by base station 1.

[0069] Sharp peaks in the angular power spectrum may be detected by, for example, using a two threshold test. For example, determine a first continuous angular extent (in degrees or radians) at which the power spectrum exceeds a first threshold G3. Then, determine a second continuous angular extent at which the power spectrum exceeds a second threshold G2 (lower than first threshold G3). When the ratio of the first angular extent divided by the second angular extent is less than a predetermined value, peaks are indicated.

[0070] When peaks are indicated, angle diversity management (i.e., the management of the direction of arrival of the beams) is invoked, and possibly beam width management is invoked. The sharpness of the spectral peaks may be determined by comparing the angular power spectrum against two thresholds. For example, in FIG. 18, three peaks exceed the threshold G2, but only two peaks exceed the threshold G3. The angular spread of a single peak determined according to threshold G2 is broader than the angular spread determined according to threshold G3. The ratio of the angular spread of the single peak determined by G3 as compared to the spread determined by G2 is a measure of the sharpness of the peak. Alternatively, the threshold against which the angular power spectrum is measured may be moved adaptively until there are at most two peaks in the angular power spectrum above the threshold to reveal the directions of paths 3 and 5. For example, when two sharp peaks occur in the angular power spectrum and the base station transmits two beams, the base station defines the direction of these peaks (i.e., the two distinct angular directions where the power spectrum exceeds threshold G3) to be the angular directions for paths 3 and 5 (FIG. 1). This is referred to as angle of arrival diversity. The base station points steerable beams, or selects fixed beams to point, along respective paths 3 and 5. Persons skilled in the art will appreciate how to extend angular diversity management to more than two beams.

[0071] On some occasions, the angular power spectrum includes three or more angular positions that correspond to respective peaks in the angular power spectrum. When the base station has two beams, the base station selects first and second angular positions from the three or more angular positions either (1) based on the avoidance of angles at which co-channel users are located so as to minimize co-channel interference on a system wide basis, or (2) so as to balance power distribution in amplifiers of the transmit station.

[0072] The beam widths in a phased array antenna are generally selectable by controlling an amplitude of elements in the beam steering vector (e.g., vector C of FIG. 7). When the antenna system includes a phased array antenna with controllable beam widths and the spectral peaks are sharp, the base station sets or selects beams to be as narrow as practical given the antenna system in order to concentrate the transmit power in directions along respective paths 3 and 5. Paths 3 and 5 are expected to have good transmission properties since the spectral power peaks are sharp.

[0073] On the other hand, when the angular power spectrum is so diffuse that peaks are weak or not indicated, a general angular window is determined based on the angular extent over which the power spectrum exceeds a threshold (e.g., G2 of FIG. 18) or at least the continuous angular extent needed to cover the peaks where the angular power spectrum exceeds the threshold. In such a case, preferred embodiments of the invention select beams such that the sum of the beam widths for all beams used for down link transmissions approximately equals angular spread AS.

[0074] When the antenna system includes a phased array antenna with controllable beam widths but the spectral peaks are not so sharp, the base station first determines the angular spread to be the angular extent of the power spectrum that is greater than a threshold or at least the continuous angular extent needed to cover the peaks where the angular power spectrum exceeds the threshold. Then, the base station sets or selects the beam widths for the beams to approximately cover the angular spread. This is referred to as angular power diversity or beam width management. For example, a two beam base station that seeks to cover the angular spread will select a beam width for both beams to be about half of the angular extent, and the base station points the two beams to substantially cover the angular spread.

[0075] Extensions to more beams are straightforward as will be appreciated by persons skilled in the art. For example, when the base station has capability for beamspace time encoding in a four beam base station, a beam width is selected for each beam that is approximately one-fourth of the angular spread. In this way the down link transmission will spatially match the channel. It is advantageous to match the coverage of orthogonal beams to the angular spread of the channel to obtain maximum angular diversity gain. However, usually two to four beams are adequate.

[0076] When the base station has an antenna system with plural fixed beams (as with a hex corner reflector antenna) and when the angular power spectrum is diffuse and angular spread AS exceeds the beam width of a single beam, a desirable variant of the invention combines two adjacent beams into a single broader beam (e.g., combine two 60 degree beams into a single 120 degree beam) to better match the radio channel. In such a case, the two adjacent beams are used as a single broader beam employing the same pilot code or orthogonalizing code. In fixed beam base stations, it is advantageous that the number of beams M that can be generated is large (e.g., M>4, and preferably at least 8) so that high beam resolution can be achieved. When a broader beam is needed to better match the channel, two adjacent beams may be combined.

[0077] The present invention fits well in a base station where the antenna system employs digital beam forming techniques in a phase array antenna (e.g., antenna 20 of FIG. 7 and antenna 40 of FIG. 10). With digital beam forming techniques, the apparent number elements in an antenna array (i.e., the apparent aperture dimension) can be electronically adjusted by using zero weighting in some of the elements according to the available angular spread. In this fashion, the beam width can be easily adapted by the base station to match the angular spread. This beam width control operates as an open loop control system.

[0078] In an alternative embodiment, beam hopping techniques are employed when the angular power spectrum exceeds the threshold in one large angular extent. A beam hopping technique is a technique that covers the angular spread sequentially. For example, when the transmit beams in any one time slot do not cover the angular spread, the angular spread may be covered during subsequent time slots. Consider an exemplary system that has a two beam base station capable of forming 30 degree beams where the angular spread covers 120 degrees (i.e., the width of four beams). In a beam hopping system, the base station forms two 30 degree beams for transmission during a first time slot so as to cover a first 60 degree sector of the 120 degree angular spread, and forms two other 30 degree beams for transmission during a second time slot so as to cover the remaining 60 degree sector of the 120 degree angular spread.

[0079] Beam hopping greatly improves performance in radio environments with large angular spreads. It is known that the down link performance degrades in frequency division duplex cellular radio systems when the angular spread becomes large, due at least in part to the increased angular uncertainty in the optimal selection of directions for transmission. In frequency division duplex systems, the up link directions determined to have good power transmission capacity (low attenuation) could be in a deep fade for a down link transmission due to the different carrier frequencies.

[0080] With a large angular spread in the radio environment, the number of possible directions for down link transmission will be large. Instead of selecting the two best directions, spatial diversity is achieved by sequentially forming down link beams to cover all of the potentially good directions where the angular power spectrum exceeds a threshold. This is particularly important in micro-cells or pico-cells where the angular spread can cover the whole sector or the whole cell.

[0081] In a scenario where remote station 2 is fixed or of low mobility, beam hopping has additional advantages over selection of the two strongest directions. When the best two directions are selected as the beam transmit directions for a large number of consecutive bursts, there is considerable penalty (in terms of loss of data) if the selected directions are a wrong choice (e.g., down link in deep fade even though up link is good). However, by hopping the beams over a group of potential directions, the loss of data from any one direction that turns out to be in deep fade will be for only a limited duration (e.g., only one time slot). This angular diversity tends to "whiten" the errors generated by selection of bad transmission directions.

[0082] Furthermore, the co-channel interference to other remote stations generated during beam hopping transmissions will tend to be whitened by the spatial spreading of the transmitted signal. Co-channel interference can be particularly troublesome when high data bit rate connections are required since high bit rate connections are achieved with high beam powers. The large amount of beam power involved in the high bit rate connection generates highly colored interference (not uniformly distributed) when a non-hopping scheme is employed by the base station for beam selection.

[0083] In FIG.19, another embodiment of the invention includes base station 210 and remote station 230 as described with reference to FIG. 14. In the present embodiment, base station 210 includes weighting amplifiers 102 and 104 to apply respective weights W1 and W2 to respective feed signals CH1 and CH2. In the present embodiment, weights W 1 and W2 are complex numbers or at least phase and amplitude pairs to control both the amplitude and phase of the signal transmitted from antennas 16 and 18. The weighted signals may alternatively be transmitted from directional antennas 106 and 108. FIG. 19 depicts diplexers 16D and 18D coupled between the weighting amplifiers and the respective antennas to duplex the antennas so they may be used in an up link receive mode as well as a down link transmit mode; however, a separate base station antenna may be used to receive up link signals.

[0084] In a preferred variant, one antenna is used as a reference with its corresponding weight set to 1+j0 (or amplitude = 1, phase = 0°). The other weight is determined relative to the reference weight. In general, base station 210 may employ two or more channels, each with an antenna, diplexer, weighting amplifier and all associated encoders. If M is the number of transmitting antennas, then the number of weights that must be determined is M - 1 since only differential information (i.e., weights) need to be determined. Without loss of generality, the following description focusses on two transmitting antennas (M = 2) so that only one complex number weight need be determined.

[0085] In FIG. 19, remote station 230 includes remote station antenna 232, remote station receiver 234 coupled to remote station antenna 232 through diplexer 233, signal measurement circuit 238, and processor 240. Receiver 234 constitutes a circuit by which remote station 230 receives first and second signals from respective first and second transmit antennas. Signal measurement circuit 238 and processor 240 and control modules described herein constitute a circuit by which remote station 230 determines channel state information based on the received first and second signals and segments the channel state information into a plurality of channel state information segments. Signal measurement circuit 238 measures the signal strength (and phase) received from each of the plural orthogonal antennas, and processor 240 determines channel state information. Signal measurement circuit 238 measures an instantaneous signal strength (and phase) received, or in an alternative variant, measures an averaged signal strength received and a phase at a reference time.

[0086] The processor determines the channel state information from information provided by signal measurement circuit 238. The processor selects a reference signal from among the signals received from the different antennas. For each of the plural antennas, the processor divides the received signal strength (and phase) determined by signal measurement circuit 238 by the selected reference signal strength (and phase). This ratio is determined as a ratio of complex numbers (or phase/amplitude pairs). The ratio for the reference antenna is, by definition, 1 +j0. In the case of two antennas, there is only one ratio to be sent, the ratio of the reference antenna being a constant reference.

[0087] Processor 240 determines the channel state information from the normalized ratio or ratios. Each ratio includes both amplitude and angle information. It is the object of this process to adjust the phase of signal transmitted from the two antennas (or more) so that they will constructively reinforce at remote station 230. To ensure constructive reinforcement, it is desired to phase delay or advance a signal transmitted from each antenna relative to the reference antenna. For example, if first antenna 16 is the reference antenna, then the angle portion of the ratio for the signal received from second antenna 18 is further examined. If this angle is advanced 45 degrees relative to the reference antenna, it will be necessary to introduce a 45 degree delay at the transmitter for second antenna 18 to achieve constructive reinforcement at remote station 230. Thus, processor 240 determines the amount of phase delay or advance needed to achieve constructive reinforcement at remote station 230 by adding the desired additional delay to the phase of the initial transmitted signal, and if the addition result is greater than 360, then subtracting 360. This phase angle then becomes the phase angle transmitted as part of the channel state information.

[0088] Processor 240 also determines the amplitude part of the channel state information. The object here is to emphasis the antenna with the best path (i.e., lowest attenuation path) from the antenna to remote station 230. The total power transmitted from all antennas may be regarded here as constant. The question to be resolved by the amplitude part of the channel state information is how to divide up the total transmitted power.

[0089] To do this, processor 240 measures the channel gain (the inverse of the attenuation) by computing, for each antenna, the ratio of the power received divided by the power received in the reference signal. The power received is the square of the signal strength measured by signal measurement circuit 238 (i.e., $P_i=(a_i)^2$ where a_i is the signal strength from antenna i). The signal transmitted through each different antenna or antenna beam includes its unique and mutually orthogonal pilot code modulated on a signal transmitted at signal power P_{TX}. The remote station measures the complex channel impulse response, $H_i=a_i\exp(\phi_i)$ as a ratio of the signal received divided by the reference signal received where ϕ_i is the relative phase of the signal being measured and a_i is the relative signal strength. Then P_i is determined as the square of a_i. The relative channel response for each antenna is measured in terms of received power. If only one bit were reserved in the up link signaling channel for amplitude feedback information, the bit would preferably command 80% of the total power to be transmitted by the antenna with the lowest attenuation path to remote station 230 and command 20% of the total power to be transmitted by the antenna with the highest attenuation path.

[0090] If two bits were reserved in the up link signaling channel for amplitude feedback information, the bits could define four amplitude states. For example, processor 240 would compute a ratio between the path attenuation from antenna 16 and the path attenuation from antenna 18 and then slice the ratio according a predetermined range of values that this ratio can take. The slicing process defines four sub-ranges and identifies into which of the four ranges the computed ratio fits. Each sub-range would define the desired split of the total power transmitted by two antennas 16 and antenna 18 to be, for example, 85%/15%, 60%/40%, 40%60% and 15%/85%, respectively. The two bits would thus encode one of these splits as the desired split in the total power transmitted by two antennas.

[0091] Persons skilled in the art will appreciate, in light of these teachings, that the amplitude portion of the channel state information may be computed by various means. Described here is a table look up means, but other means to compute the split of the total power to be transmitted are equivalent. It will be appreciated that three or more bits may be used to define the power split.

[0092] Processor 240 also segments the channel state information (including the amplitude portion and phase angle portion described above) into a plurality of channel state information segments based on the design. Remote station 230 further includes transmitter 242 to send the plurality of channel state information segments to base station 210.

[0093] The channel state information to be transmitted is a complex coefficient in the form of phase and amplitude information, and it is to be transmitted from remote station 230 to base station 210 in a number of segments (N segments) carried in corresponding slots in an up link signaling channel. A partition of the N slots into N1 and N2 (where N = N1 + N2) is done in such a way that the first N1 slots carry phase information and the remaining N2 slots carry amplitude information. In principle N1 and N2 can be arbitrarily chosen, but a common value for these parameters could be N1 = N2 = N/2. Assume that each slot reserves K bits for carrying the corresponding information segment. The the phase can be resolved to an accuracy of:

$$\phi_{\min} = \frac{360}{2^{N,K}},$$

and the amplitude can be resolved to an accuracy of:

$$A_{min} = \frac{A_{\max}}{2^{N_2K}},$$

where A_{max} is the maximum amplitude.

[0094] For example, assume that the number of slots, N, is 6, and three slots are reserved for each of N1 and N2. Assume that the number of bits per slot, K, is 1, and assume that the maximum amplitude, A_{max}, is 3 volts. Then, the accuracy of the phase and amplitude are ϕ_{min} = 45°, and the amplitude A_{min} is 0.375 volts. However, if the number of bits per slot, K, were increased to 2, the accuracy of the phase and amplitude that could be sent would be ϕ_{min} = 5.6°, and the amplitude A_{min} is 0.05 volts.

[0095] In general, a quantized or truncated version of the exact channel state information is formed so that the bits in the truncated version exactly matches the number of bits available in the up link signaling channel. The truncated version is segmented into phase segments ϕ_i (i = 1 to N1), and the segments are transmitted in a hierarchal order so that the most significant bit (MSB) is transmitted in the first segment and the least significant bit (LSB) is transmitted in the last segment. Similarly, each amplitude segment, A_i (i = I to N2) contains a quantized or truncated segment of the exact channel state information (the ratio) and it is transmitted in a hierarchal order.

[0096] The present embodiment of the invention improves the down link performance of mobile communications due to improved phase angle and amplitude accuracy for use in forming down link beams. This embodiment is particularly suitable for low mobility environments, and it suits high data rate applications in indoor and pedestrian environments. The embodiment is particularly suited for high bit-rate wireless data applications for laptop computers.

[0097] For example, assume the remote station is moving at a speed of v = 1 meter per second (3.6 kilometer per hour) and the carrier frequency is 2 gigahertz (λ = 0.15 meters). The maximum Doppler frequency f_D is v/λ and the channel coherence time T_C is computed to be:

$$T_C = 1/(2f_D) = \lambda/(2v) \fallingdotseq 75 \text{ milliseconds.}$$

It can be assumed that the channel state information will remain stable (nearly constant) over a time period equal to $T_C/10$, and therefore, the channel state information may be sent from remote station 230 to base station 210 in during this stable time period of 7.5 milliseconds. Since wideband CDMA (WCDMA) standards define slot durations to be 0.625 milliseconds, one can use 12 slots to send the channel state information back to the base station.

[0098] There are several ways to pack the channel state information in the up link slots. Table 1 illustrates an example based on only one bit per slot (K = 1). In Table I three-bit accuracy is used for both the phase angle and the amplitude information. The phase angle is transmitted in the first 6 slots, and the amplitude information is transmitted in the last 6 slots. In both cases, the most significant bits are transmitted first. In slot I, the most significant bit of the three-bit phase angle is transmitted. In slot 2, the same bit is repeated to improve reliability. After that, the remaining phase angle bits are transmitted, and the amplitude information bits are sent in the same fashion. The first bit gives the phase angle to an accuracy of 180° as if in a one-bit. After slot 3, the phase angle is sent to an accuracy of 90° as if in a two-bit, and after slot 5, the phase angle is sent to an accuracy of 45° as in the three-bit. If it is assumed that the phase angle changes about 360° during the coherence time of the channel, then in the above example, the phase angle will change about 36° in the 7.5 millisecond time period it takes to send 12 slots. This corresponds well to the phase accuracy achievable with three-bit data (45°).

[0099] After slot 7, the amplitude information is sent to an accuracy of 0.5 of the maximum amplitude as if in a one-bit. After slot 9, the amplitude information is sent to an accuracy of 0.25 of the maximum amplitude as if in a two-bit, and after slot 11, the amplitude information is sent to an accuracy of 0.125 of the maximum amplitude as in a three-bit .

Table 1

Format For Sending Channel State Information To The Base Station			
Slot Number	Feedback Bit	Slot Number	Feedback Bit
1	Phase MSB	7	Amplitude MSB
2	Phase MSB	8	Amplitude MSB
3	Phase Bit 2	9	Amplitude Bit 2
4	Phase Bit 2	10	Amplitude Bit 2
5	Phase LSB	11	Amplitude LSB
6	Phase LSB	12	Amplitude LSB

[0100] In general the phase information is more important than the amplitude information. The optimum maximal ratio combining performs only about 1 dB better than the equal gain combining that would be used if there were no amplitude information feedback, and thus, a larger allocation to phase bits (N1) and a lesser allocation to amplitude bits (N2) has advantages. For example, one could allocate three phase bits and two amplitude bits so that the feed back channel state information could be sent in a WCDMA format without redundancy in 3.125 milliseconds.

[0101] The tradeoff between the allowed feedback capacity (e.g., one or more bits/slot), the feedback reliability (e. g., number of repeated or redundant bits) and the feedback accuracy (e.g., number of phase angle and amplitude bits) is application and environment specific. For example, a three-bit check code in a well known SECDED (single error correct, double error detect) format may be appended to 8 bits of information to provide redundancy error checking. Persons of ordinary skill in the art, in light of these teaching, will appreciate how to match the feedback capacity, the feedback reliability and the feedback accuracy to the application and environment.

[0102] Processor 240 (FIG. 19) segments the channel state information into a plurality of channel state information segments according to the format defined by the system modes. In fact, a system may be designed with multiple modes, each mode defining different formats. For example, one mode may send only phase angle correction information commanding equal amplitudes to each of the antennas, and another mode may send three bits of phase angle information and one bit of amplitude information. Then transmitter 242 encodes the plurality of channel state information segments in an up link signaling channel and sends the encoded information through diplexer 233 and antenna 232 to base station 210.

[0103] In one variant of the embodiment, there are several modes requiring from 1 to, for example, 20 bits to express the channel state information in the up link signaling channel. In this variant, processor 240 determines the rate at which the channel state information changes based on changes from update to update. When the rate is slow, indicating a slow moving or stationary remote station, the feedback mode is adaptively changed to a mode that permits more data bits of the channel state information to be sent to the base station. However, when the channel state information changes rapidly, indicating that the remote station is rapidly moving, then the feedback mode is adaptively changed to a mode that sends fewer bits for each channel state information update.

[0104] Base station 210 receives the information encoded in the up link signaling channel and decodes the plurality of channel state information segments in receiver/detector 220. Processor 220P then reconstructs the channel state information from the received plurality of channel state information segments and produces weights W1 and W2. Weights W1 and W2 are provided to respective amplifiers 102 and 104 to weight first and second feed signals CH1 and CH2 to feed to the respective first and second antennas 16 and 18 based on the reconstructed channel state information.

[0105] Two variants of this embodiment may be implemented in processor 220P. First, the processor may collect all segments to reconstruct the total channel state information before forming weights W1 and W2 to apply to amplifiers 102 and 104. Alternatively, the channel state information is sent to the base station phase angle first and within the phase angle segments, most significant bit first. The values of W1 and W2 may be updated within the processor as each bit is received to provide more immediate feedback to amplifiers 102 and 104. This produces, in effect, a higher feedback bandwidth.

[0106] In FIG. 20, a method practice on processor 240 includes several steps that are typically implemented in the processor with software modules and/or logic. However, persons skilled in the art will appreciate that the steps may be implemented in the processor using ASIC or other custom circuitry.

[0107] In step S2, for each of the plural antennas, the processor receives the received signal strength and phase (a complex number) as determined by signal measurement circuit 238. In step S4, the processor selects one of the received signals to be a reference signal. This selection may be arbitrary or it may be to select the signal with the greatest phase lag (least likely to need to or want to be slowed down). In step S6, the processor divides the received signal strength and phase (a complex number) determined by signal measurement circuit 238 by the received reference signal strength and phase (a complex number). The ratio for the reference antenna is, by definition, 1+j0. In the case of two antennas, there is only one ratio to be determined and sent, the ratio of the reference antenna being a constant reference.

[0108] In step S8 (FIG. 20), processor 240 determines the amount of phase delay or advance needed at each transmitting antenna to achieve constructive reinforcement at remote station 230. If the reference signal is chosen to be the signal with the most lag, the remaining signals may achieve phase alignment with the reference signal by adding a delay at the antenna. Step S8 determines the required additional delay, but if the addition phase delay added to the phase of the non-reference signal results in a phase that is greater than 360 degrees, then subtract 360. This phase angle then becomes the phase angle transmitted as part of the channel state information. Persons skilled in the art in light of these teachings will appreciate that step S8 may be performed in the base station so that only the phase angle of the channel impulse response need be sent in the up link signaling channel.

[0109] In step S10, power management information to define the transmit distribution (the allocation of the total power among the transmit antennas) is determined. Persons skilled in the art will appreciate in light of these teachings, that the amplitude portion of the channel state information may be computed by various means. Described here is a table look up means, but other means to compute the split of the total power to be transmitted are equivalent.

[0110] For example, the relative amplitude and relative phase of the signal from each antenna may be transmitted in the up link signaling channel for the base station to further process. Alternatively, the remote station may determinine in step S10 an indicia of the desired power distribution. If only one bit were reserved in the up link signaling channel for amplitude feedback information, the bit would preferably command 80% of the total power to be transmitted by the antenna with the lowest attenuation path to remote station 230 and command 20% of the total power to be transmitted by the antenna with the highest attenuation path. If two bits were reserved in the up link signaling channel for amplitude feedback information, the bits could define four amplitude sub-ranges. For example, 85%/15%, 60%/40%, 40%60% and 15%/85%, respectively. The two bits would thus encode one of these sub-ranges as the desired split in the total power transmitted by two antennas. Extensions to more antennas or to the use of more bits to represent the amplitude portion of the channel state information will be apparent to persons of ordinary skill in the art. The exact nature of the table look up or other means depends on the number of bits reserved in the up link format to carry the amplitude portion of the channel state information.

[0111] In step S12, the channel state information is segmented and packed into the formats described herein (e.g., Table 1). In step S14, the segments are sequentially transmitted in the up link signaling channel to the base station. From there, the respective weights for the antennas are recovered and applied to amplifiers 102 and 104 (FIG. 19).

[0112] In Frequency Division Duplexed systems where up link and down link communications are carried out over different frequencies, it is not possible to exactly determine the down link channel state from up link information since the two directions are based on different frequencies. The present system has the advantage of measuring the down link channel state from down link data and then sending commands in the up link signaling channel to adjust the amplitude and phase of the transmitted down link signals.

[0113] In FIG. 21, antenna 1 of the base station is a sector coverage type of antenna. Antenna I sends a signal to remote station 2 over direct path 3; however, another multi-path signal reflects off of radio wave scatter 4 and travels over multi-path 5. As a result, remote station 2 receives two replicas of the signal at slightly different times. In FIG. 22, the two replicas are depicted as signals received at time nT and time nT+τ where τ is the additional time delay that occurs due to the additional length of multi-path 5 when compared to direct path 3. The multi-path delay may be such as to cause destructive interferences between the two signals received over the two paths. Additional radio wave scatterers may create even more multi-path signals.

[0114] A conventional Rake receiver correlates a local signal (e.g., the spreading code of a CDMA signal) and the received signal that includes signal replicas received with different delays. With correct delays, the signals are coherently combined to reinforce energies. When the local signal (e.g., desired spreading code) is correlated with a signal from a desired signal path, the local signal is also correlated with every one of the other signal replicas (e.g., signal replicas from signal paths with different delays). The terms corresponding to the correlation with the other signal replicas are unwanted terms, and they tend to degrade the performance of the system. The unwanted correlation terms also cause a loss of orthogonality between different users with different codes, and as a result, co-channel users start to interfere with each other. The degradation effect becomes more pronounced with short spreading codes that are typically used in high bit rate links.

[0115] The present invention operates the Rake receiver in an unconventional fashion. Using beam forming, the present invention separates different signal paths and applies pre-transmission time shift compensation on each signal replica (e.g., each beam) so that all signal replicas arrive at the receiver simultaneously. In this manner, the receiver appears to receive a signal processed only through a 1-tap channel even though it actually receives and coherently combines multiple signals over multiple paths (e.g., paths 3 and 5 in FIG. 1). This avoids a loss of orthogonality and minimizes or eliminates cross correlation terms that might otherwise degrade system performance.

[0116] In an embodiment of the present invention, the desired data is included in two or more space-time coded signals. The signals are identified by unique and mutually orthogonal signature codes. If one of the space-time coded signals is significantly delayed with respect to another, the orthogonality of the signature codes may be reduced. It is preferred to delay'the shortest path signal so as to arrive at remote station 2 at the same time that the longer path signal arrives at remote station 2.

[0117] In FIG. 23, an exemplary system includes antenna 1 and remote station 2. Exemplary antenna 1 may be a Butler matrix multi-beam antenna array or any other multi-beam antenna array. The desired data in this example are encoded into two space-time coded signals 12 and 15. Space-time coded signals 12 and 15 are transmitted in beams D2 and D5, respectively. Beam D5 sends signal 15 to remote station 2 over direct path 3. Beam D2 sends signal 12 to remote station 2 over indirect multi-path 5.

[0118] In FIG. 26, an exemplary encoder for the generation of space-time coded signals 12 and 15 is depicted. FIG. 26 is similar to FIG. 2, except that antennas 16 and 18 of FIG. 2 are replaced by the multi-beam antenna of FIG. 23 and a programmable delay line (e.g., a selectable multi-tap delay line) is coupled between multiplier 14 and the multi-beam antenna. Multiplier 12 encodes signal CH1 with a signature code (OC) that is mutually orthogonal to the signature code that is encoded in the signal CH2 by multiplier 14. The signature codes may be variously orthogonal training sequences, pilot codes or spreading sequences. Using these signature codes, remote station 2 separates the signal that is received in a direct path from beam D5 from the signal that is received in an indirect path from beam D2 as long as the signature codes remain orthogonal. Persons skilled in the art will appreciate that the two beams and corresponding space-time coded signals depicted in FIGS. 23 and 26 may be generalized to more than two and that additional programmable delay lines may be needed to time synchronize all signals.

[0119] The direct signal from beam D5 is received at remote station 2 before the indirect signal from beam D2 is received by a time τ as depicted in FIGS 24 and 25. In order to maintain best orthogonality between the signature codes, it is desirable to align the signals in time. A receiver (possibly at the base station and possibly at remote station 2 as discussed below) determines the time delay τ necessary to align the signals. The last signal received at remote station 2 (e.g., signal 12) may be regarded as a reference space-time coded signal. The remaining signals may then be regarded as at least one remaining space-time coded signal (e.g., signal I5). In this embodiment, the at least one remaining space-time coded signal is delayed in the programmable delay line of the base station (see FIG. 26) before being transmitted. The signal or signals is or are delayed by a sufficient delay to ensure that each of the at least one remaining space-time coded signal will align in time with the reference signal when received at the remote station. In the example depicted in FIG. 23, the last signal received at remote station 2 is signal I2 due to the extended length of multi-path 5. Signal 15 will need to be delayed so that it will arrived at remote station 2 at the same time that signal 12 arrives at remote station 2.

[0120] In both the space-time diversity technology (FIG. 2) and the beam-space diversity (FIG. 23), it is important for the remote receiver to separate signals CH1 and CH2 as discussed above. This is achieved by using orthogonal signature codes in various forms. The difference in time of arrival when the signals from the two paths, direct path 3 and multi-path 5, arrive at remote station 2 is referred to as the delay spread. When the delay spread does not exist or is minimal, the orthogonality of the signature codes is preserved. However, in frequency selective channels where there exists a considerable delay spread of the signature codes, the orthogonality between the channels may be lost, and remote station 2 will find it difficult to separate signals carried in the respective channels. Most common coding sequences are characterized by non-ideal cross-correlation functions (CCFs) which have a low or zero value only for a given phase relationship between the signature codes, and for other phase relationships, the CCFs are non-zero.

[0121] Plural space-time diversity signals intended for transmission to remote station 2 over multi-path channels will undergo different delays. Because the value of the CCF at a given out-of-phase position is typically non-zero and different from position to position, the effect of different path delays imposed by the radio channels on the transmitted signals will be to diminish the orthogonality between the signature codes used by remote station 2 to separate the signals. This loss of orthogonality results in a deterioration in the diversity gain that would otherwise be achieved by the space-time code transmission of signals between a base station and a remote station in a wireless communication system.

[0122] In the present embodiment, a multi-beam antenna array associated with the base station receives an up link signal from the remote station of interest in each of the plural beams of the multi-beam antenna array. The up link signal may be a pilot signal, an up link signaling channel, or any other up link channel that identifies the source of the signal as the remote station of interest. The up link signal is received as plural signals derived from radio signals received in corresponding plural beams of the multi-beam antenna array.

[0123] For each of the plural received signals, a receiver at the base station separates a signal component identified by a signature code as originating at the particular remote station of interest. The received signal component of each of the plural beams includes a replica of the identified signal for the particular remote station of interest at a particular time delay or delay spread relative to the signal component of a reference beam. A receiver at the base station processes the plural signal components from their respective beams to identify a reference beam as containing the last received signal component and a delay spread needed to align each of the other signal components received from their respective beams with the signal component received in the reference beam. When the base station serves more than one remote station, this process can be repeated for each remote station or for selected remote stations. The selected remote stations could be those with high transmit power. High transmit power might be required by, for example, high data rate requirements.

[0124] FIG. 27 depicts a representative channel impulse response or delay distribution profile 300 for a 16 beam base station system that is similar to the 8 beam base station system depicted in FIG. 23. The base station measures the delay spreads τ associated with each beam of the multi-beam antenna. For signals received that have signal strengths above a threshold, an "x" indicates instantaneous and/or averaged signal strength exceeding a given threshold. Directions D3, D6 and D12 depicted at 304, 306 and 308 respectively, include signals with a minimum delay spread (e.g., spanning delays τ_4 through τ_6). If several potential directions are available, preferred directions among the available directions are selected based on additional criteria, such as the whitening of generated interference, the even distribution of power in the plurality of power amplifiers used by the base station and the avoidance of directions where greater than average interference could be caused to co-channel users. For example, a high power beam could cause interference to one or many low bit rate users if the low bit rate users are located within the area illuminated by the high power beam. In some favorable situations, beam hopping can also be applied in order to achieve more effective interference whitening.

[0125] In operation, the base station selects directions having minimal delay spreads. For example, the base station selects at least two beams of plural beams that may be formed by the multi-beam antenna array for transmission of at least two space-time coded signals in corresponding beams of the at least two beams. The at least two beams include a reference beam and at least one remaining beam. The base station also determines from delay distribution profile 300 a time delay corresponding to each beam of the at least one remaining beam for use in programming the programmable delay line.

[0126] The base station encodes each signal of the at least two space-time coded signals with a signature code that is mutually orthogonal to each other signature code encoded in the at least two space-time coded signals so as to form a reference space-time coded signal and at least one remaining space-time coded signal (see 12 and 14 of FIG. 26). In the example of FIG. 23, the reference space-time coded signal may be regarded as signal 12 and the at least one remaining space-time coded signal may be regarded as signal I5. However, persons skilled in the art will appreciate in light of these teaching how to extend the present embodiment to more than two space-time coded signals.

[0127] The base station delays each signal of the at least one remaining space-time coded signal to form at least one delayed space-time coded signal (e.g., signal 15 in FIG. 26). The base station then transmits the reference space-time coded signal (e.g., signal I2) and the at least one delayed space-time coded signal (e.g., signal I5) in respective beams of the at least two beams so that both the reference space-time coded signal and the at least one remaining space-time coded signal arrive at remote station 2 at the same time.

[0128] The present embodiment does not rely on a feedback channel from the remote station to the base station. Instead, directions of transmission are selected by the base station solely from up link measurements of normal signaling signals. By averaging the up link channel response over a long time to mitigate fast fading, the power response of the down link channel response can be estimated. The indicated up link and down link channels are reciprocal in the power sense.

[0129] However, in frequency division duplex (FDD) systems, a feedback measurement could provided improved results at the cost of additional complexity. In frequency division duplexed systems where up link and down link communications are carried out over different frequencies, it is not possible to exactly determine the down link channel state from up link information since the two directions are based on different frequencies.

[0130] The just described embodiment describes an embodiment where the base station measures the up link channel response as a surrogate for the down link channel response. To obtain the complete down link channel impulse response, it is necessary to measure the down link channel directly, and send the down link channel information in a feedback channel from the remote station that does the measuring to the base station that needs the measurements (e.g., delay distribution profile 300).

[0131] Rather than performing the calculation required for direction selection and delay in the base station, the remote station participates in or performs these functions. An agreed upon standard signal is sent from the base stations to all remote stations with an identifier or signature coded encoded in each beam, such as mutually orthogonal pilot or training sequences or spreading codes. The remote station would then measure the channel impulse response (e.g., delay distribution profile 300) and inform the base station of the preferred directions and delays for transmission.

[0132] Persons skilled in the art will appreciate in light of these teachings that the channel performance may be measured in a two step process. In the first step, the base station makes an estimate of the up link channel's impulse response and uses this estimate as a surrogate for the down link channel's impulse response. Then, the base station applies the delays to the at least one remaining space-time coded signal that are indicated by the first estimate process.

[0133] In the second step, the down link channel is measured directly. An agreed upon standard signal is sent from the base station to all remote stations with an identifier or signature coded encoded in each beam, such as mutually orthogonal pilot or training sequences or spreading codes. The remote station would then measure the channel impulse response (e.g., delay distribution profile 300) and inform the base station over a feedback channel of the preferred directions and delays for transmission.

[0134] In FIG. 28, set up process S200 measures the up link channel response and sets the measured delays to control the down link channel transmission. Process S200 includes step S202 to measure the channel response, step S204 to select beams to use, step S206 to determine time delays for the selected beams, and step S208 to configure variable delay lines in the base station (see FIG. 26) to impose the determined delays. The variable delay lines maybe constructed from a sequence of fixed delay elements with multiple taps disposed between the elements. The delay line is varied by selecting different taps as an output using a switch. In step S204, the base station selects at least two beams of plural beams formed by a multi-beam antenna array associated with a base station (although only two beams are shown in FIGS. 23 and 26). In the beams are transmitted corresponding at least two space-time coded signals produced by a space-time encoder (although only two signals are shown in FIGS. 23 and 26). The at least two beams include a reference beam and at least one remaining beam. In step S206, the base station determines a time delay corresponding to each beam of the at least one remaining beam. In step S208, the base station sets into a variable delay line the time delay corresponding to each beam of the at least one remaining beam. Each variable delay line is coupled between the multi-beam antenna array and the space-time encoder (see FIG. 26).

[0135] In FIG. 29, time align process S220 marks the space-time coded signal for each selected beam with a signature code orthogonal to all other beams in step S222, delays selected beams according to determined delay spreads in step S224 and transmits the delayed signals to the base station in step S226. In step S222, the base station encodes each signal of the at least two space-time coded signals with a signature code that is mutually orthogonal to each other signature code encoded in the at least two space-time coded signals so as to form a reference space-time coded signal and at least one remaining space-time coded signal. In step S224, the base station delays each signal of the at least one remaining space-time coded signal in a respective variable delay line to form at least one delayed space-time coded signal. In step S226, the base station transmits the reference space-time coded signal and the at least one delayed space-time coded signal in respective beams of the at least two beams.

[0136] In FIG. 30, a remote station using feedback process S240 measures down link complex channel state information and feeds this information back to the base station. Process S240 includes step S242 to receive at least two identifier signatures (e.g., different pilot signals) from an antenna system associated with a base station, step S244 to determine complex channel state information based on the received signals, step S246 to segment the complex channel state information into a plurality of channel state information segments, and step S248 to send the plurality of channel state information segments in a sequence to the base station. The sequence of segments sends the most significant bits of the phase angle before the least significant bits of the phase angle. The sequence of segments sends the most significant bits of the amplitude before the least significant bits of the amplitude. The sequence of segments sends a bit of the phase angle before a corresponding bit of amplitude having the same level of bit significance. It is noted that for feedback of the channel impulse response measurements, each beam (or antenna) should be associated with a unique pilot signature that is orthogonal to all other pilot signatures.

[0137] It will be appreciated by persons skilled in the art in light of these teachings that various system components may be implemented in electrical circuitry, special application specific integrated circuits (ASICs) or computers or processors that executed software programs or use data tables. For example, encoder 10, multipliers 12, 14 and amplifiers 102, 104 of FIG. 4, 5, 11 or 12 may be implemented in circuitry or ASICs or in some cases, software controlled processors, depending on performance requirements. Beam former 40 of FIG. 11 is typically implemented in circuitry or ASICs and modulators 101,103 and multiplexers 105, 107 are typically implemented in circuitry or ASICs but may be implemented in software controlled processors. Various base station components 212, 214, 216, 218, 220 and 222 and various remote station components 232, 234, 238, 240 and 242 of FIG. 14 may be implemented in circuitry or ASICs but may be implemented in software controlled processors. Various base station components 16D, 18D, 102, 104, 220 and 220P and various remote station components 232,233,234,238, 240 and 242 of FIG. 19 may be implemented in circuitry or ASICs but may be implemented in software controlled processors. It will be appreciated by persons skilled in the art that the various functions described herein may be implemented in circuitry, ASICs or in software controlled processors as the performance requirement dictate.

[0138] Having described preferred embodiments of a novel closed loop feedback system for improved down link performance (which are intended to be illustrative and not limiting), it is noted that modifications and variations can be made by persons skilled in the art in light of the above teachings. It is therefore to be understood that changes may be made in the particular embodiments of the invention disclosed which are within the scope and spirit of the invention as defined by the appended claims.

[0139] Having thus described the invention with the details and particularity required by the patent laws, what is claimed and desired protected by Letters Patent is set forth in the appended claims.

Claims

1. A method comprising steps of :

   selecting at least two beams of plural beams formed by a multi-beam antenna array associated with a first station for transmission of a corresponding at least two space-time coded signals produced by a space-time encoder;
   determining a time delay associated with each of the at least two space-time coded signals as received in each respective beam; and
   setting into a variable delay line the time delay corresponding to each beam, each variable delay line being coupled between the multi-beam antenna array and the space-time encoder.

2. The method of claim 1, further comprising a step of measuring a channel response based on an up link signal from a second station.

3. The method of claim 2, wherein;

the step of measuring includes receiving plural signal components of the up link signal in corresponding plural beams of the multi-beam antenna array;
the step of selecting includes selecting the at least two beams based on the received plural signal components; and
the step of determining includes determining delay spreads for each of the received plural signal components and assigning to each beam the determined delay spread as the time delay to be set into the respective variable delay line.

4. The method according to any of the preceding claims, further comprising steps of:

encoding each signal of the at least two space-time coded signals with a signature code that is mutually orthogonal to each other signature code encoded in the at least two space-time coded signals so as to form a reference space-time coded signal and at least one remaining space -time coded signal, wherein the step of setting includes delaying each signal of the at least one remaining space-time coded signal in a respective variable delay line to form at least one delayed space-time coded signal; and
transmitting the reference space-time coded signal and the at least one delayed space-time coded signal in respective beams of the at least two beams.

5. The method of claim 4, further comprising steps of :

receiving the reference space-time coded signal and the at least one delayed space-time coded signal from the multi-beam antenna array;
determining complex channel state information based on the received reference space-time coded signal and the received at least one delayed space-time coded signal; and
sending the complex channel state information to the first station.

6. The method of claim 5, further comprising a step of segmenting the complex channel state information into a plurality of channel state information segments, wherein the steps of sending the complex channel state information includes sending the plurality of channel state information segments in a sequence.

7. A system comprising a base station, the base station including :

a multi-beam antenna array;
first circuitry to select at least two beams of plural beams formed by the multi-beam antenna array for transmission of a corresponding at least two space-time coded signals produced by a space-time encoder;
second circuitry to determine a time delay associated with each of the at least two space-time coded signals as received in each respective beam;
at least two variable delay lines, each variable delay line being coupled between the multi-beam antenna array and a space-time encoder; and
third circuitry to set the time delay corresponding to each beam of the at least two beams into a corresponding delay line of the at least two variable delay lines.

8. The system of claim 7, wherein the first circuitry includes logic to measure a channel response based on an up link signal from a remote station.

9. The system of claim 7, wherein:

the up link signal includes plural signal components, each signal component being a received signal component in a corresponding beam of the plural beams of the multi-beam antenna array;
the logic to measure the channel response includes logic to receive the plural signal components of the up link signal and logic to select the at least two beams based on the received plural signal components; and
the second circuitry includes logic to determine delay spreads for each of the received plural signal components and logic to assign to each beam the determined delay spread as the time delay to be set into the respective variable delay line.

10. The system according to any of claims 7 to 9, wherein:

the base station further includes the space-time encoder;
the space-time encoder encodes each signal of the at least two space-time coded signals with a signature code that is mutually orthogonal to each other signature code encoded in the at least two space-time coded signals so as to form a reference space-time coded signal and at least one remaining space-time coded signal; and
the at least one variable delay line delays each respective signal of the at least one remaining space-time coded signal in a respective variable delay line to form at least one delayed space-time coded signal, the base station transmitting the reference space-time coded signal and the at least one delayed space-time coded signal in respective beams of the at least two beams.

11. The system of claim 10, further comprising a remote station, the remote station including:

a receiver to receive the reference space-time coded signal and the at least one delayed space-time coded signal from the multi-beam antenna array;
a processor to determine complex channel state information based on the received reference space-time coded signal and the received at least one delayed space-time coded signal; and
a transmitter to send the complex channel state information to the base station.

12. The system of claim 11, wherein:

the processor includes a processor module to segment the complex channel state information into a plurality of channel state information segments; and
the transmitter includes circuitry to send the complex channel state information in a sequence of the channel state information segments.

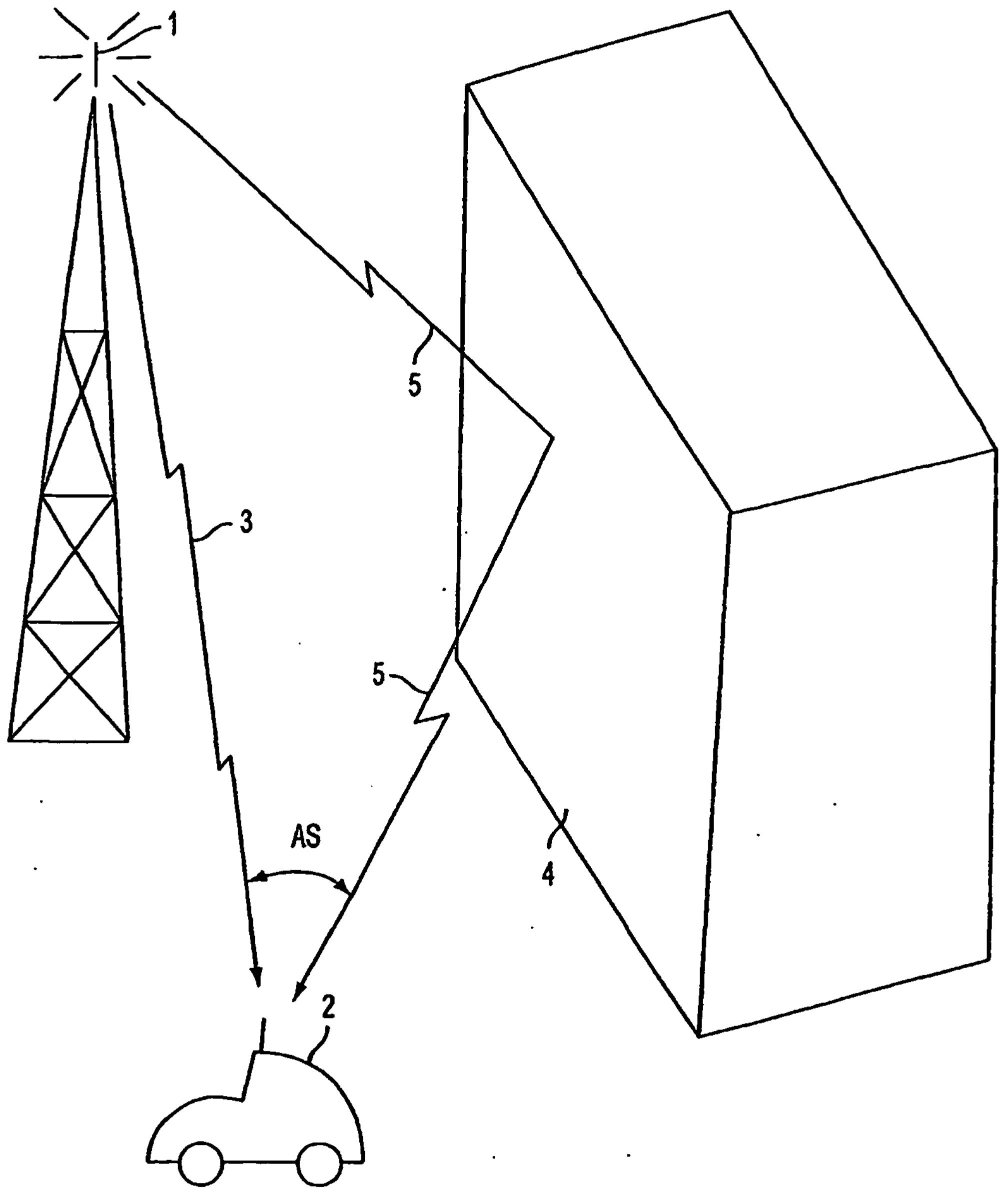


FIG. 1

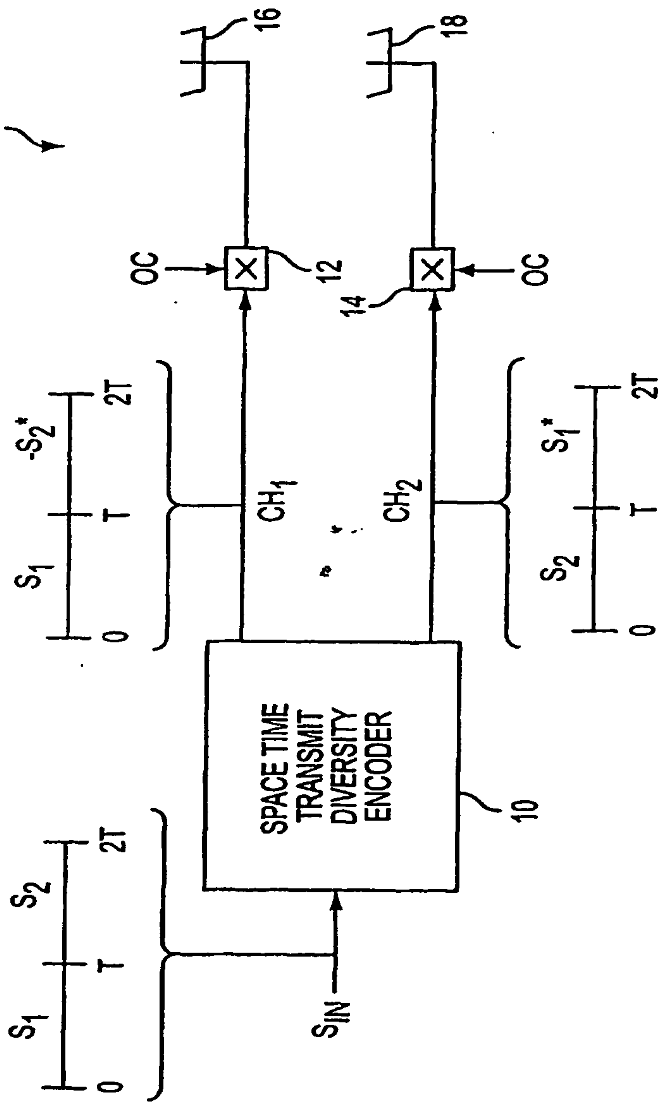


FIG. 2
(PRIOR ART)

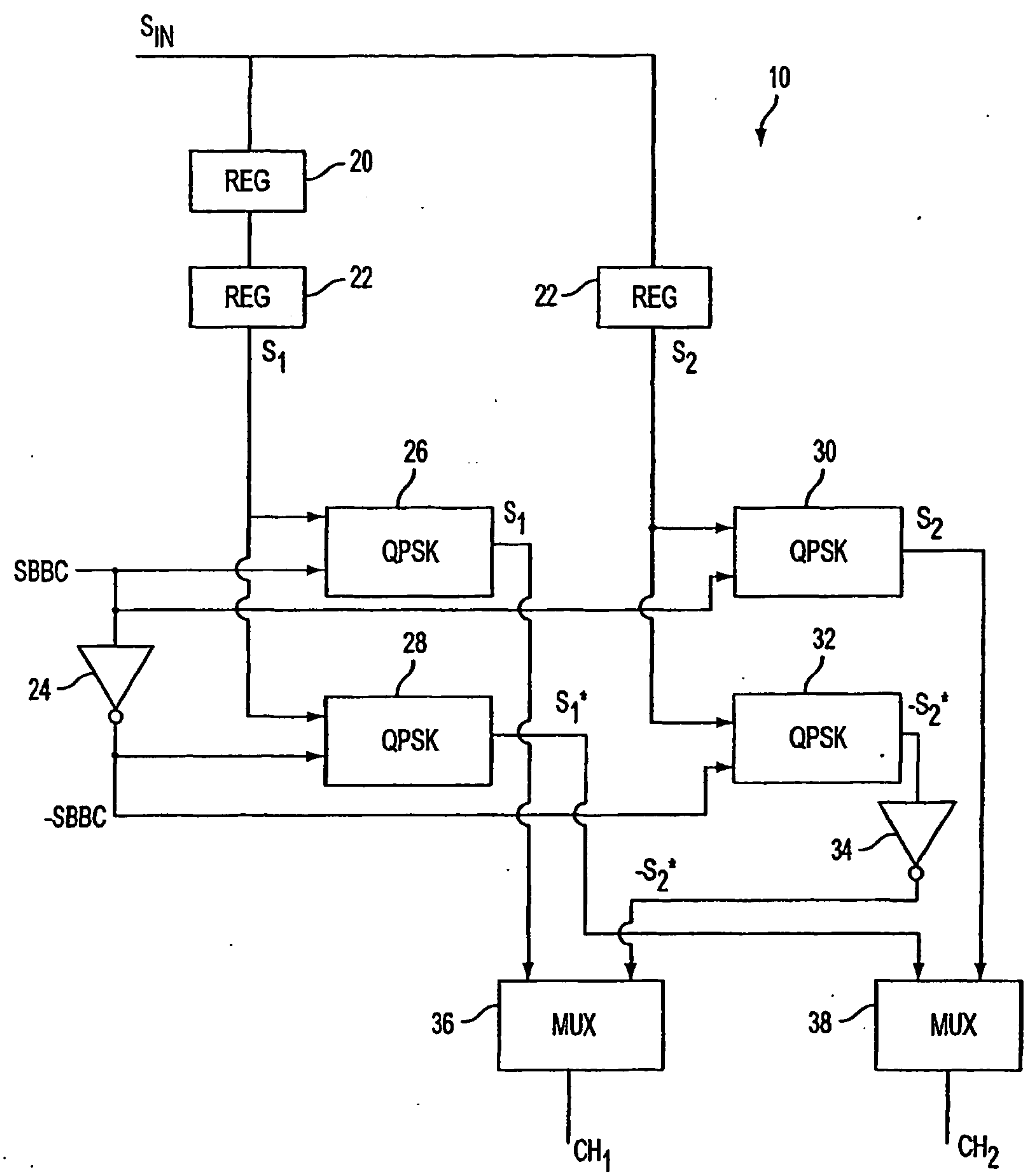
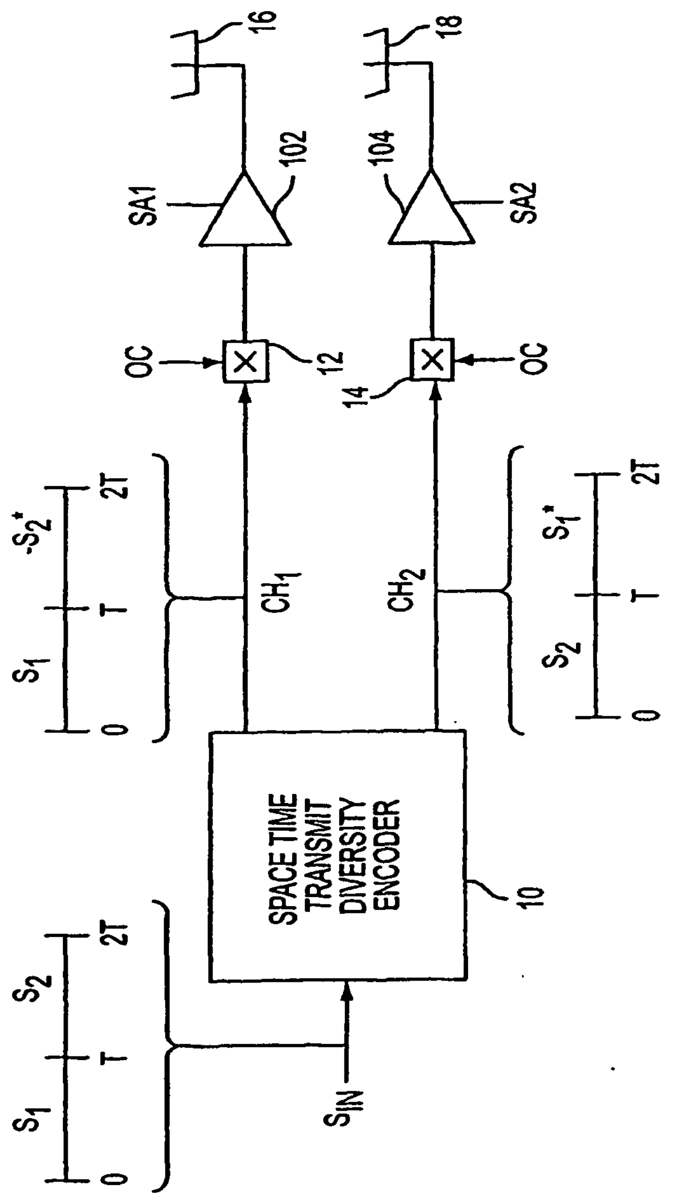


FIG. 3
(PRIOR ART)



S1
T
S2
0
2T
SIN
SPACE TIME TRANSMIT DIVERSITY ENCODER
10
S1
-S2*
CH1
CH2
S2
S1*
OC
12
14
OC
SA1
102
104
SA2
16
18

FIG. 4

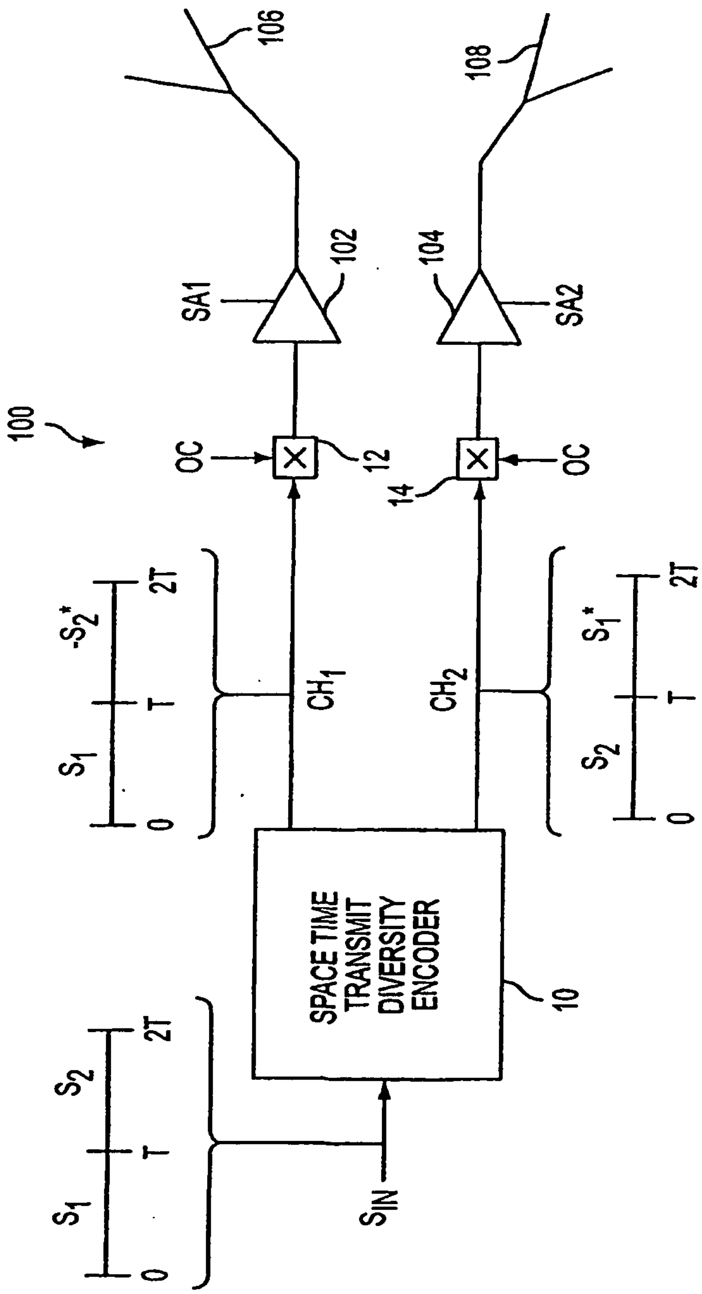

100
SPACE TIME TRANSMIT DIVERSITY ENCODER
10
S_{IN}
S_1
S_2
0
T
2T
S_1
$-S_2^*$
CH_1
CH_2
S_2
S_1^*
OC
12
14
SA1
SA2
102
104
106
108

FIG. 5

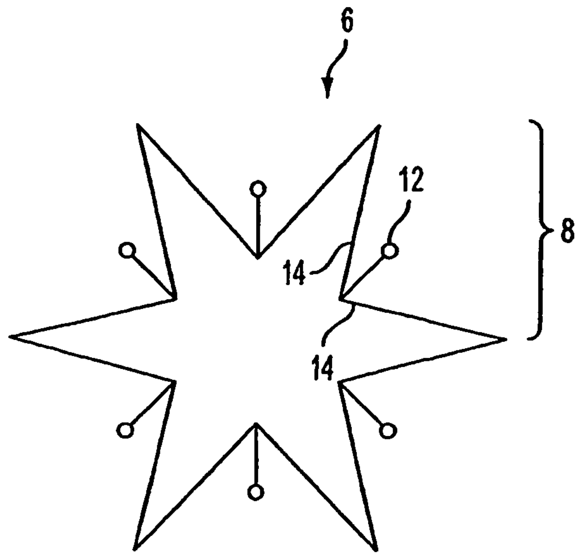


FIG. 6
(PRIOR ART)

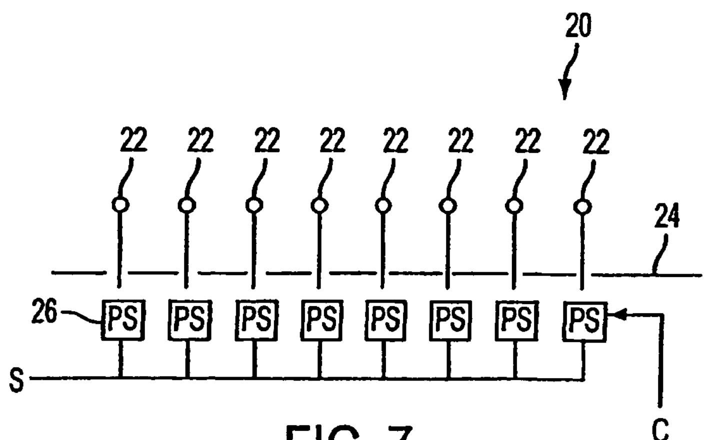


FIG. 7
(PRIOR ART)

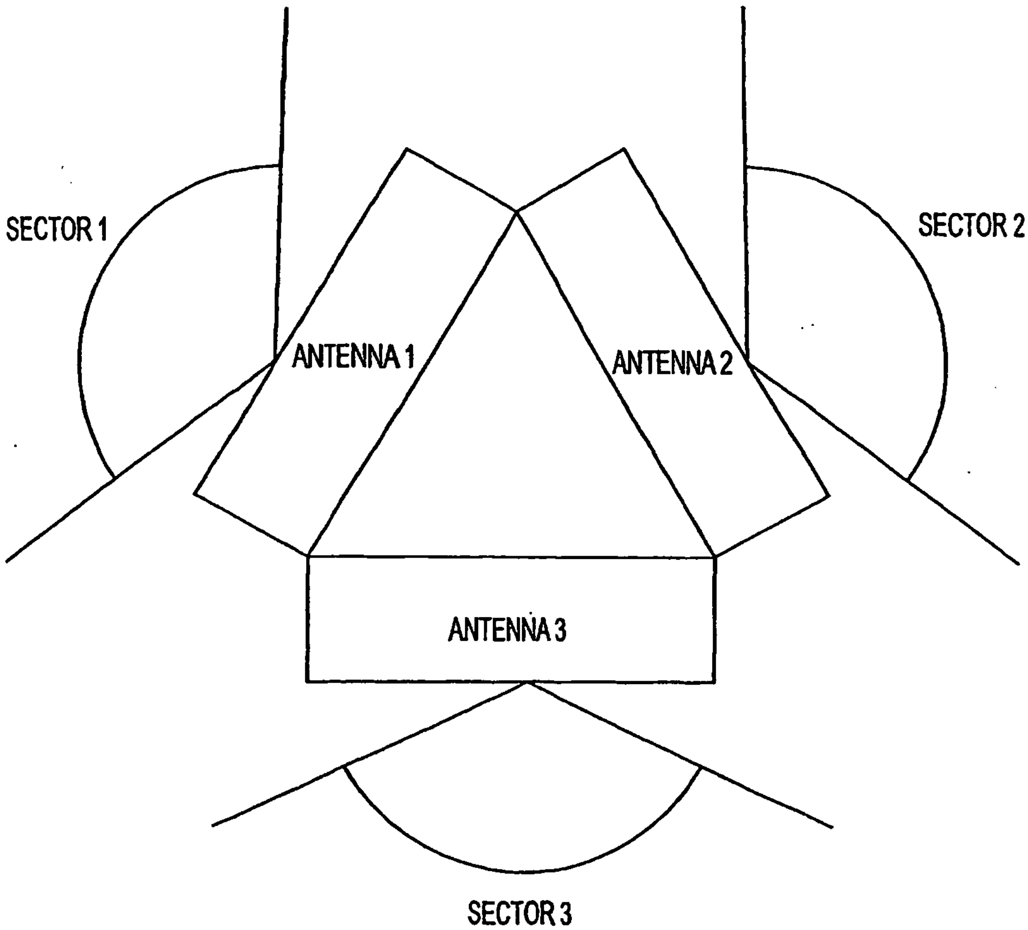


FIG. 8
(PRIOR ART)

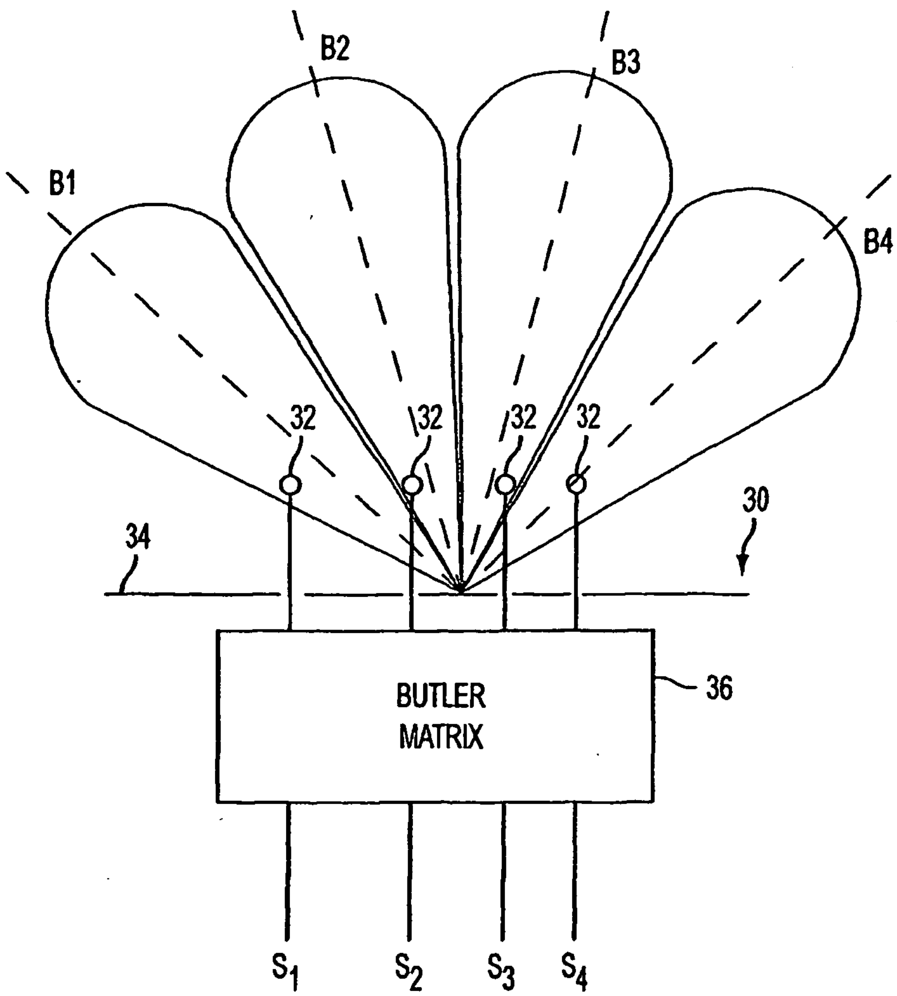


FIG. 9
(PRIOR ART)

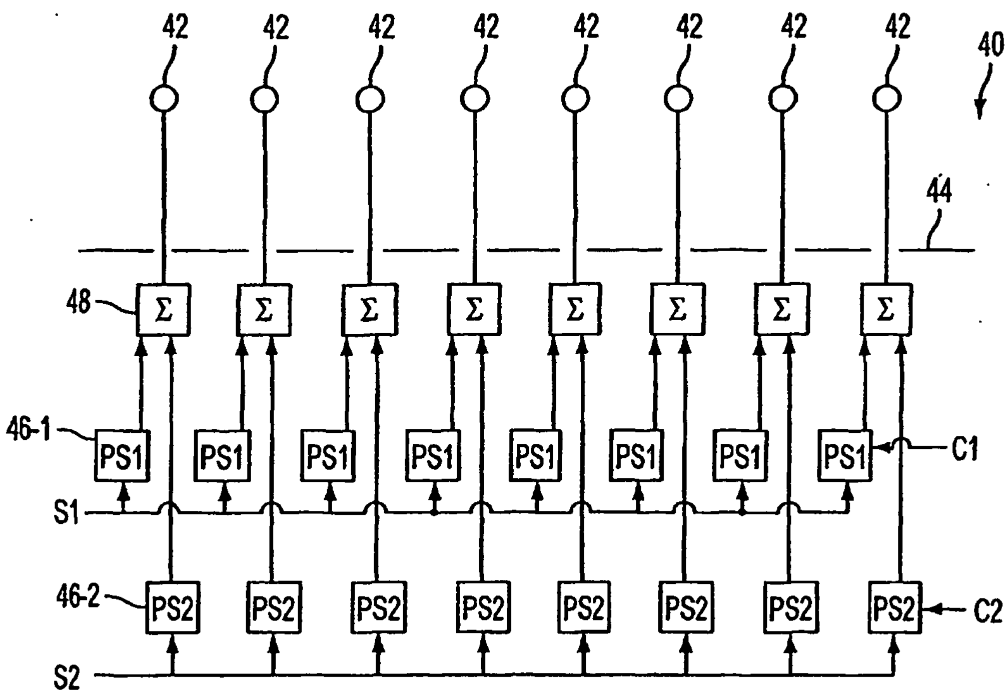


FIG. 10
(PRIOR ART)

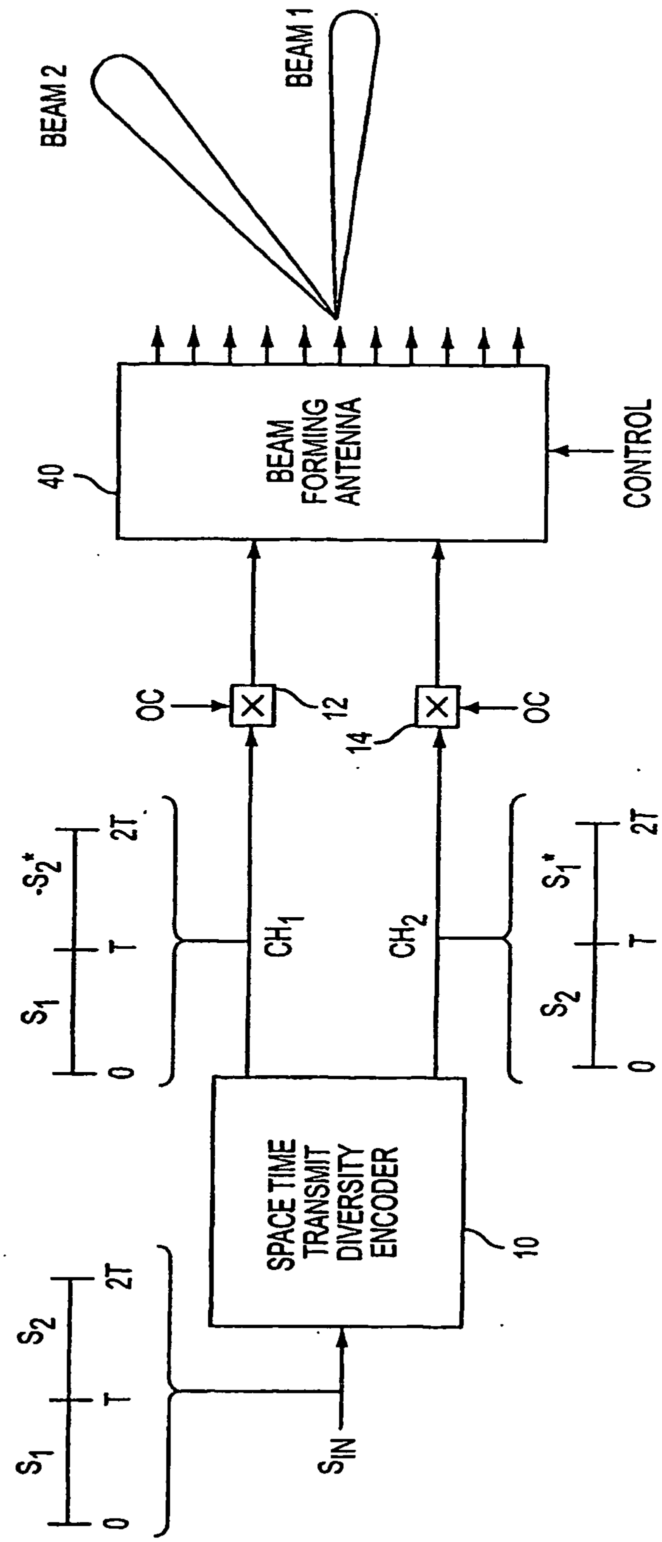

BEAM 2
BEAM 1
40
BEAM FORMING ANTENNA
CONTROL
OC
12
14
OC
S_1
$-S_2^*$
0
T
2T
CH_1
CH_2
S_2
S_1^*
SPACE TIME TRANSMIT DIVERSITY ENCODER
10
S_{IN}
S_1
S_2

FIG. 11

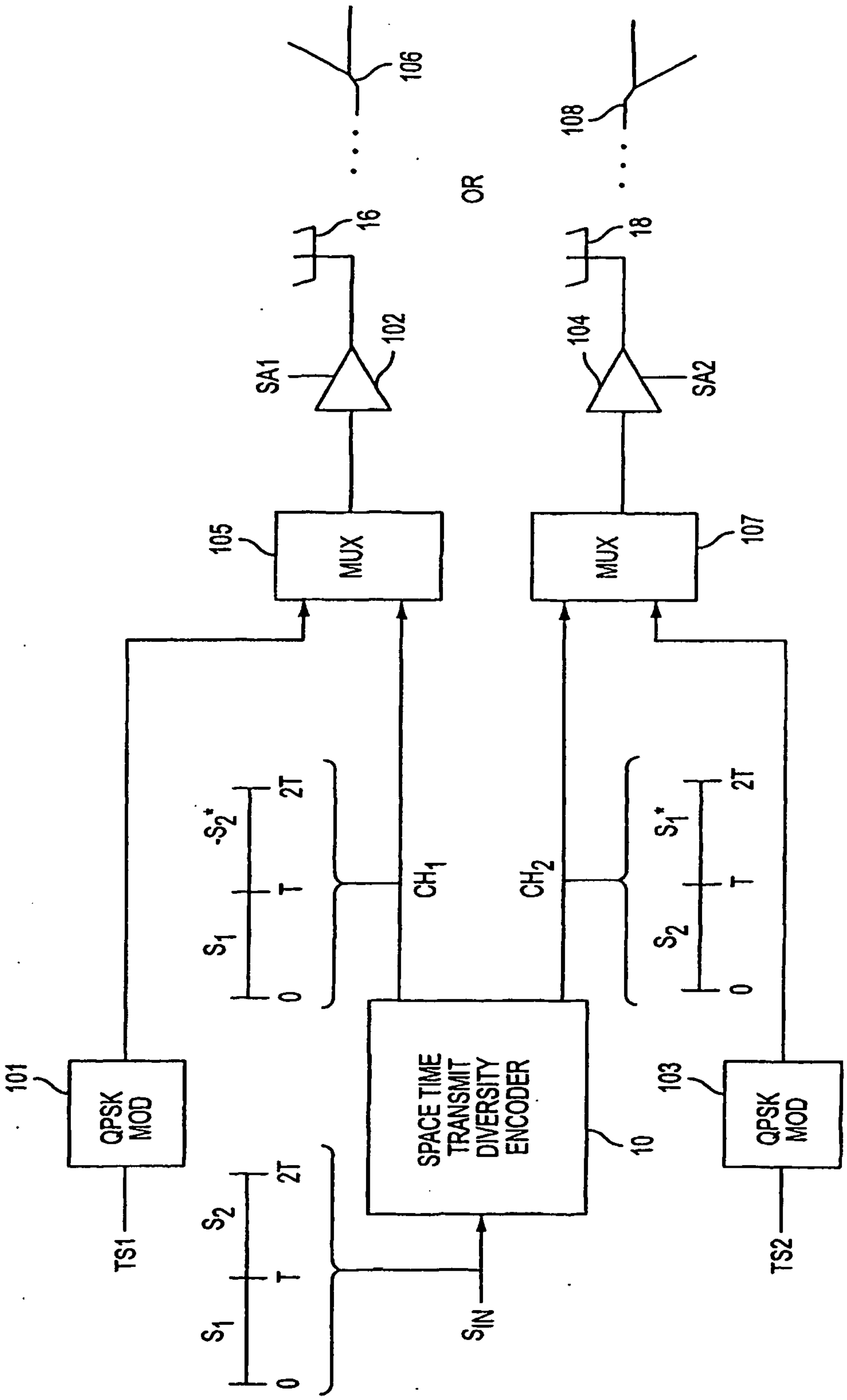

TS1
QPSK MOD
101
TS2
QPSK MOD
103
S_{IN}
S_1
S_2
0
T
2T
SPACE TIME TRANSMIT DIVERSITY ENCODER
10
S_1
$-S_2^*$
CH_1
CH_2
S_2
S_1^*
MUX
105
MUX
107
SA1
102
SA2
104
16
18
106
108
OR

FIG. 12

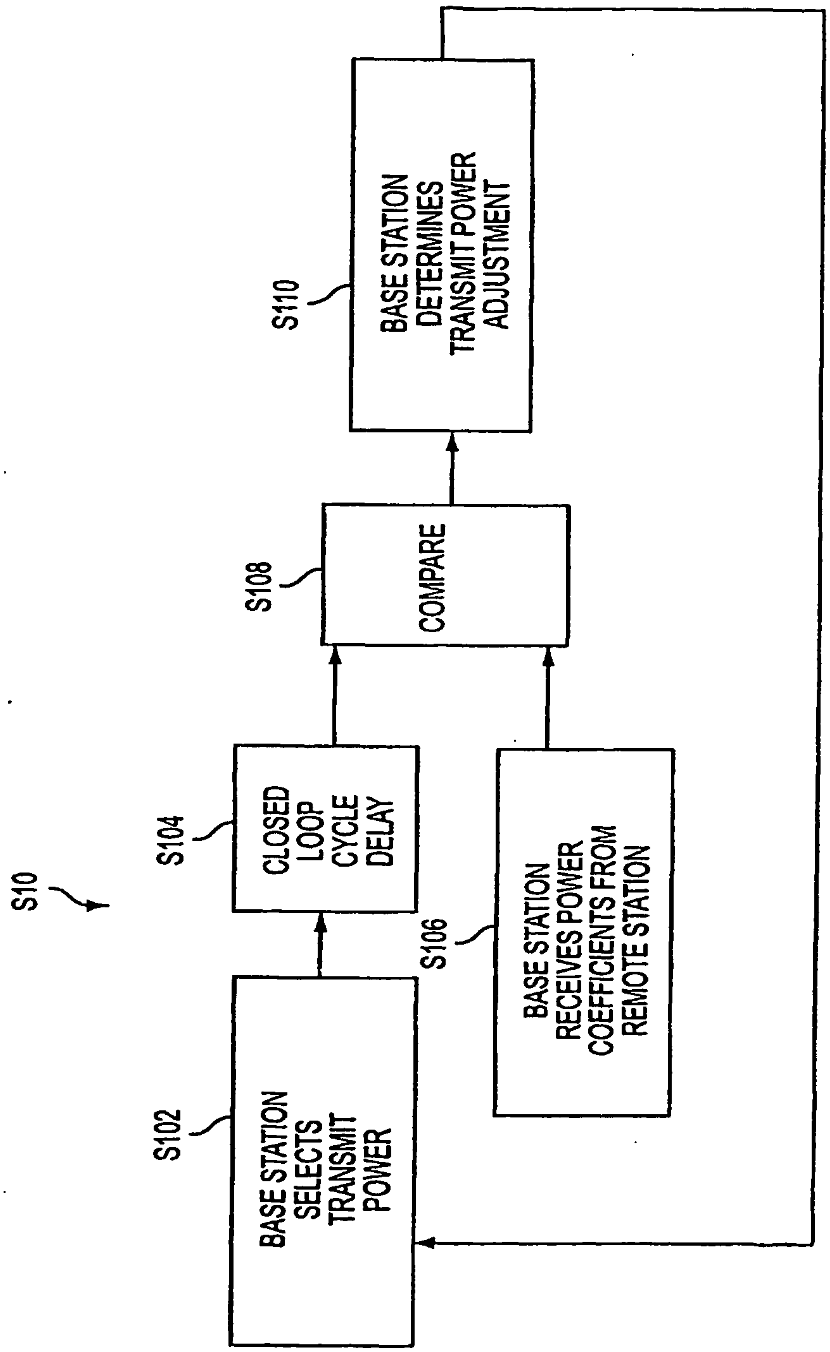

S10
S102
BASE STATION SELECTS TRANSMIT POWER
S104
CLOSED LOOP CYCLE DELAY
S106
BASE STATION RECEIVES POWER COEFFICIENTS FROM REMOTE STATION
S108
COMPARE
S110
BASE STATION DETERMINES TRANSMIT POWER ADJUSTMENT

FIG. 13

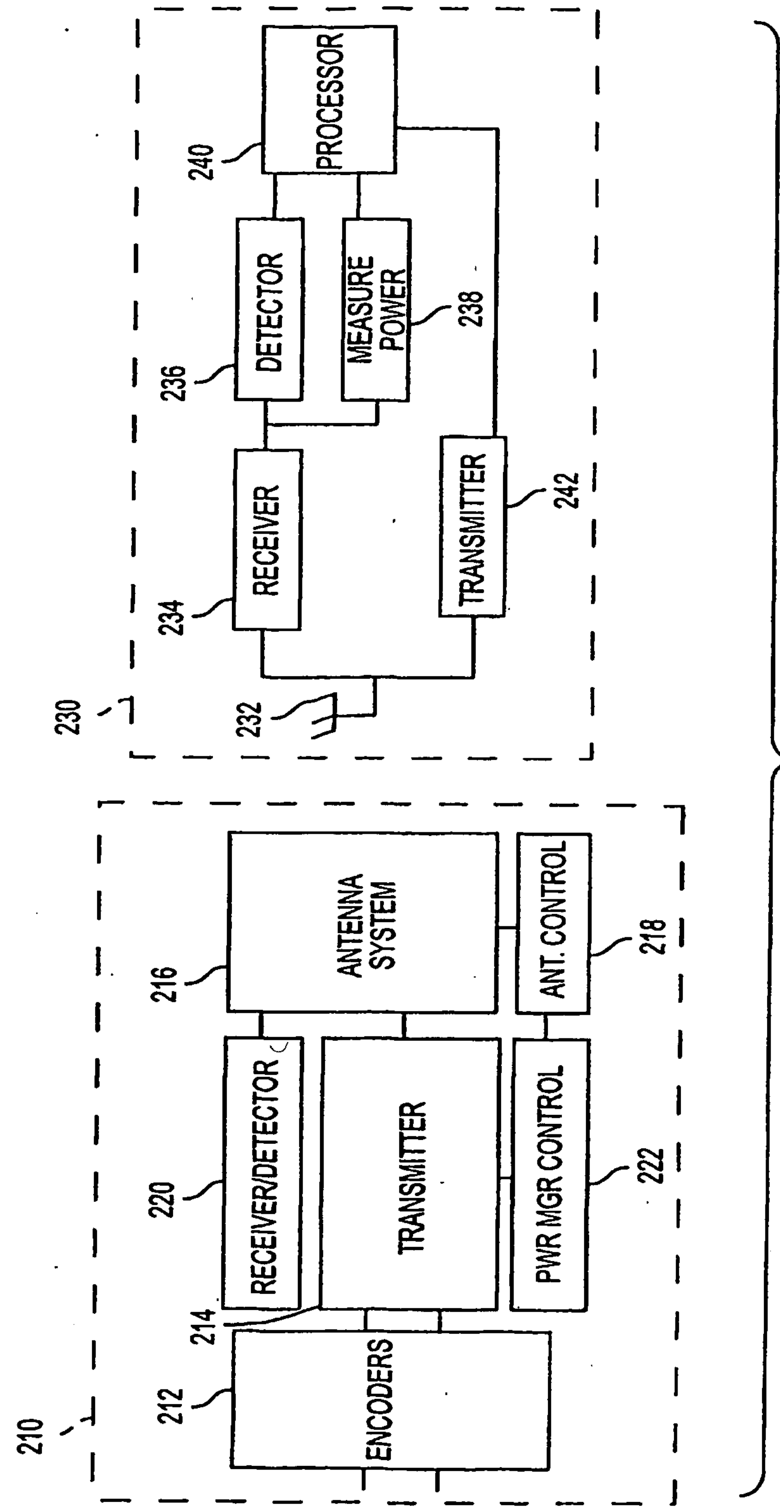

230
232
234
RECEIVER
236
DETECTOR
MEASURE POWER
238
240
PROCESSOR
TRANSMITTER
242
210
212
ENCODERS
214
220
RECEIVER/DETECTOR
TRANSMITTER
PWR MGR CONTROL
222
216
ANTENNA SYSTEM
ANT. CONTROL
218

FIG. 14

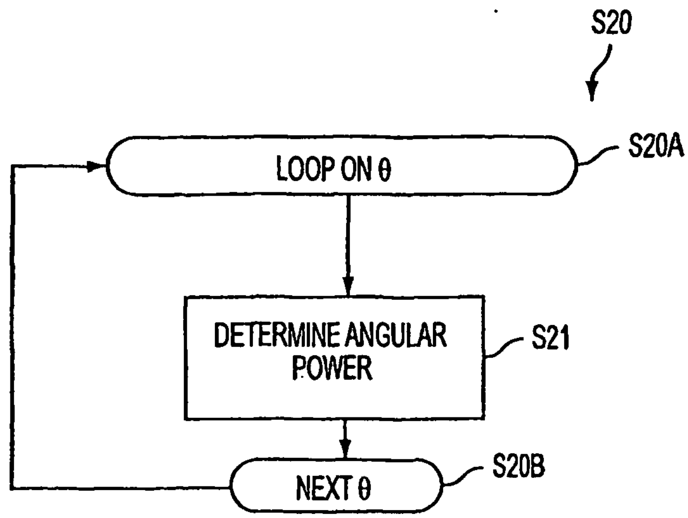

S20
LOOP ON θ
S20A
DETERMINE ANGULAR POWER
S21
NEXT θ
S20B

FIG. 15

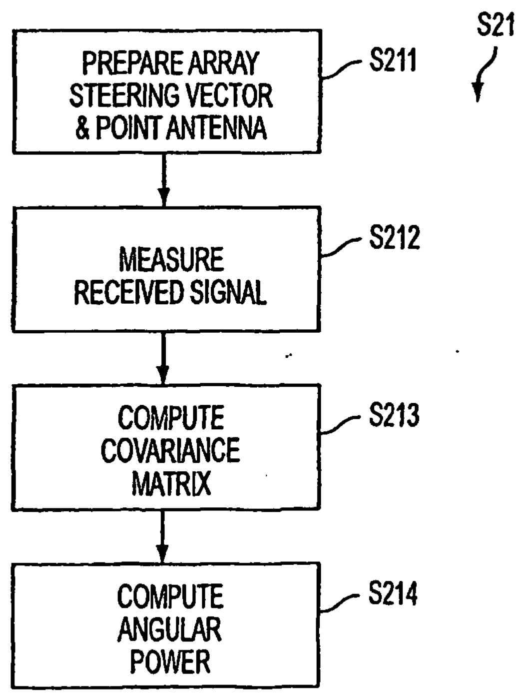

S21
PREPARE ARRAY STEERING VECTOR & POINT ANTENNA
S211
MEASURE RECEIVED SIGNAL
S212
COMPUTE COVARIANCE MATRIX
S213
COMPUTE ANGULAR POWER
S214

FIG. 16

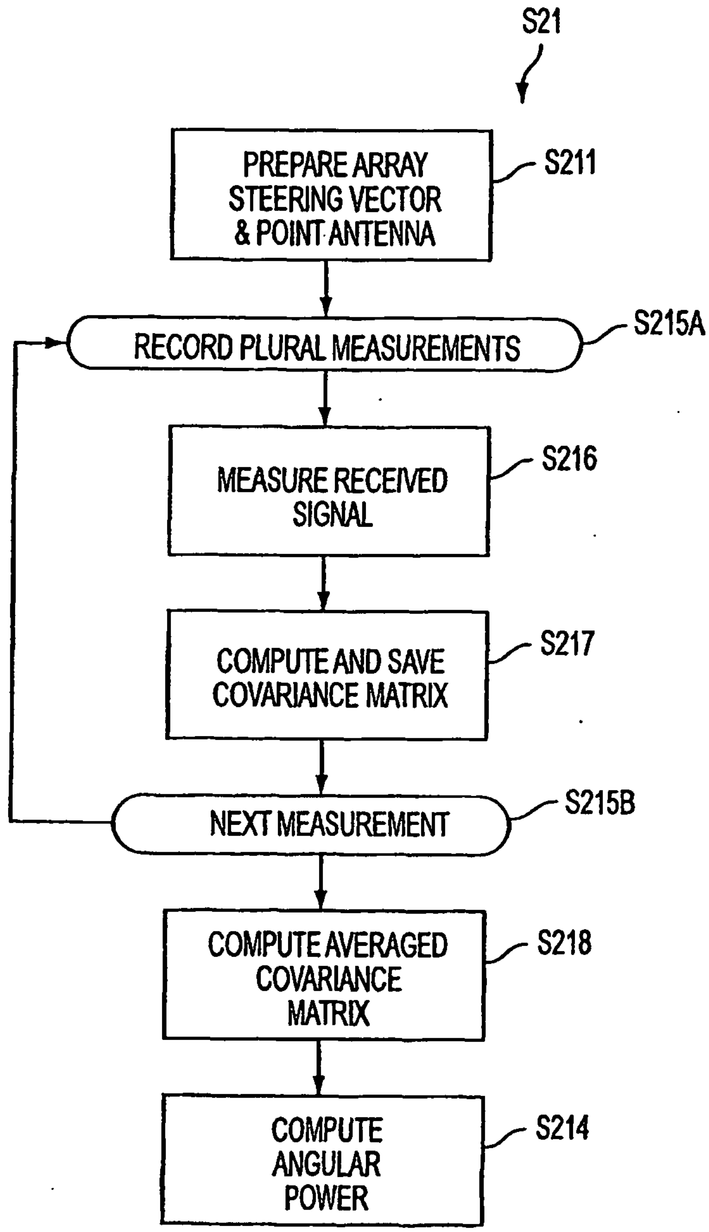

S21
PREPARE ARRAY STEERING VECTOR & POINT ANTENNA
S211
RECORD PLURAL MEASUREMENTS
S215A
MEASURE RECEIVED SIGNAL
S216
COMPUTE AND SAVE COVARIANCE MATRIX
S217
NEXT MEASUREMENT
S215B
COMPUTE AVERAGED COVARIANCE MATRIX
S218
COMPUTE ANGULAR POWER
S214

FIG. 17

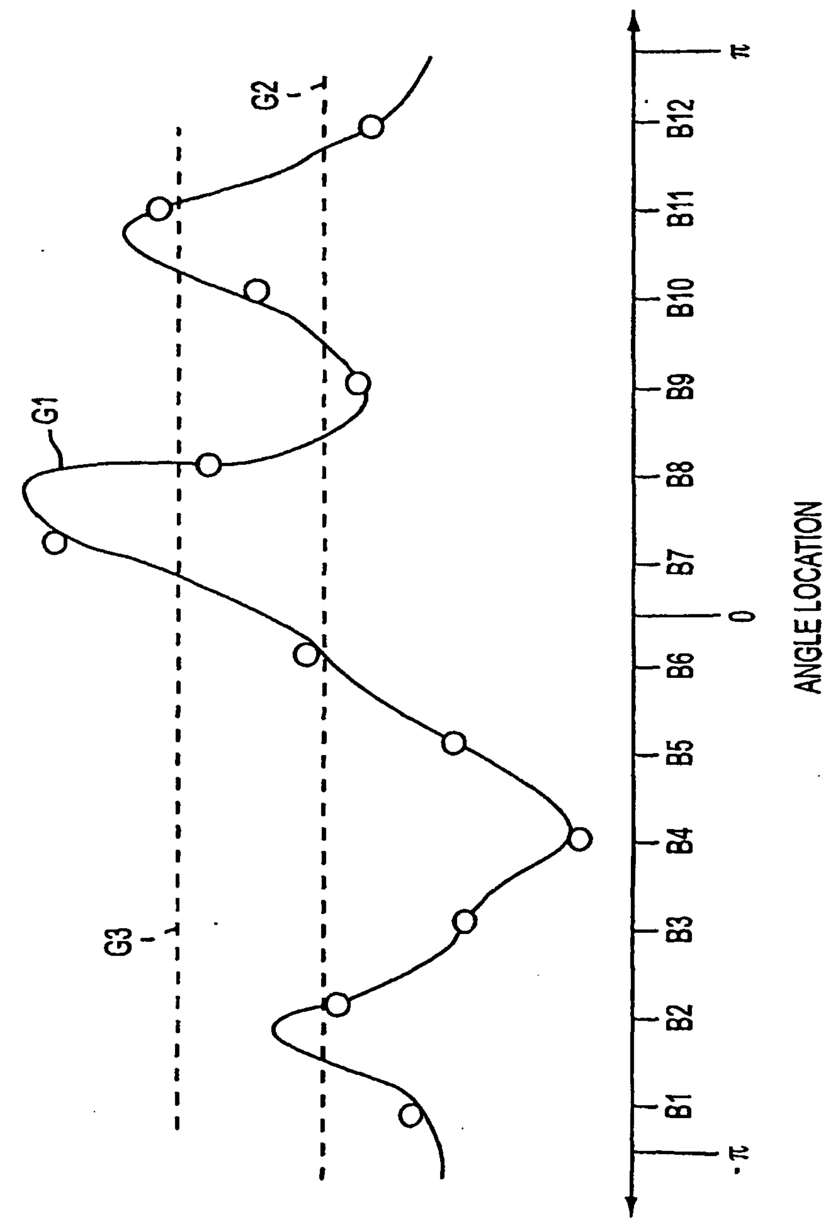


FIG. 18

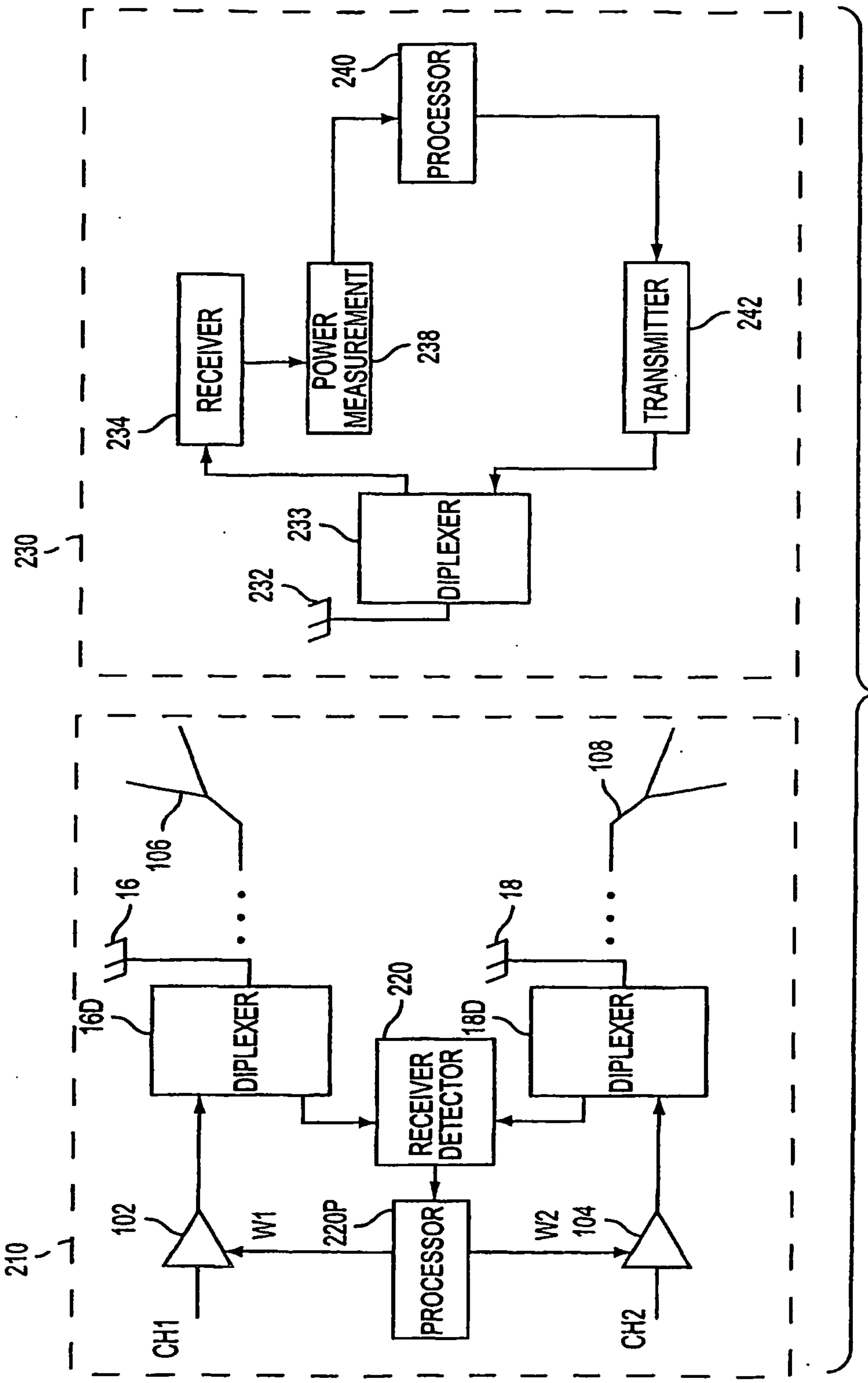

210
CH1
102
W1
220P
PROCESSOR
W2
104
CH2
RECEIVER DETECTOR
220
16D
DIPLEXER
16
106
18D
DIPLEXER
18
108
230
232
233
DIPLEXER
234
RECEIVER
POWER MEASUREMENT
238
240
PROCESSOR
TRANSMITTER
242

FIG. 19

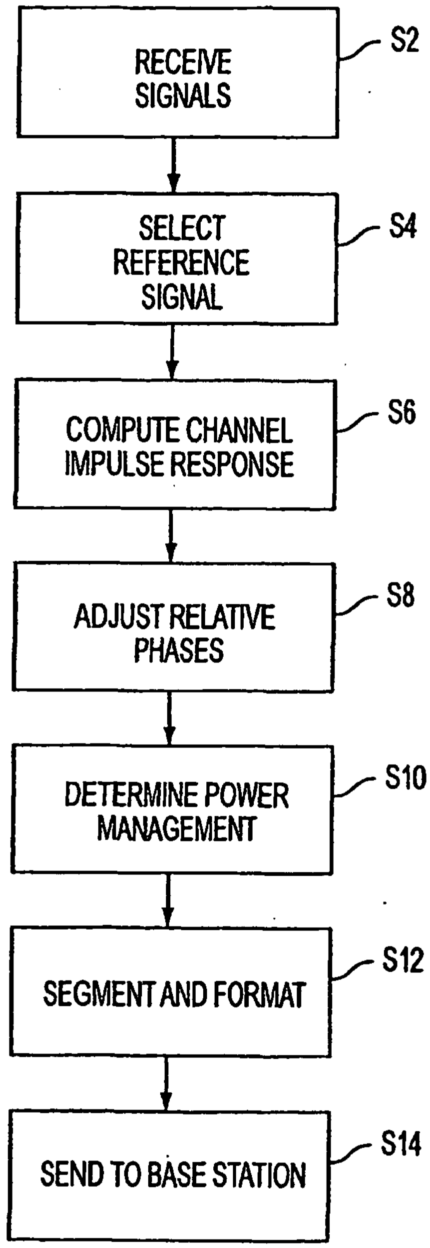

RECEIVE SIGNALS
S2
SELECT REFERENCE SIGNAL
S4
COMPUTE CHANNEL IMPULSE RESPONSE
S6
ADJUST RELATIVE PHASES
S8
DETERMINE POWER MANAGEMENT
S10
SEGMENT AND FORMAT
S12
SEND TO BASE STATION
S14

FIG. 20

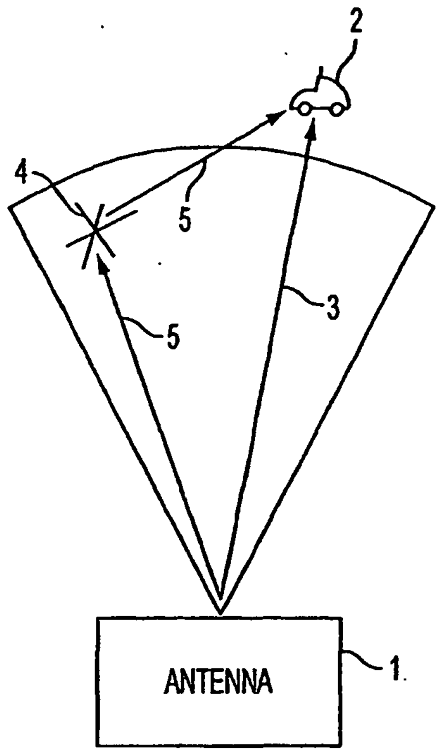


FIG. 21

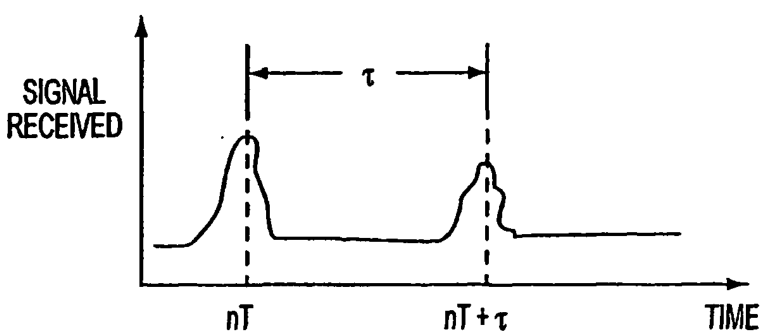


FIG. 22

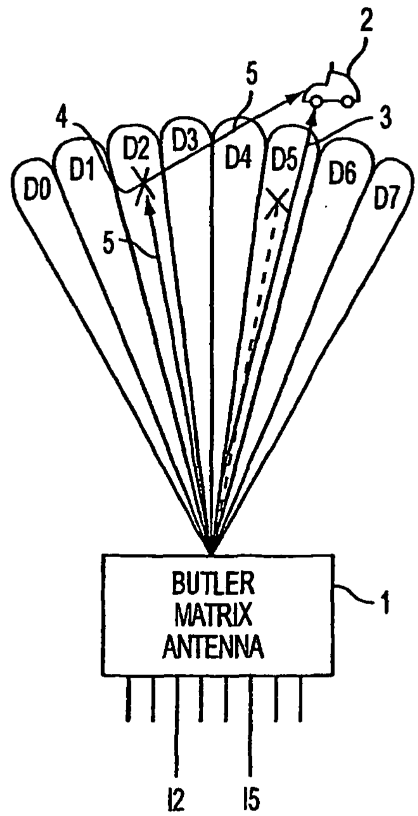


FIG. 23

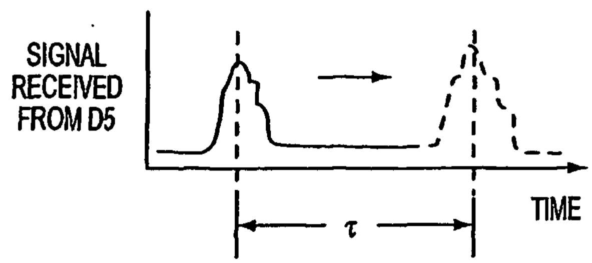


FIG. 24

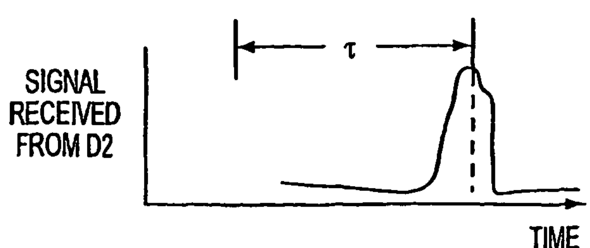


FIG. 25

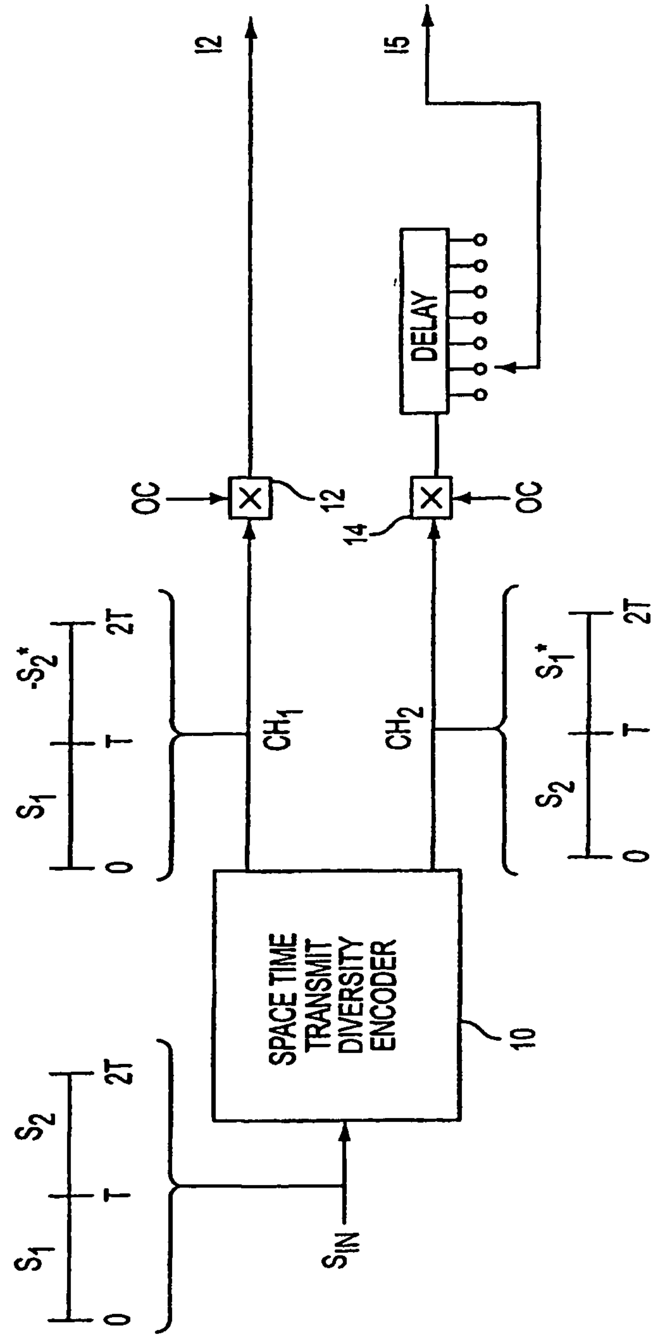

S1
T
S2
2T
0
SIN
SPACE TIME
TRANSMIT
DIVERSITY
ENCODER
10
S1
-S2*
CH1
CH2
S2
S1*
OC
12
14
OC
DELAY
12
15

FIG. 26

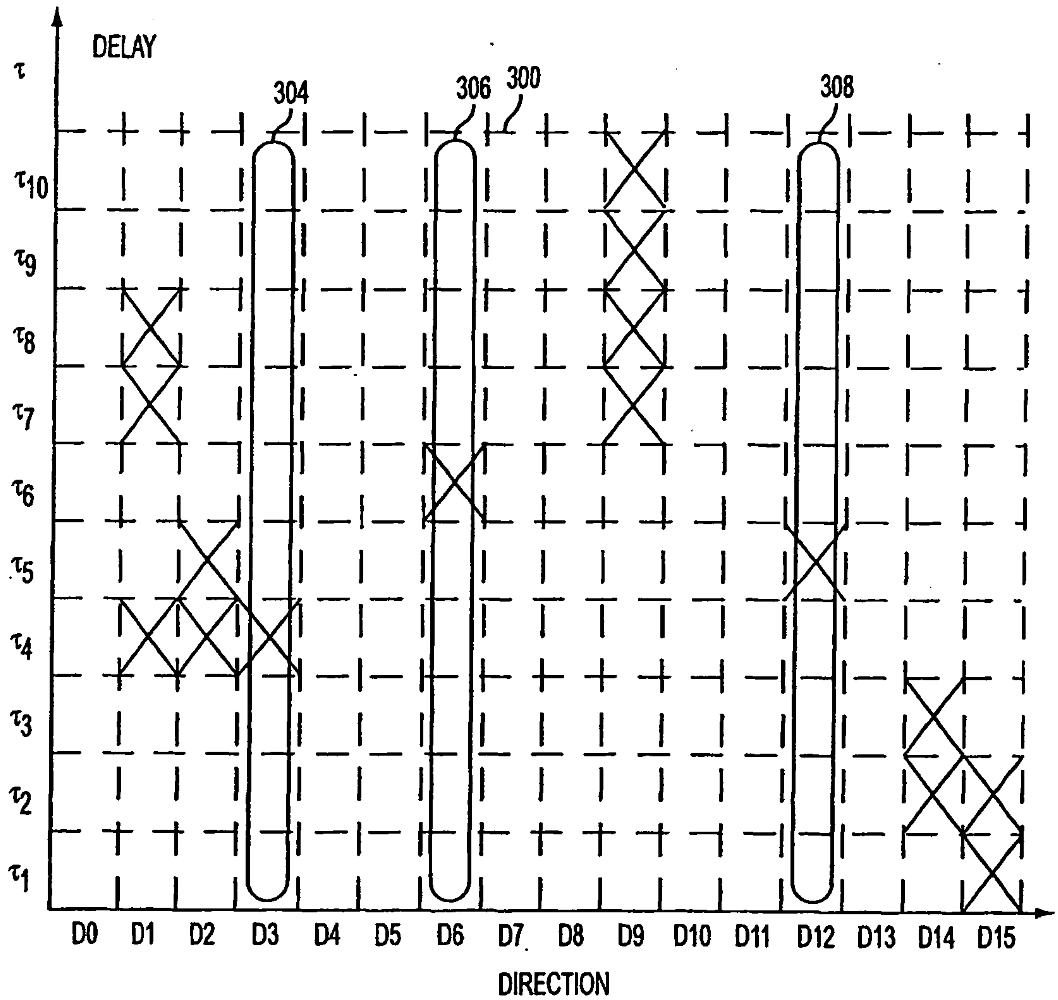

DELAY
τ
τ10
τ9
τ8
τ7
τ6
τ5
τ4
τ3
τ2
τ1
304
306
300
308
D0 D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15
DIRECTION

FIG. 27

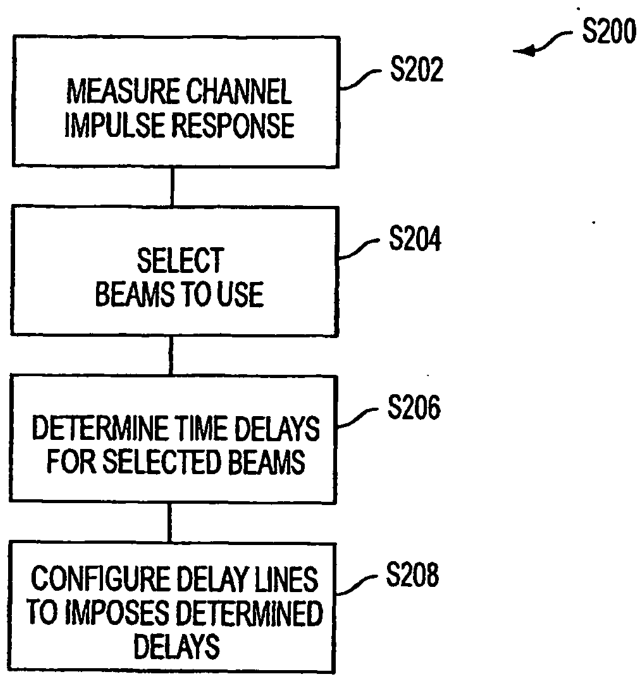

S200
MEASURE CHANNEL IMPULSE RESPONSE
S202
SELECT BEAMS TO USE
S204
DETERMINE TIME DELAYS FOR SELECTED BEAMS
S206
CONFIGURE DELAY LINES TO IMPOSES DETERMINED DELAYS
S208

FIG. 28

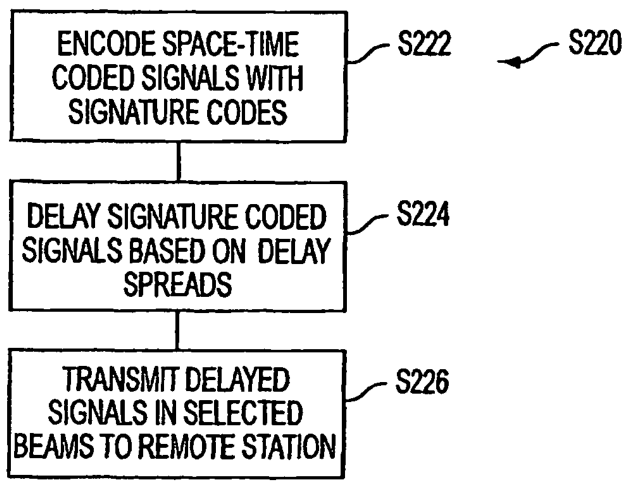

ENCODE SPACE-TIME CODED SIGNALS WITH SIGNATURE CODES
S222
S220
DELAY SIGNATURE CODED SIGNALS BASED ON DELAY SPREADS
S224
TRANSMIT DELAYED SIGNALS IN SELECTED BEAMS TO REMOTE STATION
S226

FIG. 29

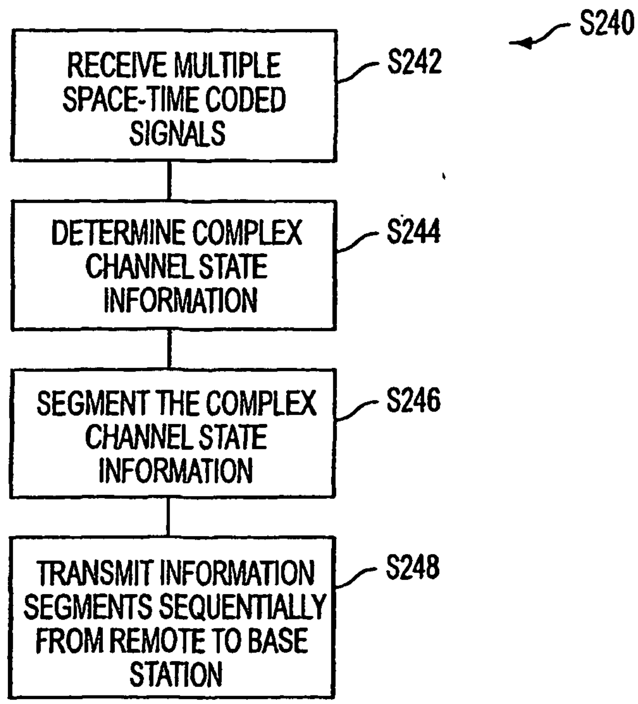

S240
RECEIVE MULTIPLE SPACE-TIME CODED SIGNALS
S242
DETERMINE COMPLEX CHANNEL STATE INFORMATION
S244
SEGMENT THE COMPLEX CHANNEL STATE INFORMATION
S246
TRANSMIT INFORMATION SEGMENTS SEQUENTIALLY FROM REMOTE TO BASE STATION
S248

FIG. 30

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 04 02 0209

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	EP 1 003 297 A (LUCENT TECHNOLOGIES INC) 24 May 2000 (2000-05-24) * abstract * * paragraph [0009] - paragraph [0010] * * column 5, lines 36-42 * * column 8, lines 5-9; figures 5,6 *	1-12	H04B7/06 H04B7/04
X	EP 0 969 610 A (LUCENT TECHNOLOGIES INC) 5 January 2000 (2000-01-05) * column 3, lines 53-57 * * column 4, lines 29-33 * * column 4, lines 45-48 * * abstract * * figure 1A *	1-12	
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X	US 5 613 219 A (VOGEL MARTIN DR-ING ET AL) 18 March 1997 (1997-03-18) * column 4, line 49 - line 60 *	1-12	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H04B
X	US 6 067 290 A (HEATH JR ROBERT W ET AL) 23 May 2000 (2000-05-23) * column 29, line 15 - line 35 * * column 26, line 9 - line 60 * * figures 9A,10A,11A *	1-12	
X	WO 98/09381 A (UNIV LELAND STANFORD JUNIOR) 5 March 1998 (1998-03-05) * page 3, line 1 - page 7, line 34 *	1-12	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	15 October 2004	Bodin, C-M

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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P : intermediate document

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& : member of the same patent family, corresponding document

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			DE	69725995	D1	11-12-2003
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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 July 2003 (03.07.2003)

PCT

(10) International Publication Number
WO 2003/055097 A3

(51) International Patent Classification[7]: H04B 7/06

(21) International Application Number: PCT/US2002/038082

(22) International Filing Date: 26 November 2002 (26.11.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/008,332 6 December 2001 (06.12.2001) US

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(74) Agents: **MAY, Steven A.** et al.; Motorola, Inc., Intellectual Property Dept., 1303 East Algonquin Road, Schaumburg, IL 60196 (US).

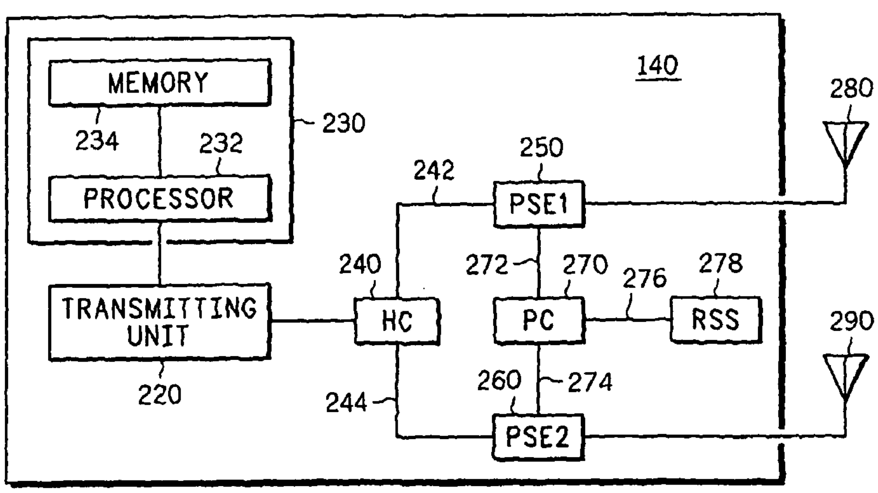
(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

[Continued on next page]

(54) Title: METHOD AND BASE STATION FOR PROVIDING PHASE-SHIFT TRANSMIT DIVERSITY



(57) Abstract: In accordance with the preferred embodiments of the present invention, a method (400) and a base station (140) for providing phase-shift transmit diversity in a wireless communication system are described herein. The base station (140) phase-shift modulates a first signal with a reference signal to produce a first phase-shift modulated signal including a first phase shift. Further, the base station phase-shift modulates a second signal with the reference signal to produce a second phase-shift modulated signal including a second phase shift. The second phase shift is distinct from the first phase shift such that the second phase-shift modulated signal is diverse relative to the first phase-shift modulated signal. Accordingly, the base station transmits the first phase-shift modulated signal via a first antenna and the second phase-shift modulated signal via a second antenna to a plurality of mobile stations.

WO 2003/055097 A3

(88) Date of publication of the international search report:
26 February 2004

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

METHOD AND BASE STATION FOR PROVIDING PHASE-SHIFT TRANSMIT DIVERSITY

Field of the Invention

The present invention relates to wireless communication systems, and more particularly, to a method and a base station for providing phase-shift transmit diversity in a wireless communication system.

Background of the Invention

A wireless communication system is a complex network of systems and elements. Typically elements include (1) a radio link to the mobile stations (e.g., cellular telephones), which is usually provided by at least one and typically several base stations, (2) communication links between the base stations, (3) a controller, typically one or more base station controllers or centralized base station controllers (BSC/CBSC), to control communication between and to manage the operation and interaction of the base stations, (4) a call controller (e.g., mobile switching center (MSC)) or switch, typically a call agent (i.e., a "softswitch"), for routing calls within the system, and (5) a link to the land line or public switch telephone network (PSTN), which is usually also provided by the call agent.

One aspect of designing a wireless communication system is to optimize the performance of forward link or downlink transmissions. That is, the voice and packet data transmissions from a base station to a mobile station. However, multipath fading may cause multiple copies of the transmissions to be received at the mobile station with time-varying attenuation, phase shift and delay because of multiple reflections on the path.

One technique to mitigate the effects of multipath fading in a wireless communication channel is error correcting code. Along with error correction code, bit interleaving can compensate for bit errors caused by multipath fading. In particular, bit interleaving scatters the bit errors among the uncorrupted bits (i.e., "good" bits) so that the error correction codes can better correct the error bits interspersed among the "good" bits. However, the fading intervals must be fast enough to cause a burst of bit errors that are much shorter than the bit interleaving period (i.e., a frame) for bit interleaving to be effective. For example, a slow moving mobile station (e.g., a mobile station used by a pedestrian or an in-building user) creates slow fading receiving channels such that fading bursts on the wireless communication channel are longer than the frame. As a result, the error correction code may not compensate for the error bits.

Diversity is another technique used to reduce the effect of multipath fading. In particular, multiple antennas at the reception end, e.g., the mobile station, may be used to combine, select and/or switch to improve the quality of the transmission from the transmission end, e.g., the base station. However, receive diversity techniques increase cost, size, and power consumption of the mobile station.

Forward link or downlink performance may be optimized by implementing diversity on the transmission end. In particular, phase-shift transmit diversity (PSTD) may be implemented to reduce multipath fading effects. To provide PSTD, a base station generally includes a signal source, a transmitting unit, a signal split element, a phase-shift element, a main antenna and a diversity antenna. A basic flow for providing PSTD may start with the signal source providing a baseband signal to the transmitting unit, which in turn modulates the baseband signal to produce a radio frequency (RF) signal and amplifies the RF signal with a power amplifier. The signal splitter separates the RF signal into two paths, i.e., a main path and a diversity path. The main antenna transmits the RF signal on the main path whereas the RF signal on the diversity path is phase-shift modulated by the phase-shift element to produce a phase-shift modulated RF signal. Typically, the phase-shift element may be a high-power handling, slow changing 360° phase-shift element. That is, the RF signal on the diversity path (i.e., the phase-shift modulated RF signal) may be phase-shift modulated relative to the RF signal on the main path such that the phase shifts a full cycle from 0° to 360° at least once during a frame. Accordingly, the diversity antenna coupled to the phase-shift element transmits the phase-shift modulated RF signal. However, the phase-shift element suffers from high insertion loss variation and non-linear phase change (e.g., hysteresis and temperature variation effects).

In an alternate method to implement PSTD, the base station may include two separate power amplifiers. Prior to the power amplifiers, a RF signal may be separated into two signals for a main path and a diversity path, i.e., a main signal and diversity signal, respectively. On the main path, the main signal may be amplified and transmitted via a main antenna. On the diversity path, the diversity signal may be phase-shift modulated (i.e., applying a time-varying phase shift) prior to being amplified and transmitted via a diversity antenna. However, cost of the base station may increase because of the additional power amplifier. Therefore, a need exists for implementing phase-shift transmit diversity that minimizes the insertion loss variation and the phase non-linearities.

Another aspect of designing a wireless communication system is to increase the capacity of the system by adding carriers to existing infrastructure as needed.

That is, several carriers may be combined at the same location but each carrier may be individually amplified and modulated with voice and data information. One method for carrier combination is to use a resistive or hybrid combiner at a high radio frequency (RF) power level for transmission through a common antenna. However, this method loses more than half of the transmission power because of resistive losses in the hybrid combiner. Another method for carrier combination is to use a high power frequency multiplexer for transmission through a common antenna. Even though this method typically has a low power loss, the use of a high power frequency multiplexer may be limited to non-adjacent carriers because of filter limitations. Another method for carrier combination is space combination in which a main carrier is transmitted via a main antenna and adjacent carriers are transmitted via a diversity antenna. This method also has a low power loss, but the difference in radiation patterns between the main antenna and the diversity antenna may cause uneven carrier loading and below capacity use of the communication system.

Therefore, a need exists for carrier combination with low power loss at high RF power level for transmission of both adjacent and non-adjacent carriers via a common antenna.

Brief Description of the Drawings

FIG. 1 is a block diagram representation of a wireless communication system that may be adapted to operate in accordance with the preferred embodiments of the present invention.

FIG. 2 is a block diagram representation of a base station that may be adapted to operate in accordance with the preferred embodiments of the present invention.

FIG. 3 is a block diagram representation of a phase-shift unit that may be adapted to operate in accordance with the preferred embodiments of the present invention.

FIG. 4 is a flow diagram illustrating a method for providing phase-shift transmit diversity in accordance with the preferred embodiments of the present invention.

Detailed Description of the Preferred Embodiments

Preferred embodiments of a method and a base station for providing phase-shift transmit diversity in a wireless communication system are described. The wireless communication system provides communication services to a plurality of mobile stations. In particular, a base station provides phase-shift transmit diversity by phase-shift modulating a first signal S_1 with a first control signal to produce a first phase-shift modulated signal $S_1 * \exp(-j\,\theta_1)$, where first phase shift $\theta_1(t) = C_1 + P_1(t)$ includes a first constant phase C_1 and a time-varying phase shift $P_1(t) = P_1(m_1(t))$. Further, the base station phase-shift modulates a second signal S_2 with a second control signal to produce a second phase-shift modulated signal $S_2 * \exp(-j\,\theta_2)$, where second phase shift $\theta_2(t) = C_2 + P_2(t)$ includes a second constant phase shift C_2 and a time-varying phase shift $P_2(t) = P_2(m_2(t))$. The second phase shift is distinct from the first phase shift such that the second phase-shift modulated signal is diverse relative to the first phase-shift modulated signal. That is, the first phase shift may be a phase shift of 180° peak deviation operable in a first direction whereas the second phase shift may be a phase shift of 180° peak deviation operable in a second direction to generate a time-varying relative phase shift from -180° to 180°. In the same cycle, for example, the first phase shift may be a phase shift of 180° peak deviation operable in an ascending direction (i.e., from 0° to 180°) whereas the second phase-shift modulated signal may include a phase shift of 180° peak deviation operable in a descending direction (i.e., 180° to 0°). In another example, a first constant phase shift deviation C_1 may be added to the first phase shift and a second constant phase shift deviation C_2 may be added to the second phase shift to generate a relative phase shift between -180° +)C and 180° +)C, where)C = $C_1 - C_2$ is the phase difference.

Accordingly, the base station transmits the first phase-shift modulated signal via a first antenna and the second phase-shift modulated signal via a second antenna to the plurality of mobile stations.

A communication system in accordance with the present invention is described in terms of several preferred embodiments, and particularly, in terms of a wireless communication system operating in accordance with at least one of several standards. These standards include analog, digital or dual-mode communication system protocols such as, but not limited to, the Advanced Mobile Phone System (AMPS), the Narrowband Advanced Mobile Phone System (NAMPS), the Global System for Mobile Communications (GSM), the IS-55 Time Division Multiple Access (TDMA) digital cellular, the IS-95 Code Division Multiple Access (CDMA) digital cellular, CDMA 2000, the Personal Communications System (PCS), 3G and variations and evolutions of these protocols. As shown in FIG. 1, a wireless communication system 100 includes a communication network 110, a plurality of base station controllers (BSC), generally shown as 120 and 122, servicing a total service area 130. The wireless communication system 100 may be, but is not limited to, a frequency division multiple access (FDMA) based communication system, a time division multiple access (TDMA) based communication system, and code division multiple access (CDMA) based communication system. As is known for such systems, each BSC 120 and 122 has associated therewith a plurality of base stations (BS), generally shown as 140, 142, 144, and 146, servicing communication cells, generally shown as 150, 152, 154, and 156, within the total service area 130. The BSCs 120 and 122, and base stations 140, 142, 144, and 146 are specified and operate in accordance with the applicable standard or standards for providing wireless communication services to mobile stations (MS), generally shown as 160, 162, 164, and 166, operating in communication cells 150, 152, 154, and 156, and each of these elements are commercially available from Motorola, Inc. of Schaumburg, Illinois.

Referring to FIG. 2, the base station 140 generally includes a transmitting unit 220, a controller 230, a hybrid coupler (HC) 240, a first phase-shift element (PSE1) 250, a second phase-shift element (PSE2) 260, a phase controller (PC) 270, a first antenna 280, and a second antenna 290. The transmitting unit 220 is operatively coupled to the controller 230, which includes, but is not limited to, a processor 232 and a memory 234. The processor 232 is operatively coupled to the memory 234, which stores a program or a set of operating instructions for the processor 232. In particular, the processor 232 executes the program or the set of operating instructions such that the base station 140 operates in accordance with a preferred embodiment of the invention. The program or the set of operating instructions may be embodied in a computer-readable medium such as, but not limited to, paper, a programmable gate array, application specific integrated circuit, erasable programmable read only memory, read only memory, random access memory, magnetic media, and optical media. Further, the transmitting unit 220 is operatively coupled to the hybrid coupler 240 as one of ordinary skill in the art will readily recognize. The hybrid coupler 240 and the phase controller 270 are operatively coupled to the first phase-shift element 250 and the second phase-shift element 260. In particular, the hybrid coupler 240 provides a first signal via a first path 242 to the first phase-shift element 250 and a second signal via a second path 244 to the second phase-shift element 260. The phase controller 270 provides a first control signal via a first control path 272 to the first phase-shift element 250 and a second control signal via a second control path 274 to the second phase-shift element 260. The first and second control signals are time synchronized to a reference signal 276 provided by a reference signal source (RSS) 278, e.g., a base station reference clock and an internal high accuracy oscillator. The reference signal 276 may be, but is not limited to, an integer multiple of 1.2288 MHz (i.e., the IS-95 CDMA chip rate), and an integer multiple of 50 Hz (i.e., the IS-95 CDMA frame rate). For example, the reference signal may be 19.6 MHz, which is 16 times 1.2288 MHz. The first phase-shift element 250 is operatively coupled to the first antenna 280 whereas the second phase-shift element 260 is operatively coupled to the second antenna 290. The first phase-shift element 250 and the second phase-shift element 260 may be, but are not limited to, an open loop calibration circuit operable by a digital and/or analog means, and a closed loop compensation circuit as described in further detail below.

To provide phase-shift transmit diversity, the base station 140 transmits a first phase-modulated signal via the first antenna 280 (e.g., a main antenna) and a second phase-modulated signal via the second antenna 290 (e.g., a diversity antenna). The first phase-shift element 250 generates the first phase-shift modulated signal based on the first signal via the first path 242 and the first control signal via the first control path 272 whereas the second phase-shift element 260 generates the second phase-shift modulated signal based on the second signal via the second path 244 and the second control signal via the second control path 274. That is, a first phase shift is added to the first signal to produce the first phase-shift modulated signal, and a second phase shift is added to the second signal to produce the second phase-shift modulated signal. In particular, the second phase shift is distinct from the first phase shift such that the second phase-shift modulated signal is diverse relative to the first phase-modulated signal. The first phase shift may be, but is not limited to, a phase shift of 180° peak deviation operable in a first direction, and the second phase shift may be, but is not limited to a phase shift of 180° peak deviation operable in a second direction. That is, the first phase shift and the second phase shift are operable in opposite directions from one another. For example, the first phase shift may be a phase shift from 0° to 180° (i.e., in an ascending direction) whereas the second phase shift may be a phase shift from 180° to 0° (i.e., in a descending direction). In another example, the first phase shift may be a phase shift from 90° to 270° (i.e., in an ascending direction) whereas the second phase shift may be a phase shift from 225° to 45° (i.e., in a descending direction). The first and second phase modulated signals may span over more than one carrier. As a result, a mobile station may receive the first and second phase-shift modulated signals on a first carrier whereas another mobile station may receive the first and second phase-shift modulated signals on a second carrier from a common base station (e.g., base station 140) such that the first and second phase-shift modulated signals on the first and second carriers are diverse relative to each other.

As noted above, the first and second phase-shift elements 250, 260 may be, but are not limited to, an open loop linearization and compensation circuit and a closed loop linearization and compensation circuit (i.e., calibration-free) as shown in FIG. 3. Referring to FIG. 3, each of the first phase-shift element 250 and the second phase-shift element 260 generally includes a first directional coupler 310, a second directional coupler 320, a phase shifter 330, a phase comparator 340, a combination circuit 350 and a loop filter and high current controller 360. The first directional coupler 310 is operatively coupled to the phase comparator 340, which in turn is operatively coupled to the second directional coupler 320 and the combination circuit

350. In particular, the combination circuit 350 is operatively coupled to the loop filter and high current controller 360, which in turn is operatively coupled to the phase shifter 330, which may be, but is not limited to, an 180° ferrite variable phase shifter. The first directional coupler 310 is also operatively coupled to the phase shifter 330, which in turn, is operatively coupled to the second directional coupler 320.

A basic flow for phase-shift modulating a radio frequency (RF) signal that may be applied with the preferred embodiment of the present invention shown in FIG. 3 may start with the phase shifter 330 generating a phase-shift modulated signal based on an RF signal from a hybrid coupler (one shown as 240 in FIG. 2) and an output from the loop filter and high current controller 360 as further described in detail below. In particular, the first directional coupler 310 provides a sample of the input to the phase shifter (i.e., the RF signal) to the phase comparator 340. Also, the second directional coupler 320 provides a sample of the output of the phase shifter 330 (i.e., the phase-shift modulated signal) to the phase comparator 340. Accordingly, the phase comparator 340 generates an output signal that is proportional to the phase difference between the sample of the RF signal from the first directional coupler 310 and the sample of the phase-shift modulated signal from the second directional coupler 320. In response to the output signal from the phase comparator 340, the combination circuit 350 generates an error signal based on a control signal from a phase controller (one shown as 270 in FIG. 2). The loop filter and high current controller 360 filters and amplifies the error signal to generate a control signal to the phase shifter 330. As a result, the phase shifter 330 generates the phase-shift modulated signal based on the control signal from the loop filter and high current controller 360. Thus, the phase shifter 330 provides the phase-shift modulated signal to the antenna (e.g., the first antenna 280 and the second antenna 290) for transmission to a mobile station.

In an alternate embodiment, the hybrid coupler shown as 240 in FIG. 2 may be a four-port hybrid combination circuit to provide carrier combination. For example, the four-port hybrid combination circuit may be, but is not limited to, a 90E four-port hybrid combination circuit and a 180E four-port hybrid combination circuit. Referring to FIG. 4, the four-port hybrid combination circuit 400 generally includes a first port 410, a second port 420, a third port 430 and a fourth port 440. The first and second ports 410, 420 may be operatively coupled to transmitting units such as the transmitting unit 220 shown in FIG. 2. The third and fourth ports 430, 440 may be operatively coupled to the first and second paths 242, 244 shown in FIG. 2, respectively.

Referring back to FIG. 4, a basic flow of the four-port hybrid combination circuit 400 may start with the first and second ports 410, 420 receiving two input signals (i.e., a first input signal a_1 and a second input signal a_2) to produce a composite signal, which turn, is separated into a first output signal b_3 and a second output signal b_4 (i.e., the first and second signals via the first and second paths 242, 244, respectively). The first and second output signals b_3, b_4 are linear combination of the first and second input signals a_1 and a_2. For example, the first output signal b_3 may be the first input signal a_1 at half power (i.e., divided by two) combined with the second input signal a_2 at half power and shifted by 90E, and the second output signal b_4 may be the first input signal at half power and shifted by 90E combined with the second input signal a_2 at half power. The third port 430 provides the first signal (i.e., the first output signal b_3) to the first phase-shift element 250 via the first path 242 whereas the fourth port 440 provides the second signal (i.e., the second output signal b_4) to the second phase-shift element 260 via the second path 244. Accordingly, the first and second signals are each phase-shift modulated and transmitted as described above. In particular, the first signal is phase-shift modulated by the first phase-shift element 250 to produce the first phase-shift modulated signal at half power and the second signal is phase-shift modulated by the second phase-shift element 260 to produce the second phase-shift modulated signal at half power. The first and second phase-shift modulated signals are transmitted via the first and second antennas 280, 290 shown FIG. 2, respectively. The carriers of the first and second phase-shift modulated signals are recombined at the mobile station to recover full power of the first and second input signals a_1, a_2.

In accordance with the preferred embodiments of the present invention, and with references to FIG. 5, a method 500 for providing phase-shift transmit diversity in a wireless communication system is shown. Method 500 begins at step 510, where a base station phase-shift modulates a first signal with a first control signal to produce a first phase-shift modulated signal including a first phase shift. In particular, the first phase shift may be, but is not limited to, a first constant phase shift and a time-variable phase shift of 180° peak deviation operable in a phase direction. For example, the first phase-shift modulated signal may include a time-variable phase shift from 0° to 180° in an ascending phase direction. At step 520, the base station phase-shift modulates a second signal with a second control signal to produce a second phase-shift modulated signal including a second phase shift. The first control signal is synchronized with the second control signal. The second phase shift is distinct from the first phase shift such that the second phase-shift modulated signal is diverse relative to the first phase-shift modulated signal. That is, the second phase shift may be, but is not limited to, a second constant phase shift and a second time-variable phase shift of 180° peak deviation operable in a phase direction. For example, the second phase-shift modulated signal may include a phase shift from 180° to 0° in a descending phase direction. At step 530, the base station transmits the first phase-shift modulated signal via a first antenna (e.g., a main antenna). At step 540, the base station transmits the second phase-shift modulated signal via a second antenna (e.g., a diversity antenna). As a result, the base station provides phase-shift transmit diversity with the first and second phase-shift modulated signals.

Many changes and modifications could be made to the invention without departing from the fair scope and spirit thereof. The scope of some changes is discussed above. The scope of others will become apparent from the appended claims.

What is Claimed:

1. In wireless communication system, the communication system providing communication services to a plurality of mobile stations, a method for providing phase-shift transmit diversity, the method comprising:

phase-shift modulating a first signal with a first control signal to produce a first phase-shift modulated signal including a first phase shift;

phase-shift modulating a second signal with a second control signal to produce a second phase-shift modulated signal including a second phase shift, the second phase shift being distinct from the first phase shift such that the second phase-shift modulated signal is diverse relative to the first phase-shift modulated signal;

transmitting the first phase-shift modulated signal via a first antenna; and

transmitting the second phase-shift modulated signal via a second antenna,

wherein the first control signal is synchronized with the second control signal.

2. The method of claim 1, wherein the step of phase-shift modulating a first signal with a first control signal to produce a first phase-shift modulated signal including a first phase shift comprises phase-shift modulating a first signal with a first control signal to produce a first phase-shift modulated signal including a first constant phase shift and a first time-variable phase shift of 180° peak deviation operable in a phase direction.

3. The method of claim 1, wherein the step of phase-shift modulating a second signal with a second control signal to produce a second phase-shift modulated signal including a second phase shift comprises phase-shift modulating a second signal with

a second control signal to produce a second phase-shift modulated signal including a second constant phase shift and a second time-variable phase shift of 180° peak deviation operable in a phase direction.

4. The method of claim 1, wherein the step of phase-shift modulating a first signal with a first control signal to produce a first phase-shift modulated signal including a first phase shift comprises phase-shift modulating a first signal with a first control signal to produce a first phase-shift modulated signal including a first constant phase shift and a first time-variable phase shift of 180° peak deviation operable in an ascending phase direction, and wherein the step of phase-shift modulating a second signal with a second control signal to produce a second phase-shift modulated signal including a second phase shift comprises phase-shift modulating a second signal with a second control signal to produce a second phase-shift modulated signal including a second constant phase shift and a second time-variable phase shift of 180° peak deviation operable in a descending phase direction.

5. The method of claim 1 further comprising the steps of:

combining a first input signal and a second input signal to produce a composite signal; and

generating the first signal and the second signal based on the composite signal, wherein the first signal is based on a first carrier and the second signal is based on a second carrier.

6. In a wireless communication system, the communication system providing

communication services to a plurality of mobile stations, an apparatus for providing phase-shift transmit diversity, the apparatus comprising:

a first signal path operable to provide a first signal;

a second signal path operable to provide a second signal;

a phase-shift controller adapted to provide a first control signal and a second control signal, the first control signal being synchronized with the second control signal;

a first phase-shift element coupled to the first signal path and the phase-shift controller, the first phase-shift element being operable to generate a first phase-shift modulated signal including a first phase shift based on the first signal and the first control signal;

a second phase-shift element coupled to the second signal path and the phase-shift controller, the second phase-shift element being operable to generate a second signal including a second phase shift based on the second signal and the second control signal;

a first antenna coupled to the first phase-shift element, the first antenna being operable to transmit the first phase-shift modulated signal; and

a second antenna coupled to the second phase-shift element, the second antenna being operable to transmit the second phase-shift modulated signal,

wherein the second phase shift being distinct from the first phase shift such that the second phase-shift modulated signal is diverse relative to the first phase-shift modulated signal.

7. The base station of claim 6, wherein the first phase shift comprises a first constant phase shift and a first time-variable phase shift of 180° peak deviation operable in a phase direction.

8. The base station of claim 6, wherein the second phase shift comprises a second constant phase shift and a second time-variable phase shift of 180° peak deviation operable in a phase direction.

9. The base station of claim 6, wherein the first phase shift comprises a first constant phase shift and a first time-variable phase shift from 0° to 180° operable in an ascending phase direction and wherein the second phase shift comprises a second constant phase shift and a second time-variable phase shift of 180° peak deviation operable in a descending phase direction.

10. The base station of claim 6, wherein each of the first and second phase-shift elements comprises a phase-shift element operable to provide a phase shift of 180° peak deviation.

11. The base station of claim 6, wherein the phase-shift controller comprises a four-port hybrid combination element, wherein the four-port hybrid combination element is operable to provide carrier combination.

12. In a wireless communication system, the communication system for

providing communication service for a plurality of mobile stations, wherein a processor operates in accordance with a computer program embodied on a computer-readable medium for providing transmit diversity, the computer program comprising:

a first routine that directs the processor to phase-shift modulate a first signal with a first control signal to produce a first phase-shift modulated signal including a first phase shift;

a second routine that directs the processor to phase-shift modulate a second signal with a second control signal to produce a second phase-shift modulated signal including a second phase shift, the second phase shift being distinct from the first phase shift such that the second phase-shift modulated signal is diverse relative to the first phase-shift modulated signal;

a third routine that directs the processor to transmit the first phase-shift modulated signal via a first antenna; and

a fourth routine that directs the processor to transmit the second phase-shift modulated signal via a second antenna,

wherein the first control signal is synchronized with the second control signal.

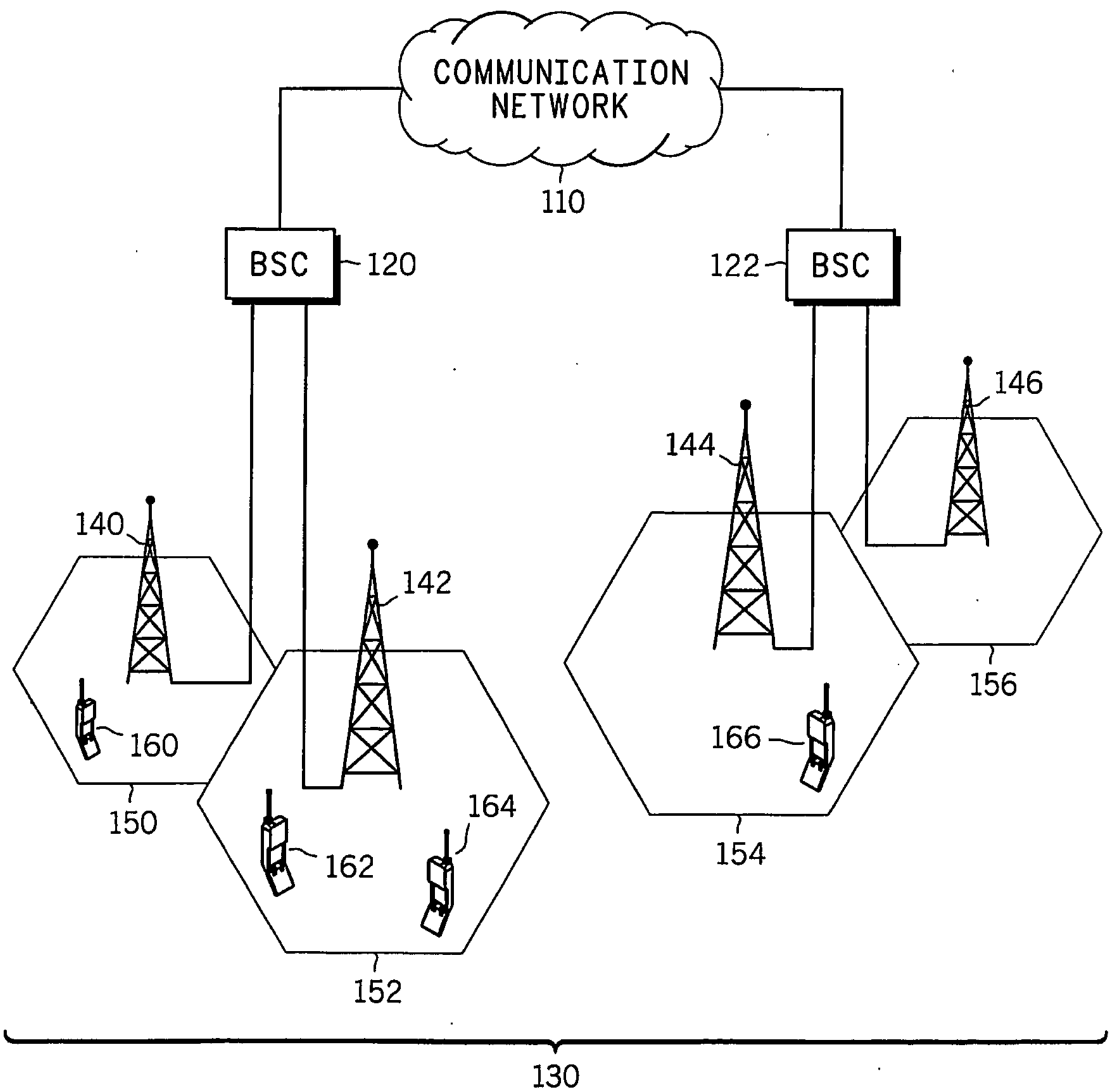
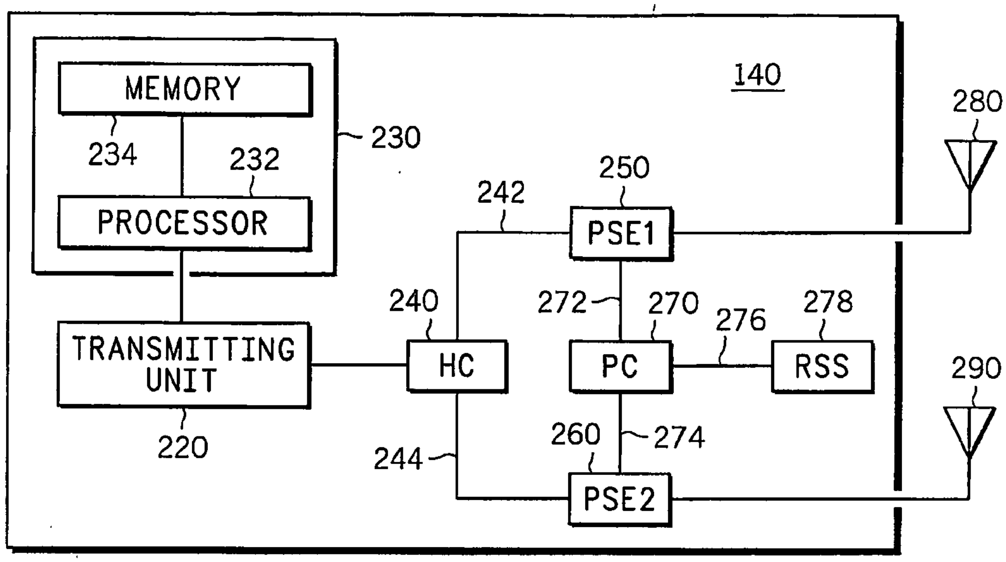
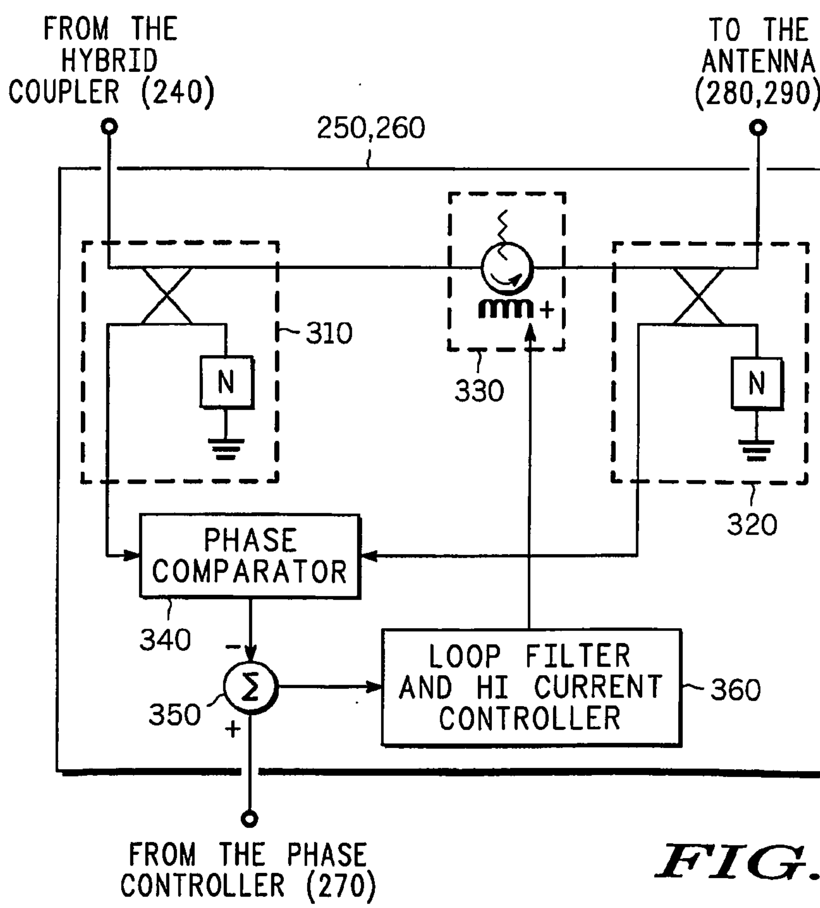

COMMUNICATION NETWORK
110
BSC
120
122
BSC
140
142
144
146
160
150
162
164
152
166
154
156
130

FIG. 1 100



MEMORY
PROCESSOR
TRANSMITTING UNIT
HC
PSE1
PC
RSS
PSE2
140
230
234
232
220
240
242
244
250
260
270
272
274
276
278
280
290

FIG. 2



FROM THE HYBRID COUPLER (240)
TO THE ANTENNA (280,290)
250,260
N
N
310
320
330
PHASE COMPARATOR
340
LOOP FILTER AND HI CURRENT CONTROLLER
360
350
FROM THE PHASE CONTROLLER (270)

FIG. 3

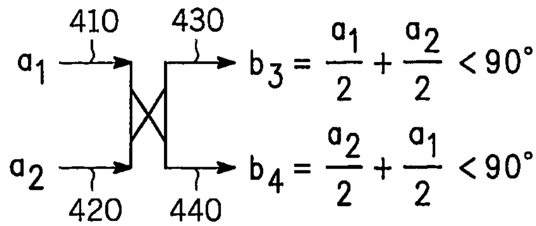
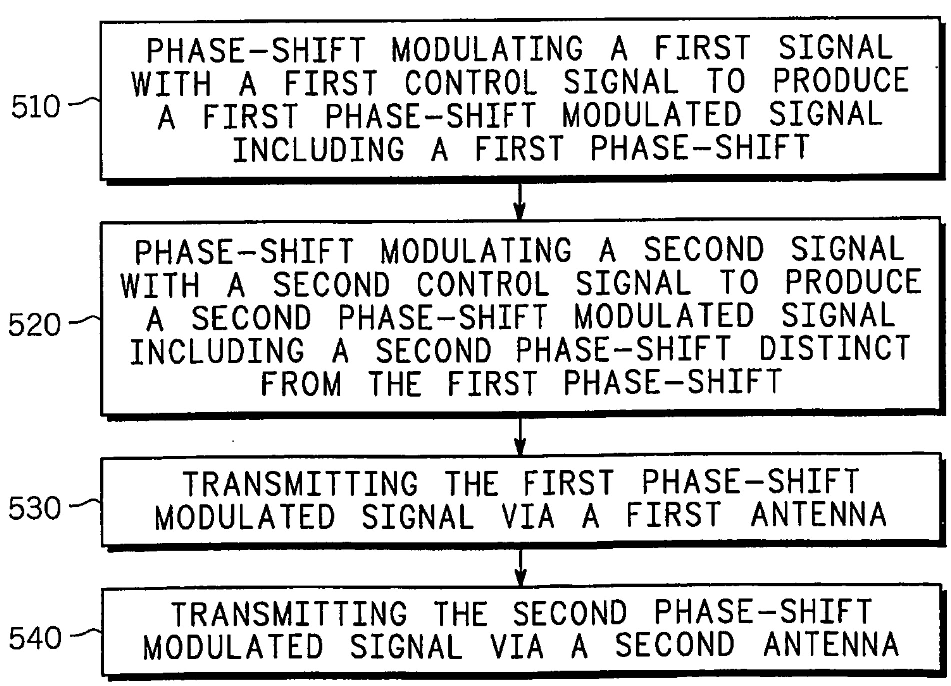


FIG. 4

400

FIG. 5

500



INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/38082

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B7/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B H03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 192 256 B1 (WHINNETT NICHOLAS) 20 February 2001 (2001-02-20)	1,6,10, 12
Y	column 2, line 32 -column 5, line 32	5,11
A	figure 2	2-4,7-9
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Y	abstract	5,11
A	column 2, line 46-65 column 6, line 25 -column 8, line 43 figure 4	2-4,7-9
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 June 2003	01.07.03

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Helms, J

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/38082

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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Y	EP 0 704 964 A (RADIO FREQUENCY SYSTEMS INC) 3 April 1996 (1996-04-03) page 4, line 16 -page 5, line 9 figures 3-5	5,11

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

national application No.
PCT/US 02/38082

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-4, 6-10, 12

   Independent claim 1 relates to a method for providing phase shift diversity comprising phase shift modulating a first signal with a first control signal, phase shift modulating a second signal with a second control signal which is synchronized with the first control signal, the second phase shift being distinct from the first phase shift such that the first phase shift modulated signal is diverse relative to the second one and transmitting the first and the second phase shift modulated signals via first and second antennas, respectively.

   Independent claims 6 and 12 are directed to the corresponding base station and computer program.

   Claims 2-5 depending on claim 1 and claims 7-10 depending on claim 6 relate to details of the phase shifting.

2. Claims: 5, 11

   Claims 5 and 11 depending on claim 1 and 6, respectively, relate to the combination of signals being based on different carriers.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 02/38082

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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 April 2006 (13.04.2006)

PCT

(10) International Publication Number
WO 2006/037364 A1

(51) International Patent Classification[7]: H04B 7/06

(21) International Application Number: PCT/EP2004/011204

(22) International Filing Date: 7 October 2004 (07.10.2004)

(25) Filing Language: English

(26) Publication Language: English

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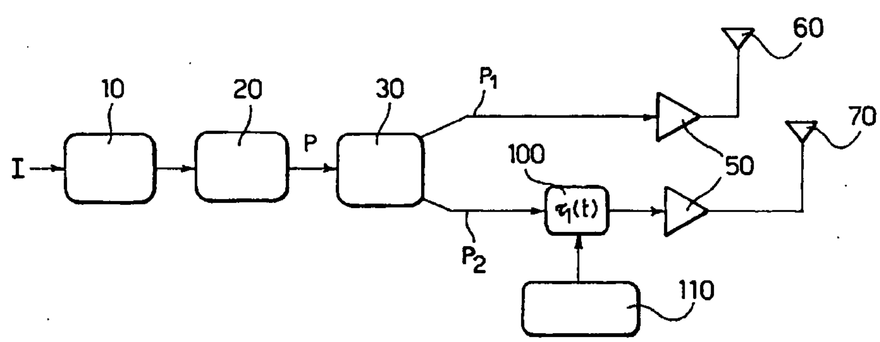
(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** VARIABLE DELAY TRANSMIT DIVERSITY



(57) **Abstract:** A system for transmitting a signal via diversity antennas (60, 70; 150, 160, 170, 180; 190, 200) includes: at least one delay element (100) for generating at least one delayed replica of the signal subject to a given delay; the signal and the at least one delayed replica being adapted to be transmitted via the diversity antennas (60, 70; 150, 160, 170, 180; 190, 200), and a control unit (110) for the at least one delay element (100) for varying (110) the given delay (100), whereby the signal and the at least one delayed replica, transmitted via the diversity antennas (60, 70; 150, 160, 170, 180; 190, 200), give rise to alternate constructive and destructive combinations therebetween.

WO 2006/037364 A1

VARIABLE DELAY TRANSMIT DIVERSITY

Field of the invention

The present invention relates to communication systems.

The invention was developed by paying specific attention to the possible application in mobile communication networks, and more specifically those mobile communication networks including radio base stations, repeaters and/or mobile terminals adapted to be equipped with multiple transmission antennas. Reference to this possible field of application of the invention is not however to be construed in a limiting sense of the scope of the invention.

Description of the related art

Data services are driving the demand for increased data rate and increased system capacity in communication systems and networks, including mobile communication networks. Unlike two-way voice services, that are essentially symmetric in their use of radio up and downlink, many advanced mobile services, such as web browsing or live video streaming, place greater demands on the radio downlink than on the uplink, with more traffic coming to the user (downlink) than from the user (uplink). Therefore, improvement of downlink capacity is one of the main challenges for the evolution of wireless systems. Moreover, many of the proposed data services are likely to be used in low mobility environments characterised by single-path propagation conditions. Poor performance due to prolonged deep fades of the channel is one of the problems associated with this scenario.

Channel coding in conjunction with interleaving is widely used to exploit temporal diversity. However, in very slow fading channels, as typically experimented by low mobility users, the interleaving required to spread long deeply faded blocks into decodable sequences is very long. The interleaving depth available in practice, on the other hand, is often rather limited because of strict requirements in terms of allowable service delay and usage of memory.

A possible technique used to address this problem is transmission antenna diversity, based on the utilization of two or more transmission antennas that introduce additional radio paths and thereby increase the available diversity level. Exploiting spatial diversity in systems with multiple antennas at the transmitter requires that the signal should be pre-processed or pre-coded prior to transmission. In fact, a system with N transmission antennas, where each antenna transmits the same signal with power P/N, provides exactly the same performance of a single antenna system with transmission power P. In order to exploit spatial diversity some kind of pre-processing or pre-coding of the transmitted signals is thus required.

The spacing among the multiple antennas also affects the degree of correlation among the propagation channels observed at the mobile phone. Large antenna spacing in the order of several wavelengths, leads to uncorrelated fading, which corresponds to maximum performance gain due to spatial diversity. In the case of third generation (3G) communication systems, for example, many kinds of transmitter diversity arrangements have been investigated. Some of these operate at the base-band level on each physical channel separately, and have been standardized by the 3GPP/3GPP2 groups (e.g. Space Time Transmit Diversity (STTD), Closed Loop Transmit Diversity (CLTD)).

Other transmission diversity techniques operate at radio frequency (RF) on the composite W-CDMA signal of the base station or repeater and therefore are typically not standardized. The relevance of these techniques is that they can be implemented as add-on modules to the existing equipments.

By way of direct explanation a first method used in the prior art to increase the diversity level over a communication channel involves the transmission of multiple delayed replicas of the same signal. This method is generally denoted as diversity transmission using a fixed delay. The transmitter is comprised of N antennas and each antenna transmits with power P_j ($1 \le j \le N$). The sum of the various powers P_j, is equal to the power P transmitted by a single antenna system taken as reference

$$P = P_1 + P_2 + P_3 + \dots + P_N$$

The other antennas in addition to the first antenna transmit the same signal with a fixed delay T_j ($2 \le j \le N$). Delay is introduced by means of delay lines and the signal for each transmission antenna is provided to a RF amplifier (High Power Amplifier or HPA).

The block diagram of a diversity transmission apparatus using a fixed delay in case of N=2 is shown in Figure 1.

Referring to Figure 1 the input signal, designated I, is fed to a base-band block 10 that outputs the signal in its base-band version. The signal from block 10 is fed to an Intermediate Frequency/Radio Frequency (IF/RF) block 20 and then to a splitter block 30. Before the splitter block the power of the signal is equal to P. The block 30 outputs two signals with power levels equal to P1 and P2, respectively.

The first signal is fed to a High Power Amplifier HPA block 50, and then to a main antenna 60. The second signal is fed to a delay line block 40, with delay equal to T_1, and then to a High Power Amplifier HPA block 50. T_1 is fixed, and it is usually larger than the delay spread of the channel (in a range of some μs). Finally, the second signal is fed to a diversity antenna 70.

The delays T_j are different for the additional antennas j=2, …,N. These delays are chosen in order to achieve sufficient time separation among the signal replicas and permit their coherent summation at the receiver. This kind of transmission scheme introduces additional radio paths, with respect to a single antenna system, and thereby increases the available diversity, as shown in Figure 2 for a two-antenna system.

Specifically, Figure 2a refers to a single antenna system comprising a single transmitter antenna and a single receiver antenna. Figure 2b shows a diversity transmission system using a fixed delay comprising two transmitter antennas and a single receiver antenna.

In the specific case of a 3G system the delays T_j have to be greater than the chip period but, at the same time, they must not exceed the User Equipment (UE) receiving window size, i.e. the memory buffer used to align the different multipath components of the received signal. Typically, the various delays T_j are chosen in an interval ranging from 10 to 40 times the chip period, which corresponds to a delay in the range from 2.5 μs to about 10 μs for the W-CDMA version of the 3G standard.

A second known method used to increase diversity is Phase Sweeping Transmit Diversity (PSTD). In Phase Sweeping Transmit Diversity, the transmitted signal is processed exactly as in a system with no transmission diversity, up to the RF power amplifier stage.

The block diagram of a Phase Sweeping Transmit Diversity (PSTD) transmitter is shown in Figure 3. In Figure 3 references 10, 20, 30, 50, 60, and 70 designates blocks that implement the same functions of the correspondingly blocks in Figure 1 in connection with an input signal I.

Upstream of the HPA amplifiers 50, the signal is split into two parts with power P_1 and P_2 respectively (in the typical configuration $P_1=P_2=P/2$). The first signal is amplified and transmitted via the main Antenna 60. A phase shifter block 80 applies a phase sweep to the second signal, which is a time variant phase rotated version of the second RF signal with respect to the first. The phase shifter block 80 is controlled by a phase control unit block 90. The second signal is then amplified by the HPA 50 and transmitted from the Diversity Antenna 70.

The introduction of a time variant phase rotation is equivalent to shifting the carrier frequency of the second signal. In fact, by denoting with $\vartheta_s(t)$ the phase sweep function, the instantaneous carrier frequency $f_s(t)$ of the signal transmitted by the second antenna 70 is equal to

$$f_s(t) = f_0 + \frac{1}{2\pi}\frac{d\vartheta_s(t)}{dt}$$

where f_0 is the carrier frequency without PSTD. We also notice that, at a given time instant t_k, all the frequency components within the signal bandwidth B are phase rotated of the same quantity $\vartheta_s(t_k)$. Therefore, the phase shift curve as a function of frequency at a given time instant t_k is a constant function as shown in Figure 4.

A number of patent documents disclose arrangements that are essentially related to the two basic arrangements discussed in the foregoing.

For instance, US-A-5 781 541 is exemplary of fixed delay techniques and describes an arrangement providing improved coverage and resistance to multipath fading in a CDMA system. The system uses multiple spatially-diverse antennas and a diversity transmission technique using a fixed delay. The spatially-diverse antennas emit identical CDMA-modulated signals towards a serving area at different times. Specifically, each CDMA-modulated signal sent from one antenna has a sufficient delay to avoid mutual interference with the signals sent from the other antennas. The delay assigned to each antenna is within a range greater than a chip interval, and less than or equal to a base station sequence offset between base stations. As a result, a subscriber station is able to separately demodulate the received CDMA-modulated signals from the different antennas using a Rake receiver.

Document WO-A2-03/055097 is exemplary of those techniques involving phase shifting and describes a method for providing Phase Shift Transmit Diversity (PSTD) in a wireless communication system. The base station phase shift modulates a first signal with a reference signal to produce a first phase-shift modulated signal. Further, the base station phase shift modulates a second signal with a different reference signal to produce a second phase shift modulated signal. The second phase shift is distinct from the first phase shift such that the second phase shift modulated signal is different relatively to the first phase shift modulated signal. Accordingly, the base station transmits the first phase-shift modulated signal via a first antenna and the second phase shift modulated signal via a second antenna to a plurality of mobile stations.

Document GB-A-2 365 281 describes the application of diversity transmission using a fixed delay combined with the Phase Shift Transmit Diversity (PSTD) in case of the GSM system. The downlink signal is transmitted by two antennas and the two signals have a mutual time delay and phase difference. The time delay is fixed and is chosen such that a user equipment (UE) including an equalizer can demodulate the aggregate signal received from the two transmission antennas. Preferably, the maximum delay equals the maximum allowable delay spread in accordance with the GSM standard. The phase difference between the two signal changes periodically, for example between successive time slots.

Document WO-A-02/19565 presents some methods and a related apparatus wherein diversity transmission using a fixed delay and Phase Shift Transmit Diversity (PSTD) techniques are combined. An input symbol stream is offset in time by M symbols periods to generate an offset symbol stream. The original input symbol stream is then transmitted on a first set of N antennas and the offset input symbol stream is transmitted on a second set of N antennas. The Phase Shift Transmit Diversity (PSTD) technique is applied on each set of N antennas in order to further increase the diversity level. The phase shifting of

PSTD may be either a continuous phase sweep or discrete phase hopping in every burst period.

The cost and size of a delay line of several microseconds, operating on an analog signal in the GHz range penalize those arrangements that apply a diversity transmission with a fixed delay. The delay line can be implemented for example by means of a RF cable and this solution has several drawbacks such as cost, size and transmission losses of the cable.

Moreover, in case of slow moving or still users it may occur that both the received signal replicas are attenuated thus producing a prolonged deep fade at the receiver. If the communication system utilizes a closed loop power control in order to keep a constant SNIR (Signal-to-Noise-plus-Interference-Ratio) at the receiver, the deep fade is compensated by increasing the transmitted power at the base station. However, a prolonged increase of the transmitted power corresponds to an increase of the interference level in the system and thus a reduction of the system capacity.

Conversely, a basic drawback of those techniques involving phase shifting lies in that, whenever a signal other than a purely sinusoidal signal is involved, phase shifting is a rather complex process to implement. The practical unavailability of simple arrangements adapted to implement phase shifting of a generic signal practically outweighs the potential advantages of such techniques.

Object and summary of the invention

In view of the foregoing, the need is felt for an efficient arrangement for countering the effect of fading and/or multipath in communication networks, and more specifically in mobile communication networks including radio base stations, repeaters and/or mobile terminals adapted to be equipped with multiple transmission antennas. This with the basic aim of increasing the data rate and improving the downlink capacity and coverage, while dispensing with the intrinsic limitations of the prior art arrangements considered in the foregoing.

The object of the invention is to provide a response to such a need.

According to the present invention, that object is achieved by means of a method having the features set forth in the claims that follow, such claims constituting an integral part of the disclosure of this application. The invention also relates to a corresponding apparatus, a related network and communication equipment as well as a related computer program product, loadable in the memory of at least one computer and including software code portions for performing the steps of the method of the invention when the product is run on a computer. As used herein, reference to such a computer program product is intended to be equivalent to reference to a computer-readable medium containing instructions for controlling a computer system to coordinate the performance of the method of the invention. Reference to "at least one computer" is evidently intended to highlight the possibility for the present invention to be implemented in a distributed/ modular fashion.

A preferred embodiment of the invention is thus a method of transmitting a signal including the steps of:

- generating at least one replica of said signal subject to a given delay, and

- transmitting said signal and said at least one replica of said signal subject to a given delay via diversity antennas; the method includes the step of varying said given delay, whereby said signal and said at least one replica of said signal subject to said varying delay and transmitted via diversity antennas give rise to alternate constructive and destructive combinations therebetween.

The invention is applicable to any kind of communication equipment adapted to be included in a communication network such as a mobile communication network. While particularly adapted to be applied in communication equipment such as a radio base station or a repeater in a mobile communication network, the invention may also be applied in other communication equipment of the mobile type (e.g. mobile user terminals).

Brief description of the annexed drawings

The invention will now be described, by way of example only, with reference to the enclosed figures of drawing, wherein:

- Figures 1 to 4 have already been described in the foregoing;

- Figure 5 shows a basic block diagram of a dynamic delay diversity transmitter as described herein;

- Figure 6, includes two parts designated a) and b), respectively, that show exemplary implementations of delay lines within the framework of the arrangement described herein;

- Figure 7 shows a linear function phase shift curve;

- Figure 8, 8a, and 8b show the rotation of the phasor of the signal of the second antenna in a two-antenna system;

- Figures 9 and 10 show, by way of direct comparison, the received power level in two otherwise equivalent arrangements without and with transmission diversity;

- Figure 11 shows an example of delay function applied to the second transmission antenna in a two-antenna system;

- Figure 12 shows an arrangement where a variable delay is introduced on both transmission antennas in a two-antenna system;

- Figure 13 shows an example of delay functions applied to two transmission antennas in a two-antenna system;

- Figure 14 shows an arrangement where diversity transmission using a fixed delay and dynamic delay diversity are combined; and

- Figure 15 shows an arrangement including two transmission antennas, where diversity transmission using a fixed delay and dynamic delay diversity are combined.

<u>Detailed description of preferred embodiments of the invention</u>

The arrangement described herein implements a diversity technique, operating at RF and therefore independent from a particular wireless system, adapted for a simple implementation, and providing significant performance improvement in low mobility scenarios. In brief, the arrangement described herein provides a new method to exploit the diversity offered by two or multiple transmission antennas. This arrangement can be designated as a dynamic delay diversity arrangement in that it is based on the introduction of a variable delay on the signal transmitted by the additional antennas. The transmitted signal is processed exactly as in a system with no transmission diversity, up to the RF power amplifiers.

In case of a system with N=2 transmission antennas the signal is split into two parts with power P_1 and P_2 respectively (in the typical configuration $P_1=P_2=P/2$). The first signal is amplified and transmitted from the main antenna, while a time variant delay is applied to the second signal.

The delay varies from zero to about the period of the carrier frequency $T_0 = 1/f_0$ with a given law that can be e.g. linear, sinusoidal, etc. The second signal is then amplified by a high power amplifier (HPA) and transmitted from a diversity antenna.

The block diagram of a corresponding dynamic delay diversity transmitter is illustrated in Figure 5. In Figure 5 references 10, 20, 30, 50, 60, and 70 again designate blocks that implements the same functions of the corresponding blocks shown in Figures 1 and 3 in connection with an input signal I. Consequently, these blocks will not be described again here.

The variable delay is introduced by means of a delay line block 100 controlled by a delay control unit (DCU) 110 that controls the law of variation of the delay $\tau_1(t)$ over time. Typically, $\tau_1(t)$ is variable in the range of few nanoseconds (ns).

Figure 6a shows a first exemplary implementation of the delay line 100 in the form of a tapped delay line (TDL), namely as the cascade of elementary delay units 100a, …, 100k. Each such delay unit (e.g. a transmission line stub) may generate a delay of, say, 0.1 ns.

The various tap points in the line come down to a RF switch 101. The switch 101 is controlled by the delay control unit (DCU) 110 making it possible to select a particular tap of the tapped delay line and therefore a given value of the delay produced by the block 100. Changing the position of the switch 101 makes it possible to change the value of the delay.

Stated otherwise, in the exemplary embodiment shown a varying delay is produced by providing a cascade of elementary delay units 100a, …, 100k and by selectively varying, via the switch 101, the number of elementary delay units included in the cascade.

Figure 6b shows a second exemplary implementation of the delay line 100 in the form of a plurality of delay elements 100a', …, 100k' (these may again be comprised of transmission line stubs) each producing a respective delay of e.g. 0.1 ns., 0.2 ns., 0.3 ns., and so on.

Two switches 101a and 101b are controlled in a coordinated manner by the delay control unit (DCU) 110 making it possible to select a particular delay element 100a', …, 100k' and therefore a given value of the delay produced by the block 100. Changing the position of the switches 101a and 101b makes it possible to change the value of the delay.

Typically, this delay is varied in the range between tenths of nanoseconds (ns) and units of nanoseconds (ns).

It will be appreciated that such a delay does not introduce any phase distortion on the transmitted signal. In fact, Fourier analysis shows that applying a delay to a signal having a given frequency spectrum is equivalent to applying a linear phase shift in the frequency domain, that is a phase shift that varies as a linear function of frequency. Therefore, at a given time instant t_k, the frequency components within the signal bandwidth B are phase rotated of a different quantity equal to $\vartheta_s(f) = 2\pi\ f\ \tau(t_k)$, where $\tau(t_k)$ is the delay introduced at the time instant t_k.

No phase distortion is introduced. In fact, the phase shift curve as a function of frequency at a given time instant t_k is a linear function as shown in Figure 7.

In that respect, it will be appreciated that applying a time delay is equivalent to applying a phase shift - only - in the case of a single frequency (e.g. a purely sinusoidal) signal, whose power spectrum is concentrated at a single frequency and is represented by a Dirac function. Conversely, when a multifrequency signal, i.e. a signal having a power spectrum covering plural frequencies is considered, applying a time delay is - not - equivalent to applying a phase shift. Applying a time delay to such a multifrequency signal is equivalent to applying a linear phase shift in the frequency domain, that is a phase shift that varies as a linear function of frequency. Conversely, applying a phase shift to such a multifrequency signal is equivalent to applying a phase shift that is constant in the frequency domain, that is a phase shift that does not vary as a function of frequency.

The effect of the variable delay can be explained from the propagation point of view as schematically shown in Figure 8.

By referring, for the sake of simplicity, to the case of two transmission antennas, for each path or echo, the received signal is composed by the sum of two contributions each corresponding to the signal as transmitted by one of the two transmission antennas. Each of these two signal contributions typically has an amplitude with a Rayleigh distribution and random phase with uniform distribution. The two signals arrive at the mobile antenna at about the same time instant (i.e. they are not time resolvable) and combine according to a phasor addition.

This combination may be destructive if the two signals have about the same amplitude and a phase difference in the vicinity of 180 degrees. Moreover, when the receiving (mobile) terminal is moving very slowly or it is stationary, this destructive combination may cause long, deep fades with a corresponding large burst of errors.

By introducing the variable delay the phasor of the signal corresponding to the second antenna is forced to rotate with respect to the first as shown in Figure 8.

The overall received signal for a given path is:

$r(t)= r_1(t) + r_2(t)$

where $r_1(t) = x(t)\ c_1(t)$ is the contribution from the first transmission antenna,

and $r_2(t) = x(t-\tau)\ c_2(t)$ is the contribution from the second transmission antenna.

In Figure 8a reference 120 designates the case of two transmitting antennas with fixed delay on the second antenna, while in Figure 8b reference 130 designates the case of dynamic delay diversity with two antennas.

In either case, the dynamic delay diversity causes an oscillation in the received signal power. The received signal power/amplitude depends on the relative strengths of the two received signals. When one signal is much stronger than the other, the variation is small, and the received signal power is approximately equal to the power of the stronger signal. When the two signals are comparable in strength, however, the variation in the received power ranges from close to zero (destructive combination) to a value four times above the level of each of the individual signals (constructive combination).

In fact, by denoting with A the amplitude of each signal received from one of the two transmission antennas, the combined signal in case of coherent addition has an amplitude A_c equal to:

$A_c = 2 \cdot A$

This corresponds to a power four times above the level of each individual signals or, by using logarithmic units, +6dB above the level of each individual signal.

The explanation above can be extended to the case of N transmission antennas, with N > 2. In such a case the received power level varies from close to zero (destructive combining) to a value N^2 times above the level of each of the individual signals (constructive combining).

The effect of the variable delay on the received power level is shown in Figure 9 and Figure 10.

Figure 9 shows the received power level without transmission diversity. Figure 10 shows the received power when using dynamic delay diversity at the transmitter. In both diagrams, for the particular case of the W-CDMA system, the abscissa scale indicates the number of time slots over which the received power is observed.

In both cases, the user terminal speed is equal to 10 km/h. In the presence of dynamic delay diversity the signal fades at a faster rate than the signal in the absence of transmission diversity. This is due to the periodic alternation of constructive and destructive combination. The variable delay generates an artificial fast fading even in very slowly fading channels and thus improves performance of wireless systems employing channel encoding technique with a given interleaver length: in fact, in the presence of a faster fading the interleaver has more opportunity to spread the errors over the coded frame. The result of applying dynamic delay diversity is therefore to improve the link performance and reduce the downlink power requirement for the same value of quality of service (QoS) measured for instance in terms of Block Error Rate (BLER).

In general, the variable delay functions $\tau_1(t)$ is chosen such that the delay change over a symbol period is small compared to the period of the carrier. In the particular case of a CDMA system, for example, the previous assumption ensures that there is a minimal energy loss in the sum (integrate) and dump operation that are performed at the receiver. If we denote with T_c the chip period and with SF the spreading factor, the symbol period T_s before the spreading operation is equal to

$$T_s = SF \cdot T_c$$

Therefore, in order to have a minimal energy loss in the sum and dump operation it is necessary to satisfy the condition

$$\left| \tau_1(t_k + T_s) - \tau_1(t_k) \right| << T_0 \qquad \forall\ t_k \qquad (1)$$

where t_k is a generic time instant and T_0 is the period of the carrier (for example T_0 = 0.5 ns for a 2 GHz carrier frequency). The delay function $\tau_1(t)$ is then chosen in order to satisfy the condition (1) but also in order to introduce a sufficient variability of the fading process within the interleaving span. A possible rule of thumb for determining the periodicity of the delay function $\tau_1(t)$ is to choose a value which is comparable to value of the interleaving length. For example, in case of the W-CDMA version of the 3G standard which has an interleaving span ranging from 10 to 80 ms, a possible choice of the period of the delay functions is in the order of 10÷20 ms.

Figure 11 shows an example of the delay function $\tau_1(t)$, applied at the second transmission antenna. In this case the delay is caused to vary (e.g., by acting on the switch 101 of Figure 6) in discrete steps between zero and T_0. Those of skill in the art will promptly appreciate that such a law is a purely exemplary one and that notionally - any kind of law of delay variation - can be implemented with the arrangement shown.

As an alternative to varying the delay in discrete steps as shown in connection with the exemplary embodiments of Figure 6, in other possible implementations of the delay line 100 the delay is caused to vary continuously. A possible implementation of the delay line 100 with continuous variation of the introduced delay can be found in the article "Time Delay Phase Shifter Controlled by Piezoelectric Transducer on Coplanar Waveguide", IEEE Microwave and Wireless Components Letters, Vol. 13, No. 1, pag. 19-20, January 2003. In particular, the continuous delay line 100 may be implemented by inserting on a coplanar waveguide a piezoelectric transducer whose perturbations vary the effective dielectric constant of the coplanar waveguide.

An important advantage of the dynamic delay diversity technique described herein lies in that the delay to be introduced on the transmitted signal is significantly lower than the delay required by the diversity transmission using a fixed delay. In fact, the delay required by the dynamic delay diversity technique described herein is in the order of few nanoseconds as compared to a delay of some microseconds required by the diversity transmission technique using a fixed delay. The size, cost and complexity of the delay line are reduced in case of the dynamic delay diversity technique described herein.

The embodiment shown in Figure 5 is a preferred embodiment of the solution described herein for a communication system equipped with two transmission antennas: this may represent the typical configuration of a radio base station or a repeater for wireless mobile communications. A base station equipment includes two main parts: the baseband processing unit 10 that performs the digital operations at symbol and chip level and the IF/RF processing unit 20 that performs the digital to analog conversion, filtering and frequency up-conversion to the Radio Frequency (RF). In case of a repeater the base-band unit is not present as the signal processing is performed only at analog level, for example at a suitable intermediate frequency (IF).

As already indicated, in order to provide the dynamic delay diversity, the RF signal is split in two parts by means of a signal splitter 30. The signal, with power P_1 and P_2, is then available at each output port of the signal splitter respectively (in the typical configuration $P_1=P_2=P/2$). The first output of the signal splitter is fed to a first high power amplifier (HPA) 50 to be transmitted by the main antenna 60. The second output from the signal splitter 30 is provided to the programmable delay line 100 that introduces a time variant delay on the signal. The delayed signal is fed to a second high power amplifier (HPA) 50 to be transmitted by the diversity antenna 70.

In the exemplary embodiments of the delay line 100 shown in Figure 6, the delay variation is controlled by the delay control unit that determines the minimum and maximum value of the delay and the variation of such delay between these two limits. The delay varies typically from zero to about the period of the carrier frequency $T_0 = 1/f_0$ with a particular law that can be for example linear, sinusoidal, etc. An example of delay function $\tau_1(t)$ applied to the second transmission antenna is shown in Figure 11, in case of delay that varies with discrete steps between zero and T_0.

Those of skill in the art will promptly appreciate that the effectiveness of the arrangement shown is retained if no HPA(s) is/are used, or if a single HPA, placed "upstream" of the splitter 30, is used.

There are in fact cases (e.g. pico/micro cells) where no HPA is required in view of the limited coverage range.

Using a single HPA placed before the splitter 30 is advantageous in terms of cost. This choice may however impose strict requirements on the insertion loss and linearity of the delay line 100. It will be appreciated that the solution shown in Figure 6 permits the implementation of a delay line with minimum insertion loss and good linearity.

In a further alternative embodiment, variable delays 100 may be associated with both transmission antennas, as shown in Figure 12. In that case, the delay function $\tau_2(t)$ of the diversity antenna 70 is different from the delay function $\tau_1(t)$ of the main antenna 60. In that way, alternate constructive and destructive combinations between the two transmitted signals are obtained at the receiving antenna, as shown in Figure 8. Exemplary delay functions

$\tau_1(t)$ and $\tau_2(t)$ adapted to be applied to the two transmission antennas in the arrangement of Figure 12 are shown in Figure 13.

The architecture described in Figure 12 can be extended to a system including N antennas (where N>2) and N delay functions $\tau_j(t)$ (with $1 \leq j \leq N$), different among them, applied to the respective transmission antenna.

A still further alternative embodiment is shown in Figure 14. There, diversity transmission using a fixed delay and dynamic delay diversity are combined. The RF signal is split in four paths by means of a signal splitter block 30. Two of these paths, with powers P_1 and P_2, respectively, are subject to dynamic delay diversity processing (by means of a first delay line 100) as previously described and transmitted via two separate antennas 150 and 160. The two other paths, with powers P_3 and P_4, respectively, are first subject to fixed delays T in delay blocks 40, and then to dynamic delay diversity processing (by means of a second delay line 100). The fixed delays T are generally larger than the chip period and the channel delay spread in order to achieve sufficient time separation of the signal replicas permitting their coherent summation at the receiver. The signals over these two latter paths are transmitted via two other separate antennas 170 and 180. The system is then composed by four transmission antennas. The variable delay functions $\tau_1(t)$ and $\tau_2(t)$ applied to each antenna pair are in general different. However, in the case of the W-CDMA system, for example, the two functions $\tau_1(t)$ and $\tau_2(t)$ can be identical if the fixed delay T is greater than the chip period: in such a case the fixed delay produces separate echoes that can be time resolved at the receiver for example by using a Rake receiver.

Still another alternative embodiment that combines diversity transmission using a fixed delay and dynamic delay diversity, by using only two transmission antennas, is shown in Figure 15. The RF signal is first split at a splitter 30 in three parts with powers P_1, P_2 and P_3 (in a typical configuration P_1=P_2=P/4 and P_3=P/2). The first signal, with power P_1, is transmitted by the first antenna 190 without being subject to further delay processing. The second signal with power P_2, is subject to a variable delay $\tau_1(t)$ according to the dynamic delay diversity technique described herein. The third signal, with power P_3, is subject to a fixed delay T, in a delay block 40, to be then combined, by means of a combiner node 210, with the second signal. The combined signal is subsequently transmitted via the second antenna 200.

In brief the arrangements shown in Figures 14 and 15 are based on the concept of:

- generating at least one first delayed replica of the signal subject to a varying delay ($\tau_1(t)$ and, possibly, $\tau_2(t)$),

- generating at least one second delayed replica of the signal subject to a fixed delay (i.e. T), and

- transmitting the signal together with the delayed replicas via diversity antennas.

In the specific case of the arrangement shown in Figure 14, at least one third delayed replica of the signal is generated which is subject to a fixed delay (i.e. T) plus a further varying delay (i.e. $\tau_2(t)$). The signal and the first, second and third delayed replicas are then transmitted via respective diversity antennas 150, 160, 170, and 180.

Consequently, without prejudice to the underlying principles of the invention, the details and the embodiments may vary, also appreciably, with reference to what has been described by way of example only, without departing from the scope of the invention as defined by the annexed claims.

CLAIMS

1. In a wireless telecommunication system, the telecommunication system providing communication services to a plurality of terminals, a method of transmitting a signal including the steps of:

- generating (30) at least one delayed replica of said signal subject to a given delay (100), and

- transmitting said signal and said at least one delayed replica via diversity antennas (60, 70; 150, 160, 170, 180; 190, 200),

the method including the step of varying (110) said given delay (100), whereby said signal and said at least one delayed replica, transmitted via said diversity antennas (60, 70; 150, 160, 170, 180; 190, 200), give rise to alternate constructive and destructive combinations therebetween.

2. The method of claim 1, characterized in that it includes the steps of:

- subjecting said signal to splitting (30) to generate at least one replica thereof, and

- subjecting said at least one replica to a variable delay (100, 110) to produce said at least one delayed replica.

3. The method of claim 1, characterized in that it includes the step of generating (30) one delayed replica of said signal.

4. The method of claim 1, characterized in that it includes the step of generating (30) a plurality of delayed replicas of said signal, each replica of said plurality having a respective variable delay ($\tau_j(t)$) different from the delays of the other delayed replicas in the plurality.

5. The method of claim 1, characterized in that it includes the steps of:

- associating (20) with said signal a carrier frequency with a given period ($T_0 = 1/f_0$), and

- varying (110) said given delay from zero to a value lower then or equal to said period ($T_0 = 1/f_0$) of said carrier frequency.

6. The method of claim 1, characterized in that it includes the step of varying (110) said given delay with a linear law over time.

7. The method of claim 1, characterized in that it includes the step of varying (110) said given delay with a sinusoidal law over time.

8. The method of claim 1, characterized in that it includes the step of varying (110) said given delay in the range between tenths of nanoseconds (ns) and units of nanoseconds (ns).

9. The method of claim 1, characterized in that it includes the steps of generating said varying delay by providing a cascade of elementary delay units (100a, ..., 100k) and selectively varying the number of elementary delay units (100a, ..., 100k) included in the cascade.

10. The method of claim 9, characterized in that it includes the steps of:

- providing a tapped delay line comprised of elementary delay units (100a, ..., 100k) in a cascaded arrangement, and

- selectively contacting the tap points in said tapped delay line via a switch (101), whereby changing the position of the switch (101) changes the value of the delay.

11. The method of claim 1, characterized in that it includes the steps of generating said varying delay by providing a plurality of delay elements (100a', ..., 100k') having respective delay values and selecting (101a, 101b) at least one delay element (100a', ..., 100k') out of said plurality.

12. The method of claim 11, characterized in that it includes the steps of providing at least two switches (101a, 101b) for contacting said plurality of delay elements (100a', ..., 100k') and controlling at least two switches (101a, 101b) in a coordinated manner, whereby

changing the position of said at least two switches (101a, 101b) changes the value of the delay.

13. The method of claim 1, characterized in that it includes the step of varying (110) said given delay continuously.

14. The method of claim 13, characterized in that it includes the step of varying (110) said given delay continuously by means of a coplanar waveguide having associated a piezoelectric transducer whose perturbations vary the effective dielectric constant of the coplanar waveguide.

15. The method of claim 1, characterized in that it includes the steps of associating respective variable delays (100; $\tau_1(t)$, $\tau_2(t)$) both to said signal and said at least one replica, wherein said respective variable delays (100; $\tau_1(t)$, $\tau_2(t)$) are different from each other.

16. The method of claim 1, characterized in that it includes the steps of associating respective variable delays ($\tau_j(t)$) both to said signal and a plurality of replicas thereof, wherein said respective variable delays ($\tau_j(t)$) are different among them.

17. The method of claim 1, characterized in that it includes the steps of:

- generating (30) at least one first delayed replica of said signal subject to a varying delay (100, $\tau_1(t)$),

- generating (30) at least one second delayed replica of said signal subject to a fixed delay (40, T), and

- transmitting said signal and said at least one first and second delayed replicas via diversity antennas (190, 200).

18. The method of claim 17, characterized in that it includes the step of:

- generating at least one third delayed replica of said signal subject to a fixed (40,T) plus a further varying delay (100, $\tau_2(t)$), and

- transmitting said signal and said at least one first, second and third delayed replicas via diversity antennas (150, 160, 170, 180).

19. The method of claim 18, characterized in that said further varying delay ($\tau_2(t)$) is different from said varying delay ($\tau_1(t)$).

20. The method of claim 18, characterized in that, said signal having a given chip period:

- said fixed delay (T) is greater than the chip period of said signal.

21. In a wireless telecommunication system, the telecommunication system providing communication services to a plurality of mobile terminals, an apparatus for transmitting a signal via diversity antennas (60, 70; 150, 160, 170, 180; 190, 200), the apparatus including:

- at least one delay element (100) for generating at least one delayed replica of said signal subject to a given delay, said signal and said at least one delayed replica to be transmitted via said diversity antennas (60, 70; 150, 160, 170, 180; 190, 200),

- a control unit (110) of said at least one delay element (100) for varying (110) said given delay (100), whereby said signal and said at least one delayed replica, transmitted via said diversity antennas (60, 70; 150, 160, 170, 180; 190, 200), give rise to alternate constructive and destructive combinations therebetween.

22. The apparatus of claim 21, characterized in that it includes:

- a splitter (30) for splitting said signal to generate at least one replica of said signal, and

- at least one variable delay element (100) for subjecting said at least one replica to a variable delay to produce said at least one delayed replica.

23. The apparatus of claim 21, characterized in that it includes one variable delay element (100) for generating one delayed replica of said signal.

24. The apparatus of claim 21, characterized in that it includes:

- a splitter (30) for splitting said signal to generate a plurality of replicas of said signal,

- a plurality of variable delay elements (100) to produce a plurality of delayed replicas of said signal, each replica of said plurality having a respective variable delay ($\tau_j(t)$) different from the delays of the other replicas in the plurality.

25. The apparatus of claim 21, characterized in that it includes:

- a RF stage (20) for associating with said signal a carrier frequency with a given period ($T_0 = 1/f_0$), and

- said at least one delay element (100) configured for varying (110) said given delay from zero to about said period ($T_0 = 1/f_0$) of said carrier frequency.

26. The apparatus of claim 21, characterized in that it includes said at least one delay element (100) configured for varying (110) said given delay with a linear law over time.

27. The apparatus of claim 21, characterized in that it includes said at least one delay element (100) configured for varying (110) said given delay with a sinusoidal law over time.

28. The apparatus of claim 21, characterized in that it includes said at least one delay element (100) configured for of varying (110) said given delay in the range between tenths of nanoseconds (ns) and units of nanoseconds (ns).

29. The apparatus of claim 21, characterized in that said at least one delay element (100) includes a cascade of elementary delay units (100a, ..., 100k) and a selector (101) for selectively varying the number of elementary delay units (100a, ..., 100k) included in the cascade.

30. The apparatus of claim 29, characterized in that it includes:

- a tapped delay line comprised of elementary delay units (100a, ..., 100k) in a cascaded arrangement, and

- a switch (101) for selectively contacting the tap points in said tapped delay line, whereby changing the position of the switch (101) changes the value of the delay.

31. The apparatus of claim 21, characterized in that said at least one delay element (100) includes a plurality of delay elements (100a', …, 100k') having respective delay values and at least one selector (101a, 101b) configured selecting at least one delay element (100a', …, 100k') out of said plurality.

32. The apparatus of claim 31, characterized in that said at least one delay element (100) includes at least two switches (101a, 101b) for contacting said plurality of delay elements (100a', …, 100k') and a controller (110) for controlling said at least two switches (101a, 101b) in a coordinated manner, whereby changing the position of said at least two switches (101a, 101b) changes the value of the delay.

33. The apparatus of claim 21, characterized in that it includes said at least one delay element (100) configured for varying (110) said given delay continuously.

34. The apparatus of claim 33, characterized in that it includes a coplanar waveguide having associated a piezoelectric transducer whose perturbations vary the effective dielectric constant of the coplanar waveguide, thus varying said given delay continuously.

35. The apparatus of claim 21, characterized in that it includes respective variable delay elements (100; $\tau_1(t)$, $\tau_2(t)$) configured for applying respective variable delays (100; $\tau_1(t)$, $\tau_2(t)$) both to said signal and said at least one replica, wherein said respective variable delays (100; $\tau_1(t)$, $\tau_2(t)$) are different from each other.

36. The apparatus of claim 21, characterized in that it includes respective variable delay elements (100, $\tau_j(t)$) configured for applying respective variable delays ($\tau_j(t)$) both to said signal and a plurality of replicas thereof, wherein said respective variable delays ($\tau_j(t)$) are different among them.

37. The apparatus of claim 36, characterized in that

it includes:

- at least one first delay element (100) configured for generating at least one first delayed replica of said signal subject to a varying delay (100, $\tau_1(t)$),

- at least one second delay element (40) configured for generating at least one second delayed replica of said signal subject to a fixed delay (40, T); said at least one first and second delayed replicas being adapted to be transmitted together with said signal via said diversity antennas (190, 200).

38. The apparatus of claim 37, characterized in that it includes at least one third delay element (40, 100) configured for generating at least one third delayed replica of said signal subject to a fixed (40,T) plus a further varying delay (100, $\tau_2(t)$); said at least one third delayed replica being adapted to be transmitted together with said signal and said first and second delayed replicas via said diversity antennas (150, 160, 170, 180).

39. The apparatus of claim 38, characterized in that said further varying delay ($\tau_2(t)$) is different from said varying delay ($\tau_1(t)$).

40. The apparatus of claim 38, characterized in that, said signal having a given chip period:

- said further varying delay ($\tau_2(t)$) is identical to said varying delay ($\tau_1(t)$), and

- said fixed delay (T) is greater than the chip period of said signal.

41. A communication network including at least one communication equipment equipped with diversity transmission antennas (60, 70; 150, 160, 170, 180; 190, 200), said at least one communication equipment including the apparatus of any of claims 21 to 40.

42. The network of claim 41, in the form of a mobile communication network.

43. The network of claim 42, characterized in that said at least one communication equipment is selected from the group consisting of a radio base station, a repeater

and a mobile terminal of said mobile communication network.

44. A communication equipment equipped with diversity transmission antennas (60, 70; 150, 160, 170, 180; 190, 200) and including the apparatus of any of claims 21 to 40.

45. A computer program product loadable in the memory of at least one computer and including software code portions for performing the steps of the method of any of claims 1 to 20.

Fig.1

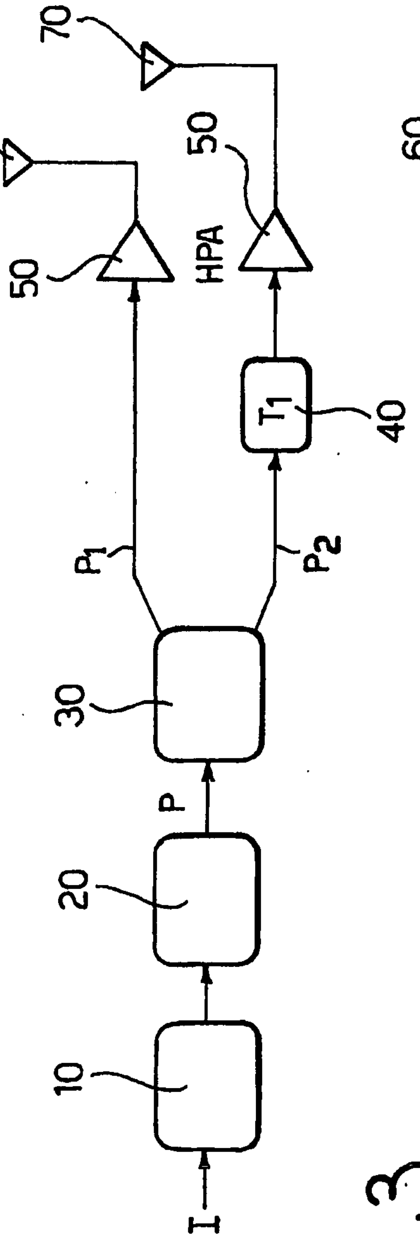

60
70
50
50
HPA
10
20
30
P
P1
P2
T1
40
I

Fig.3

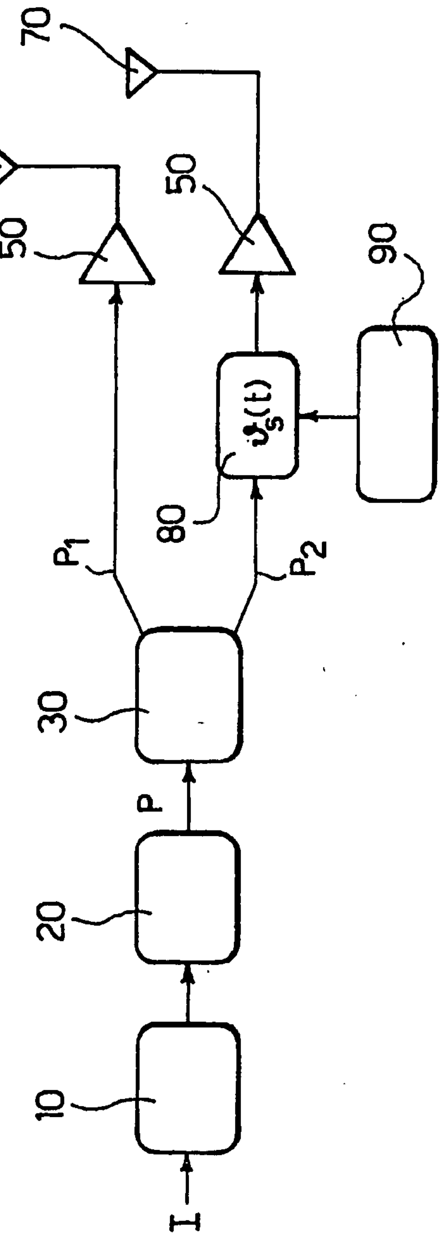
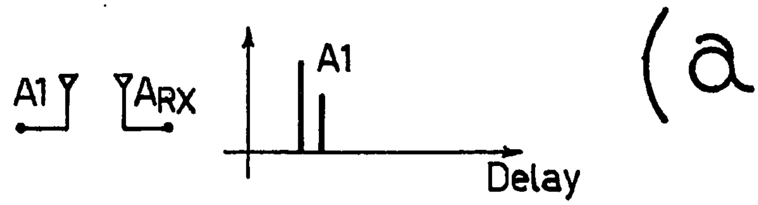

60
70
50
50
10
20
30
P
P1
P2
ϑs(t)
80
90
I

Fig.2


(a
A1
ARX
A1
Delay

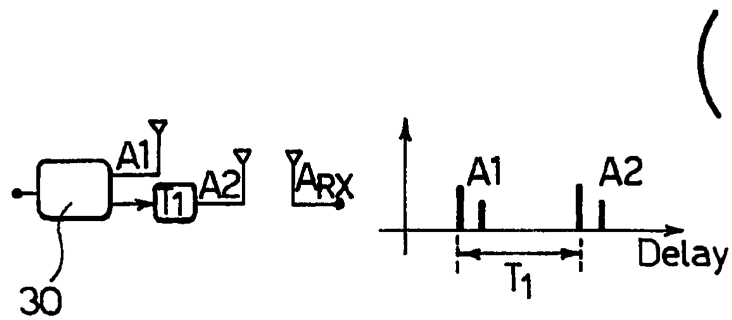

(b
A1
T1
A2
ARX
30
A1
A2
Delay
T1

Fig.4

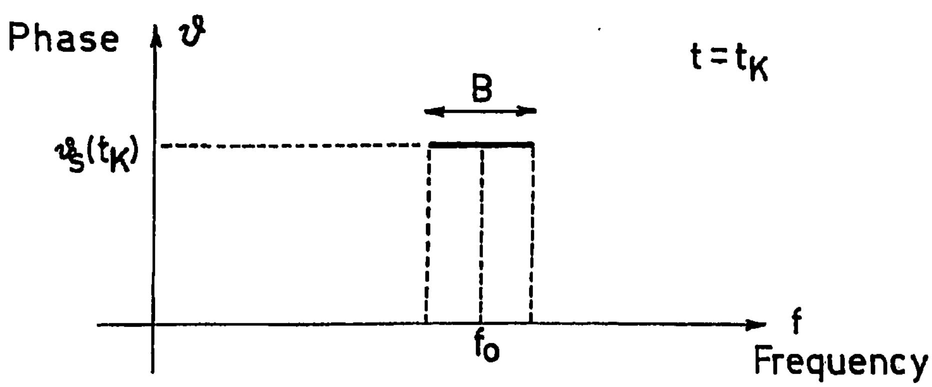

Phase
ϑ
t = tK
B
ϑS(tK)
f
f0
Frequency

Fig_5

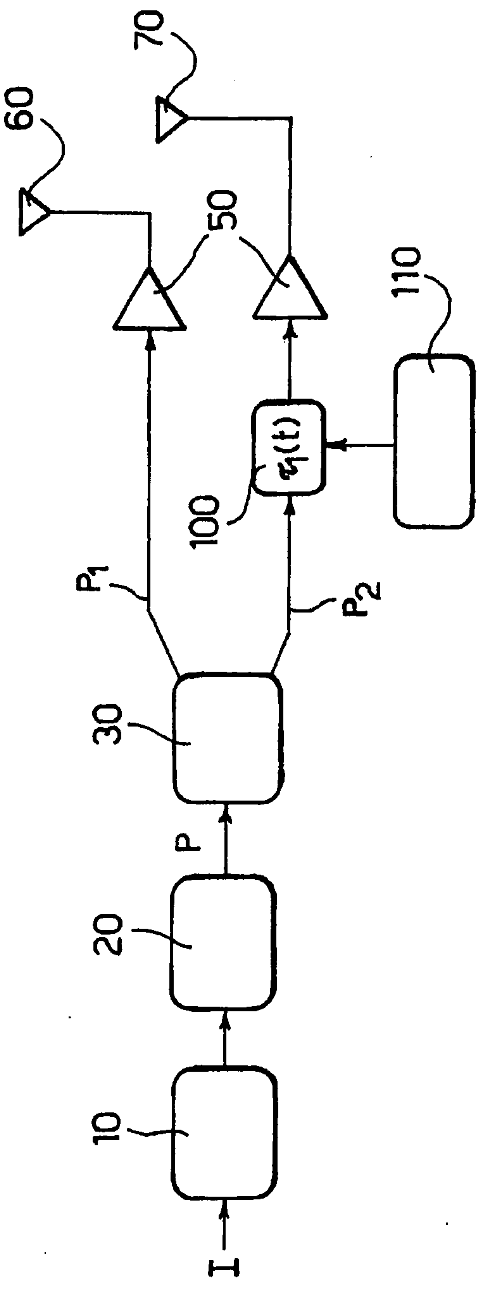

I
10
20
P
30
P1
P2
100
$\varphi_1(t)$
110
50
60
70

Fig_6

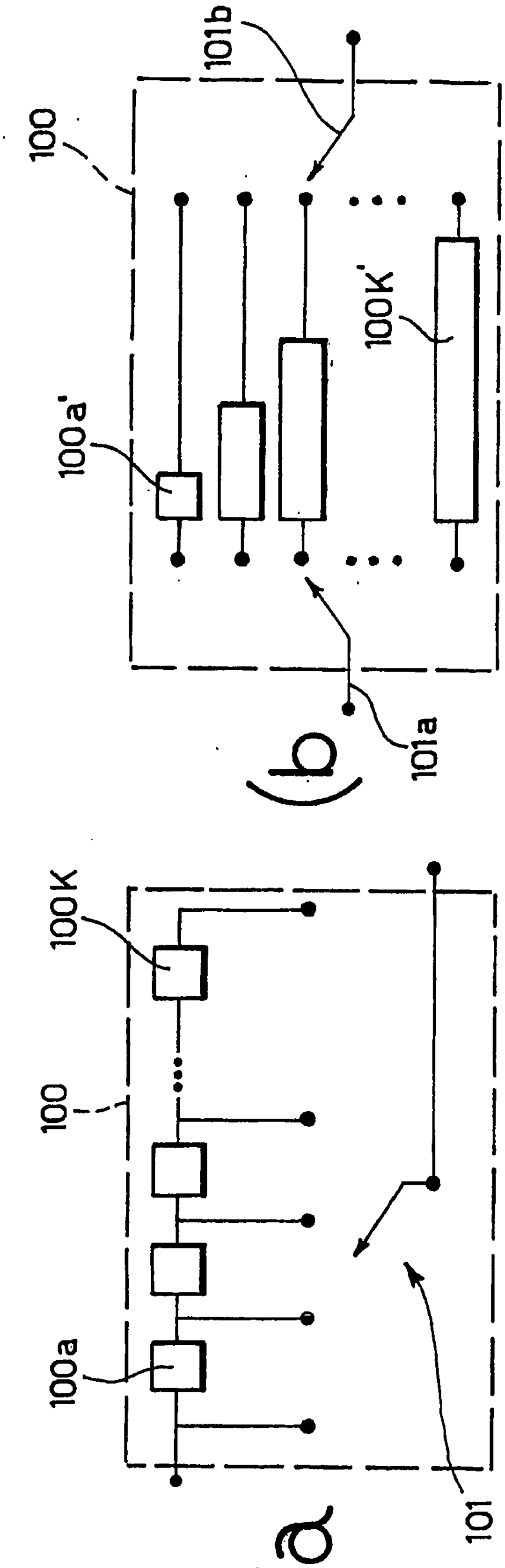

(a)
100a
100
100K
101
(b)
100a'
100
100K'
101a
101b

Fig. 7

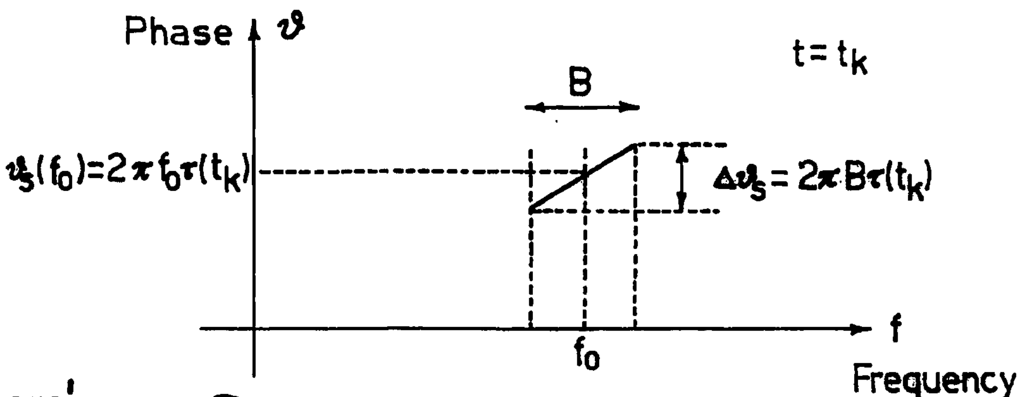


Fig. 9

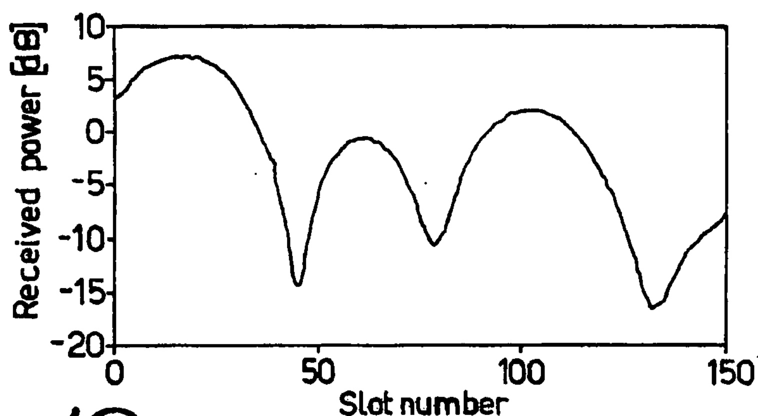
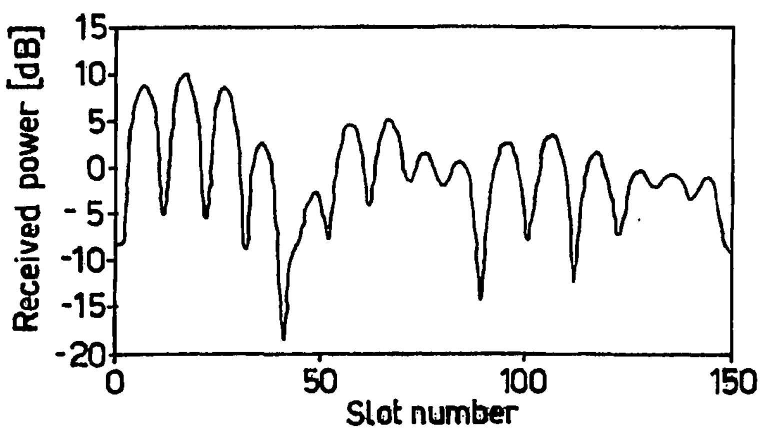


Fig. 10



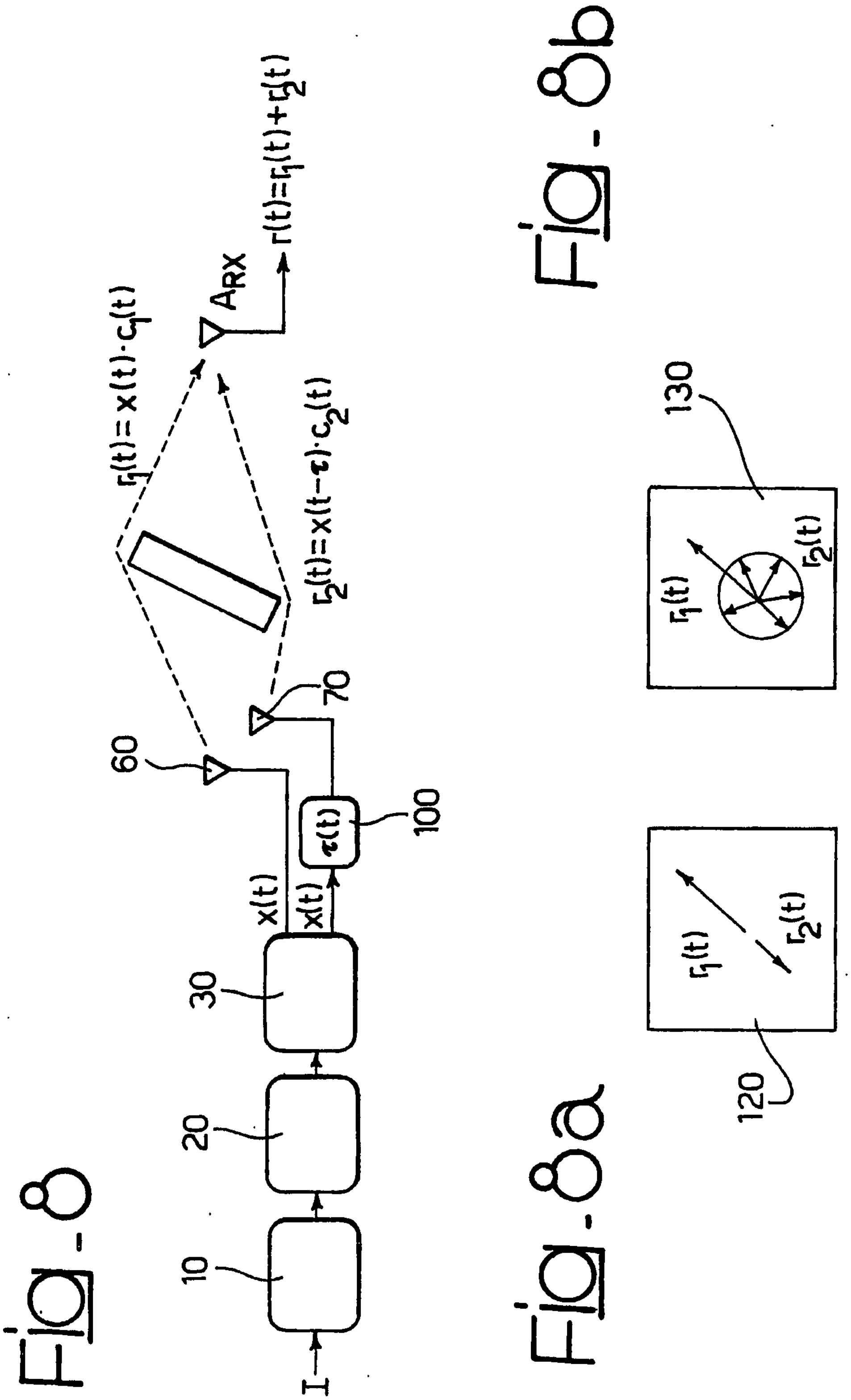


Fig. 8

Fig. 8a

Fig. 8b

Fig. 11

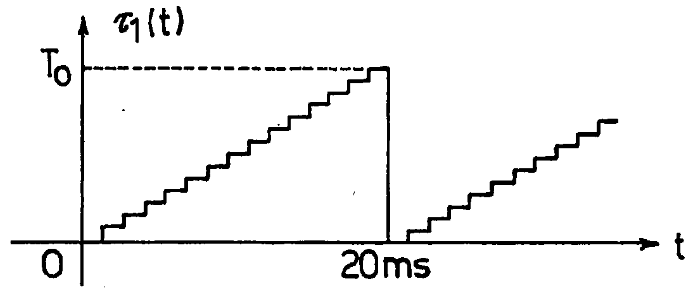


Fig. 13

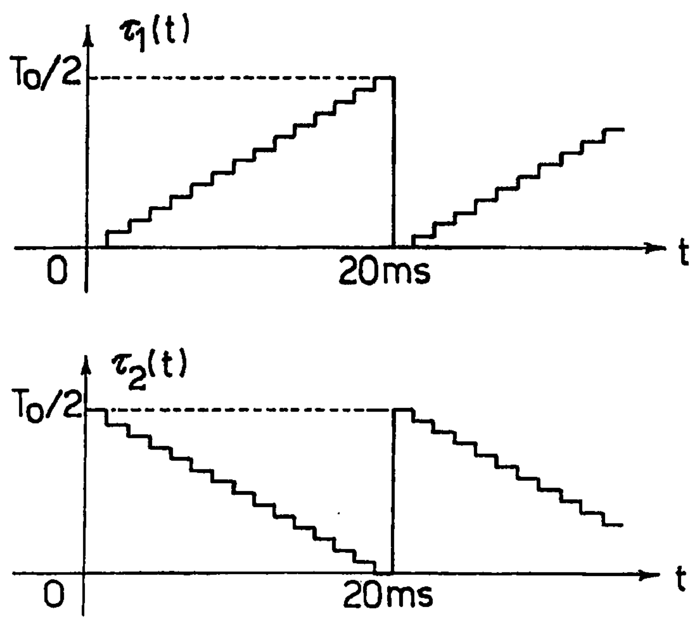
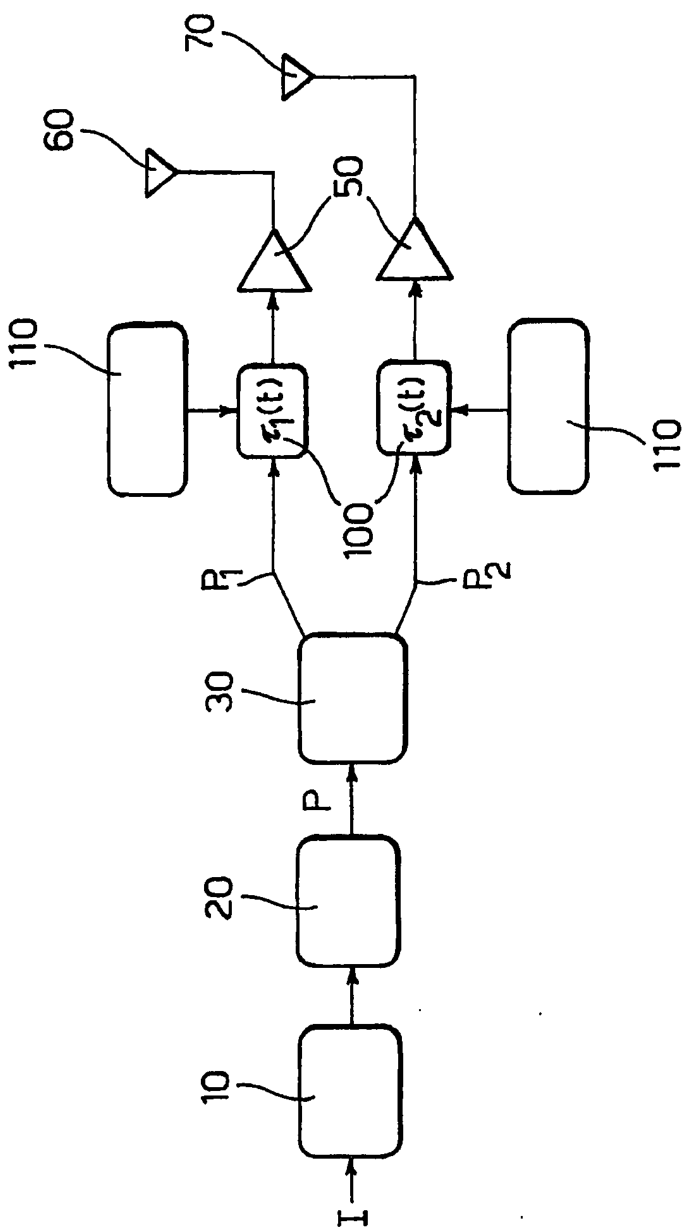


Fig. 12



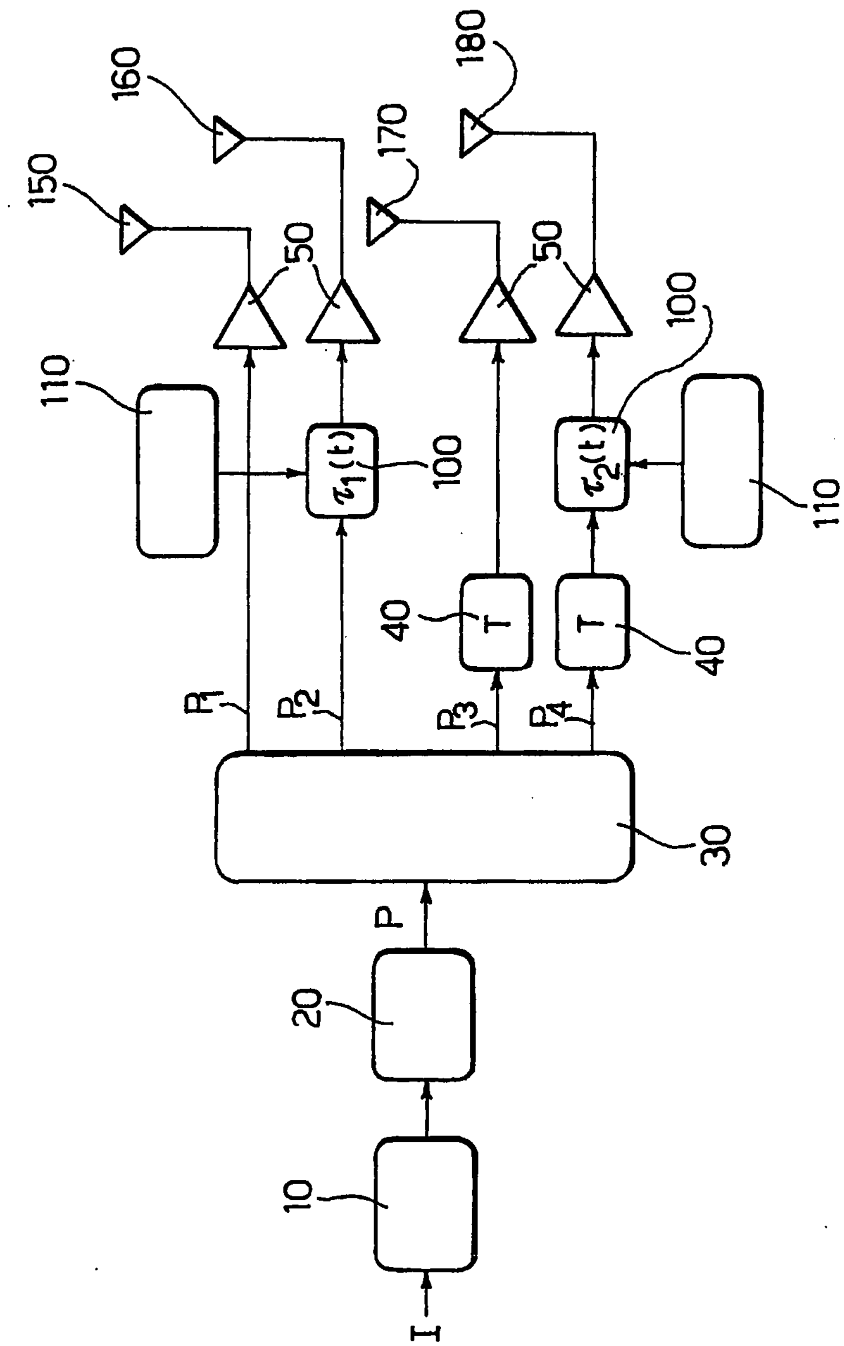

150
160
170
180
50
50
110
100
100
110
40
40
T
T
P1
P2
P3
P4
30
P
20
10
I

Fig. 14

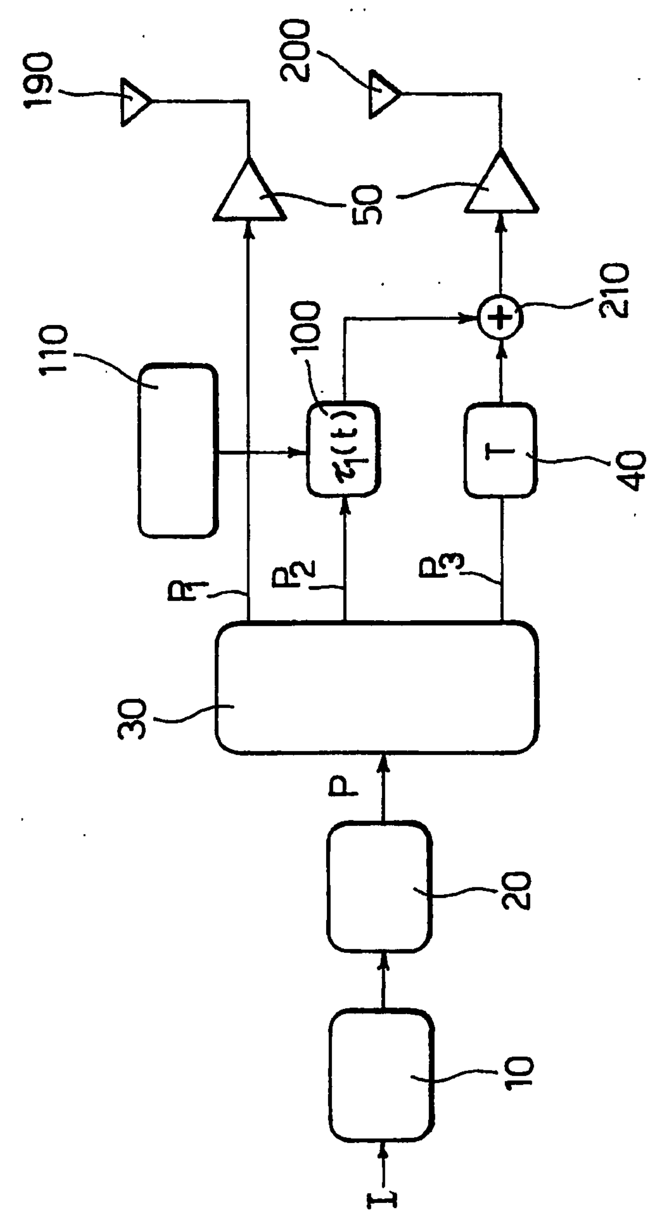


Fig_15

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP2004/011204

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B7/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 574 989 A (WATSON ET AL) 12 November 1996 (1996-11-12) abstract column 1, line 24 - line 27 column 2, line 40 - line 62 column 4, line 33 - line 45 figure 1	1-45
X	EP 1 164 718 A (NEC CORPORATION) 19 December 2001 (2001-12-19) abstract paragraphs ‘0004!, ‘0005!, ‘0013!, ‘0014!, ‘0031!, ‘0035!, ‘0038!, ‘0039! figures 1,2,7	1-45

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 May 2005	01/06/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lustrini, D

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP2004/011204

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	SANG-GYU KIM ET AL: "TIME-DELAY PHASE SHIFTER CONTROLLED BY PIEZOELECTRIC TRANSDUCER ON COPLANAR WAVEGUIDE" IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 1, no. 13, January 2003 (2003-01), pages 19-20, XP001141843 ISSN: 1531-1309 cited in the application the whole document	13,14, 33,34
X	US 2003/153322 A1 (BURKE JOSEPH P ET AL) 14 August 2003 (2003-08-14) abstract paragraphs '0053!, '0055!, '0061! figures 5,7	1-45
A	WO 02/19565 A (NOKIA MOBILE PHONES LIMITED; KUCHI, KIRAN) 7 March 2002 (2002-03-07) cited in the application figures 1a,2,3a,4 page 2, line 21 - page 3, line 20	17-20, 37-40

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP2004/011204

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			EP 1164718	A2	19-12-2001
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			BR 0111295	A	30-09-2003
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			JP 2004502376	T	22-01-2004
US 2003153322	A1	14-08-2003	NONE		
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			WO 0219565	A2	07-03-2002

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 April 2007 (12.04.2007)

PCT

(10) International Publication Number
WO 2007/038969 A1

(51) International Patent Classification:
H04B 7/06 (2006.01) *H04B 7/08* (2006.01)

(21) International Application Number: PCT/EP2005/010799

(22) International Filing Date: 5 October 2005 (05.10.2005)

(25) Filing Language: English

(26) Publication Language: English

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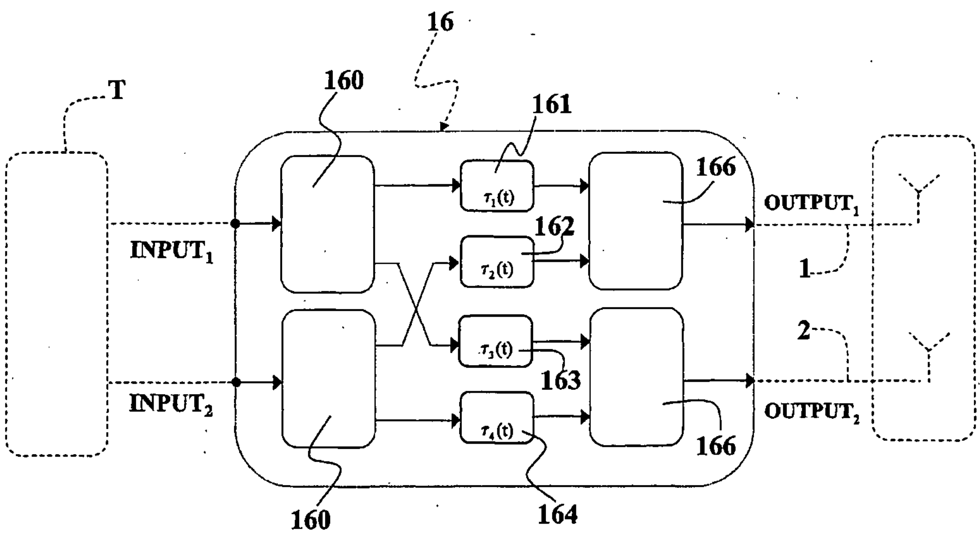
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS, RELATED APPARATUS AND CORRESPONDING COMPUTER PROGRAM PRODUCT



(57) **Abstract:** A system for diversity processing two signals (INPUT$_1$, INPUT$_2$) transmitted and/or received via two diversity antennas (1, 2) includes at least four respective propagation paths coupling the signals to the two diversity antennas (1, 2). Diversity processing is primarily in the form of decorrelation achieved by means of time variable delay elements (161 to 164; 261 to 264; 1261 to 1264) that apply time variable delays to the signals propagating over at least two of the propagation paths in the system. The related processing may take place either at RF or IF, or at baseband, whereby the time variable delays are applied by subjecting the baseband signals to multiplication by a complex signal.

WO 2007/038969 A1

"Method and system for multiple antenna communications, related apparatus and corresponding computer program product"

* * *

Field of the invention

The present invention relates to communication systems and was developed with specific attention paid to its possible application in radio transmitters and receivers for mobile communication networks equipped with multiple antennas.

Description of the related art

Data services are driving the demand for increased data rate and thus increased system capacity. Many of these data services are likely to be used in low-mobility environments under single-path condition. Poor performance due to prolonged deep fading of the channel is one of the problems associated with this scenario. In wireless systems, channel coding is widely used in conjunction with interleaving to exploit time diversity and thus to improve radio link performance. However, in very slowly fading channels, which is a typical situation for low mobility users, interleaving required to spread long deeply faded blocks into decodable sequences is very long. The interleaving depth available in practice, on the other hand, is often fairly limited because of strict requirements for the allowable service delay and usage of memory.

Antenna diversity is a viable technique for overcoming the negative effects of prolonged multi-path fading in wireless systems. In diversity transmission, and similarly in diversity reception, two or more physically separated antennas (space diversity) or one or more cross-polarized antenna (polarization diversity) are respectively used to transmit or receive a given signal. By placing the antennas at a sufficient distance or by using +/- 45 degrees slant cross-polarized antenna it is possible to minimize the amplitude correlation of the signals transmitted or received by the different antennas. In practice, the physical separation between the antennas is limited due to size or environmental constraints and thus the signals may still exhibit a significant degree of amplitude correlation. A significant degree of signal correlation can also be present in the signals transmitted or received through cross polarized antennas, in particular when the vertical-to-horizontal polarization power ratio, also referred to as cross-polar discrimination (XPD), takes high values.

As a consequence, a number of diversity techniques has been developed in order to improve the radio link performance by reducing the temporal autocorrelation of the received signals in low mobility scenarios while also minimizing the cross-correlation between the signals transmitted or received by the different antennas. These diversity techniques are applicable in wireless systems that have already been standardized, with minimal modifications on the deployed equipments and networks. The improvement of the radio link performance obtained with such diversity techniques leads to an increase of the system capacity or in an improvement of the QoS (Quality of Service) perceived by the users.

As schematically shown in figure 1, in the case of transmit diversity techniques operating at RF, the signals to be transmitted may be in the form of data from Layer 2 subject to baseband processing in a block

10 to be then fed via digital-to-analog converters 12 to respective IF/RF transmitters 14. The signals from the transmitters 14 are then fed to a RF network, denoted as transmission (TX) diversity processor 16. The TX diversity processor 16 feeds with its output signals the antenna transmission subsystem 1, 2.

Similarly, when the diversity technique is applied at the receiving side, the signals received by the various antennas 1, 2 are first processed by a receiver (RX) diversity processor 26 and then provided for the subsequent demodulation to a conventional receiver. As shown in Figure 2, this receiver may include RF/IF receivers 24 having cascaded thereto analog-to-digital converters 22 and a baseband processing block 20 that outputs the received Layer 2 data stream. The TX and RX diversity processors 16, 26 are comprised of different RF elements such as signal splitters, combiners, delay lines, amplifiers, an so on. By combining these elementary blocks several structures of the diversity processor can be conceived.

While arrangements including two antennas will be referred to throughout this description for the sake of simplicity, those of skill in the art will appreciate that diversity arrangements able to operate with a number of antennas in excess of two can be easily devised starting from the information here provided in connection with two-antenna arrangements.

Many diversity techniques operating at RF have been considered in the literature. A first known method, denoted as fixed Delay Diversity (fixed DD), is used to increase the frequency diversity of the communication channel. The fixed DD technique is a simple transmit delay diversity technique that involves transmitting from a pair of antennas a signal and a delayed version of the same. The delay introduced in the signal transmitted from the second antenna is fixed and is typically chosen to be greater than the channel delay spread (i.e. in the order of microseconds). If the transmit antennas are widely spaced, the transmitted signals experience uncorrelated fading resulting in increased diversity and higher transmission reliability. The fixed DD technique can be also applied as a receiver diversity technique. In that case the receiver is equipped with two antennas. The signal received from one of the antennas is subject to a fixed delay, still greater than the channel delay spread, and then is recombined at RF level with the signal received from the second antenna. The combined signal is then provided to a conventional receiver for the subsequent demodulation.

The fixed DD technique was first proposed for the application in flat fading channels in an article of A. Wittneben "*A New Bandwidth Efficient Transmit Antenna Modulation Diversity Scheme for Linear Digital Modulation*", ICC Conference - pages 1630-1634, Geneva, May 1993. The application of fixed DD as a receiver diversity technique is described in US-A-5 930 293, in case of a wireless repeater (applicant remarks that the same technique is applicable without modifications in a base station receiver). Specifically, US-A-5 930 293 describes the application of the fixed DD technique for achieving antenna receive diversity in a wireless repeater. The repeater is equipped with two receiving antennas for receiving a signal from a wireless terminal. The signal received from one of the antennas is subject to a fixed delay and is recombined at RF with the other received signal. The combined signal is subsequently transmitted to the base station by means of a third antenna. The fixed delay is chosen at least equal to two chip periods in order to enable the Rake receivers in the base station to resolve and combine the two signals.

A similar application of fixed DD as a receive diversity technique is also disclosed in the patent US-B-6 868 254 in case of a repeater adapted to receive differently polarized signals. Specifically, US-B-6 868 254 describes a repeater structure equipped with two receive antennas that receive signals from a plurality of wireless terminals. The two receiving antennas are implemented so that the main and diversity signals differ by one or more characteristics. Preferably the two antennas are spatially separated by four wavelengths so that the received signals differ in amplitude when measured simultaneously. Alternatively the two antennas may receive different polarization or additionally a fixed time delay is introduced in one of the two paths.

A basic problem related to the fixed DD technique is the cost and size of the delay line used to introduce such delay on an analog RF signal. The delay line can be implemented for example with a RF cable although this solution has several drawbacks such as cost, size and transmission losses of the cable.

Another known diversity method disclosed in literature is the phase sweeping transmit diversity (PSTD) technique. The application of PSTD as a transmission diversity technique is obtained by transmitting the base station signal from a pair of antennas. The two antennas radiate the same signal but the phase of one antenna is "swept" relative to the other. The phase sweep is obtained by means of an RF phase shifter that introduces a time variant phase shift $\varphi(t)$, with a given variation law (e.g. linear, sinusoidal, etc.), on the signal transmitted by the second antenna. The introduction of a time variant phase rotation is equivalent to shifting the carrier frequency of the second signal. In fact by denoting with $\varphi(t)$ the phase sweep function, the instantaneous carrier frequency $f_s(t)$ of the signal transmitted by the second antenna is equal to

$$f_s(t) = f_0 + \frac{1}{2\pi}\frac{d\varphi(t)}{dt} \qquad (1)$$

where f_0 is the carrier frequency without PSTD. We also notice that, at a given time instant t_k, all the frequency components within the signal bandwidth B are phase rotated of the same quantity $\varphi(t_k)$. The combination of two signals that differ slightly in frequency creates an amplitude-modulated signal that fades periodically and thus induces more rapid fades at the receiver. This improves the channel coding gain in a very slow multipath fading environment.

An application of PSTD is disclosed e.g. in WO-A-02/19565. This document describes the application of the PSTD technique as a transmission diversity technique, suitable for systems equipped with multiple transmitting antennas. The document presents also some methods and the related apparatus for the combination of the fixed DD and PSTD techniques. Specifically, WO-A-02/19565 presents some methods and the related apparatus for the combination of the fixed DD and PSTD techniques. In the method and apparatus, an input symbol stream is offset in time by M symbols periods to generate an offset symbol stream. The original input symbol stream is then transmitted on a first set of N antennas and the offset input symbol stream is transmitted on a second set of N antennas. On each set of N antennas the PSTD diversity technique is applied in order to further increase the diversity level. The phase shifting of PSTD may be either a continuous phase sweep or discrete phase hopping in every burst period.

Another example of application of PSTD, applied as transmission diversity technique, is provided in WO-A-03/055097. Specifically, this prior art document describes a method for providing Phase Shift Transmit Diversity (PSTD) in a wireless communication system. The base station phase shift modulates a first signal with a reference signal to produce a first phase-shift modulated signal. Further, the base station phase shift modulates a second signal with a different reference signal to produce a second phase shift modulated signal. The second phase shift is distinct from the first phase shift such that the second phase shift modulated signal is diverse relative to the first phase shift modulated signal. Accordingly, the base station transmits the first phase-shift modulated signal via a first antenna and the second phase shift modulated signal via a second antenna to a plurality of mobile stations.

Still another approach for transmission diversity is disclosed in PCT application PCT/EP2004/011204, wherein a variable time delay is used in the place of a variable phase shift. Specifically, the prior art document in question discloses a system for transmitting a signal via diversity antennas. The system is adapted for use in e.g. radio base stations, repeaters and terminals of a mobile communication network, and includes a delay element for generating a delayed replica of the signal subject to a given delay. The signal and the delayed replica are transmitted via the diversity antennas, and a control unit acts on the delay element to vary the delay. The signal and the delayed replica, transmitted via the diversity antennas, give rise to alternate constructive and destructive combinations therebetween.

Object and summary of the invention

Despite the significant efforts documented by the prior art discussed in the foregoing, the need is still felt for further improved diversity transmission/reception arrangements that may dispense with the shortcomings intrinsically related to the arrangements analysed previously, especially as regards the possibility of further reducing the degree of correlation of the resulting signals in the direction of rendering them notionally uncorrelated (which represents the optimum operating condition for diversity techniques). Additional needs/problems are related to the implementation of low-cost, compact variable time delay/phase shifter units. A specifically felt need is related to the possibility of implementing such units that can act as "reciprocal" units adapted to be used both in the transmission and in the reception of diversity signals.

The object of the present invention is thus to provide a satisfactory response to the need outlined in the foregoing.

According to the present invention, that object is achieved by means of a method having the features set forth in the claims that follow. The invention also relates to a corresponding system, a related apparatus as well as a related computer program product, loadable in the memory of at least one computer and including software code portions for performing the steps of the method of the invention when the product is run on a computer. As used herein, reference to such a computer program product is intended to be equivalent to reference to a computer-readable medium containing instructions for controlling a computer system to coordinate the performance of the method of the invention. Reference to "at least one computer" is evidently intended to highlight the possibility for the present invention to be implemented in a distributed/ modular fashion. The claims are an integral part of the disclosure of the invention provided herein.

A preferred embodiment of the invention is thus a method of diversity processing at least two signals propagated (i.e. transmitted and/or received) via at least two diversity antennas, the method including the steps of:

- coupling each said at least two signals to each said at least two diversity antennas via respective signal propagation paths, thus giving rise to at least four propagation paths, and

- subjecting the signals propagating over at least two of said propagating paths to time variable delays.

As described herein, diversity processing shall primarily involve "decorrelating", i.e. reducing the degree of correlation between the signals considered, in the directions of rendering them notionally uncorrelated. As is well known (see e.g. A. Papoulis: "Probability, Random Variables, and Stochastic Processes", Mc Graw-Hill, Inc. © 1965, p.211) two random signals/variables x and y are called uncorrelated if $E\{xy\}= E\{x\}E\{y\}$.

In brief, the arrangement described herein is exemplary of a diversity method that can be applied both at the transmitter and at the receiver side in a wireless communication system in order to improve the link level performance: in that respect, reference to at least two signals that are "propagated", is intended to highlight the fact that the invention applies both to signals that are transmitted and to signals that are received. This approach, which can be designated a Dynamic Delay Diversity (DDD) approach, involves introducing a time variable delay on the signals transmitted and/or received by the different antennas. The delay required to make effective the technique is significantly smaller when compared to other diversity techniques such as the fixed DD. In general, the required delay varies between zero and the period T_0 of the RF signal (i.e. the carrier signal). For example, the application of the DDD technique described herein in a base station transceiver compliant with the UMTS (Universal Mobile Telecommunications System) standard requires the introduction of a delay that varies between zero and the carrier period $T_0 = 1/(1920\ MHz) = 0.52$ nanoseconds. Typically, the time variable delays considered herein lie in the range between tenths of nanoseconds (ns) and units of nanoseconds (ns).

The delay functions, according to which the delay varies as a function of time, are not restricted to particular functions and can be continuous functions (e.g. linear, sinusoidal) or discrete step functions.

A significant advantage of the DDD technique described herein in comparison with other diversity techniques is the low value of delay to be introduced in order to make the technique effective. The delay required by the technique described herein is in the order of few nanoseconds, compared to a delay of some microseconds as required by the fixed DD. As a consequence the implementation problems, related to size, cost and transmission losses of the delay line, are significantly reduced in case of the DDD technique described herein with respect to other diversity techniques.

Another advantage of the DDD technique described herein is represented by its better linearity when compared with other techniques such as the PSTD. By using a time variant delay line, the phase shift $\varphi(f)$

introduced on the signal is, by definition, a linear function of the frequency. As a consequence the DDD technique described herein will not cause phase distortions, even when dealing with wideband signals. On the other hand, as disclosed in several prior-art references, the realization of a phase shifter that introduces a constant phase shift over a wide frequency band makes the RF design complicated and costly and thus it is suitable only for narrowband signals.

The invention thus refers to a diversity technique that can be employed both in transmission and in reception in conjunction with any wireless communication apparatus (e.g. base stations and/or mobile terminals in a mobile communication network) equipped with two or more antennas. The invention is applicable in any wireless communication system, including those that have already been standardized. Preferably, the invention is intended to be implemented at the RF level: however, the basic principle of the diversity technique underlying the invention is also applicable at a different stage in the radio transmission and reception chain such as at the Intermediate Frequency (IF) stage or at the Base Band (BB) stage.

Brief description of the annexed drawings

These and other characteristics of this invention will become evident from the following description of a preferred embodiment of the same, given by way of a non-limiting example, and from the attached drawings, wherein:

- Figures 1 and 2 have been already described in the foregoing;

- Figure 3 is a schematic block diagram of a diversity arrangement as described herein when applied on the transmitter side;

- Figures 4a and 4b are exemplary of two possible embodiments of one of the components included in the arrangement of Figure 3;

- Figures 5 and 6 are schematic block diagrams of possible variants of use and implementation of a diversity arrangement as described herein when applied on the transmitter side;

- Figure 7 includes two diagrams representative of certain parameters involved in operation of the arrangement described herein;

- Figure 8 is a schematic block diagram of another possible variant of a diversity arrangement as described herein when applied on the transmitter side;

- Figures 9 to 12 are block diagrams essentially corresponding to the block diagrams of Figures 3, 5, 6, and 8 and referring to a diversity arrangement as described herein when applied on the receiver side;

- Figures 13 to 15 are block diagrams referring to "reciprocal" diversity arrangements adapted to operate both as transmitters and as receivers;

- Figures 16 to 18 are block diagrams that illustrate different system architectures involving diversity arrangements as described herein both in transmission and reception; and

- Figures 19 to 22 are exemplary of a number of practical embodiments of the arrangement described herein including possible non-RF implementations.

<u>Detailed description of exemplary embodiments of the invention</u>

In the following, the application of the Dynamic Delay Diversity (DDD) technique described herein will be first discussed in connection with its use as a transmit technique and subsequently in connection with its use as a receive diversity technique.

In general terms, the DDD technique as first described herein is realized by means of a diversity processor that is connected at the output of a conventional transmitter T (elements 10, 12, and 14 as shown in Figure 1) or at the input of a conventional receiver R (elements 20, 22, and 24 as shown in Figure 2. The various implementations of the diversity processors, realized according to the principle of the DDD, are denoted in ~~the sub~~sequent description as DDD TX processors 16 (transmit diversity) or DDD RX processors 26 (receive diversity).

For the sake of simplicity, the system description provided herein will not consider specific circuit details, such as e.g. the utilization of Low Noise Amplifiers (LNAs) or High Power Amplifiers (HPAs), which can be connected at the input and/or at the output of the DDD processors, in order to improve the overall receiver noise figure or to increase the transmitted power respectively.

A general implementation of a DDD TX processor 16 is shown in the block diagram of Figure 3. The DDD TX processor is fed with the output signals of the conventional transmitter T and, after the DDD processing, the signals reach the transmission antennas 1, 2. The general structure of the DDD processor shown in Figure 3 is employed when the conventional transmitter T supports by itself some form of transmission antenna diversity. In such a case the conventional transmitter T provides at the output two different RF signals that feed the two inputs of the DDD processor.

The DDD TX processor is composed of two signal splitters 160 that divide each input signal in two parts. Each of the four signals at the output of the splitters are provided to four Time Variant Delay Lines (TVDL) 161, 162, 163, and 164.

Each time variant delay line introduces on the corresponding RF signal a delay $\tau_n(t)$ ($1 \leq n \leq 4$) that varies between zero and a maximum value in the order of the carrier period T_0. The signals at the output of the four TVDLs 161, 162, 163, and 164 are then combined in two pairs by means of two RF combining units (combiners 166) and subsequently feed the antennas 1, 2 for radio transmission.

The arrangement illustrated, as applied to signals being transmitted by means of the two diversity antennas 1, 2 involves:

- splitting (at 160) each of the two signals being transmitted $INPUT_1$, $INPUT_2$ over respective transmission paths (to the number of four, as a whole) towards the diversity antennas 1, 2, and

- combining (at 166) at each of the diversity antennas 1, 2 the respective transmission paths of the two signals being transmitted.

As will be demonstrated in the following, the various delay function $\tau_n(t)$ are selected in order to maximize the temporal variations of the signal to noise plus interference (SNIR) ratio measured at the receiver and/or to minimize the cross-correlation between the transmitted (transmit diversity) or received (receiver diversity) signals. It is possible to demonstrate that combining two signals that slightly differ in terms of delay creates an amplitude-modulated signal that fades periodically. This effect determines a reduction of the Average Fade Duration (AFD) at the receiver, which measures how long the signal envelope or power stays below a given target threshold, and thus brings an improvement of the signal demodulation performance at the receiver.

Figure 4a shows a first exemplary implementation of any of the TVDLs (e.g. those indicated by 161 to 164 in Figure 3) in the form of a tapped delay line, namely as the cascade of elementary delay units T_D. Each such delay unit (e.g. a transmission line stub) may generate a delay T_D of, say, 0.1 ns. The various tap points in the line come down to a RF switch 18. The switch is controlled by a delay control unit DCU making it possible to select a particular tap of the tapped delay line and therefore a given value of the delay produced by the block. Changing the position of the switch makes it possible to change the value of the delay applied to the output signal O with respect to the input signal I.

By resorting to the arrangement illustrated in Figure 4a, the variable time delays (TVDLs) are generated by providing a cascaded elementary delay units (T_D) and selectively varying the number of elementary delay units included in the cascade. This is preferably provided in the form of a tapped delay line comprised of elementary delay units in a cascaded arrangement, and the switch 18 selectively contacts the tap points in the tapped delay line, whereby changing the position of the switch 18 changes the value of the delay.

Figure 4b shows a second exemplary implementation of the delay line in the form of a plurality of delay elements TD_1, TD_2, ..., TD_N. These may again be comprised of transmission line stubs) each producing a respective delay of e.g. TD1 = 0.1 ns., TD2 = 0.2 ns., TD3 = 0.3 ns., and so on. Two switches 181, 182 are controlled in a coordinated manner by the delay control unit DCU making it possible to select a particular delay element and therefore a given value of the delay introduced by the block. Changing the position of the switches makes it possible to change the value of the delay applied to the output signal O with respect to the input signal I. Typically, this delay is varied in the range between tenths of nanoseconds (ns) and units of nanoseconds (ns).

As an alternative to varying the delay in discrete steps, as shown in connection with the exemplary embodiments of Figure 4a and Figure 4b, in other possible implementations of the time variant delay line the delay is caused to vary continuously. A possible implementation of the delay line with continuous variation of the introduced delay can be found in the article "*Time Delay Phase Shifter Controlled by Piezoelectric Transducer on Coplanar Waveguide*", IEEE Microwave and Wireless Components Letters, Vol. 13, No. 1, pag. 19-20, January 2003. In particular, the continuous delay line may be implemented by inserting on a coplanar waveguide a piezoelectric transducer whose perturbations vary the effective dielectric constant of the coplanar waveguide.

The block diagram of Figure 5 refers to the case of a conventional transmitter T' that does not support any transmission diversity technique. The transmitter T' provides in this case a single RF output signal that is provided to one input of the DDD TX processor, while the second input of the DDD TX processor is not fed with any signal (i.e. it is connected to ground). The representation of Figure 5 is intended to highlight that the general structure of the DDD processor illustrated in Figure 3 can be still used (in a "degenerated" manner as shown in Figure 5), even though some of the RF components, represented using dashed lines, are not essential for the operation of the diversity processor.

A third possible structure of a DDD TX processor 16 is shown in Figure 6. In this case only two time variant delay lines 163, 164 are used while the other two delay lines are replaced with a wire connection. With a proper choice of the delay functions $\tau_3(t)$ and $\tau_4(t)$, the DDD TX processor works as a signal decorrelator by providing two output signals that have a lower cross-correlation coefficient than the cross-correlation coefficient of the two input signals.

In particular the DDD TX processor works as a signal decorrelator by using two delay functions $\tau_3(t)$ and $\tau_4(t)$ that satisfy the following condition

$$\tau_4(t) = \tau_3(t) + \frac{T_0}{2} \qquad (2)$$

where T_0 is the carrier period. An example of delay functions, applicable with the DDD TX processor 16 of Figure 6, which satisfy the condition (2) are shown in Figure 7.

In view of the relationship (2) above, the structure of the DDD TX processor 16 shown in Figure 6 can be further simplified as shown in Figure 8. There, the two time variant delay lines 163, 164 illustrated in Figure 7 are replaced by the combination of:

- a delay element 165 having a fixed delay equal to $T_0/2$, realized for example with a half wavelength transmission line stub, arranged on the portion of the propagation path of the input signal INPUT2 to the antenna 2, and

- a single TVDL 164 inserted after the combiner 166, namely on that portion of the propagations paths of the input signals $INPUT_1$ and $INPUT_2$ to the antenna 2 that is common to both signals.

The following is a description of the application of the DDD technique described herein as a receiver diversity technique. A general implementation of the DDD RX processor 26 is shown in the block diagram of

Figure 9. The DDD RX processor is fed with the signals received by the antennas 1, 2 and, after the DDD processing, the signals are provided to a conventional receiver R for the subsequent demodulation. The general structure of the DDD processor as shown in Figure 9 is employed when the conventional receiver R is equipped with two separate radio chains that allow the independent demodulation of two signals.

The DDD RX processor 26 is composed of two signal splitters 260 that divide in two parts the signals received from the antennas. Each of the four signals at the output of the splitters are provided to four Time Variant Delay Lines (TVDL) 261, 262, 263, and 264. Each time variant delay line 261, 262, 263, and 264 introduces on the corresponding RF signal a delay $\tau_n(t)$ ($1 \leq n \leq 4$) that varies between zero and a maximum value in the order of the carrier period T_0. The signals at the output of the four TVDLs 261, 262, 263, and 264 are then combined in two pairs by means of two RF combining units (combiners 266) and subsequently feed the two inputs of the conventional receiver R.

The arrangement illustrated in Figure 9, as applied to signals being received by means of the two diversity antennas 1, 2, involves:

- splitting (at 260) each of the two signals being received $INPUT_1$, $INPUT_2$ over respective reception paths (again to the number of four, as a whole) from the diversity antennas 1, 2, and
- combining (at 266) the respective reception paths of the two signals being received from different ones of the two diversity antennas 1, 2.

The performance improvement introduced by the DDD RX processor 26 can be explained by calculating the average and the instantaneous Signal to Noise Ratio (SNR) of the signals at the output of the processor.

The general input-output signal transfer function of the DDD RX processor can be expressed as follows

$$\begin{cases} z_1(t) = y_1[t-\tau_1(t)] + y_2[t-\tau_3(t)] \\ z_2(t) = y_1[t-\tau_2(t)] + y_2[t-\tau_4(t)] \end{cases} \qquad (3)$$

where $y_1(t)$ and $y_2(t)$ are the signals received at the two antennas, $z_1(t)$ and $z_2(t)$ are the signals at the output of the DDD RX processor.

For the sake of simplicity, the following analysis considers a single frequency component, with frequency f_0, located in the center of the signal bandwidth B. However by using the linear superposition principle, the analysis can be generalized for a wideband signal with bandwidth B. In order to simplify the calculations one may refer to the complex envelopes of the corresponding signals. Again for sake of simplicity, it is assumed that the various RF components do not introduce distortions or signal losses.

By referring to the scheme of Figure 9, the complex envelope at the frequency f_0 of the output signals $z_1(t)$ and $z_2(t)$ can be written as follows

$$\tilde{z}_1(t) = \tilde{y}_1(t) \cdot e^{j\varphi_1(t)} + \tilde{y}_2(t) \cdot e^{j\varphi_3(t)} \qquad (4)$$

$$\tilde{z}_2(t) = \tilde{y}_1(t) \cdot e^{j\varphi_2(t)} + \tilde{y}_2(t) \cdot e^{j\varphi_4(t)} \qquad (5)$$

where the instantaneous phase shifts $\varphi_j(t)$ applied on the j-th signals is equal to

$$\varphi_j(t) = 2\pi f_0 \tau_j(t) \qquad (6)$$

The equation (4) can be further expanded by expressing the two received signals $\tilde{y}_1(t)$ and $\tilde{y}_2(t)$ as the sum of a useful term $\tilde{s}_i(t)$ and a disturbing term $\tilde{n}_i(t)$ representing the sum of thermal noise and interference

$$\tilde{z}_1(t) = [\tilde{s}_1(t) + \tilde{n}_1(t)] \cdot e^{j\varphi_1(t)} + [\tilde{s}_2(t) + \tilde{n}_2(t)] \cdot e^{j\varphi_3(t)} \qquad (7)$$

The average SNR of the signal at the first output of the DDD RX processor 26 is then given by

$$SNR_{OUT_1} = \frac{E\left\{\left\| \tilde{s}_1(t) \cdot e^{j\varphi_1(t)} + \tilde{s}_2(t) \cdot e^{j\varphi_3(t)} \right\|^2\right\}}{E\left\{\left\| \tilde{n}_1(t) \cdot e^{j\varphi_1(t)} + \tilde{n}_2(t) \cdot e^{j\varphi_3(t)} \right\|^2\right\}} \qquad (8)$$

where $\|a(t)\|^2 = a(t) \cdot a(t)^*$ is the squared norm of the signal $a(t)$ and $E\{\cdot\}$ here denotes the time average (mean value) operator. Starting from the equation (8), and assuming a particular case wherein the received signals are statistically independent, it is possible to demonstrate that the average SNR of each signal at the output of the DDD RX processor 26 is equal to the average SNR measured at each receiving antenna so that it is possible to write

$$SNR_{OUT_1} = SNR_{ANT1} = \frac{E\left\{\|\tilde{s}_1(t)\|^2\right\}}{E\left\{\|\tilde{n}_1(t)\|^2\right\}} = SNR_{ANT2} = \frac{E\left\{\|\tilde{s}_2(t)\|^2\right\}}{E\left\{\|\tilde{n}_2(t)\|^2\right\}} \qquad (9)$$

However, by considering the instantaneous value of the SNR at the output of the DDD RX processor 26 one obtains that the SNR depends both on the instantaneous attenuation of the propagation channel, which affects the instantaneous amplitude of the received signals $\tilde{s}_i(t)$ and $\tilde{n}_i(t)$, but it depends also on the phase functions $e^{j\varphi_1(t)}$ and $e^{j\varphi_3(t)}$ introduced by the DDD technique at the receiver

$$SNR_{OUT_1}(t) = \frac{\left\|\tilde{s}_1(t) \cdot e^{j\varphi_1(t)} + \tilde{s}_2(t) \cdot e^{j\varphi_3(t)}\right\|^2}{\left\|\tilde{n}_1(t) \cdot e^{j\varphi_1(t)} + \tilde{n}_2(t) \cdot e^{j\varphi_3(t)}\right\|^2} \qquad (9A)$$

As a consequence, by properly selecting the phase functions $e^{j\varphi_1(t)}$ and $e^{j\varphi_3(t)}$ it is possible to induce a variation of the instantaneous SNR at the receiver and thus reduce the mean fade duration in low mobility environments.

The performance improvement introduced by the DDD RX processor can be also demonstrated by calculating the cross-correlation of the signals at the output of the processor. In fact, the DDD RX processor 26 of Figure 9 operates as a decorrelator, by providing two output signals that have a lower cross-correlation value than the cross-correlation value of the input signals. For simplicity one may again consider in the following analysis a single frequency component, with frequency f_0, located in the center of the signal bandwidth B.

The amplitude cross-correlation between the signals $y_1(t)$ and $y_2(t)$ received at the antennas is denoted with ρ_y while the cross-correlation ρ_z between the two output signals $z_1(t)$ and $z_2(t)$ is calculated as follows

$$\rho_z = E\{\tilde{z}_1(t) \cdot \tilde{z}_2^*(t)\} \tag{10A}$$

The reduction of the cross-correlation can be demonstrated by using the general expressions (4) and (5) of the two output signals and imposing, for example, the following design conditions

$$\begin{aligned} \varphi_1(t) &= 2 \cdot \omega \cdot t + \pi/2 \\ \varphi_2(t) &= 4 \cdot \omega \cdot t + 3 \cdot \pi/2 \\ \varphi_3(t) &= 2 \cdot \omega \cdot t + \pi/4 \\ \varphi_4(t) &= 4 \cdot \omega \cdot t + \pi/4 \end{aligned} \tag{10B}$$

This particular example uses linear phase function $\varphi_n(t)$ varying cyclically between 0 and 2π with different angular frequencies. However, other phase functions can be used in order to obtain two output signals that have a lower cross-correlation value than the cross-correlation value of the input signals.

By substituting the expressions (4), (5) and (10B) in the equation (10A) one then obtains the final expression of the output cross-correlation

$$\rho_z = 2 \cdot j \cdot e^{j\pi/4} E\{\mathrm{Im}[\rho_y \cdot e^{-j\omega t}]\} \tag{10C}$$

where the symbol $\mathrm{Im}[.]$ denotes the imaginary part of the argument. The equation (10C) indicates that, when the input signals are correlated (i.e. $\rho_y > 0$) the cross-correlation between the two output signals ρ_z can be reduced to zero. In fact, the average of the sinusoidal function in the equation (10C) makes the output cross-correlation equal to zero

$$E\left\{\mathrm{Im}\left[\rho_y \cdot e^{-j\omega t}\right]\right\} = E\left\{-\mathrm{Re}(\rho_y)\cdot\sin(\omega t) + \mathrm{Im}(\rho_y)\cdot\cos(\omega t)\right\} = 0 \qquad (10D)$$

where the symbol $\mathrm{Re}[.]$ denotes the real part of the argument.

The generalization of the previous demonstration to a wideband signal is straightforward, taking into account the relationship between the delays introduced on the signals and the corresponding phase shifts as a function of frequency

$$\varphi_n(t) = 2\pi f \tau_n(t) \qquad (10E)$$

For example a linear phase function varying cyclically between 0 and 2π can be obtained by inserting a linear delay function varying between 0 and the period of the carrier frequency $T_0 = 1/f_0$, where f_0 is the central frequency within the signal bandwidth B. A fixed phase shift of e.g. $\pi/2$ is instead obtained by inserting a fixed delay of $T_0/4$. Accordingly, the different angular frequencies of the phase functions in (10b) correspond to different time periods T_p of the delay functions. Examples of these linear delay functions are provided in Figure 7.

The DDD RX processor 26 described herein can also be used to improve the radio link performance of wireless systems that in origin are not designed to support receiver diversity. In this case the conventional receiver R' is equipped with a single radio chain and thus only one RF signal can be demodulated. The support of the receive diversity is obtained by exploiting only one output signal of the RX diversity processor, as shown in Figure 10. In this particular system configuration, the general structure of the DDD RX processor 26 of Figure 9 can still be used as shown in Figure 10, even though some of the RF components, represented using dashed lines, are not essential for the operation of the diversity processor.

A third possible structure of the DDD RX processor 26 is shown in Figure 11. In this case only two time variant delay lines 263, 264 are used while the other two delay lines are replaced with a wire connection. With a proper choice of the delay functions $\tau_3(t)$ and $\tau_4(t)$, the DDD RX processor of Figure 11 operates as a signal decorrelator by providing two output signals that have a lower cross-correlation value than the cross-correlation value of the two input signals.

In particular the DDD RX processor of Figure 11 operates as a signal decorrelator by using two delay functions $\tau_3(t)$ and $\tau_4(t)$ that satisfy the following condition

$$\tau_4(t) = \tau_3(t) + \frac{T_0}{2} \qquad (11)$$

where T_0 is the carrier period. Two delay functions shown in Figure 7, which satisfy the condition (11), are again applicable with the DDD RX processor of Figure 11. The delay functions $\tau_n(t)$ are designed such that the delay variation over a symbol period is significantly small compared to the carrier period T_0. In case of a CDMA system this design criteria ensures that there is a minimal energy loss in the sum and dump operations. Moreover, as previously explained, the delay functions $\tau_n(t)$ are also chosen in order to introduce a sufficient variability of the received SNR within the interleaving period. For example in case of the UMTS system, which has an interleaving period ranging from 10 to 80 ms, a possible choice of the period of the delay functions T_p is in the order of 10÷20 ms.

In view of the relationship (11) above, the structure of the DDD RX processor shown in Figure 11 can be further simplified as shown in Figure 12. In particular, the two time variant delay lines 263, 264 of Figure 11 are replaced by the combination of:

- a delay element 265 having a fixed delay equal to $T_0/2$, realized for example with a half wavelength transmission line stub, arranged on the portion of the propagation path of the input signal INPUT2 from the antenna 2 (i.e. downstream of the splitter 260), and

- a single TVDL 264 inserted upstream of the splitter, namely on that portion of the propagation paths of the output signals $OUTPUT_1$ and $OUTPUT_2$ from the antenna 2 that is common to both signals.

The DDD RX processor 26 of either of Figures 11 or 12 operates as a decorrelator, by providing two output signals that have a lower cross-correlation value than the cross-correlation value of the input signals. For simplicity one may again consider in the following analysis a single frequency component, with frequency f_0, located in the center of the signal bandwidth B.

The amplitude cross-correlation between the signals $y_1(t)$ and $y_2(t)$ received at the antennas is denoted with ρ_y while the cross-correlation ρ_z between the two output signals $z_1(t)$ and $z_2(t)$ is calculated as follows

$$\rho_z = E\{\tilde{z}_1(t)\cdot\tilde{z}_2^*(t)\} \tag{12}$$

The reduction of the cross-correlation can be demonstrated by using the general expressions (4) and (5) of the two output signals and imposing, as design condition, that the phase difference between $\varphi_3(t)$ and $\varphi_4(t)$ is constant and equal to 180 degrees

$$\varphi_1(t) = \varphi_2(t) = 0$$
$$\varphi_4(t) = \varphi_3(t) + \pi \qquad (13)$$

By substituting the expressions (4), (5) and (13) in the equation (12) one then obtains the final expression of the output cross-correlation

$$\rho_z = -\rho_y \cdot E\{\cos[\varphi_3(t)] - j\sin[\varphi_3(t)]\} + \rho_y^* \cdot E\{\cos[\varphi_3(t)] + j\sin[\varphi_3(t)]\} \qquad (14)$$

The equation (14) indicates that, when the input signals are correlated (i.e. $\rho_y > 0$) the cross-correlation between the two output signals ρ_z can be reduced to zero. In particular, by selecting a phase function $\varphi_3(t)$ that satisfies the following conditions

$$E\{\cos[\varphi_3(t)]\} = 0 \quad \text{and} \quad E\{\sin[\varphi_3(t)]\} = 0 \qquad (15)$$

the value of output cross-correlation ρ_z can be reduced to zero. For example, a linear phase function varying cyclically between 0 and 2π such as

$$\varphi_3(t) = m \cdot t \qquad (16)$$

satisfies the conditions (15) and can be used in the present invention. However, other phase functions satisfying the condition (15) can be used in order to obtain the same result. The generalization of the previous demonstration to a wideband signal is straightforward, taking into account the relationship between the delay introduced on the signals and the corresponding phase shift as a function of frequency

$$\varphi_n(t) = 2\pi f \tau_n(t) \qquad (17)$$

For example a linear phase function varying cyclically between 0 and 2π can be obtained by inserting a linear delay function varying between 0 and the period of the carrier frequency $T_0 = 1/f_0$, where f_0 is the central frequency within the signal bandwidth B. Correspondingly the design condition (13) can be rewritten in a similar relationship between the delay functions

$$\tau_4(t) = \tau_3(t) + \frac{T_0}{2} \qquad (18)$$

The DDD processors 16 and 26 described up to now are unidirectional devices that can be used separately for transmission or reception. However, by comparing the architectures of Figure 3 (DDD TX processor 16) and Figure 9 (DDD RX processor 26) it is evident that the two circuits are symmetrical.

As a consequence, a single DDD TX/RX processor 126, implemented with reciprocal components, can be used simultaneously both for transmission and reception. The same consideration holds for the other architectures such those shown in Figure 5 and Figure 10, used together with conventional transceivers that do not support transmit or receive diversity. Similarly the architectures in Figure 6 and Figure 11 that work as signal decorrelators have symmetrical structures.

Figure 13 shows the general structure of a DDD TX/RX processor 126 realized with reciprocal components that can be used simultaneously for transmission and reception. Specifically, two first reciprocal elements 1260 may act as splitters and combiners, when the processor 126 acts as a transmitter and a receiver, respectively. Similarly, two further reciprocal elements 1266 may act as combiners and splitters, when the processor 126 acts as a trasmitter and a receiver, respectively. Four TVDLs 1261, 1262, 1263, and 1264 - that are intrinsically reciprocal elements - are interposed between the first and second reciprocal elements 1260 and 1266.

The block labelled as TR in Figure 13 and in the next figures represents a unit that includes the functionalities of both the conventional transmitter and conventional receiver detailed in Figure 1 and Figure 2 respectively.

Figure 14 shows the architecture of the DDD TX/RX processor 126 realized with reciprocal components and using only two TVDLs 1263, 1264. Similarly, Figure 15 shows a further simplified structure of the DDD TX/RX processor 126 that is used as signal decorrelator, implemented by using only reciprocal components, including a single TVDL 1264 interposed between the second pair of elements 1266 and the antenna 2 and fixed ($T_0/2$) delay element 1265 interposed between the first and second pairs of elements 1260 and 1266

The various implementations of the DDD processors described herein can be combined in order to obtain different system architectures where the DDD processing is introduced both in transmission and reception.

For instance, Figure 16 shows a first system architecture based on non-reciprocal DDD transmit and receive processors 16 and 26, respectively. The separation between transmit and receive paths between two transceivers TX_1/RX_1, TX_2/RX_2 and the antennas 1, 2 is obtained by means of two first duplexer elements 51, 52 - at the transmitter/receiver side - and two second duplexer elements 61, 62 at the antenna side.

Figure 17 shows a system architecture based on a reciprocal DDD processor 126 that is used simultaneously for transmission and reception between two transceivers TX_1/RX_1, TX_2/RX_2 and two antennas 1, 2.

Figure 18 shows an asymmetric architecture based on non-reciprocal processors. This architecture includes a transceiver TX_1/RX_1 and a receiver RX_2 and thus comprises a single transmission unit while the receiver is equipped with two receiving units for supporting diversity. A reciprocal duplexer 150 is interposed between the transceiver TX_1/RX_1 and the non-reciprocal processors 16 and 26.

The basic principle of the DDD technique heretofore exemplified as performed at the RF level is also applicable at a different stage in the radio transmission chain such at the Base Band (BB) stage. The following is a description of the general structure of a DDD TX and RX processor suitable for the operation at Base Band Level.

This alternative application of the invention is suitable for communication networks that use Remote Radio Head (RRH) units. By direct reference to the block diagram of Figure 19, a RRH is a compact unit 104 adapted to be mounted near an antenna (such as the antennas 1, 2 considered herein) that integrates several base station functions for transmission and reception.

The transmission functions that are typically integrated in the RRH unit are digital to analog conversion (DAC), frequency up-conversion, digital pre-distortion and MCPA (Multi Carrier Power Amplifier). The receiving functions that are integrated in the RRH are the RF front-end, frequency down-conversion and analog to digital conversion (ADC).

The RRH is fed from the remainder of the base station with baseband (I/Q) signals via a baseband modem 100 over optical fibre cables 102. The interface between the RRH 104 and the baseband modem 100 is normally compliant with the Common Public Radio Interface (CPRI) standard or with the interface defined by the OBSAI (Open Base Station Standard Initiative) forum. The baseband modem 100 can be relocated from a cabinet near to the antenna to a remote location with clear benefits in terms of deployment costs and network management.

As previously observed, the application of the DDD technique can be extended to operate at baseband level in the digital domain. The signal processing operations are performed in this case at baseband level by means of a so-called DDD baseband processor. This unit represents an add-on digital module that can be easily integrated in the RRH 104 or, alternatively, in the baseband modem 100. In order to contemplate both these alternatives, the block diagram of Figure 20 illustrates a DDD baseband transmission (TX) processor 216 and a DDD baseband reception (RX) processor 226 as separate elements arranged over the optical fibre connection 102 between the baseband modem 100 and the RRH 104. The general architectures of the DDD baseband TX processor 216 and of the DDD baseband RX processor 226 are shown in Figures 21 and 22 respectively.

The following is a detailed description of the principles underlying the structure and operation of the DDD baseband RX processor 226 and its application with a RRH arrangement. However, a thoroughly similar description applies - *mutatis mutandis* - to the DDD baseband TX processor 216. The DDD baseband RX processor 226 receives as its the input two digital signals $\widetilde{y}_1(n)$ and $\widetilde{y}_2(n)$ from the main and diversity antennas 1, 2 and provides as output the processed signals $\widetilde{z}_1(n)$ and $\widetilde{z}_2(n)$.

All the signals considered hereafter are digital complex signals, sampled at the frequency F_S and quantized over a finite number of bits. By denoting with n the discrete time index (where $0 \le n \le \infty$), the two signals $\widetilde{y}_1(n)$ and $\widetilde{y}_2(n)$ can be also expressed as follows

$$\widetilde{y}_1(n) = \mathrm{Re}\{\widetilde{y}_1(n)\} + j \cdot \mathrm{Im}\{\widetilde{y}_1(n)\} = \mathrm{Re}\{\widetilde{y}_1(n \cdot T_S)\} + j \cdot \mathrm{Im}\{\widetilde{y}_1(n \cdot T_S)\} \quad (19)$$

$$\widetilde{y}_2(n) = \mathrm{Re}\{\widetilde{y}_2(n)\} + j \cdot \mathrm{Im}\{\widetilde{y}_2(n)\} = \mathrm{Re}\{\widetilde{y}_2(n \cdot T_S)\} + j \cdot \mathrm{Im}\{\widetilde{y}_2(n \cdot T_S)\} \quad (20)$$

where $T_S = 1/F_S$ is the sampling period. The mathematical representation used for the two signals $\widetilde{y}_1(n)$ and $\widetilde{y}_2(n)$ is applicable to all the signals considered in the following description.

One notices that the four delay lines are replaced by four complex multipliers 2261, 2262, 2263, and 2264 (resp. 2161, 2162, 2163, and 2164, in the case of the

TX processor 216 of Figure 21). Each multiplier 2261, 2262, 2263, and 2264 receives at the first input one of the two signals $\tilde{y}_1(n)$ or $\tilde{y}_2(n)$ and, on the second input, a signal $\tilde{p}_i(n)$ with $1 \le i \le 4$. By properly selecting the four digital signals $\tilde{p}_i(n)$ it is possible to modify the phase of the two received signals $\tilde{y}_1(n)$ on $\tilde{y}_2(n)$ and therefore, to introduce the desired variation of the instantaneous SNR on the two output signals $\tilde{z}_1(n)$ and $\tilde{z}_2(n)$ together with the correspondent de-correlation effect.

This concept has been described previously for the application of the invention that operates at radiofrequency, but the same principle remains effective also at baseband. As an example, the signals $\tilde{p}_i(n)$ can be selected in order to introduce a linear phase variation on the two signals $\tilde{y}_1(n)$ or $\tilde{y}_2(n)$. In such a case the phase functions $\tilde{p}_i(n)$ can be expressed as follows

$$\tilde{p}_1(n) = k_1 \cdot e^{j\left(2\pi \cdot \frac{f_{D1}}{F_s} \cdot n + \psi_1\right)} \tag{21}$$

$$\tilde{p}_2(n) = k_2 \cdot e^{j\left(2\pi \cdot \frac{f_{D2}}{F_s} \cdot n + \psi_2\right)} \tag{22}$$

$$\tilde{p}_3(n) = k_3 \cdot e^{j\left(2\pi \cdot \frac{f_{D3}}{F_s} \cdot n + \psi_3\right)} \tag{23}$$

$$\tilde{p}_4(n) = k_4 \cdot e^{j\left(2\pi \cdot \frac{f_{D4}}{F_s} \cdot n + \psi_4\right)} \tag{24}$$

where $k_i = 2^{N_i}$ is the amplitude factor that is introduced in order to allow the quantization of the functions $\tilde{p}_i(n)$ over N_i+1 bits. The factor f_{Di} represent the frequency according to which the phase varies and ψ_i is the initial phase of each function $\tilde{p}_i(n)$. Clearly, the phase functions given by the equations (21)-(24) are just examples and other functions can be used in order to obtain the desired variation of the instantaneous SNR or to reduce to zero the correlation between the output signals $\tilde{z}_1(n)$ and $\tilde{z}_2(n)$.

According to the architecture of Figure 22, the signals at the output of the multipliers 2261, 2262, 2263, and 2264 are then recombined by means of two complex adders 2266. In fact the RF combiners 266 of Figure 9 are replaced with complex adders that operate on digital sampled signals. After the digital recombination the resolution of the signals is increased and thus it may be necessary to reduce this resolution by means of a scaling operation performed by means of signal scaling blocks 2268. The scaling operation reduces the number of bits necessary to represent a digital signal by eliminating some LSB (Least Significant bits) or MSB (Most Significant Bits) that can be neglected without adversely affecting system performance.

In the case of the transmitter processor 216 of Figure 21, the signals at the output of the multipliers 2161, 2162, 2163, and 2164 are then recombined by means of two complex adders 2166. Here again, the RF combiners 166 of Figure 3 are replaced with complex adders that operate on digital sampled signals. After the digital recombination the resolution of the signals is increased and thus it may be necessary to reduce this resolution by means of a scaling operation performed by means of signal scaling blocks 2168. The scaling operation reduces the number of bits necessary to represent a digital signal by eliminating some LSB (Least Significant bits) or MSB (Most Significant Bits) that can be neglected without adversely affecting system performance.

Like the DDD TX and RX processors operating at RF described in the foregoing, the general architectures of Figure 21 and Figure 22 can be simplified in order to obtain the other processor architectures, such the DDD processors that work as signal de-correlators by using only two multiplying units 2163, 2164 and 2263, 2264 instead of four and possibly only one multiplying unit 2164 and 2264 in combination with a sign inversion unit playing a role analogous to the role of the fixed delay elements 165, 265 of figures 8 and 12.

Those of skill in the art will further promptly appreciate that the DDD processor arrangements described herein, both in the version operating at radiofrequency or at baseband, ideally lend themselves to use in wireless apparatus such as e.g. a base station or a mobile terminal equipped with two or more antennas.

Consequently, without prejudice to the underlying principles of the invention, the details and the embodiments may vary, even appreciably, with reference to what has been described by way of example only, without departing from the scope of the invention as defined by the annexed claims.

CLAIMS

1. A method of diversity processing at least two signals ($INPUT_1$, $INPUT_2$) propagated via at least two diversity antennas (1, 2), the method including the steps of:

- coupling each said at least two signals to each said at least two diversity antennas (1, 2) via respective signal propagation paths, thus giving rise to at least four propagation paths, and

- subjecting the signals propagating over at least two of said propagation paths to time variable delays (161 to 164; 261 to 264; 1261 to 1264).

2. The method of claim 1, characterised in that it includes the step of subjecting to time variable delays (161 to 164; 261 to 264; 1261 to 1264) the signals propagating over all of said signal propagation paths.

3. The method of claim 1, characterised in that it includes the step of subjecting to time variable delays two signals propagating over two propagation paths associated with the same (2) of said diversity antennas (1, 2).

4. The method of claim 1, characterised in that it includes the step of subjecting to time variable delays the signals propagating over at least two of said propagation paths by:

- providing, in the propagation paths for said at least two signals, respective distinct propagation portions and a combined propagation portion for said at least two signals,

- subjecting said at least two signals to a time variable delay (164, 264; 1264) over the common portion of said propagation paths, and

- subjecting one of said at least two signals to a fixed delay (165; 265; 1265) over the respective distinct portion of said propagation paths.

5. The method of claim 4, wherein said at least two signals ($INPUT_1$, $INPUT_2$) have a carrier frequency with a given period (T_0), characterised in that said fixed delay (165; 265; 1265) is equal to half said given period ($T_0/2$).

6. The method of any of the previous claims, applied to signals transmitted by means of said at least two diversity antennas (1, 2), characterised in that it includes the steps of:

- splitting (160) each of said at least two signals transmitted ($INPUT_1$, $INPUT_2$) over respective transmission paths towards said diversity antennas (1, 2), and

- combining (166) at each of said diversity antennas (1, 2) the respective transmission paths of said at least two signals transmitted.

7. The method of any of the previous claims 1 to 5, applied to signals received by means of said at least two diversity antennas (1, 2), characterised in that it includes the steps of:

- splitting (260) each of said at least two signals received ($INPUT_1$, $INPUT_2$) over respective reception paths from said diversity antennas (1, 2), and

- combining (266) the respective reception paths of said at least two signals received from different ones of said at least two diversity antennas (1, 2).

8. The method of any of the previous claims 1 to 5, applied to signals transmitted and received by means of said at least two diversity antennas (1, 2), characterised in that it includes the steps of:

- splitting (1260) each of said at least two signals transmitted over respective transmission paths towards said diversity antennas (1, 2),

- splitting (1266) each of said at least two signals received over respective reception paths from said diversity antennas (1, 2),

- combining (1266) at each of said diversity antennas (1, 2) the respective transmission paths of said at least two signals transmitted, and

- combining (1260) the respective reception paths of said at least two signals received from different ones of said at least two diversity antennas (1, 2),

wherein said steps of splitting and combining are performed by means of reciprocal elements (1260, 1266)

9. The method of any of the previous claims 6 to 8, characterised in that it includes the step of subjecting said signals to time variable delays (161 to 164; 261 to 264; 1261 to 1264) between said steps of splitting (160; 260; 1260, 1266) and combining (166; 266; 1266, 1260).

10. The method of claim 4 in combination with any of the previous claims 6 to 8, characterised in that it includes the steps of:

- subjecting said one of said at least two signals to a fixed delay (165; 265; 1265) between said steps of splitting (160; 260; 1260, 1266) and combining (166; 266; 1266, 1260), and

- subjecting said at least two signals to a time variable delay (164, 264; 1264) either before said step of splitting (160; 260; 1260, 1266) or after said step of combining (166; 266; 1266, 1260)

11. The method of any of the previous claims, wherein said at least two signals ($INPUT_1$, $INPUT_2$) have a carrier frequency having a given period (T_0), the method characterised in that it includes the step of varying said time variable delays from zero to about said period (T_0) of said carrier frequency.

12. The method of any of the previous claims, characterised in that it includes the steps of varying (DCU) said time variable delays with a linear law over time.

13. The method of any of the previous claims 1 to 11, characterised in that it includes the steps of varying (DCU) said time variable delays with a sinusoidal law over time.

14. The method of any of the previous claims, characterised in that it includes the steps of varying (DCU) said time variable delays in the range between tenths of nanoseconds (ns) and units of nanoseconds (ns).

15. The method of any of the previous claims, characterised in that it includes the steps of generating said variable time delays by providing cascaded elementary delay units (T_D) and selectively varying (18) the number of elementary delay units included in the cascade.

16. The method of any of claims 1 to 14, characterised it includes the step of generating said

time variable delays by providing a plurality of delay elements (T_{D1} ... T_{DN}) having respective delay values and selecting (181, 182; DCU) at least one delay element out of said plurality.

17. The method of any of claims 1 to 14, characterised in that it includes the step of varying said time variable delays continuously.

18. The method of any of the previous claims, characterised in that said signals ($INPUT_1$, $INPUT_2$) are selected out of radiofrequency (RF) signals and intermediate frequency (IF) signals.

19. The method of any of the previous claims 1 to 17, characterised in that said signals are baseband signals.

20. The method of claim 19, characterised in that it includes the step of conveying said baseband signals with respect to said diversity antennas (1, 2) over an optical fibre link (102).

21. The method of either of claims 19 or 20, characterised in that said time variable delays are applied to said at least two of said signals propagated via said at least two diversity antennas (1, 2) by subjecting said baseband signals to multiplication (2161 to 2164; 2261 to 2264) by a complex signal ($\tilde{p}_1(n)$ to $\tilde{p}_4(n)$).

22. A system for diversity processing at least two signals ($INPUT_1$, $INPUT_2$) propagated via at least two diversity antennas (1, 2), the system including:

- at least four respective propagation paths coupling each said at least two signals to each said at least two diversity antennas (1, 2), and

- time variable delay elements (161 to 164; 261 to 264; 1261 to 1264) for subjecting to time variable delays the signals propagating over at least two of said propagation paths.

23. The system of claim 22, characterised in that it includes time variable delay elements (161 to 164; 261 to 264; 1261 to 1264) arranged over all of said signal propagation paths for subjecting to time variable delays the signals propagating over all of said signal propagation paths.

24. The system of claim 22, characterised in that it includes time variable delay elements (161 to 164; 261 to 264; 1261 to 1264) arranged on two propagation paths associated with the same (2) of said diversity antennas (1, 2) for subjecting to time variable delays two signals propagating over said two propagation paths associated with the same (2) of said diversity antennas (1, 2).

25. The system of claim 22, characterised in that it includes:

- in the propagation paths for said at least two signals, respective distinct propagation portions and a combined propagation portion for said at least two signals,

- a respective time variable delay element (164, 264; 1264) arranged over the common portion of said propagation paths for subjecting said at least two signals to a time variable delay over said common portion of said propagation paths, and

- a fixed delay element (165; 265; 1265) arranged over the respective distinct portion of said propagation paths for subjecting one of said at least two signals to a fixed delay over said respective distinct portion of said propagation paths.

26. The system of claim 25, for diversity processing said at least two signals ($INPUT_1$, $INPUT_2$) having a carrier frequency with a given period (T_0), characterised in that said fixed delay element (165; 265; 1265) has a delay equal to half said given period ($T_0/2$).

27. The system of any of the previous claims 22 to 26, for diversity processing signals transmitted by means of said at least two diversity antennas (1, 2), characterised in that it includes:

- splitter elements (160) for splitting each of said at least two signals transmitted ($INPUT_1$, $INPUT_2$) over respective transmission paths towards said diversity antennas (1, 2), and

- combiner elements (166) for combining at each of said diversity antennas (1, 2) the respective transmission paths of said at least two signals transmitted.

28. The system of any of the previous claims 22 to 26, for diversity processing signals received by means of said at least two diversity antennas (1, 2), characterised in that it includes:

- splitter elements (260) for splitting each of said at least two signals received ($INPUT_1$, $INPUT_2$) over respective reception paths from said diversity antennas (1, 2), and

- combiner elements (266) for combining the respective reception paths of said at least two signals received from different ones of said at least two diversity antennas (1, 2).

29. The system of any of the previous claims 22 to 26, for diversity processing signals transmitted and received by means of said at least two diversity antennas (1, 2), characterised in that it includes:

- first reciprocal splitter/combiner elements (1260) for splitting each of said at least two signals transmitted over respective transmission paths towards said diversity antennas (1, 2),

- second reciprocal splitter/combiner elements (1266) for splitting each of said at least two signals received over respective reception paths from said diversity antennas (1, 2) and combining (1266) at each of said diversity antennas (1, 2) the respective transmission paths of said at least two signals being transmitted,

- said first reciprocal splitter/combining elements (1260) also combining the respective reception paths of said at least two signals received from different ones of said at least two diversity antennas (1, 2).

30. The system of any of the previous claims 27 to 29, characterised in that it includes said time variable delays (161 to 164; 261 to 264; 1261 to 1264) arranged between said splitter elements (160; 260; 1260, 1266) and said combiner elements (166; 266; 1266, 1260).

31. The system of claim 25 in combination with any of the previous claims 27 to 29, characterised in that it includes:

- said fixed delay element (165; 265; 1265) arranged between said splitter elements (160; 260; 1260, 1266) and combiner elements (166; 266; 1266, 1260), and

- said respective time variable delay element (164, 264; 1264) arranged either upstream of said splitter elements (160; 260; 1260, 1266) or downstream of said combiner elements (166; 266; 1266, 1260)

32. The system of any of the previous claims 22 to 31, characterised in that said variable time delay elements include cascaded elementary delay units (T_D) and a switch (18) for selectively varying (18) the number of elementary delay units included in the cascade.

33. The system of any of the previous claims 22 to 31, characterised in that said variable time delay elements include a plurality of delay elements (T_{D1} ... T_{DN}) having respective delay values and at least one switch (181, 182) for selecting at least one delay element out of said plurality.

34. The system of any of the previous claims 22 to 33, characterised in that it includes an optical fibre link (102) for conveying said signals with respect to said diversity antennas (1, 2) as baseband signals.

35. The system of either of claims 22 or 34, characterised in that it includes multiplier elements (2161 to 2164; 2261 to 2264) for multiplying by a complex signal ($\tilde{p}_1(n)$ to $\tilde{p}_4(n)$) said at least two of said signals propagated via said at least two diversity antennas (1, 2) while said signals are in the form of baseband signals, whereby said time variable delays are applied to said at least two of said signals propagated

via said at least two diversity antennas (1, 2) by subjecting said baseband signals to multiplication (2161 to 2164; 2261 to 2264) by a complex signal ($\tilde{p}_1(n)$ to $\tilde{p}_4(n)$).

36. A wireless communication apparatus including the system of any of claims 22 to 35.

37. A computer program product, loadable into the memory of at least one computer and including software code portions for performing the method of any of claims 1 to 21.

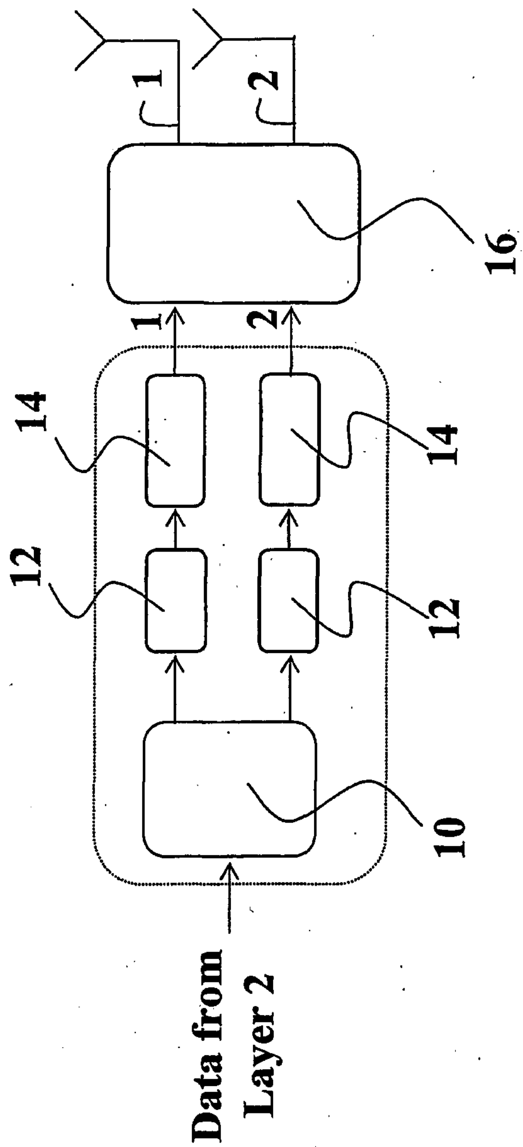


Fig. 1

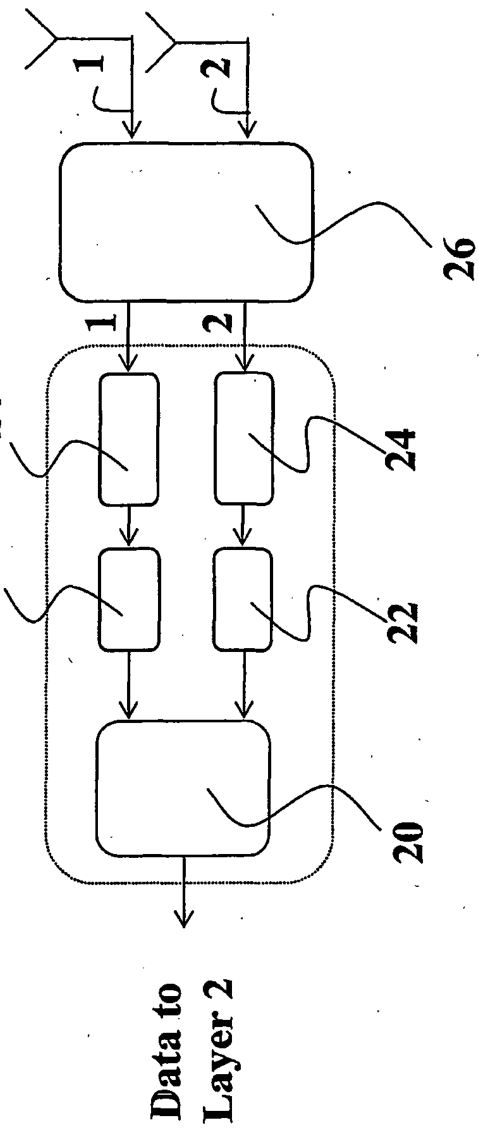


Fig. 2

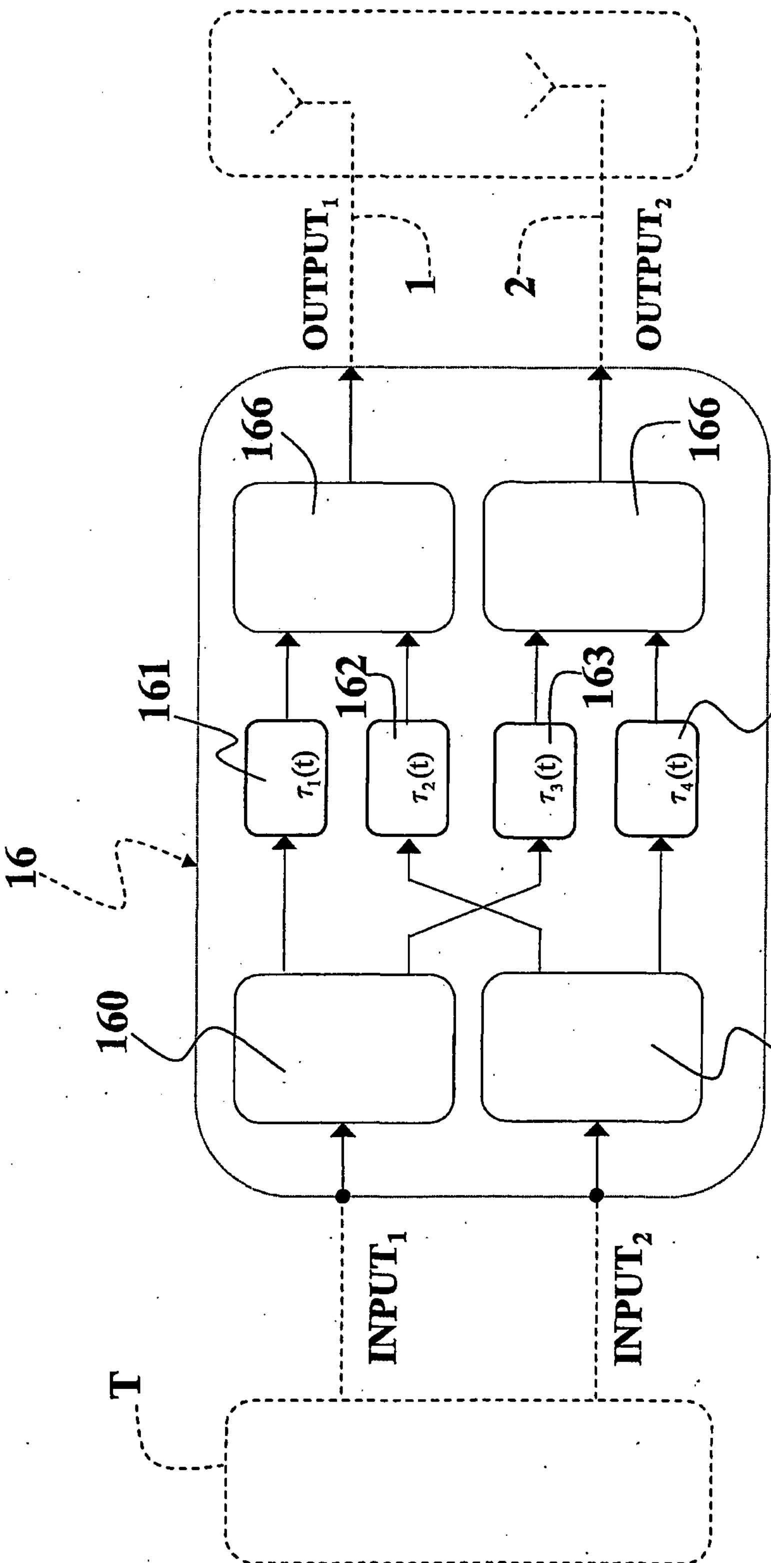

OUTPUT$_1$
OUTPUT$_2$
1
2
166
166
161
162
163
164
$\tau_1(t)$
$\tau_2(t)$
$\tau_3(t)$
$\tau_4(t)$
16
160
160
INPUT$_1$
INPUT$_2$
T

Fig. 3

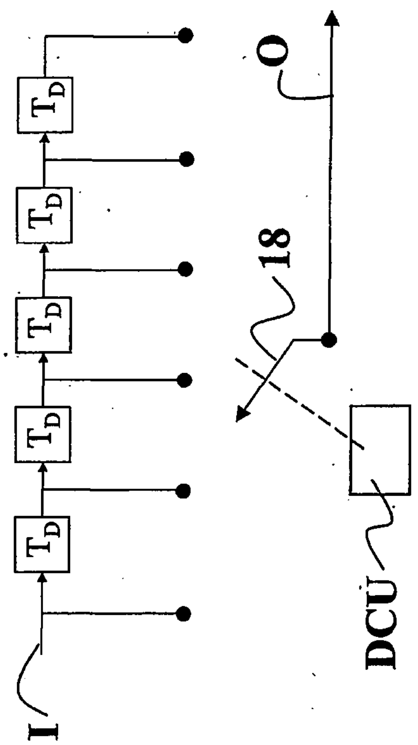


Fig. 4a

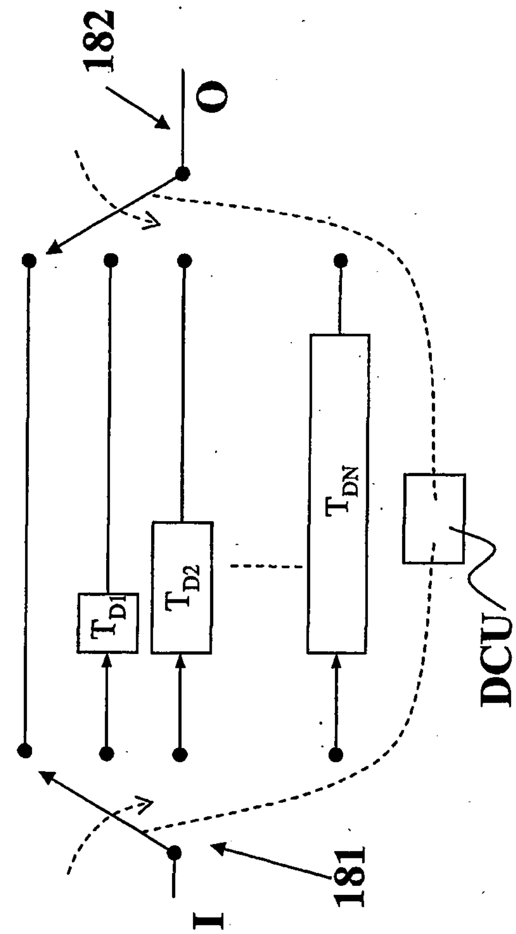


Fig. 4b

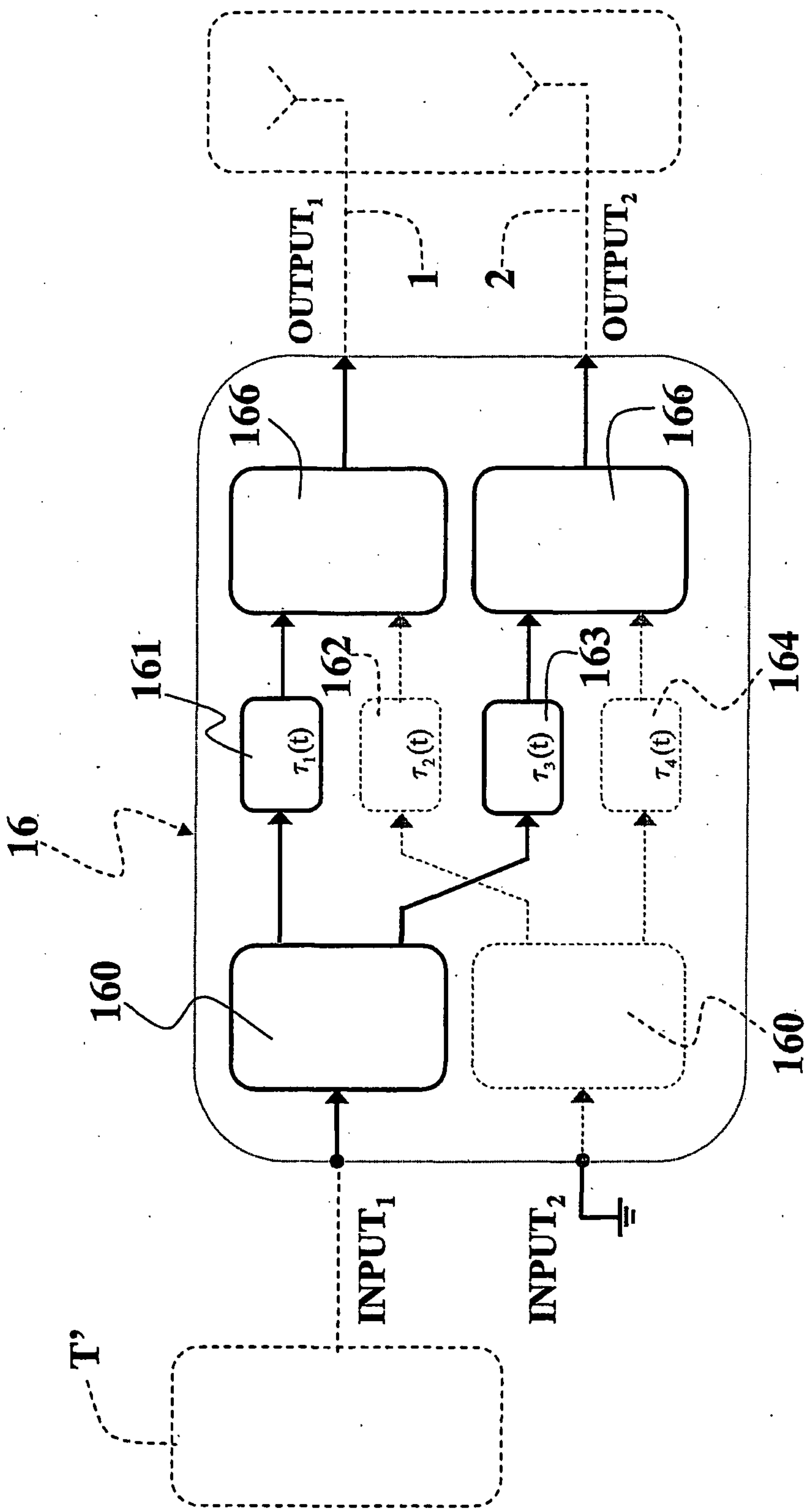

OUTPUT$_1$
OUTPUT$_2$
1
2
166
166
161
162
163
164
τ_1(t)
τ_2(t)
τ_3(t)
τ_4(t)
16
160
160
INPUT$_1$
INPUT$_2$
T'

Fig. 5

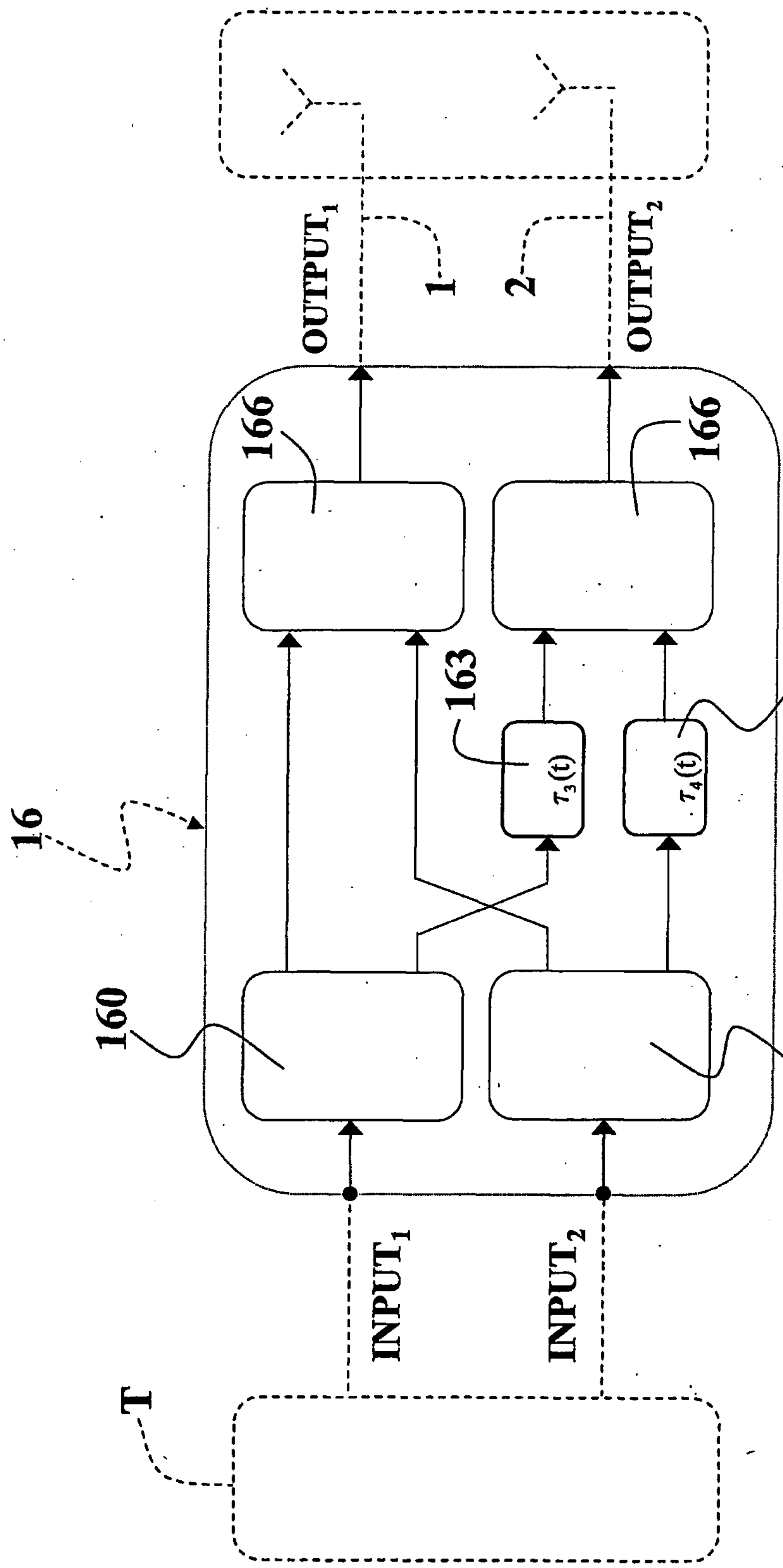

OUTPUT$_1$
OUTPUT$_2$
1
2
166
166
163
164
$\tau_3(t)$
$\tau_4(t)$
16
160
160
INPUT$_1$
INPUT$_2$
T

Fig. 6

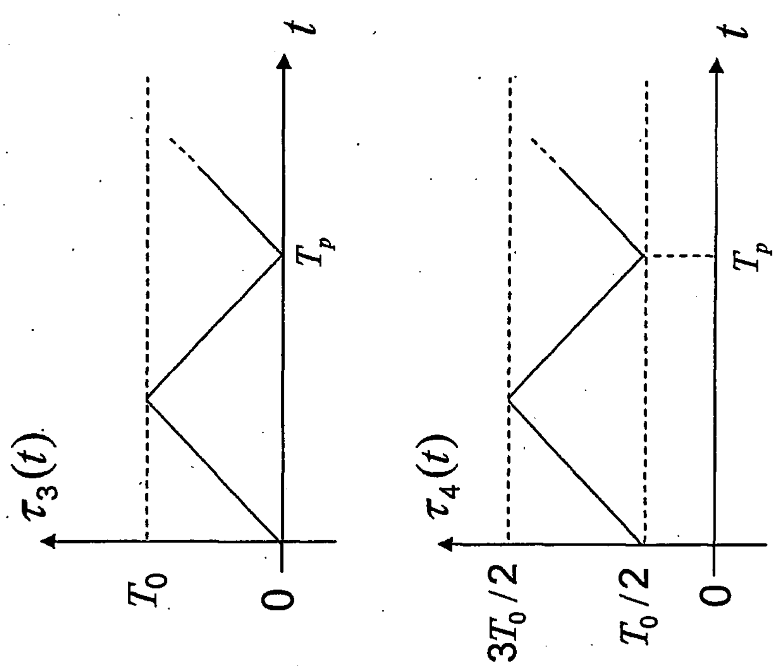


Fig. 7

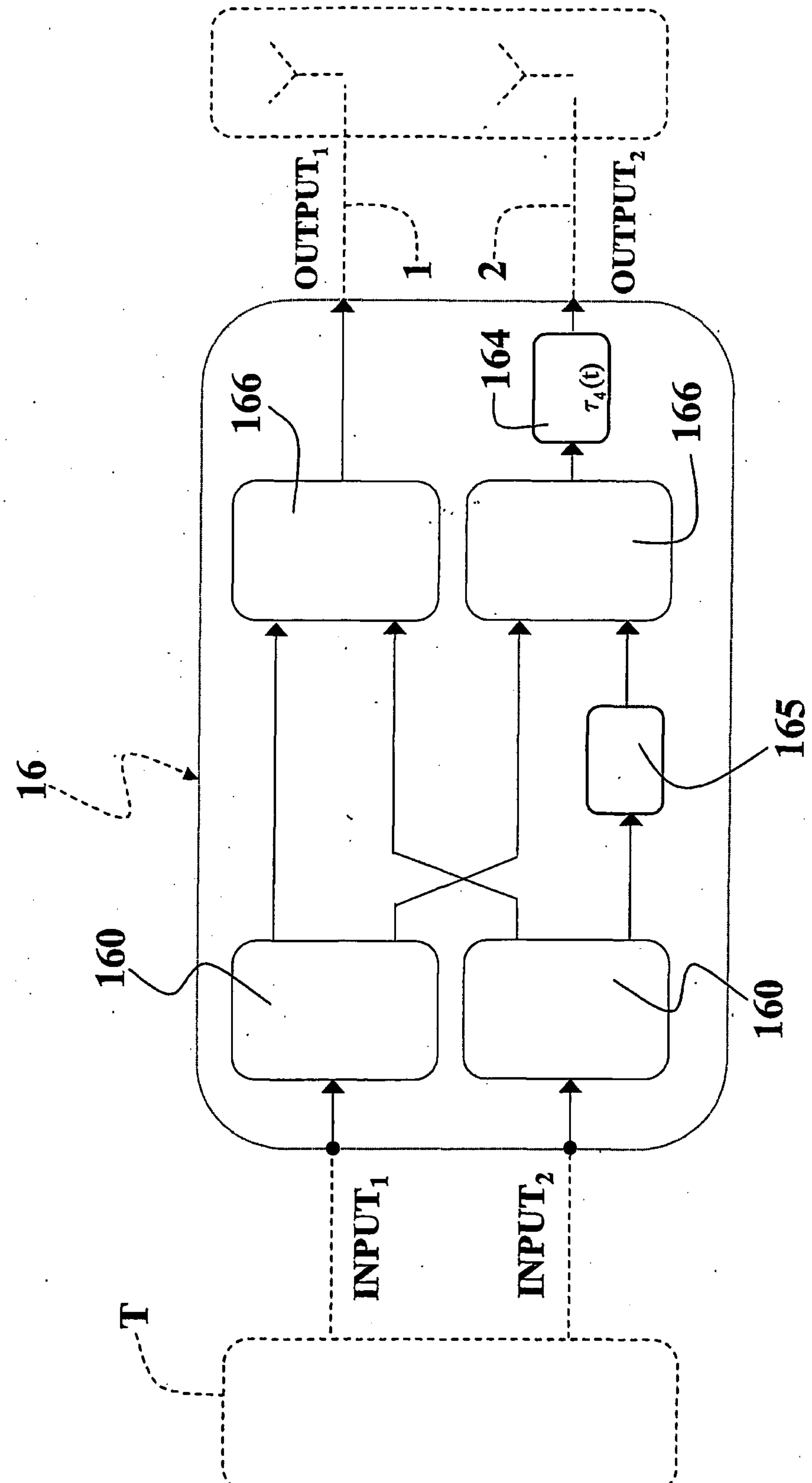
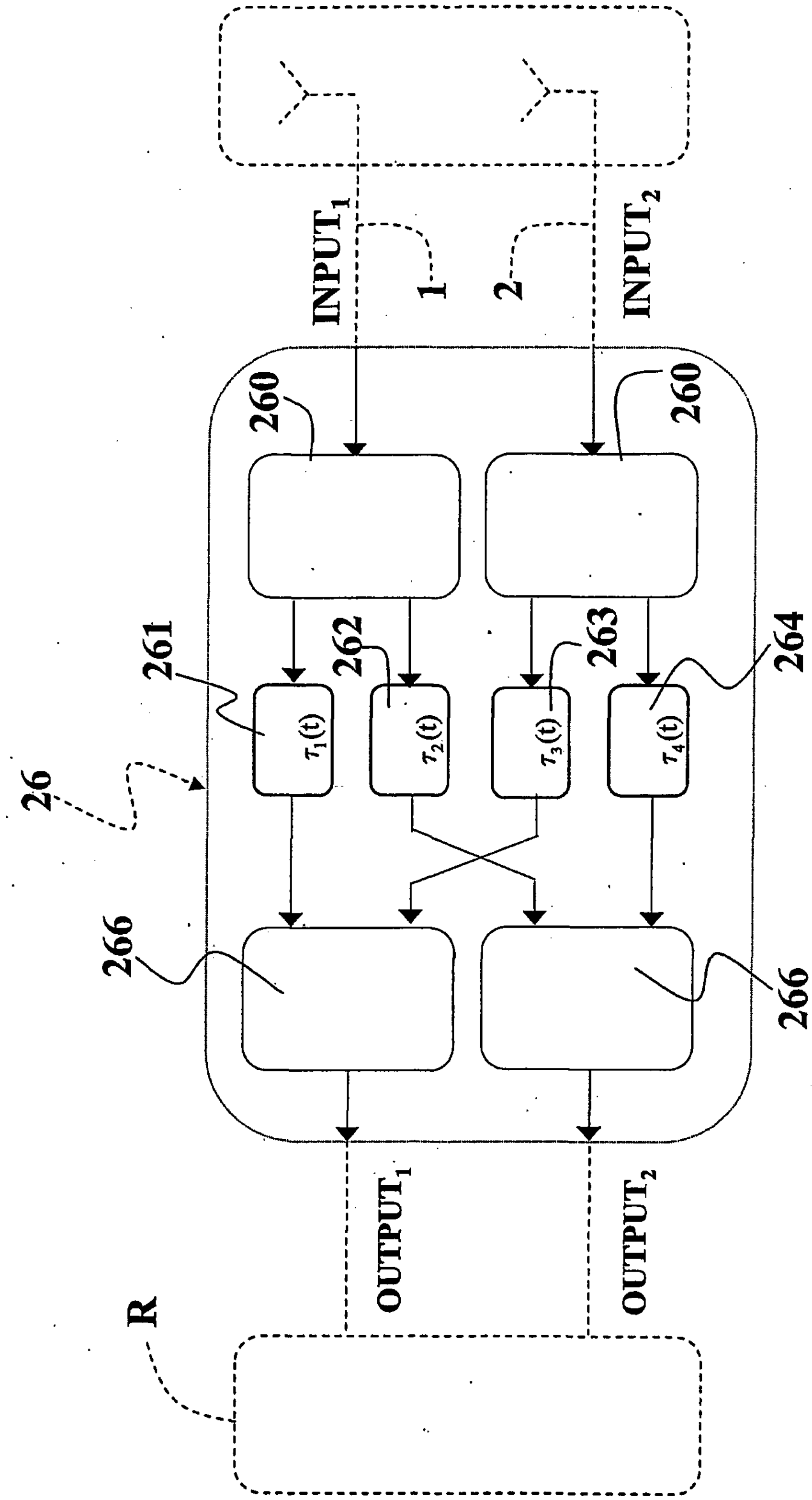

OUTPUT$_1$
OUTPUT$_2$
1
2
166
164
$\tau_4(t)$
166
165
16
160
160
INPUT$_1$
INPUT$_2$
T

Fig. 8



INPUT$_1$
INPUT$_2$
1
2
260
260
261
262
263
264
$\tau_1(t)$
$\tau_2(t)$
$\tau_3(t)$
$\tau_4(t)$
26
266
266
OUTPUT$_1$
OUTPUT$_2$
R

Fig. 9

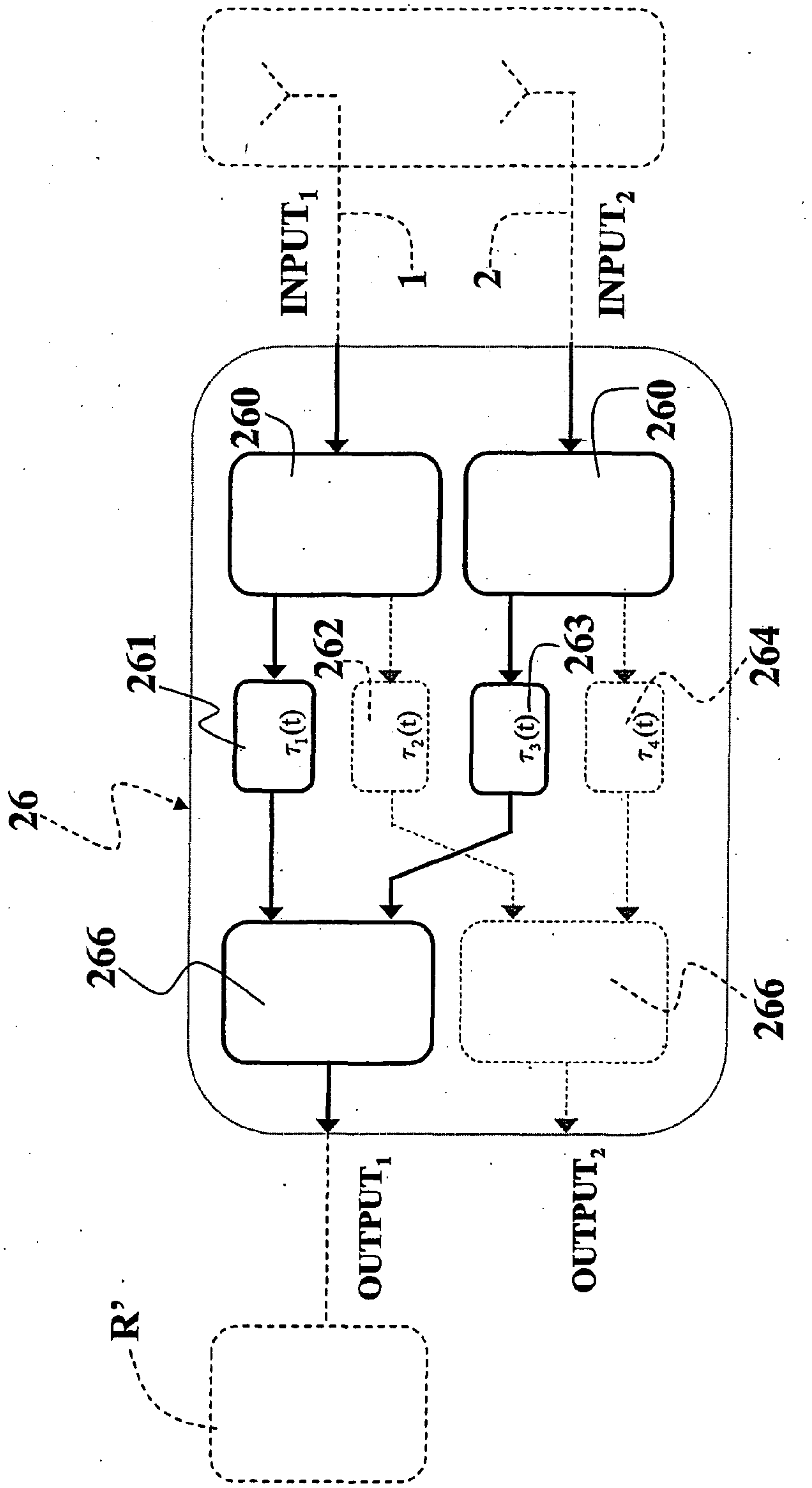

INPUT$_1$
INPUT$_2$
1
2
260
260
261
262
263
264
$\tau_1(t)$
$\tau_2(t)$
$\tau_3(t)$
$\tau_4(t)$
26
266
266
OUTPUT$_1$
OUTPUT$_2$
R'

Fig. 10

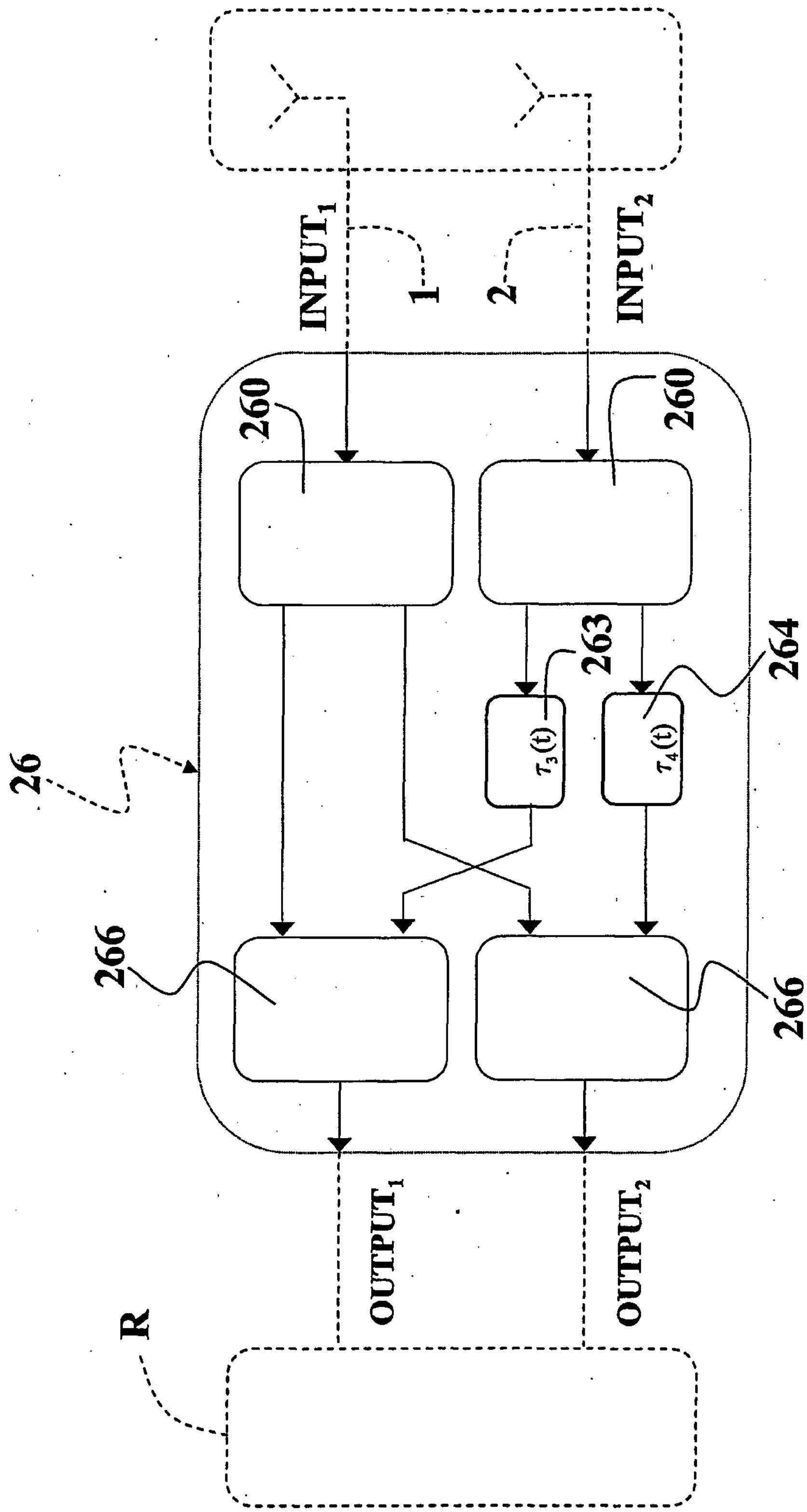

INPUT$_1$
INPUT$_2$
1
2
260
260
263
264
$\tau_3(t)$
$\tau_4(t)$
26
266
266
OUTPUT$_1$
OUTPUT$_2$
R

Fig. 11

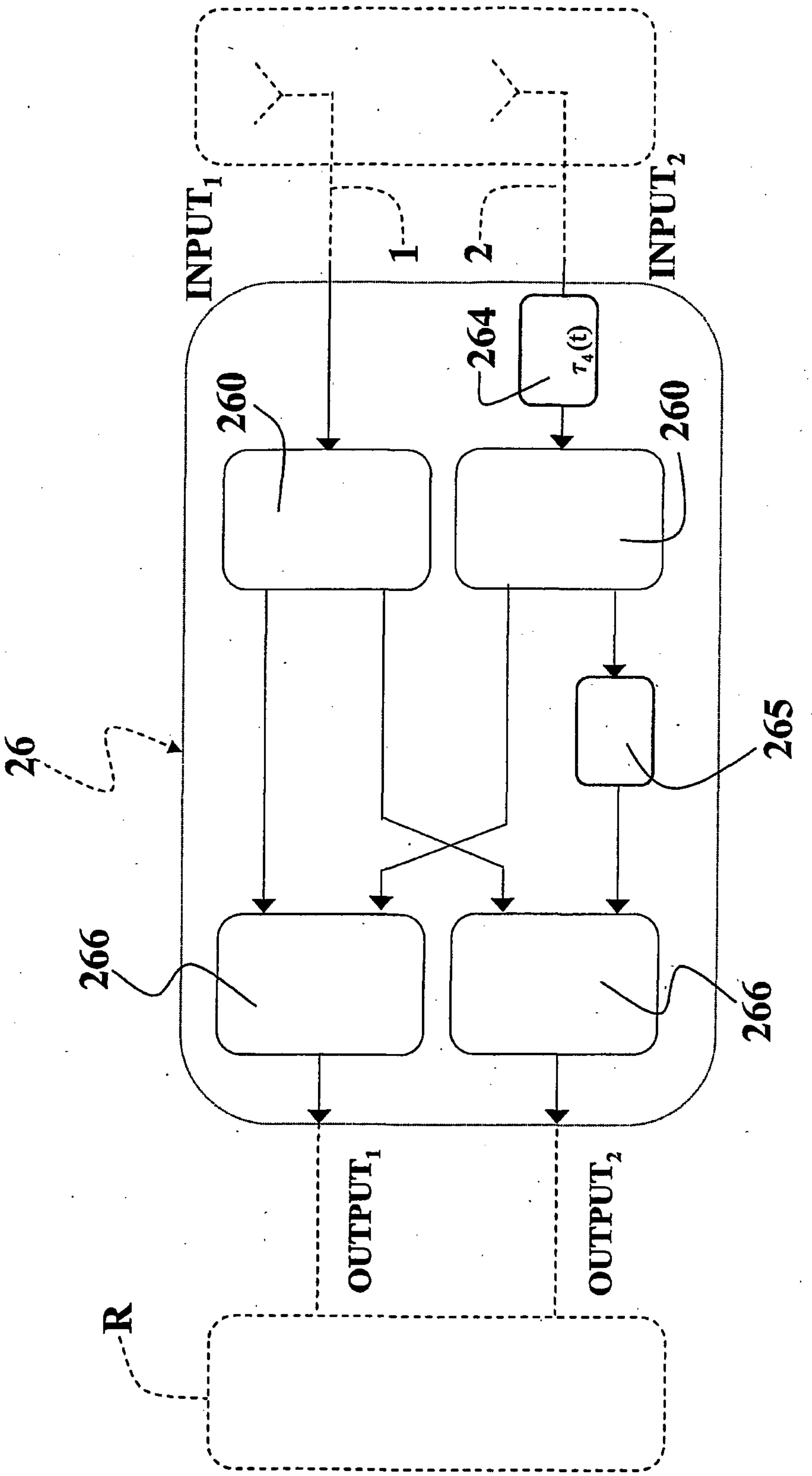

INPUT$_1$
INPUT$_2$
1
2
264
$\tau_4(t)$
260
260
26
265
266
266
OUTPUT$_1$
OUTPUT$_2$
R

Fig. 12

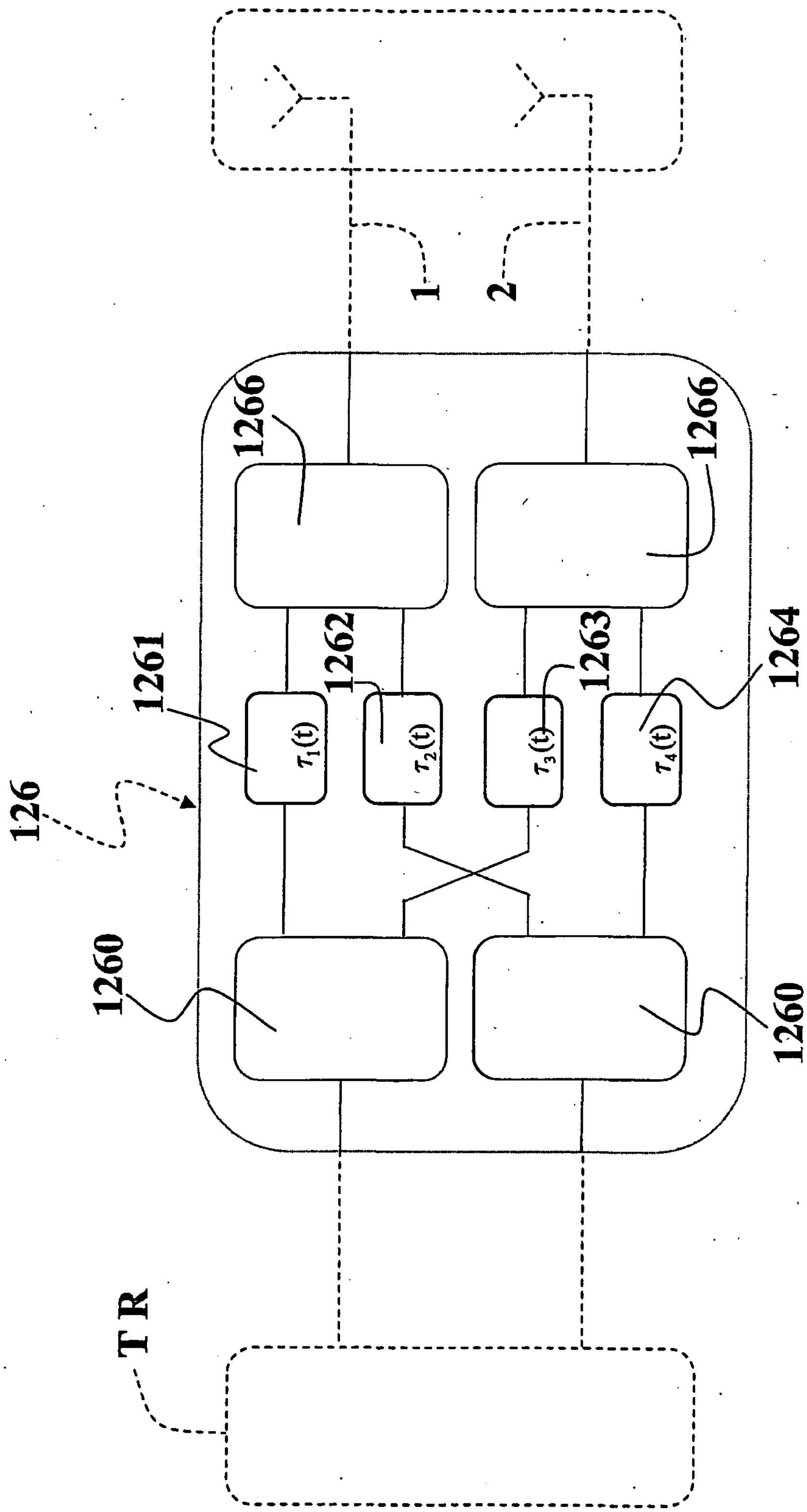

1
2
1266
1266
1261
1262
1263
1264
$\tau_1(t)$
$\tau_2(t)$
$\tau_3(t)$
$\tau_4(t)$
126
1260
1260
T R

Fig. 13

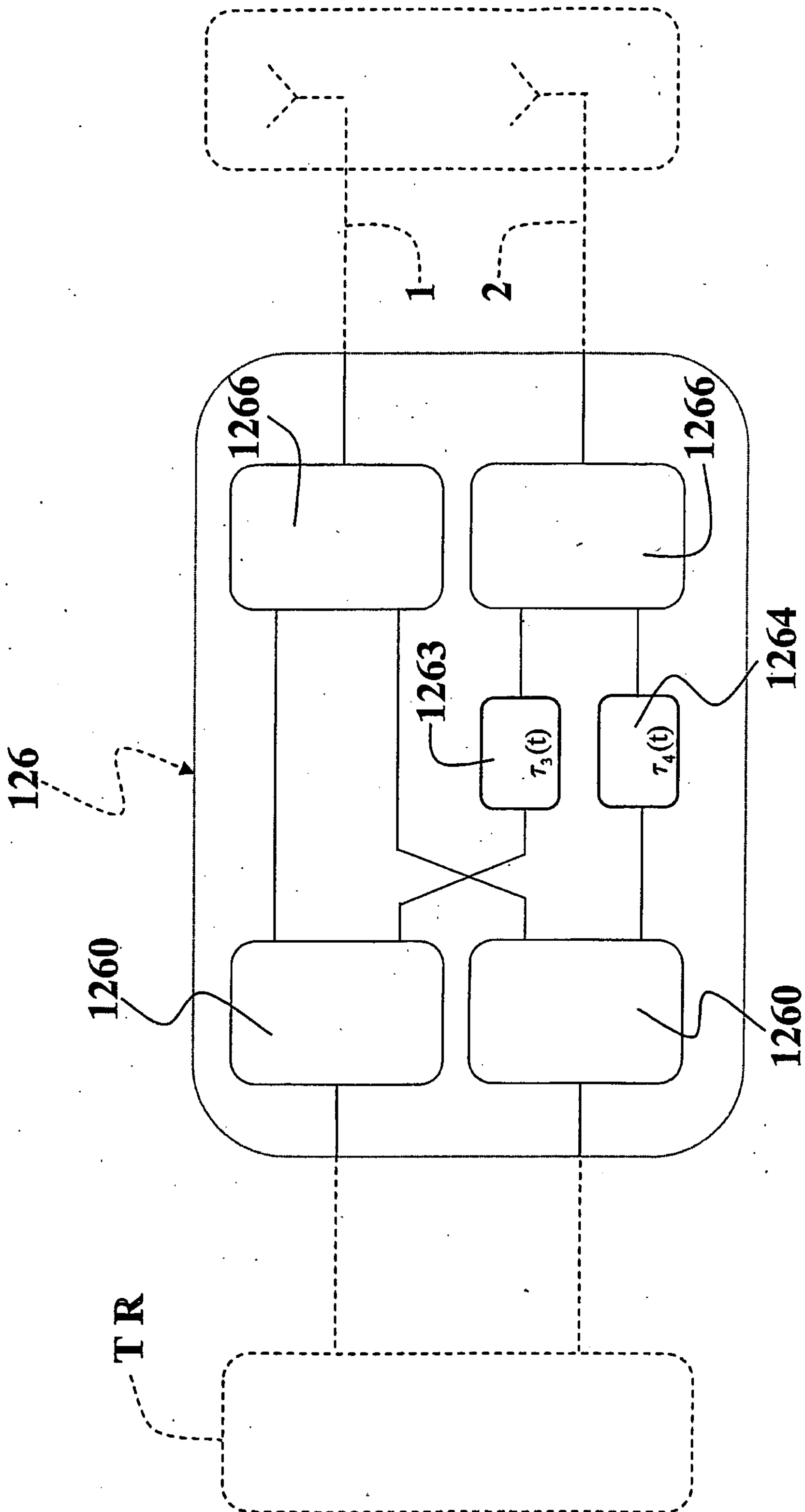


Fig. 14

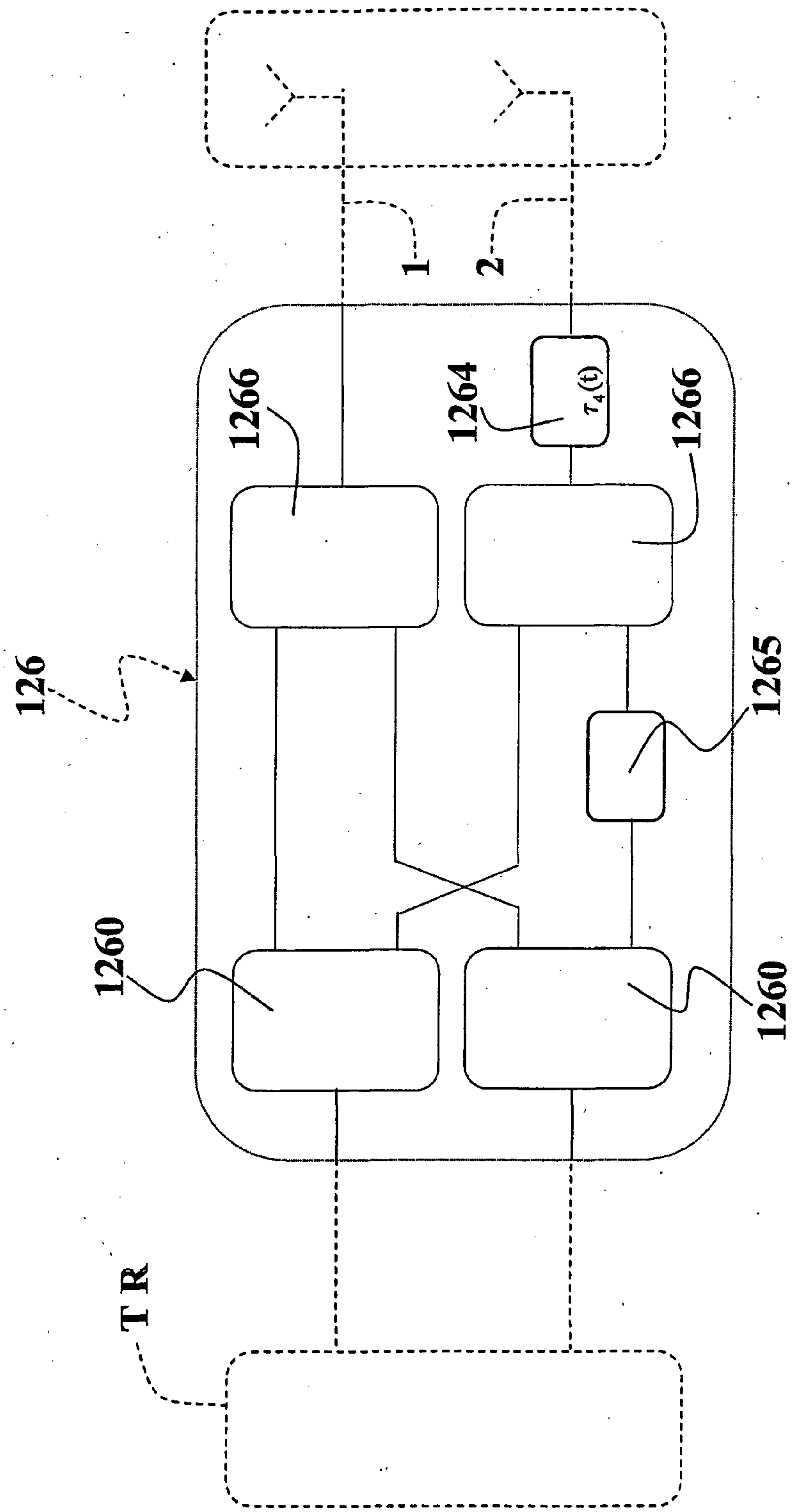


Fig. 15

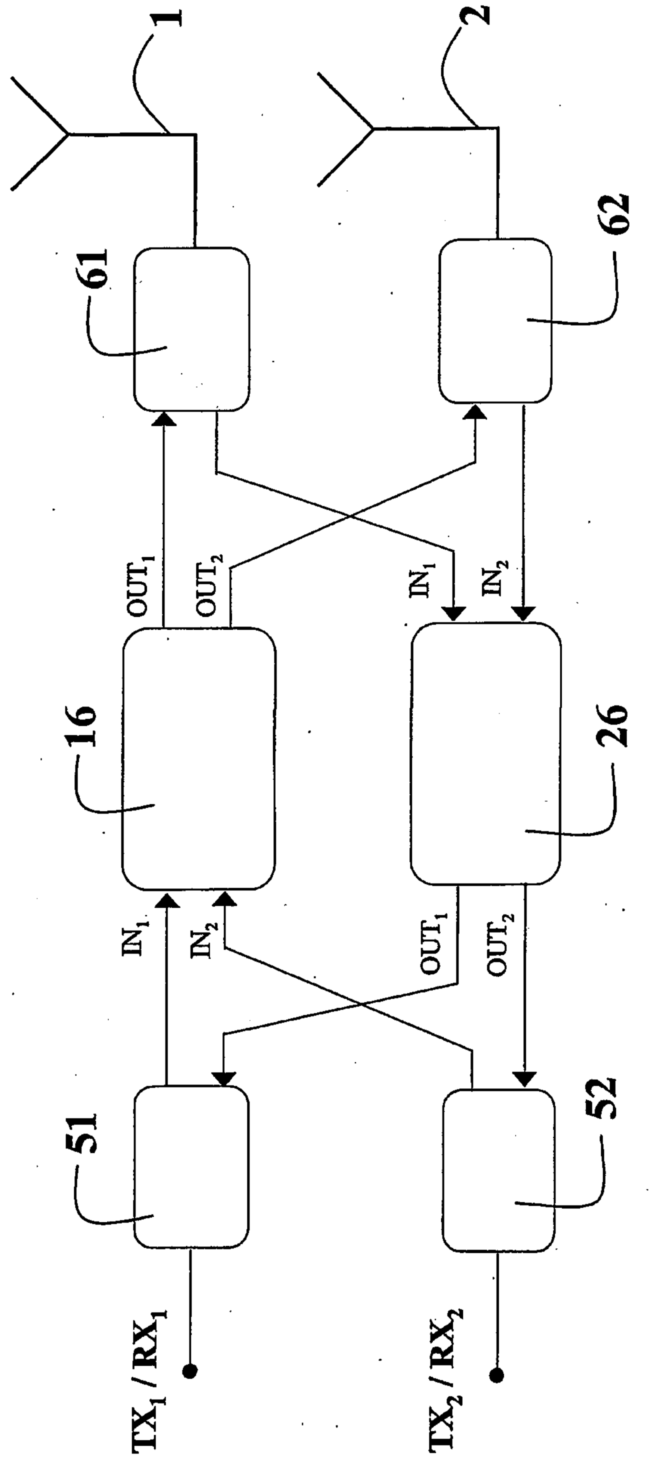

1
2
61
62
OUT$_1$
OUT$_2$
IN$_1$
IN$_2$
16
26
IN$_1$
IN$_2$
OUT$_1$
OUT$_2$
51
52
TX$_1$ / RX$_1$
TX$_2$ / RX$_2$

Fig. 16

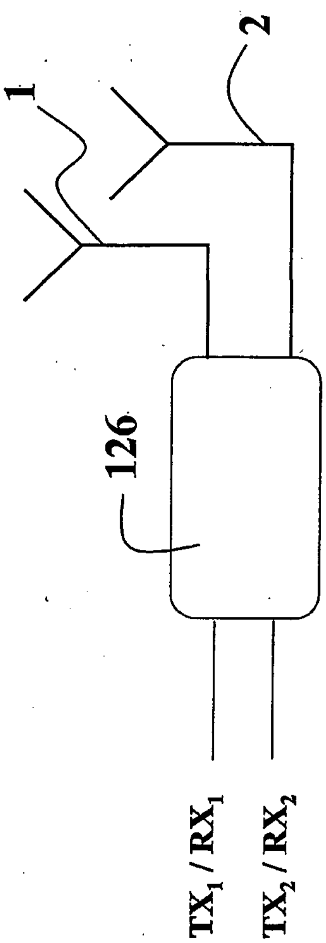


Fig. 17

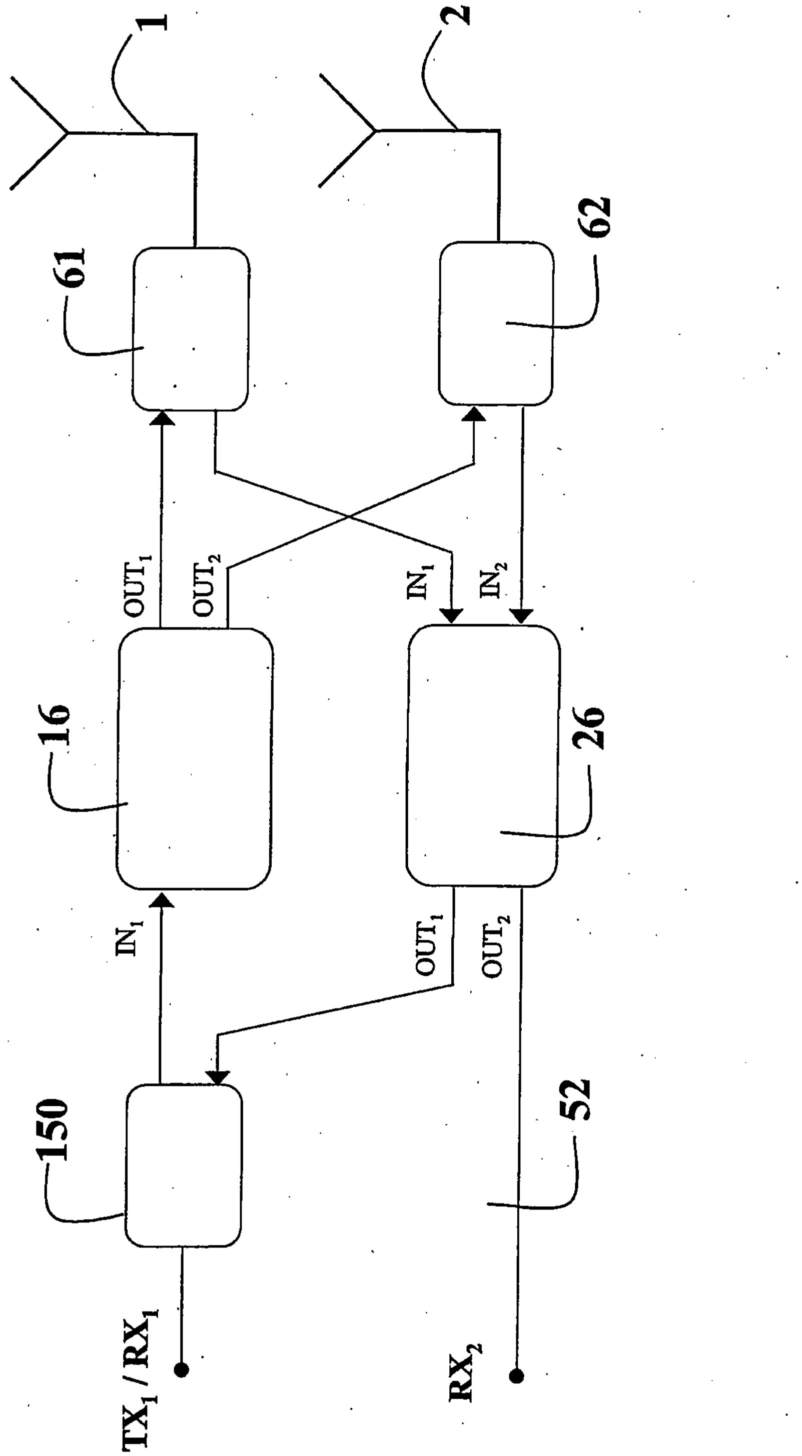


Fig. 18

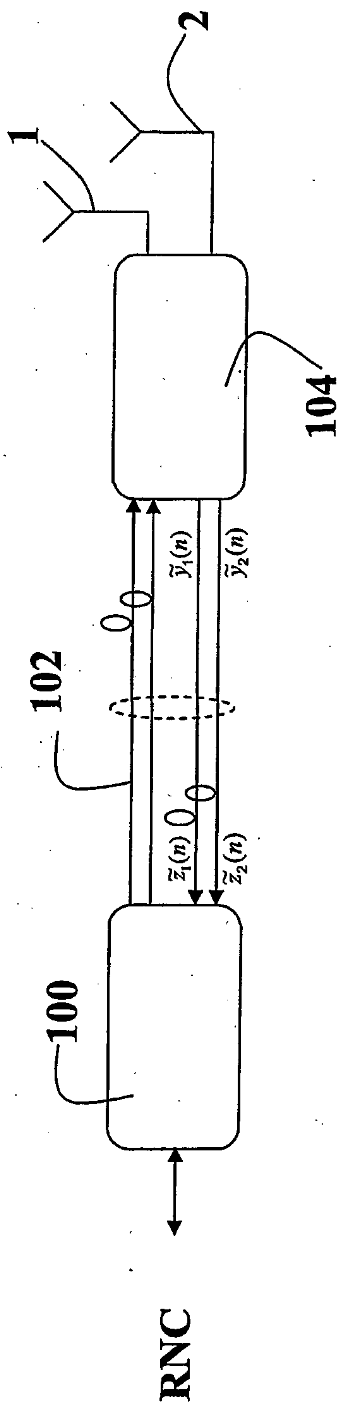


Fig. 19

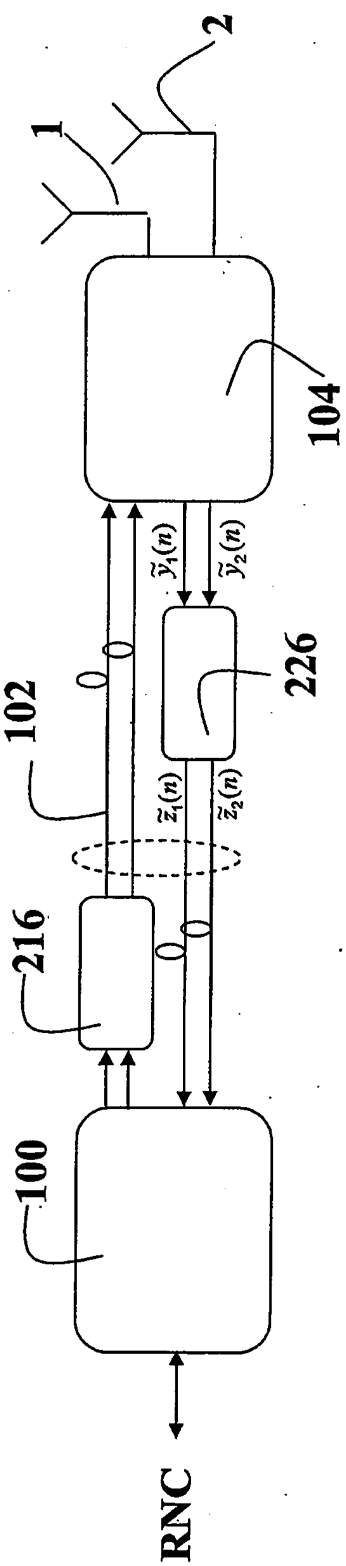

1
2
104
$\tilde{y}_1(n)$
$\tilde{y}_2(n)$
102
226
$\tilde{z}_1(n)$
$\tilde{z}_2(n)$
216
100
RNC

Fig. 20

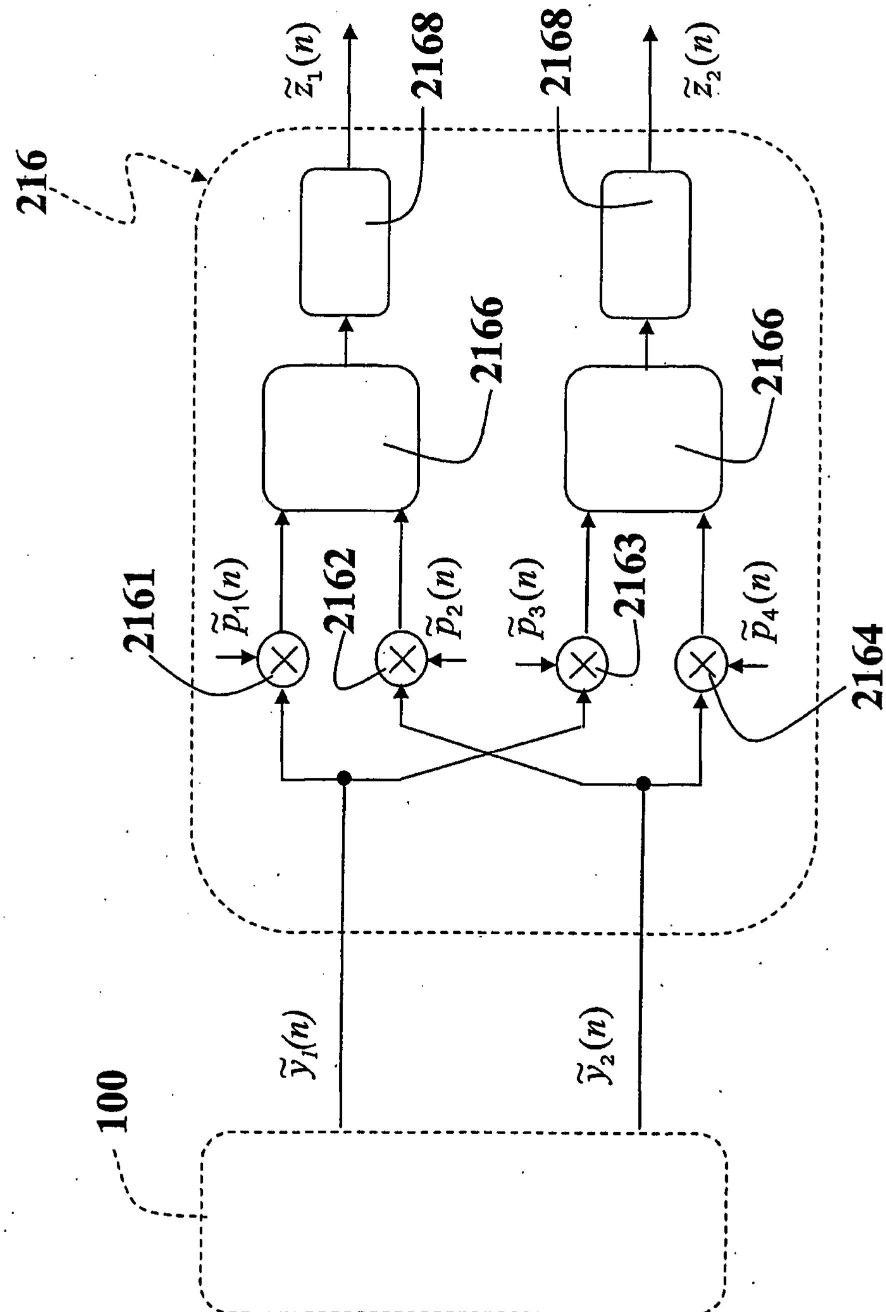

216
2168
2168
$\tilde{z}_1(n)$
$\tilde{z}_2(n)$
2166
2166
2161
2162
2163
2164
$\tilde{p}_1(n)$
$\tilde{p}_2(n)$
$\tilde{p}_3(n)$
$\tilde{p}_4(n)$
$\tilde{y}_1(n)$
$\tilde{y}_2(n)$
100

Fig. 21

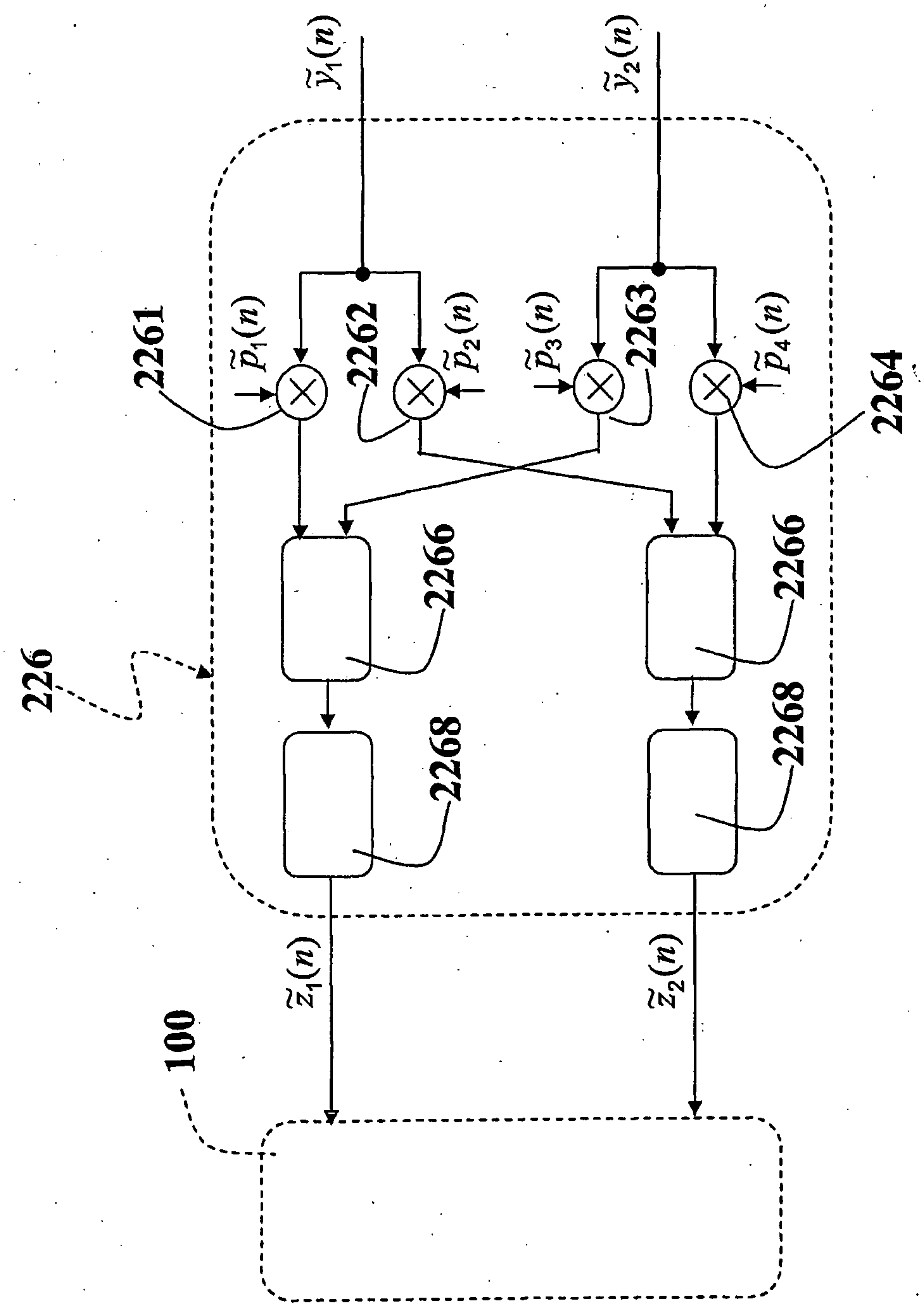

$\tilde{y}_1(n)$
$\tilde{y}_2(n)$
2261
2262
2263
2264
$\tilde{p}_1(n)$
$\tilde{p}_2(n)$
$\tilde{p}_3(n)$
$\tilde{p}_4(n)$
2266
2266
2268
2268
226
$\tilde{z}_1(n)$
$\tilde{z}_2(n)$
100

Fig. 22

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2005/010799

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/06 H04B7/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 259 430 A (* MOTOROLA LIMITED) 10 March 1993 (1993-03-10) abstract page 1, line 15 - page 3, line 18 page 4, line 3 - page 5, line 17 page 7, line 5 - page 9, line 10 claims 1,2,6,12 figures 1,3-5	1-37
X	EP 1 164 718 A (NEC CORPORATION) 19 December 2001 (2001-12-19) abstract paragraphs [0001], [0005] - [0008], [0012] - [0028] figures 1,2,6,7	1-37

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
1 June 2006	14/06/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Fernández Cuenca, B

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 574 989 A (WATSON ET AL) 12 November 1996 (1996-11-12) abstract column 1, line 55 - column 2, line 16 column 2, line 40 - column 4, line 45 figures 1,3	1-37
X	US 4 278 978 A (EASTERLING, MAHLON E ET AL) 14 July 1981 (1981-07-14) abstract column 1, line 55 - column 2, line 48 column 3, line 5 - column 5, line 11 claims 1-3 figures 1,4	22,23
X	US 2005/157683 A1 (YLITALO JUHA ET AL) 21 July 2005 (2005-07-21) paragraphs [0152] - [0157]; figure 26	1-3, 6-15, 22-24,37

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2005/010799

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			CA	2076290	A1	08-03-1993
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			PL	295855	A1	04-05-1993
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			WO	0201732	A2	03-01-2002
			JP	2004502376	T	22-01-2004
			US	2005157684	A1	21-07-2005

PATENT APPLICATION SERIAL NO.________________________

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

04/29/2008 GFREY1 00000057 12084134

01 FC:1631	310.00 OP
02 FC:1633	210.00 OP
03 FC:1642	410.00 OP
04 FC:1615	150.00 OP

PTO-1556
(5/87)

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 May 2007 (03.05.2007)

PCT

(10) International Publication Number
WO 2007/048427 A1

(51) International Patent Classification:
H04B 7/06 (2006.01) *H04B 7/08* (2006.01)

(21) International Application Number: PCT/EP2005/011529

(22) International Filing Date: 27 October 2005 (27.10.2005)

(25) Filing Language: English

(26) Publication Language: English

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(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **MELIS, Bruno** [IT/IT]; Telecom Italia S.p.A., Via G. Reiss Romoli, 274, I-10148 Torino (IT). **RUSCITTO, Alfredo** [IT/IT]; Telecom Italia S.p.A., Via G. Reiss Romoli, 274, I-10148 Torino (IT). **SEMENZATO, Paolo** [IT/IT]; Tim Italia S.p.A., Via del Giorgione, 159, I-00147 Roma (IT). **MELE, Renata** [IT/IT]; Pirelli Labs S.P.A., Viale Sarca 222, I-20126 Milano (IT). **GRASSANO, Giuseppe** [US/US]; Pirelli Labs S.p.A., Viale Sarca, 222, I-20126 Milano (US).

(74) Agents: **GIANNESI, Pier, Giovanni** et al.; Pirelli & C. S.p.A., Viale Sarca, 222, I-20126 Milano (IT).

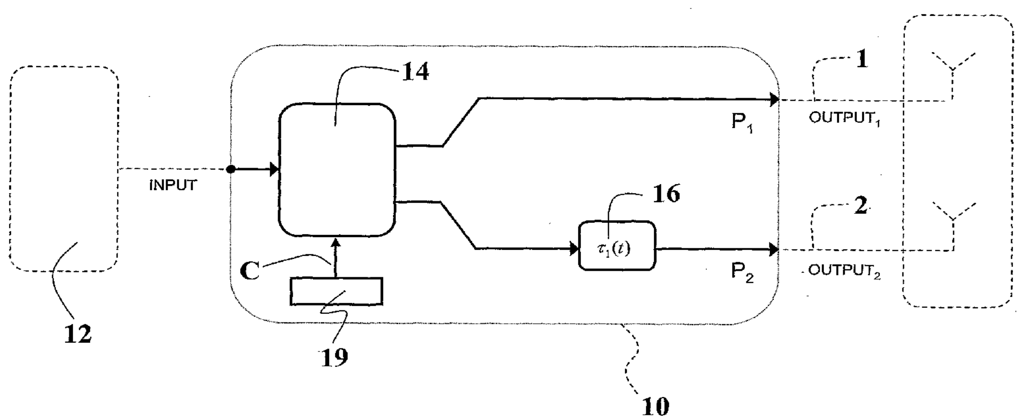
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND SYSTEM FOR MULTIPLE ANTENNA COMMUNICATIONS USING MULTIPLE TRANSMISSION MODES, RELATED APPARATUS AND COMPUTER PROGRAM PRODUCT



(57) Abstract: A system for diversity processing a signal (INPUT) propagated via two diversity antennas (1, 2) includes: respective propagation paths for propagating two replicas of the signal (INPUT), these propagation paths being coupled to the two diversity antennas (1, 2), so that the replicas are propagated via different antennas (1, 2) ; a time variable delay element (16) for subjecting at least one of the replicas to a time variable delay; and a level adjusting element, such as an asymmetric 15 splitter (14) to produce a level imbalance (A) between the power levels of the replicas propagated via the two diversity antennas (1, 2).

WO 2007/048427 A1

"Method and system for multiple antenna communications using multiple transmission modes, related apparatus and computer program product"

* * *

Field of the invention

The present invention relates to wireless communication systems. The invention was developed by paying specific attention to the possible application in radio transmitters and receivers.

Description of the related art

Radio transmitters and receivers used in systems that provide voice and data services by means of multiple transmission mode currently adopt different transmission modes characterized by different transmission parameters such as e.g. the channel coding rate.

Examples of these communication systems are GPRS (General Packet Radio Service), EDGE (Enhanced Data rates for Global Evolution) and HSDPA (High Speed Downlink Packet Access) that has been recently introduced in the UTRA (UMTS Terrestrial Radio Access) Release 5 specifications.

The idea underlying the wireless communication systems listed above is to adapt the transmission parameters in order to take advantage of prevailing channel conditions. The basic parameters adapted typically include channel coding rate and modulation. However, other quantities can be adjusted during communication for the benefit of the system. This adaptive approach, denoted in literature as Link

Adaptation (LA), is now widely recognized as a key solution to increase the spectral efficiency of wireless communication systems.

Figure 1 of the annexed drawing illustrates a set of transmission modes (MCS-1 to MCS-9) suitable for use in an EDGE system. Each mode listed in the left-hand column (Transmisson Mode or TM) is identified by the type of modulation (MOD - i.e. 8 PSK or GMSK) and the channel coding rate (i.e. the ratio of the "useful", payload bits to the total number of bits transmitted - right-hand column CR). The modes are listed in the figure in a decreasing order in terms of the maximum throughput (third column TM) in kbps, whereby MCS-9 and MCS-1 are the first and the last mode in the list, respectively. Since each mode has a different maximum data rate (expressed in bits per second) and robustness level (minimum signal-to noise ratio needed to activate the mode), the modes are optimal for use in different channel quality regions.

The goal of link adaptation is thus always to ensure that the most efficient mode is used, over varying channel conditions, based on a mode selection criterion (maximum data rate, minimum transmit power, and so on). For instance, by considering the example of the EDGE system in Figure 1, the transmission mode denoted as MCS-1 ensures the highest protection of the transmitted information as it uses a low channel coding rate, of about 0.5, and a robust modulation scheme such the GMSK (Gaussian Minimum Shift Keying) modulation. Similarly, the transmission mode denoted as MCS-5 provides a high level of protection of the transmitted information because it uses a channel coding rate of about 0.37 and uses the 8-PSK modulation scheme, which is less robust than the GMSK but is able to provide a throughput three times higher. These two transmission modes are selected under unfavourable channel conditions, as it may occur when the user is located at the cell edge.

On the other hand, the transmission mode denoted as MCS-9 ensures the lowest protection of the information transmitted as it does not use any channel coding scheme and the coding rate is unitary. This transmission mode ensures the highest throughput and is used under very good channel conditions, as for example when the user is located near to the base station.

HSDPA may be considered as a further example of a wireless system that uses multiple transmissions modes with different coding rates and modulations. HDSPA (High Speed Downlink Packet Access) is a new feature introduced in 3GPP Release 5 specifications of UTRA. It includes a wide range of physical layer solutions able to increase user peak data rate and cell throughput, supporting a new downlink shared transport channel. The physical layer solutions include in particular multiple transmission modes characterized by different modulation and coding rates.

The characteristics of some of the HSDPA transmission modes (1 to 22 - column labelled TM) are listed in Figure 2, for the User Equipment (UE) categories 1 to 6, with a number of spreading codes allocated to the High Speed Physical Downlink Shared CHannel (HS-PDSCH) between 1 and 5 (column labelled NC). Modulation (MOD) may be either QPSK (for modes 1 to 15) or 16-QAM (for modes 16 to 22). The modes are listed in increasing order in terms of maximum throughput (MT) in kbps. Here again, the channel coding rate (CR) varies from very low values of about 1/5 to rather high values of about 3/4.

Unless otherwise indicated, the acronyms and abbreviations appearing in Figures 1 and 2 are well known to those of skill in the art, thus making it unnecessary to provide more detailed explanations herein.

Even when using link adaptation techniques, the spectral efficiency of current wireless networks may still be insufficient to satisfy the growing throughput demand by the users, originated by the increased penetration of new data services. Moreover, these new data services are likely to be used in - potentially adverse - low mobility conditions by still or walking users in indoor or pedestrian scenarios.

Antenna diversity is a technique that can be used to improve spectral efficiency and to reduce the negative effects of prolonged multi-path fading in wireless systems. In diversity transmission (and, similarly, in diversity reception), two or more physically separated antennas (space diversity) or one or more cross-polarized antenna (polarization diversity) are respectively used to transmit or receive a given signal. By placing the antennas at a sufficient distance or by using a +/-45 degrees slant cross-polarized antennas it is possible minimize the amplitude correlation of the signals transmitted or received by the different antennas. In practice, the physical separation between the antennas is limited due to size or environmental constraints and thus the signals can have a significant amplitude correlation. A significant signal correlation can also be present in the signals transmitted or received through cross polarized antennas, in particular when the vertical to horizontal polarization power ratio, also referred to as cross-polar discrimination (XPD), takes high values.

The arrangement described in the article of A. Wittneben "A New Bandwidth Efficient Transmit Antenna Modulation Diversity Scheme for Linear Digital Modulation", ICC Conference - pages 1630-1634, Geneva, May 1993 is exemplary of antenna diversity including a fixed delay diversity (DD) between antennas.

Another fixed DD receiver arrangement is described in US-A-5 930 293. This document describes the application of the fixed DD technique for achieving antenna receive diversity in a wireless repeater. The repeater is equipped with two receiving antennas for receiving a signal from a wireless terminal. The signal received from one of the antennas is subject to a fixed delay and is recombined at RF with the other received signal. The combined signal is subsequently transmitted to the base station by means of a third antenna. The fixed delay is chosen at least equal to two chip periods in order to enable the Rake receivers in the base station to resolve and coherently combine the two signals.

The document WO-A-03/055097 describes a method for providing Phase Shift Transmit Diversity (PSTD) in a wireless communication system. A base station modulates the phase of a first signal with a reference signal to produce a first phase modulated signal. Further, the base station modulates the phase of a second signal with a different reference signal to produce a second phase modulated signal. The second phase shift is distinct from the first phase shift such that the second phase modulated signal is diverse relative to the first phase modulated signal. Accordingly, the base station transmits the first phase modulated signal via a first antenna and the second phase modulated signal via a second antenna to a plurality of mobile stations.

PCT Applications PCT/EP2004/011204 and PCT/EP2005/010799 disclose antenna diversity techniques that improve radio link performance by reducing the temporal autocorrelation of the signals transmitted/received in low mobility scenarios and also minimize the cross-correlation among the signals received by the different antennas. These arrangements are applicable in wireless systems that have already been standardized, with minimal modifications on the deployed equipments and networks.

These antenna diversity arrangements essentially rely on Dynamic Delay Diversity (DDD), i.e. a time variable delay diversity. These DDD techniques introduce a time variable delay on the signals transmitted and/or received by the different antennas. The delay required to make the technique effective is significantly smaller when compared to other diversity techniques. In general, the required delay varies between zero and the period of the RF (carrier) signal T_0. Because of the low value of delay to be introduced, the implementation problems related to size, cost and transmission losses of the delay line, are significantly reduced in case of the DDD technique with respect to other antenna diversity techniques such fixed Delay Diversity (fixed DD). The DDD technique also dispenses with certain problems that are intrinsic to Phase Shift Transmit Diversity (PSTD) techniques, such as e.g. high insertion loss and non-linearity of RF phase shifter devices.

These systems lead to significant improvements in terms of link level performance in slow fading scenarios and for wireless systems that use robust channel coding techniques with coding rates lower or equal to 1/2.

Object and summary of the invention

Despite the significant improvement represented by the Dynamic Delay Diversity techniques discussed in the foregoing, the need is still felt for a diversity technique that may be advantageously applied in those wireless systems as those discussed in the introductory part of this description, namely those system that use multiple transmission modes and are characterized by different channel coding rates ranging from one (unencoded transmission) to low values (e.g. $\leq 1/2$) obtained with powerful coding schemes.

The object of the present invention is thus to provide an arrangement suitable for application in those communication systems that adapt to varying channel conditions by using different transmission modes. A specific object of the present invention is to provide an arrangement that, in the case of uncoded (e.g. EDGE mode MCS-9) or near-to-uncoded transmission, avoids that the distribution of the errors over the received data stream may cause an increase of the Block Error Rate (BLER) and thus a reduction of the user data rate.

According to the present invention, that object is achieved by means of a method having the features set forth in the claims that follow. The invention also relates to a corresponding system, a related apparatus as well as a related computer program product, loadable in the memory of at least one computer and including software code portions for performing the steps of the method of the invention when the product is run on a computer. As used herein, reference to such a computer program product is intended to be equivalent to reference to a computer-readable medium containing instructions for controlling a computer system to coordinate the performance of the method of the invention. Reference to "at least one computer" is evidently intended to highlight the possibility for the present invention to be implemented in a distributed/ modular fashion. The claims are an integral part of the disclosure of the invention provided herein.

A preferred embodiment of the invention is thus a method of diversity processing at least one signal propagated (i.e. transmitted and/or received) via at least two diversity antennas, the method including the steps of:

- propagating at least two replicas of said at least one signal over respective propagation (i.e. transmission and/or reception) paths coupled to said at least two diversity antennas, whereby said replicas are propagated via different antennas;

- subjecting at least one of said replicas to a time variable delay; and

- adjusting the power levels of said at least two replicas (e.g. via asymmetric splitters and/or combiners and/or or by applying different gains/attenuations over the respective propagation paths) to produce a level imbalance therebetween.

The arrangement described herein thus comprises a new method and a related circuit for the application of a Dynamic Delay Diversity (DDD) technique. The method and DDD circuit described herein are suitable for application in communication systems that adapt to varying channel conditions by using different transmission modes. The transmission modes are typically characterized by channel coding rates variable from 1 (unencoded transmission) to very low values (e.g. 1/3 or 1/5) obtained with powerful coding schemes.

Typically, the arrangement described herein is applied to at least one signal transmitted by selectively using one of a plurality of transmission modes (e.g. MCS-1 to MCS-9; 1 to 22, as discussed previously) and said level imbalance is selected as a function of the transmission modes used, e.g. by using the level imbalance/difference giving the best results in connection with the transmission mode having the highest probability of being used. In the case where the transmission mode used is varied during transmission (e.g. to cope with varying channel characteristics) the level imbalance can be adaptively varied as a function of the current transmission mode used.

GPRS, EDGE, HSDPA (i.e. UMTS), and HDR (i.e. CDMA-2000) are exemplary of wireless systems that represent a possible field of application of the arrangement described herein. However, other wireless communication systems that use multiple transmission modes with large variation of the channel coding rates represent a possible field of application for the arrangement described herein.

A preferred field of application of the arrangement described herein is in multi-carrier cell sites, in which the available carrier frequencies are divided among different transmission systems such GSM and GPRS/EDGE providing voice and packet data services respectively.

Brief description of the annexed representations

The invention will now be described, by way of non-limiting example only, with reference to the annexed representations, wherein:

- Figures 1 and 2 have been already described in the foregoing;

- Figure 3 includes two portions, designated 3a and 3b, representative of the general context of application of the arrangement described herein within a transmitter and a receiver, respectively;

- Figure 4 again includes two portions, designated 4a and 4b, that are exemplary of the basic characteristics of certain components included in the arrangement described herein;

- Figures 5 and 6 are schematic block diagrams of possible embodiments of a diversity arrangement as described herein when applied on the transmitter side;

- Figure 7 includes two portions, designated 7a and 7b, that are exemplary of the basic characteristics of certain components included in the arrangement described herein;

- Figure 8 is a diagram representative of a parameter involved in operation of the arrangement described herein;

- Figure 9 is a functional block diagram representative of the basic principle underlying operation of the diversity arrangement as described herein;

- Figures 10 to 14 are diagrams illustrative of the results that may be achieved by using a diversity arrangement as described herein;

- Figures 15 and 16 are schematic block diagrams of possible embodiments of a diversity arrangement as described herein when applied on the receiver side; and

- Figures 17 to 27 are block diagrams that illustrate various system architectures involving diversity arrangements as described herein.

Detailed description of exemplary embodiments of the invention

As indicated in the foregoing, the diversity arrangement described herein relies on the introduction of a time variant delay on the signals transmitted and/or received by the different antennas. Typically the delay is significantly smaller when compared to other diversity techniques. In general, if RF or IF signals modulated over a carrier are being processed according to the diversity arrangement described herein, the delay applied varies between zero and the period T_0 of the carrier signal.

For example, the application of the technique described herein in a base station transceiver compliant with the GPRS/EDGE standard involves the introduction of a delay that varies between zero and the carrier period T_0 =1/890 MHz = 1.1 nanoseconds. More generally, the delays typically considered for the arrangement described herein vary between zero and values in the range between tenths of nanoseconds (ns) and units of nanoseconds (ns).

The technique is realized by means of a diversity processor 10 (transmission or TX) that is connected at the output of a conventional transmitter 12, as shown in Figure 3a, or a diversity processor 20 (reception or RX) that is connected at the input of a conventional receiver 22 as shown in Figure 3b.

Specifically, in figures 3a and 3b digital signals (e.g. Layer 2 data in a mobile communication system - not shown as a whole) are transmitted (figure 3a) or received (figure 3b) via two diversity antennas 1 and

2. The transmitter 12 and the receiver 22 include otherwise conventional circuitry such as e.g. baseband processors, digital-to-analog (DAC) and analog-to-digital (ADC) converters, IF/RF transmitters/receivers, and so on. At least some of the embodiments detailed in the following relate to diversity processors that are "reciprocal" in that they may act both on signals being transmitted and on signals being received via the antennas 1, 2. These reciprocal arrangements will thus be in a position to be connected to and to cooperate with (in an otherwise known manner) with a "transceiver" that combines a transmitter 12 and a receiver 22.

In the following, various alternative implementations of diversity processors exploiting the principle of Dynamic Delay Diversity DDD are described. These will be generally denoted DDD TX processors (transmit diversity) or DDD RX processors (receive diversity). In the various specific embodiments considered, these TX or RX (or TX/RX, in the case of "reciprocal" embodiments) diversity processors will include various elements or components such as signal splitters, combiners, Time Variant Delay Lines (TVDL), Power Amplifiers (PA), Low Noise Amplifiers (LNA), etc. Unless otherwise specified, these elements are substantially the same in the various embodiments; these embodiments thus essentially differ in the number, type and way the various elementary blocks are combined to produce different structures of a diversity processor.

As better detailed in the following, the time varying delay required can be obtained using a delay line based on a waveguide or a microstrip device. Both devices, obtained using standard technologies as in commercial devices, are limited in power handling, where the limiting values are presently in the range of 33 - 35 dBm. This is not an issue for receive diversity applications, but might represent a limiting factor for transmission diversity applications: in several cases, in particular in the case of macro base station (for both 2G and 3G), this limiting value may not be compatible with the typical value of the transmitted power.

However, the asymmetric DDD TX processors described here involve i.a. an asymmetric splitting of the power transmitted. The power level associated to the signal replica(s) subjected to the time varying delay may thus be reduced, which largely facilitates the implementation of several architectures proposed in the following by using commercial devices.

In the following description, the designation signal splitter - see figure 4a - will apply to any device capable of splitting (i.e. dividing) an input signal S_{in} in two parts or replicas.

Such a splitter may either be:

- a symmetric splitter (see figure 4a – left hand side), capable of splitting (i.e. dividing) an input signal S_{in} in two parts or replicas α. S_{in} having the same power level; or

- an asymmetric splitter (see figure 4a – right hand side), capable of splitting an input signal S_{in} in two parts or replicas α_1. S_{in} and α_2. S_{in}, with α_1 different from α_2, having different power levels.

Similarly, the designation signal combiner - see figure 4b - will apply to any device capable of combining (i.e. adding) two parts or replicas $S_{in,1}$, $S_{in,2}$ of a given signal S_{in}.

Such a combiner may either be:

- a symmetric combiner (see figure 4b - left hand side), capable of combining (i.e. adding) two parts or replicas $S_{in,1}$, $S_{in,2}$ by applying to both the same "weights" α, to produce a combined signal $S_{in} = \alpha . S_{in,1} + \alpha . S_{in,2}$ or $S_{in} = \alpha(S_{in,1} + S_{in,2})$; or

- an asymmetric combiner (see figure 4b - right hand side), capable of combining (i.e. adding) the two parts or replicas $S_{in,1}$, $S_{in,2}$ by applying to them different "weights" α_1, α_2, with α_1 different from α_2, to produce a combined signals $S_{in} = \alpha_1 . S_{in,1} + \alpha_2 . S_{in,2}$.

Practical implementations of splitters/dividers - both symmetric and asymmetric - also for RF/IF operation, are conventional in the art and do not require to be described in detail here. A splitter implemented with passive components (e.g. as a resistor voltage divider) will generally be reciprocal, in that it will act as a combiner for the signals that propagate in the opposite direction. This characteristic is exploited in the reciprocal DDD processors described in the following, which can be used simultaneously for transmission and reception.

The right hand side portions of figures 4a and 4b highlight the possibility for an asymmetric splitter/combiner to include a control line C whereby the factors/weights α_1 and α_2 can be changed to correspondingly vary the difference/imbalance Δ. As better detailed in the following, these factors/weights may be adjusted as a function of a transmission mode used e.g. by selecting the level imbalance/difference giving the best results in connection with the transmission mode having the highest probability of being used. Alternatively these factors/weights may be adaptively varied during transmission as a function of the current transmission mode used.

A first architecture of a DDD TX processor 10 is shown in Figure 5. This processor is suitable for application with conventional transmitters 12 that do not support any form of transmission antenna diversity. Thus, in this case the conventional transmitter provides a single output signal. The DDD TX processor 10 includes an asymmetric splitter 14 that divides the input signal in two parts or replicas. The powers of the signals at the output of the asymmetric splitter are different.

The power imbalance or difference thus created between the two signals to be transmitted via the diversity antennas 1 and 2 is a design parameter that allows the application of the DDD processor in wireless systems that use multiple transmission modes with different coding rates.

Specifically, by denoting with P_1 and P_2 the powers radiated by the two antennas, the DDD power imbalance Δ (in dB) is defined as follows

$$\Delta = 10 \cdot \log_{10}\left(\frac{P_1}{P_2}\right) \qquad [\mathrm{dB}] \qquad (1)$$

The first signal with power P_1 is propagated (i.e. radiated) by the first antenna 1. The second signal with power P_2 is provided to a Time Variant Delay Line (TVDL) 16 that introduces a time variant delay $\tau_1(t)$ on the signal radiated by the second antenna 2.

By denoting with $x(t)$ the signal at the output of the conventional transmitter, the two transmitted signal $y_1(t)$ and $y_2(t)$ can be expressed as follows

$$y_1(t) = \alpha_1 \cdot x(t)$$
$$y_2(t) = \alpha_2 \cdot x(t - \tau_1(t)) \qquad (2)$$

where the amplitude coefficients α_1 and α_2 depend on the characteristic of the asymmetric splitter.

These coefficients may be possibly varied via the line C. This may either be in the form of a "*una tantum*" trimming of the system or in the form of automatic adjustment under the control of a block 19 sensitive to the current transmission mode used (e.g. any of the modes MCS-1 to MCS-9 or 1 to 22 contemplated in figures 1 and 2).

A power imbalance between the signals transmitted by the two antennas 1, 2 can also be obtained by resorting to the alternative arrangement illustrated in figure 6, where the same reference numerals already appearing in figure 5 are used to denote identical/equivalent components to those already described.

In the arrangement of figure 6, the splitter 14 is a symmetric splitter and two power amplifiers (PA) 14a and 14b with different gains G_1 and G_2 are inserted in the propagations paths of the two replicas of the signal produced by the splitter 14 towards the antennas 1, 2.

The symmetric splitter 14 provides in this case two output signals with the same power. The power imbalance or difference between the two signals to be transmitted via the diversity antennas 1 and 2 is thus produced by acting on the two gains G_1 and G_2 of the amplifiers 14a and 14b. The power imbalance or difference thus created allows the application of the DDD processor in wireless systems that use multiple transmission modes with different coding rates. Here again, a first signal with a first power level is propagated (i.e. radiated) by the first antenna 1, and the second signal with a second power level is processed (preferably before amplification at 14b) to a Time Variant Delay Line (TVDL) 16 that introduces a time variant delay $\tau_1(t)$ on the signal radiated by the second antenna 2.

The amplitude coefficients α_1 and α_2 of the formulas introduced in the foregoing are here dictated by the gains G_1 and G_2 of the amplifiers 14a and 14b. These gains/coefficients may again be possibly varied via respective control inputs C. This may be in the form of trimming of the system or in the form of automatic adjustment under the control of the block 19.

The architecture illustrated in figure 6 has the advantage that the delay element 16 can be realized with low power handling components.

The DDD TX processor architecture illustrated in Figure 6 is particularly adapted for communication networks that use Remote Radio Head (RRH) units. A RRH is a compact unit that is mounted near the antenna and integrates several base station functions for transmission and reception. The transmission functions that are typically integrated in the RRH unit are digital to analog conversion (DAC), frequency up-conversion, digital pre-distortion and MCPA (Multi Carrier Power Amplifier). The receiving functions that are integrated in the RRH are the RF front-end, frequency down-conversion and analog to digital conversion (ADC).

The RRH unit is fed from the remainder of the base station with baseband (I/Q) signals via optical fibre cables. The interface between the RRH and the baseband modem is normally compliant with the Common Public Radio Interface (CPRI) standard or with the interface defined by the OBSAI (Open Base Station Standard Initiative) forum. The baseband modem can be relocated from a cabinet near to the antenna to a remote location with clear benefits in terms of deployment costs and network management.

Figure 7a shows a first exemplary implementation of the time variable delay line 16 (and any other time variable delay line referred to in the rest of this description) in the form of a tapped delay line, namely as the cascade of elementary delay units. Each of such delay unit (e.g. a transmission line stub) generates for example a delay T_D of 0.1 ns. The various tap points in the line come down to a RF switch 18. The switch is controlled by a delay control unit (DCU) making it possible to select a particular tap of the tapped delay line and therefore a given value of the delay introduced by the block. Changing the position of the switch 18 makes it possible to change the value of the delay.

Figure 7b shows a second exemplary implementation of the time variable delay line 16 (and any other time variable delay line referred to in the rest of this description) in the form of a plurality of delay elements (these may again be comprised of transmission line stubs) each producing for example a respective delay of TD1 = 0.1 ns., TD2 = 0.2 ns., TD3 = 0.3 ns., and so on. Two switches 181, 182 are controlled in a coordinated manner by the delay control unit (DCU) making it possible to select a particular delay element and therefore a given value of the delay introduced by the block. Changing the position of the switches 181, 182 makes it possible to change the value of the delay.

As an alternative to varying the delay in discrete steps, as shown in connection with the exemplary embodiments of Figure 7a and Figure 7b, in other possible implementations (not shown) of the delay line/element the delay is caused to vary continuously. A possible implementation of the delay line with continuous variation of the introduced delay can be found in the article "Time Delay Phase Shifter Controlled by Piezoelectric Transducer on Coplanar Waveguide", IEEE Microwave and Wireless Components Letters, Vol. 13, No. 1, pag. 19-20, January 2003. In particular, the continuous delay line may be implemented by inserting on a coplanar waveguide a piezoelectric transducer whose perturbations vary the effective dielectric constant of the coplanar waveguide.

The delay function $\tau_1(t)$, according to which the delay varies as a function of time, is not restricted to particular functions and can be a continuous function (e.g. linear, sinusoidal) or a discrete step function. An example of continuous delay function $\tau_1(t)$ is shown in Figure 8, where T_0 is the carrier period and T_{DDD} is the period of the delay function $\tau_1(t)$, which in the following will be designated the period of the DDD. T_{DDD} is typically selected in the range between aprroximately one to tens of milliseconds.

The effect of the Dynamic Delay Diversity technique discussed here can be explained in connection with figure 9 by considering a single frequency component of the received signal. Here the antennas 1, 2 are assumed to be fed two signals $a_1x(t)$ and $a_2x(t-\tau)$.

The coefficients a_1 and a_2 incorporate the amplitude coefficients α_1 and α_2, plus other gain factors (assumed to be identical for both signals) inherent in the transmission chain through which the "useful" signal x(t) is propagated, while τ is representative of the (dynamic) time delay applied to the signal transmitted via the antenna 2.

As a result of propagation over a transmission channel having channel coefficients $c_1(t)$ and $c_2(t)$ for the antennas 1 and 2, respectively, the signals received (again for the sake of simplicity, a single receiving antenna A_{RX} will be considered) will take the form:

$$r_1(t) = a_1 x(t) c_1(t)$$

$$r_2(t) = a_2 x(t-\tau) c_2(t)$$

and will be summed as a resulting signal $r(t) = r_1(t) + r_2(t)$.

This is in fact equivalent to the sum of two phasors. The phasor $r_1(t)$ related to the signal transmitted by the first antenna, not subject to variable delay, varies according to the characteristic of the propagation channel. For example in indoor environments characterized by low user mobility, the amplitude and phase of this phasor have very slow variations. The second phasor $r_2(t)$, related to the signal transmitted by the antenna subject to variable delay, rotates with a frequency that is imposed by the period of the dynamic delay diversity DDD, as shown at the bottom of Figure 9. The second phasor completes a rotation of 360° in a time interval equal to the period of the DDD (namely T_{DDD}).

The combination of the two phasors at the receiving antenna A_{RX} produces a resultant signal that fades at a faster rate than the signal without DDD, due to the alternation of constructive (phasors recombine in phase) and destructive combination (phasors recombine with opposite phases). The average amplitude ratio of the two phasors is directly proportional to the power imbalance Δ set at the transmitter in the DDD processor. As a consequence, the amplitude depth of the fades induced by the DDD can be progressively reduced by means of the power imbalance.

The alternation of constructive and destructive combining reduces the length of the error bursts and thus improves the effectiveness of the transmission modes that use channel coding. The DDD technique thus affects the error statistics at the input of the channel decoder by making the error distribution more uniform over the received data stream (i.e. the error statistic becomes less bursty). The effectiveness of the channel decoding algorithms is then improved with a consequent reduction of the BLER after the decoding operation.

On the other hand, in the case of uncoded (e.g. EDGE mode MCS-9) or near-to-uncoded transmission the distribution of the errors over the received data stream may cause an increase of the BLER and thus a reduction of the user data rate. The power imbalance technique described herein provides an effective solution to this problem.

The effect of the DDD technique is shown in the diagrams of figure 10. Specifically, these diagrams provide a measure of the received signal power (ordinate scale) as a function of time (abscissa scale) in a system without DDD (diagram I) and in systems that use a DDD processor 10 at the transmitter (diagrams II and III). In this case the user speed is set equal to v = 3 km/h and the configuration parameters of the DDD processor are Δ = 0 dB (balanced transmission - diagram II) or Δ = 6 dB (unbalanced transmission - diagram III) and DDD period equal to T_{DDD} = 13 ms.

Figure 10 shows that the amplitude depth of the fades caused by the DDD is reduced by transmitting two signals with different powers. A lower amplitude depth of the induced fades reduces the probability that a block of unencoded bits is received with errors and therefore avoids any BLER degradation for the unencoded transmission modes.

This result is confirmed by experiments documented in the following. A second remarkable advantage of the unbalanced configuration is the simplification of the time variable delay line design, since the power associated to the second antenna can be significantly reduced.

The effect of the power imbalance can be measured by means of a parameter that characterizes the fade occurrence on the received signal. This parameter is the fade rate or Level Crossing Rate (LCR). The LCR is dependent on the environment characteristics (e.g. position and structure of the scattering objects) and on the relative speed between transmitter and receiver. The natural value of LCR in a given environment (e.g. indoor) can be modified by means of the DDD technique in order to improve the link level performance of the communication system. In particular, LCR can be finely tuned by properly selecting the power imbalance Δ (line/input C of figures 5 and 6) of the DDD processor in order to get optimal link performance with systems that use multiple transmission modes.

LCR is defined as the average rate at which the received signal envelope crosses a specified amplitude threshold A in a positive direction. The LCR is measured in number of fades per second, where the term fade means that the envelope crosses the threshold A. In case of a single path Rayleigh channel with classic

Doppler spectrum the LCR can be calculated analytically, as demonstrated in "CDMA systems engineering handbook", J. Lee, L. Miller, pag. 256-262. In this particular case the theoretical expression of the LCR is equal to

$$LCR = f_d \cdot \rho \cdot \sqrt{2\pi} \cdot e^{-\rho^2} \qquad \text{[fades/s]} \qquad (3)$$

where ρ is the fade-depth parameter defined as the ratio between the signal envelope threshold A and the local RMS (Root Mean Square) signal level

$$\rho = \frac{A}{A_{rms}} \qquad (4)$$

and f_d is the maximum Doppler spread given by

$$f_d = f_0 \cdot \frac{v}{c} \qquad \text{[Hz]} \qquad (5)$$

with f_0 indicating the carrier frequency, v the relative speed between transmitter and receiver and c the light speed. By substituting the equation (5) in the equation (3) we notice that, as expected, the LCR is proportional to the speed v. For example, by considering a received power threshold of 10 dB below the average signal power received, the fade depth parameter ρ is equal to

$$\rho = \sqrt{0.1} = 0.316 \qquad (6)$$

resulting, for a mobile speed v of 3 km/h and a carrier frequency f_0 of 2 GHz, in a LCR equal to

$$LCR = f_0 \cdot \frac{v}{c} \cdot \rho \cdot \sqrt{2\pi} \cdot e^{-\rho^2} = 3.9 \text{ fades/s} \qquad (7)$$

In a wireless system using the DDD TX processor of Figure 5 or Figure 6 the LCR can be evaluated by simulation as shown in Figure 11, where the LCR (ordinate scale) is given as a function of the fade depth parameter $10 \cdot \log_{10}(\rho^2)$ - abscissa scale, referred to the received power in decibel. The results indicate that the LCR reduces as the power imbalance increases (0dB, 3dB, 6dB, 9dB). A lower LCR corresponds to a lower amplitude depth of the induced fades and that reduces the probability that a block of uncoded bits is received with errors. With an accurate choice of the power imbalance is then possible to avoid the BLER degradation for the uncoded transmission modes.

The application of the DDD processor in systems that use multiple transmission modes with different coding rates requires an accurate optimisation of the DDD parameters. The experimental measurements have shown that optimum link performance can be obtained with a period of the DDD of the same order of the interleaving period used in the communication system. This choice maximizes the effectiveness of channel coding and therefore the link performance gain for the transmission modes that use channel coding (indicatively with rates $r \leq 1/2$). The power imbalance Δ is instead optimised by considering the uncoded transmission modes or the transmission modes with the highest coding rates.

The diagrams of Figures 12, 13 and 14 provide some experimental measurement results obtained with an EDGE test-bed and using the DDD TX processor of figure 5. In particular the figures show the effect of the power imbalance on the link performance. The link performance is given in terms of BLER (ordinate scale) after channel decoding as a function of C/I (Signal to Interference plus Noise Ratio - abscissa scale) for the MCS-1, MCS-5 and MCS-9 transmission mode, respectively.

The period of the DDD is set equal to 36 ms as it provides a good performance gain for the coded transmission modes, which use in the physical layer a block interleaving of 20 ms.

From the Figures one notices that, with a power imbalance Δ = 6 dB, the arrangement described herein:

- provides an appreciable performance improvement for the transmission modes MCS-1 and MCS-5 that use channel coding, and

- ensures essentially the same performance of a system without DDD for the unencoded mode MCS-9.

This is in contrast to a system without imbalance, where the use of DDD would result in at least a certain degree of performance impairment for unencoded modes (such as MCS-9) or near-to-unencoded modes, i.e. modes having a coding rate near to unity.

In particular a C/I gain of about 0.8 and 1 dB is measured for the MCS-1 and MCS-5 transmission modes at a target BLER of 10%, with respect to a system without DDD. Performance of the transmission mode MCS-9 with a power imbalance of 6 dB is the same of the conventional system without DDD, for a target BLER of 30%. The BLER targets of 10% and 30% considered are normally taken as reference working points in the deployment of the EDGE networks. The application of the DDD technique with power imbalance thus improves the overall spectral efficiency of the wireless communication system, even when multiple transmission modes with different coding rates are used.

In general, the degree of imbalance Δ will be increased as a function of the channel coding rate, which means that higher imbalance values (e.g. 6 dB) will be used for uncoded (e.g. MCS-9) or near-to-uncoded modes, so that the value of imbalance will approximately be proportional to the coding rate.

Stated otherwise, the level imbalance value Δ is selected as a function of the transmission mode by selecting increasing (i.e. higher) level imbalance values for increasing (i.e. higher) coding rates. In practice, the specific values for Δ can be properly identified via numerical simulation or experimental testing.

Experiments carried out heretofore by the applicant show that power imbalance values of 3 to 10 dB ensure that no performance degradation is caused to the uncoded or near-to-uncoded transmission modes and thus the same BLER performance of a system without DDD is obtained. With this design choice, the application of the DDD technique improves the overall spectral efficiency of the wireless communication system even when multiple transmission modes are used. Clearly, different tradeoffs between the performance of the coded and unencoded transmission modes are possible with different choices of the DDD parameters.

The following description relates to figures 15 to 27. These figures illustrate a number of possible developments of the basic DDD processing schemes described in connection with figures 5 and 6. While a corresponding description is not re-iterated for the sake of brevity, it will be appreciated that all the possible variants now described lend themselves to be implemented with selectively varying splitting/combination coefficients α_1 and α_2. Again, these coefficients may be possibly varied via a line/input C as shown in figures 5 and 6. This may either be in the form of a "*una tantum*" trimming of the system or in the form of automatic adjustment under the control of a block 19 sensitive to the current transmission mode used (e.g. any of the modes MCS-1 to MCS-9 or 1 to 22 contemplated in figures 1 and 2).

A preferred common feature to the various embodiments described herein lies in that, as the at least two signal replicas considered have respectively higher and lower power levels (i.e. the power level of the first replica is higher than the power level of the second replica, so that the power level of the second replica is lower than the power level of the first replica), the DDD arrangement described herein provides for the time variable delay being preferably applied to the replica having a lower power level. As indicated this is advantageous as it facilitates the use of low power handling components for the delay element(s).

It will be further appreciated that while - for the sake of simplicity - only arrangements including two diversity antennas 1, 2 are described herein and shown in the figures 3a, 3b, 5, 6, and 15 to 29, the invention is adapted to be applied to arrangements including any of a plural number of diversity antennas, namely three diversity antennas or more.

As a first example of an alternative embodiment, the DDD technique can be also used at the receiver side to improve the radio link performance of wireless systems even if not designed to support the receiver diversity.

In this case (see e.g. figures 15 and 16) a conventional receiver 22 is equipped with a single radio chain and thus only one RF signal can be demodulated. The DDD RX processor 20 is an add-on RF module connected between the receiving antennas 1,2 and the conventional receiver 22.

Specifically, the scheme of a DDD RX processor 20 suitable for conventional receivers that do not support antenna diversity is shown in Figure 15. The processor 20 includes an asymmetric combiner 24 and a time variant delay line 26. The asymmetric combiner 24 combines (i.e. adds) the two RF signals so that the power ratio of the two combined signals is equal to

$$\Delta = 10 \cdot \log_{10}\left(\frac{P_1}{P_2}\right) \qquad \text{[dB]} \qquad (8)$$

where P_1 and P_2 are the powers of the first and second received signals before the combination. In the scheme of Figure 15, the signal received from the first antenna 1 is provided to the first input of the asymmetric combiner 24 while a second antenna 2 is added and this received signal is subject to the time variant delay 26 and then provided to the second input of the combiner. The combined signal is then provided to the conventional receiver 22 for the subsequent demodulation.

By denoting with $r_1(t)$ and $r_2(t)$ the signals received at the two antennas 1 and 2, the signal $z(t)$ at the output of the DDD processor can be expressed as follows

$$z(t) = \alpha_1 \cdot r_1(t) + \alpha_2 \cdot r_2(t - \tau_1(t)) \qquad (9)$$

where α_1 and α_2 are the combining coefficients introduced by the asymmetric combiner. If we suppose that the two received signals $r_1(t)$ and $r_2(t)$ have the same average power, the imbalance can then be expressed as follows

$$\Delta = 10 \cdot \log_{10}\left(\frac{\alpha_1}{\alpha_2}\right)^2 \qquad (10)$$

The DDD RX processor 20 can also be realized according to the second architecture shown in Figure 16. The signals received from the antennas 1, 2 are amplified by two Low Noise Amplifiers (LNAs) 24a and 24b with different gains G_1 and G_2. The signal received from the first antenna 1 is provided to a symmetric RF combiner 24 while the signal from the second antenna 2 is subject to the time variant delay. After the insertion of the delay 26, the second signal is then provided to the other input of the symmetric combiner. The symmetric combiner adds the two input signals maintaining the power imbalance Δ of the signals at its inputs. The gains G_1 and G_2 of the LNAs 24a and 24b are set in order to obtain the desired power imbalance between the received signals prior to the RF combination.

The effect of the power imbalance, in the case of the DDD technique is applied at the receiver side, is similar to that described in connection with figure 9 with reference to transmission of a single frequency component. Again, the signals received at the antennas may be represented as two phasors, whose amplitude and phase change according to the channel characteristic. In low mobility environments these variations can be very slow thus causing prolonged signal fades. The insertion of the time variant delay on one of the received signals and the subsequent combination cause the alternation of constructive and destructive combining, which reduces the length of the error bursts and thus improves the effectiveness of the transmission modes that use channel coding. However, the alternation of constructive and destructive combining may negatively affect the Block Error Rate of the uncoded transmission modes. By introducing the power imbalance it is possible to reduce the depth of the fades induced by the DDD and thus avoid any performance degradation of the uncoded transmission modes.

The DDD processors can be also applied to improve the performance of conventional transmitters and receivers that support some kind of transmission or receive antenna diversity.

A block diagram of such a DDD TX processor is shown in Figure 17. The signals $INPUT_1$, $INPUT_2$ at the outputs of the conventional transmitter 12 feed two asymmetric splitters 141, 142. Each splitter divides the input signal in two replicas with different powers. Two of the four signals obtained after RF splitting are directly recombined in a first (symmetric) combiner 171, while the other two signals are subject to time variant delays in two delay elements 161 and 162 and then recombined in a second (symmetric) combiner 172. The signals after recombination feed the transmitting antennas 1, 2.

The power asymmetry of the splitters is designed in order to obtain the desired imbalance Δ (see equation 1) between the powers P_1 and P_2 radiated by the two antennas 1, 2. By denoting with $x_1(t)$ and $x_2(t)$ the signals at the output of the conventional transmitter, the two transmitted signals $y_1(t)$ and $y_2(t)$ can be expressed as follows

$$\begin{aligned} y_1(t) &= \alpha_1 \cdot x_1(t) + \alpha_3 \cdot x_2(t) \\ y_2(t) &= \alpha_2 \cdot x_1(t-\tau_1(t)) + \alpha_4 \cdot x_2(t-\tau_2(t)) \end{aligned} \tag{11}$$

where α_1 and α_2 are the amplitude coefficients introduced by the first asymmetric splitter, while α_3

and α_4 are the amplitude coefficients introduced by the second asymmetric splitter. In the typical configuration of the DDD TX processor, the two asymmetric splitter are identical so that we may assume $\alpha_1 = \alpha_3$ and $\alpha_2 = \alpha_4$.

As demonstrated in detail in PCT/EP2005/010799, the arrangement illustrated in figure 17 corresponds to a specific, simplified implementation of a more general layout where time variable delay lines are associated to all of the four signal propagation paths that connect the inputs $INPUT_1$ and $INPUT_2$ to the antennas 1 and 2 via the splitters 141, 142 and the combiners 171, 172.

With a proper choice of the delay functions (e.g. the two delay functions $\tau_1(t)$ and $\tau_2(t)$ of figure 17) the DDD TX processor 10 works as a signal decorrelator by providing two output signals that have a lower cross-correlation coefficient than the cross-correlation coefficient of the two input signals $INPUT_1$ and $INPUT_2$. In particular, in the embodiment illustrated in figure 17, the DDD TX processor 10 operates as a signal decorrelator by using two delay functions $\tau_1(t)$ and $\tau_2(t)$ that satisfy the following condition

$$\tau_2(t) = \tau_1(t) + \frac{T_0}{2} \tag{12}$$

where T_0 is the carrier period of the (RF or IF) input signals $INPUT_1$ and $INPUT_2$.

By taking into account the formula (12) the structure of the DDD TX processor of figure 17 can be simplified as illustrated in figure 18. There, the two time variant delay lines 161, 162 of figure 17 are replaced by:

- a single variable delay element (delay line) 161 inserted after the combiner 172, i.e. on a common portion of the propagation paths of the signals $INPUT_1$ and $INPUT_2$ towards the antenna 2; and

- a fixed delay element 1601 with a delay equal to $T_0/2$ inserted between the splitter 142 and the combiner 172, i.e. on those portions of the propagation paths of the signals $INPUT_1$ and $INPUT_2$ towards the antenna 2 that are distinct from each other.

Along the same lines of the arrangements of figures 6 and 16, the asymmetric/imbalanced arrangements of DDD TX processors of figures 17 and 18 can be also implemented by using symmetric splitters 141, 142 and cascading to the combiners 171, 172 two power amplifiers with different gains G_1 and G_2.

Figure 19 shows two such power amplifiers 14a, 14b with different gains G_1 and G_2 inserted prior to the antennas 1, 2 within the processor layout illustrated in figure 18 (the extension to the processor layout of figure 17 is straightforward and is not illustrated in detail).

The gains of the power amplifiers 14a, 14b are determined in order to obtain the desired transmission power imbalance Δ. This architecture has the advantage that the DDD processor can be realized with low power components. The application of this architecture is suitable for communication networks that use Remote Radio Head (RRH) units.

The same DDD processor concept can be also employed at the receiver side in order to improve the performance of conventional receivers that support antenna diversity. The DDD RX processor is inserted between the antenna subsystem and the two RF inputs of a conventional receiver 22.

A first architecture of such a DDD RX processor 20 is shown in Figure 20. The received signals at the antennas are provided to two splitters 241, 242. Each splitter divides the input signal in two replicas with the same power. Two of the four signals obtained after RF splitting are directly recombined by means of an asymmetric combiner 271. The other two signals are subject to time variant delays 261, 262 and then asymmetrically recombined in a combiner 272. The signals after recombination then feed the conventional receiver.

The asymmetry of the combiners 271, 272 is designed in order to obtain the desired imbalance Δ between the powers of the recombined signals.

By denoting with $r_1(t)$ and $r_2(t)$ the signals received at the two antennas, the signals $z_1(t)$ and $z_2(t)$ at the output of the DDD processor can be expressed as follows

$$\begin{aligned} z_1(t) &= \alpha_1 \cdot r_1(t) + \alpha_2 \cdot r_2(t - \tau_1(t)) \\ z_2(t) &= \alpha_3 \cdot r_1(t) + \alpha_4 \cdot r_2(t - \tau_2(t)) \end{aligned} \tag{13}$$

where α_1 and α_2 are the combining coefficients introduced by the first asymmetric combiner and α_3 and α_4 are the combining coefficients introduced by the second asymmetric combiner. By assuming that the two signals received $r_1(t)$ and $r_2(t)$ have the same average power, the power imbalance for the first output signal $z_1(t)$ can be expressed as follows

$$\Delta_1 = 10 \cdot \log_{10}\left(\frac{\alpha_1}{\alpha_2}\right)^2 \tag{14}$$

while the power imbalance for the second output signal $z_2(t)$ is equal to

$$\Delta_2 = 10 \cdot \log_{10}\left(\frac{\alpha_3}{\alpha_4}\right)^2 \quad (15)$$

In the typical configuration of the DDD RX processor, the power imbalance on the two branches are set equal (namely $\Delta_1 = \Delta_2$), which can be obtained by setting $\alpha_1 = \alpha_3$ and $\alpha_2 = \alpha_4$ or using two identical asymmetric combiners.

Again as demonstrated in detail in PCT/EP2005/010799, the arrangement illustrated in figure 20 corresponds to a specific, simplified implementation of a more general layout where time variable delay lines are associated to all of the four signal propagation paths that connect the antennas 1 and 2 to the outputs $OUTPUT_1$ and $OUTPUT_2$ via the splitters 241, 242 and the combiners 271, 272.

With a proper choice of the delay functions (e.g. the two delay functions $\tau_1(t)$ and $\tau_2(t)$ of figure 20) the DDD RX processor operates as a signal decorrelator by providing two output signals that have a lower cross-correlation coefficient than the cross-correlation coefficient of the two input signals.

By taking into account the formula (12), which - mutatis mutandis - also applies to DDD RX processing, the processor of Figure 20 can be simplified as illustrated in figure 21. There, the two time variant delay lines 261, 262 of figure 20 are replaced by:

- a single variable delay element (delay line) 261 inserted before the splitter 242, i.e. on the common portion of the signal propagation paths from the antenna 2 towards the outputs $OUTPUT_1$ and $OUTPUT_2$; and

- a fixed delay element 2601 with a delay equal to $T_0/2$ (where T_0 is the carrier period) inserted between the splitter 242 and the combiner 272, i.e. on those portions of the signal propagation paths from the antenna 2 to the outputs $OUTPUT_1$ and $OUTPUT_2$ that are distinct from each other.

Along the same lines of the arrangements of figures 6, 16, and 19 the asymmetric/imbalanced arrangements of DDD RX processors of figures 20 and 21 can be also implemented by using symmetric combiners 271, 272 and placing upstream of the splitters 241, 242 two low noise amplifiers (LNAs) with different gains G_1 and G_2.

Figure 22 shows the arrangement resulting from the use of two such amplifiers 24a, 24b inserted at the outputs of the receiving antennas 1, 2. In this case two symmetric combiners 271, 272 are used, while the gains of the LNAs 24a, 24b are designed in order to obtain the desired imbalance between the powers of the recombined signals. The application of this architecture (which can be applied also to the receiver layout of figure 20) is suitable for communication networks that use Remote Radio Head (RRH) units.

The DDD processors described up to now are unidirectional devices that can be used separately for transmission (TX) or reception (RX). Comparison of e.g. the architectures of Figure 5 (DDD TX processor) and Figure 15 (DDD RX processor) shows that the two circuits are inherently symmetrical.

As a consequence, a single DDD TX/RX processor, implemented with reciprocal components, can be used simultaneously both for transmission and reception. The same consideration holds for the architectures shown in figure 18 and figure 21, used together with conventional transceivers that support transmit and receive diversity.

Figure 23 and figure 24 show the architectures of DDD TX/RX processors 1020 realized with reciprocal components that can be used simultaneously for transmission and reception. The separation of transmit and receive paths is realized within the transceiver by means of duplexer elements.

The "transceiver" block 1222 in Figure 23 and 24 represents a unit that includes the functionalities of both the conventional transmitter and conventional receiver as shown in figures 3a and 3b, respectively.

The block 1424 of figure 23 is a reciprocal module adapted to operate as an asymmetric splitter on the signal being transmitted from the TX section of the transceiver 1222 via the antennas 1, 2 and as an asymmetric combiner on the signals being received via the antennas 1, 2 and forwarded to the RX section of the transceiver 1222.

In the system of figure 24 two signals are both transmitted and received by means of the diversity antennas.

From the functional viewpoint, the system of figure 24 thus includes:

- two first splitters for splitting the two signals transmitted to produce two respective replicas transmitted over respective transmission paths towards different ones of the diversity antennas 1, 2,

- two second splitters for splitting the two signals received via the antennas 1, 2 to produce two respective replicas received over respective transmission paths from each diversity antenna 1, 2,

- two first combiners for combining the replicas received over respective transmission paths from different ones of the diversity antennas 1, 2, and

- two second combiners for combining at each diversity antenna 1, 2 respective replicas of each of the signals transmitted.

The system being "reciprocal" leads however the first splitters and the first combiners to be in fact comprised of a first pair of reciprocal elements 14241, 14242. Similarly, the second splitters and the second combiners are in fact comprised of a second pair of reciprocal elements 17271, 17272.

Those of skill in the art will promptly appreciate that the details of the various implementations of DDD processors previously described are not unique to the implementation in respect of which they have been described and can be applied also to other implementations. Similarly, various of these details lend themselves to be substituted by equivalent arrangements.

For instance, the arrangement illustrated in figure 24 can be alternatively implemented by using two (reciprocal) time variable delay elements playing the role of the transmission delay elements 161, 162 of figure 17 and the reception delay elements 261, 262 of figure 20.

As a further example, the location of the power and low-noise amplifiers described and shown in connection with several embodiments disclosed in the foregoing represents the presently preferred design choice, but is in no way mandatory; the skilled designer may in fact easily devise different equivalent arrangements for these power and low-noise amplifiers while preserving their function of producing the power imbalance/difference underlying operation of the invention.

Similarly, those of skill in the art will appreciate that the various implementations of DDD processors previously described can be combined in order to obtain different system architectures, where the DDD processing is introduced both in transmission and reception.

For instance, figure 25 shows a first system architecture based on non-reciprocal DDD transmit and receive processors 10, 20. This architecture is suitable for conventional transceivers that do not support any form of transmit and receive antenna diversity. The internal structures of the DDD TX and RX processors 10, 20 can be e.g. those disclosed in the Figures 5 and 6 or Figures 15 and 16 for the TX and RX parts, respectively. A first duplexer element 101 separates the transmission and reception paths on the TX/RX side, and the separation between transmit and receive paths at the antennas 1, 2 is obtained by means of two further duplexer elements 102, 103.

Figure 26 illustrates another system architecture, realized with non-reciprocal processors, that is suitable for conventional transceivers that support only receive antenna diversity. The first duplexer element 101 here separates the transmission and reception paths TX_1/RX_1 at the port supporting the single transmission channel and one of the diversity reception channels, and the separation between transmit and receive paths at the antennas 1, 2 is again obtained by means of two further duplexer elements 102, 103. The DDD TX processor 10 can be implemented e.g. according to any of the structures shown in Figure 5 or 6, while the DDD RX processor 20 can be implemented e.g. according to any of the schemes described in figures 20, 21 or 22.

Figure 27 illustrates still another system architecture, realized with non-reciprocal processors, which is suitable for conventional transceivers that support both transmit and receive antenna diversity. Two first duplexer elements 1011 and 1012 here separate the transmission and reception paths TX_1/RX_1 and TX_2/RX_2 at the two ports supporting the diversity transmission and reception channels. The separation between transmit and receive paths at the antennas 1, 2 is again obtained by means of two further duplexer elements 102, 103. The DDD TX processor 10 can be implemented e.g. according to any of the structures shown in figures 17, 18 or 19, while the DDD RX processor can be implemented e.g. according to any of the schemes described in figures 20, 21 or 22.

The exemplary embodiments of the invention presented in the foregoing refer to the transmission/reception of signals selected out of radiofrequency (RF) signals and intermediate frequency (IF) signals. Those of skill in the art will however appreciate that the invention can also be applied to baseband signals, in which case the effect of time variable delays may be obtained by subjecting the baseband signal(s) to multiplication by a complex signal.

Consequently, without prejudice to the underlying principles of the invention, the details and the embodiments may vary, even appreciably, with reference to what has been described by way of example only, without departing from the scope of the invention as defined by the annexed claims.

CLAIMS

1. A method of diversity processing at least one signal (INPUT; $INPUT_1$, $INPUT_2$) propagated via at least two diversity antennas (1, 2), the method including the steps of:

- propagating at least two replicas of said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) over respective propagation paths coupled to said at least two diversity antennas (1, 2), whereby said replicas are propagated via different antennas (1, 2);

- subjecting at least one of said replicas to a time variable delay (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261); and

- adjusting (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) the power levels of said at least two replicas to produce a level imbalance (Δ) therebetween.

2. The method of claim 1, characterised in that said at least two replicas include replicas having respectively higher and lower power levels, and in that the method includes the step of subjecting to said time variable delay (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261) said replica having a lower power level.

3. The method of either of claims 1 or 2, characterised in that it includes the step of selecting said level imbalance (Δ) in the range of 3 to 10 dB.

4. The method of any of claims 1 to 3, characterised in that it includes the steps of :

- selectively using one of a plurality of transmission modes (MCS-1 to MCS-9; 1 to 22) for said at least one signal, and

- selecting said level imbalance (Δ) as a function of the transmission mode used.

5. The method of claim 4, characterised in that said plurality of transmission modes (MCS-1 to MCS-9; 1 to 22) have respective coding rates (CR), and the method includes the step of selecting said level imbalance (Δ) as a function of said coding rates, wherein higher level imbalance values are selected for higher coding rates.

6. The method of either of claims 4 or 5, characterised in that it includes the steps of:

- selectively varying the transmission mode (MCS-1 to MCS-9; 1 to 22) used, and

- adaptively varying (19, C) said level imbalance (Δ) as a function of the current transmission mode used.

7. The method of any of the previous claims, characterised in that it includes the step of subjecting to time variable delays the replicas propagating over all of said respective propagation paths.

8. The method of any of the previous claims 1 to 6, characterised in that it includes the step of subjecting to time variable delays (161, 162; 161, 1601; 261, 262; 261, 2601) two of said replicas propagating over propagation paths associated with the same (2) of said diversity antennas (1, 2).

9. The method of claim 8, characterised in that it includes the step of subjecting to time variable delays

the replicas propagating over at least two of said propagation paths by:

- providing, in the propagation paths for said at least two replicas associated with the same (2) of said diversity antennas (1, 2), respective distinct propagation portions and a combined propagation portion for said at least two replicas,

- subjecting said at least two replicas to a time variable delay (161, 261; 1261) over the common portion of said propagation paths, and

- subjecting one of said at least two replicas to a fixed delay (1601; 2601; 12601) over the respective distinct portion of said propagation paths.

10. The method of claim 9, wherein said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) has a carrier frequency with a given period (T_0), characterised in that said fixed delay (1601; 2601; 12601) is equal to half said given period ($T_0/2$).

11. The method of any of the previous claims, applied to at least one signal (INPUT; $INPUT_1$, $INPUT_2$) transmitted in the form of at least two replicas propagated over respective propagation paths towards said at least two diversity antennas (1, 2), characterised in that it includes the step of splitting (14; 141, 142; 1424; 14241; 14242) said at least one signal transmitted (INPUT; $INPUT_1$, $INPUT_2$) to produce said at least two replicas of said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) propagated over respective propagation paths coupled to said at least two diversity antennas (1, 2).

12. The method of claim 11, characterised in that said splitting (14; 141, 142; 1424; 14241; 14242) is an

asymmetric splitting producing said level imbalance (Δ) between said replicas.

13. The method of claim 11, characterised in that said splitting (14; 141, 142; 1424; 14241; 14242) is a symmetric splitting, the method further including the steps of applying different gains (14a, 14b) over said respective propagation paths coupled to said at least two diversity antennas (1, 2) to produce said level imbalance (Δ) between said replicas.

14. The method of any of claims 11 to 13, applied to at least two signals ($INPUT_1$, $INPUT_2$) transmitted by means of said at least two diversity antennas (1, 2), characterised in that it includes the step of combining (171, 172; 17271, 17272) at each of said diversity antennas (1, 2) respective replicas of said at least two signals transmitted.

15. The method of any of the previous claims, applied to at least one signal (INPUT; $INPUT_1$, $INPUT_2$) received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2), characterised in that it includes the step of combining (24; 271, 272; 1424; 14241; 14242) said at least two replicas to produce said at least one signal received (OUTPUT; $OUTPUT_1$, $OUTPUT_2$).

16. The method of claim 15, characterised in that said combining (24; 271, 272; 1424; 14241; 14242) is an asymmetric combining producing said level imbalance (Δ) between said replicas.

17. The method of claim 15, characterised in that

said combining (24; 271, 272; 1424; 14241; 14242) is a symmetric combining, the method further including the steps of applying different gains (24a, 24b) to said respective propagation paths of said replicas from said at least two diversity antennas (1, 2) to produce said level imbalance (Δ) between said replicas.

18. The method of any of claims 15 to 17, applied to at least two signals ($INPUT_1$, $INPUT_2$) received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2), characterised in that it includes the step of splitting (241, 242; 17271, 17272) at each of said diversity antennas (1, 2) the respective propagation paths of said at least two signals received.

19. The method of any of the previous claims, applied to at least one signal (INPUT) transmitted and received by means of said at least two diversity antennas (1, 2), characterised in that it includes the steps of:

- splitting (1424) said at least one signal transmitted (INPUT) to produce at least two replicas transmitted over respective transmission paths towards said diversity antennas (1, 2),
- combining (1424) said at least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2), to produce said at least one signal received (INPUT),
- wherein said steps of splitting and combining are performed by means of at least one reciprocal elements (1424).

20. The method of claim 19, applied to at least

two signals ($INPUT_1$, $INPUT_2$) transmitted and received by means of said at least two diversity antennas (1, 2), characterised in that it includes the steps of:

- a) splitting (14241, 14242) each said at least two signals ($INPUT_1$, $INPUT_2$) transmitted to produce at least two respective replicas transmitted over respective transmission paths towards different ones of said diversity antennas (1, 2),

- b) splitting (17271, 17272) each said at least two signals ($INPUT_1$, $INPUT_2$) received to produce at least two respective replicas received over respective transmission paths from each said diversity antennas (1, 2),

- c) combining (14241, 14242) replicas received over respective transmission paths from different ones of said diversity antennas (1, 2), and

- d) combining (17271, 17272) at each of said diversity antennas (1, 2) respective replicas of each said at least two signals ($INPUT_1$, $INPUT_2$) transmitted

- wherein said splitting and combining steps a) and c), and said splitting and combining steps b) and d), respectively, are performed by means of at least one reciprocal elements (14241, 14242; 17271, 17272).

21. The method of any of the previous claims, characterised in that said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) is selected out of radiofrequency (RF) signals and intermediate frequency (IF) signals.

22. The method of any of the previous claims 1 to 20, characterised in that said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) is a baseband signal, and said time variable delay is applied to said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) by subjecting said baseband signal to multiplication by a complex signal.

23. A system for diversity processing at least one signal (INPUT; $INPUT_1$, $INPUT_2$) propagated via at least two diversity antennas (1, 2), the system including:

- respective propagation paths for propagating at least two replicas of said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) said respective propagation paths being coupled to said at least two diversity antennas (1, 2), whereby said replicas are propagated via different antennas (1, 2);

- at least one time variable delay element (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261) for subjecting at least one of said replicas to a time variable delay; and

- level adjusting elements (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) arranged on said respective propagation paths to produce a level imbalance (Δ) between the power levels of said at least two replicas.

24. The system of claim 23, characterised in that it includes respective propagation paths for at least two said replicas having respectively higher and lower power levels, and in that said at least one time variable delay element (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261) is arranged on the propagation path of said replica having a lower power level.

25. The system of either of claims 23 or 24, characterised in that said level adjusting elements (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) are configured to produce a level imbalance (Δ) in the range of 3 to 10 dB.

26. The system of any of claims 23 to 25, wherein said at least one signal admits a plurality of transmission modes (MCS-1 to MCS-9; 1 to 22), characterised in that said level adjusting elements (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) are configured (C) for selecting said level imbalance (Δ) as a function of the transmission mode used.

27. The method of claim 26, wherein said plurality of transmission modes (MCS-1 to MCS-9; 1 to 22) have respective coding rates (CR), characterised in that said level adjusting elements (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) are configured (C) for selecting said level imbalance (Δ) as a function of said coding rates, wherein higher level imbalance values are selected for higher coding rates.

28. The system of either of claims 26 or 27, characterised in that it includes at least one module (19) sensitive to the current transmission mode used and configured for acting (C) on said level adjusting elements (14; 14, 14a, 14b; 141, 142; 1424; 24; 24, 24a, 24b; 241, 242; 271, 272; 14241, 14242) to adaptively vary said level imbalance (Δ) as a function of the current transmission mode used.

29. The system of any of the previous claims 23 to 28, characterised in that it includes variable delay elements (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261) for subjecting to time variable delays the replicas propagating over all of said respective propagation paths.

30. The system of any of the previous claims 23 to 28, characterised in that it includes variable delay elements (16; 161, 162; 161, 1601; 1261; 26; 261, 262; 261, 2601; 1261) for subjecting to time variable delays two said replicas propagating over propagation paths associated with the same (2) of said diversity antennas (1, 2).

31. The system of claim 30, characterised in that it includes:

- in the propagation paths for said at least two replicas associated with the same (2) of said diversity antennas (1, 2), respective distinct propagation portions and a combined propagation portion for said at least two replicas,

- a time variable delay element (161, 261; 1261) arranged over the common portion of said propagation paths for subjecting said at least two replicas to a time variable delay, and

- a fixed delay (1601; 2601; 12601) arranged over said respective distinct portions of said propagation paths for subjecting one of said at least two replicas to a fixed delay (1601; 2601; 12601).

32. The system of claim 31, wherein said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) has a carrier frequency with a given period (T_0), characterised in that said fixed delay (1601; 2601; 12601) is equal to half said given period ($T_0/2$).

33. The system of any of the previous claims 23 to 32, wherein said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) is transmitted in the form of at least two replicas propagated over respective propagation paths

towards said at least two diversity antennas (1, 2), characterised in that the system includes at least one splitter (14; 141, 142; 1424; 14241; 14242) for splitting said at least one signal transmitted (INPUT; $INPUT_1$, $INPUT_2$) to produce said at least two replicas of said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) propagated over respective propagation paths coupled to said at least two diversity antennas (1, 2).

34. The system of claim 33, characterised in that said at least one splitter (14; 141, 142; 1424; 14241; 14242) is an asymmetric splitter producing said level imbalance (Δ) between said replicas.

35. The system of claim 33, characterised in that said at least one splitter (14; 141, 142; 1424; 14241; 14242) is a symmetric splitting, the system further including gain elements (14a, 14b) to apply different gains to respective propagation paths coupled to said at least two diversity antennas (1, 2) to produce said level imbalance (Δ) between said replicas.

36. The system of any of claims 33 to 35, wherein at least two signals ($INPUT_1$, $INPUT_2$) are transmitted by means of said at least two diversity antennas (1, 2), characterised in that the system includes at least one combiner (171, 172; 17271, 17272) for combining at each of said diversity antennas (1, 2) respective replicas of said at least two signals transmitted.

37. The system of any of the previous claims 23 to 36, wherein said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) is received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2),

characterised in that the system includes at least one combiner (24; 271, 272; 1424; 14241; 14242) for cimbining said at least two replicas to produce said at least one signal received (INPUT; $INPUT_1$, $INPUT_2$).

38. The system of claim 37, characterised in that said at least one combiner (24; 271, 272; 1424; 14241; 14242) is an asymmetric combiner producing said level imbalance (Δ) between said replicas.

39. The system of claim 37, characterised in that said at least one combiner (24; 271, 272; 1424; 14241; 14242) is a symmetric combiner, the system further including gain elements (24a, 24b) for applying different gains to said respective propagation paths of said replicas from said at least two diversity antennas (1, 2) of said replicas to produce said level imbalance (Δ) between said replicas.

40. The system of any of claims 37 to 39, wherein at least two signals ($INPUT_1$, $INPUT_2$) are received in the form of at least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2), characterised in that the system includes includes at least one splitter (241, 242; 17271, 17272) for splitting at each of said diversity antennas (1, 2) respective propagation paths for replicas of said at least two signals received.

41. The system of any of the previous claims 23 to 40, wherein said at least one signal (INPUT) is transmitted and received by means of said at least two diversity antennas (1, 2), characterised in that the system includes:

- at least one splitter (1424) for splitting said at least one signal transmitted (INPUT) to produce at least two replicas transmitted over respective transmission paths towards said diversity antennas (1, 2),

- at least one combiner (1424) for combining said least two replicas propagated over respective propagation paths from said at least two diversity antennas (1, 2), to produce said at least one signal received (INPUT),

- wherein said at least one splitter and combiner are comprised of at least one reciprocal element (1424).

42. The system of claim 41, wherein at least two signals ($INPUT_1$, $INPUT_2$) are transmitted and received by means of said at least two diversity antennas (1, 2), characterised in that it includes:

- a) at least one first splitter (14241, 14242) for splitting each said at least two signals ($INPUT_1$, $INPUT_2$) transmitted to produce at least two respective replicas transmitted over respective transmission paths towards different ones of said diversity antennas (1, 2),

- b) at least one second splitter (17271, 17272) for splitting each said at least two signals ($INPUT_1$, $INPUT_2$) received to produce at least two respective replicas received over respective transmission paths from each said diversity antennas (1, 2),

- c) at least one first combiner (14241, 14242) for combining replicas received over respective transmission paths from different ones of said diversity antennas (1, 2), and

- d) at least one second combiner (17271, 17272) for combining at each of said diversity antennas (1, 2) respective replicas of each said at least two signals

($INPUT_1$, $INPUT_2$) transmitted,

- wherein said at least one first splitter and said at least one first combiner are comprised of at least one first reciprocal element (14241, 14242), and said at least one second splitter and said at least one second combiner are comprised of at least one second reciprocal element (17271, 17272).

43. The system of any of the previous claims 23 to 42, wherein said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) is a baseband signal, and said time variable delay is applied to said at least one signal (INPUT; $INPUT_1$, $INPUT_2$) by subjecting said baseband signal to multiplication by a complex signal.

44. A wireless communication apparatus including the system of any of claims 23 to 43.

45. A computer program product, loadable into the memory of at least one computer and including software code portions for performing the method of any of claims 1 to 22.

Fig. 1

TM MOD MT CR

Transmission mode	Modulation	Maximum Throughput [kbps]	Coding Rate
MCS-9	8 PSK	59.2	1
MCS-8		54.5	0.92
MCS-7		44.8	0.76
MCS-6		29.6	0.49
MCS-5		22.4	0.37
MCS-4	GMSK	17.6	1
MCS-3		14.8	0.8
MCS-2		11.2	0.66
MCS-1		8.8	0.53

Fig. 2

TM NC MOD MT CR

Transmission mode	Number of HS-PDSCH codes	Modulation	Maximum Throughput [kbps]	Coding Rate
1	1	QPSK	68.5	0.14
2	1	QPSK	86.5	0.18
3	1	QPSK	116.5	0.24
4	1	QPSK	158.5	0.33
5	1	QPSK	188.5	0.39
6	1	QPSK	230.5	0.48
7	2	QPSK	325	0.34
8	2	QPSK	396	0.41
9	2	QPSK	465.5	0.48
10	3	QPSK	631	0.44
11	3	QPSK	741.5	0.51
12	3	QPSK	871	0.60
13	4	QPSK	1139.5	0.59
14	4	QPSK	1291.5	0.67
15	5	QPSK	1659.5	0.69
16	5	16-QAM	1782.5	0.37
17	5	16-QAM	2094.5	0.44
18	5	16-QAM	2332	0.49
19	5	16-QAM	2643.5	0.55
20	5	16-QAM	2943.5	0.61
21	5	16-QAM	3277	0.68
22	5	16-QAM	3584	0.75

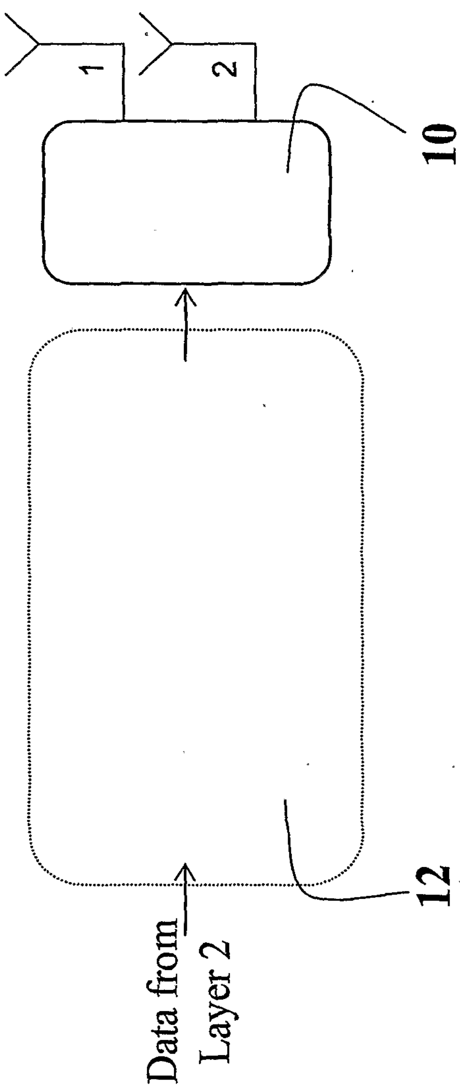


Fig. 3a

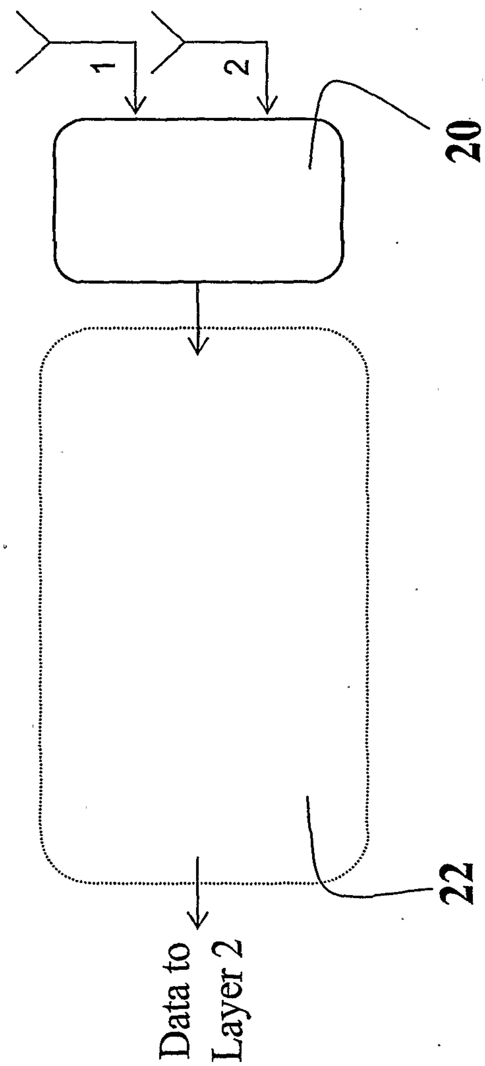


Fig. 3b

Fig. 4a

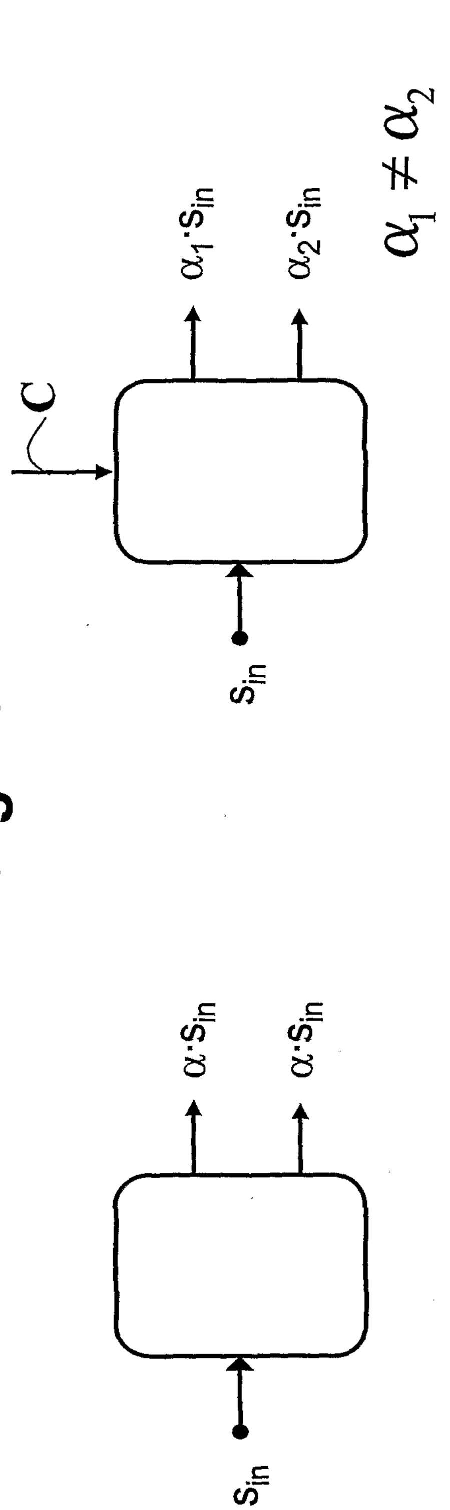

s_{in}
$\alpha \cdot s_{in}$
$\alpha \cdot s_{in}$
s_{in}
C
$\alpha_1 \cdot s_{in}$
$\alpha_2 \cdot s_{in}$
$\alpha_1 \neq \alpha_2$

Fig. 4b

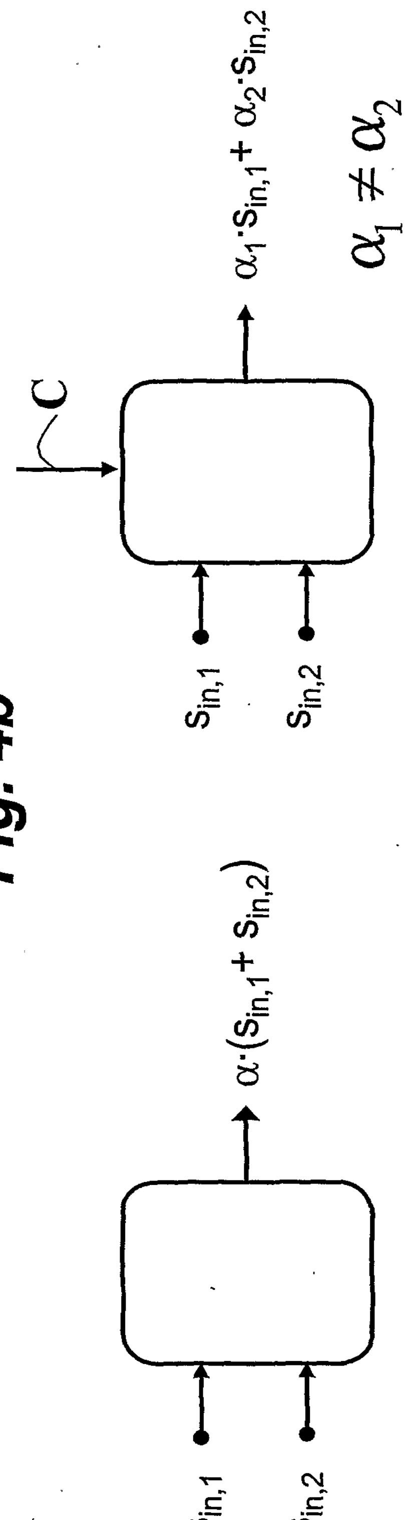

$s_{in,1}$
$s_{in,2}$
$\alpha \cdot (s_{in,1} + s_{in,2})$
$s_{in,1}$
$s_{in,2}$
C
$\alpha_1 \cdot s_{in,1} + \alpha_2 \cdot s_{in,2}$
$\alpha_1 \neq \alpha_2$

Fig. 5

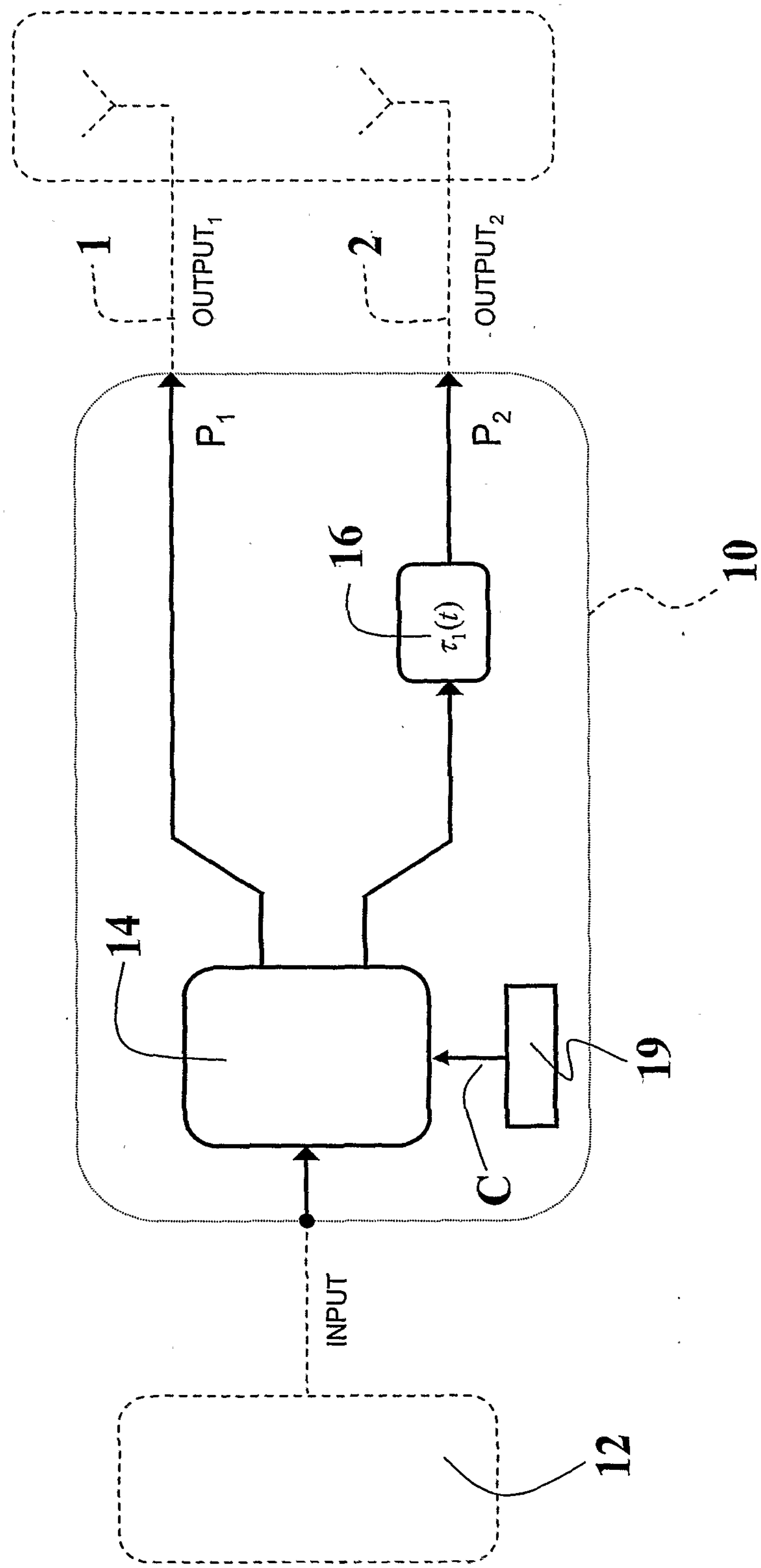


Fig. 6

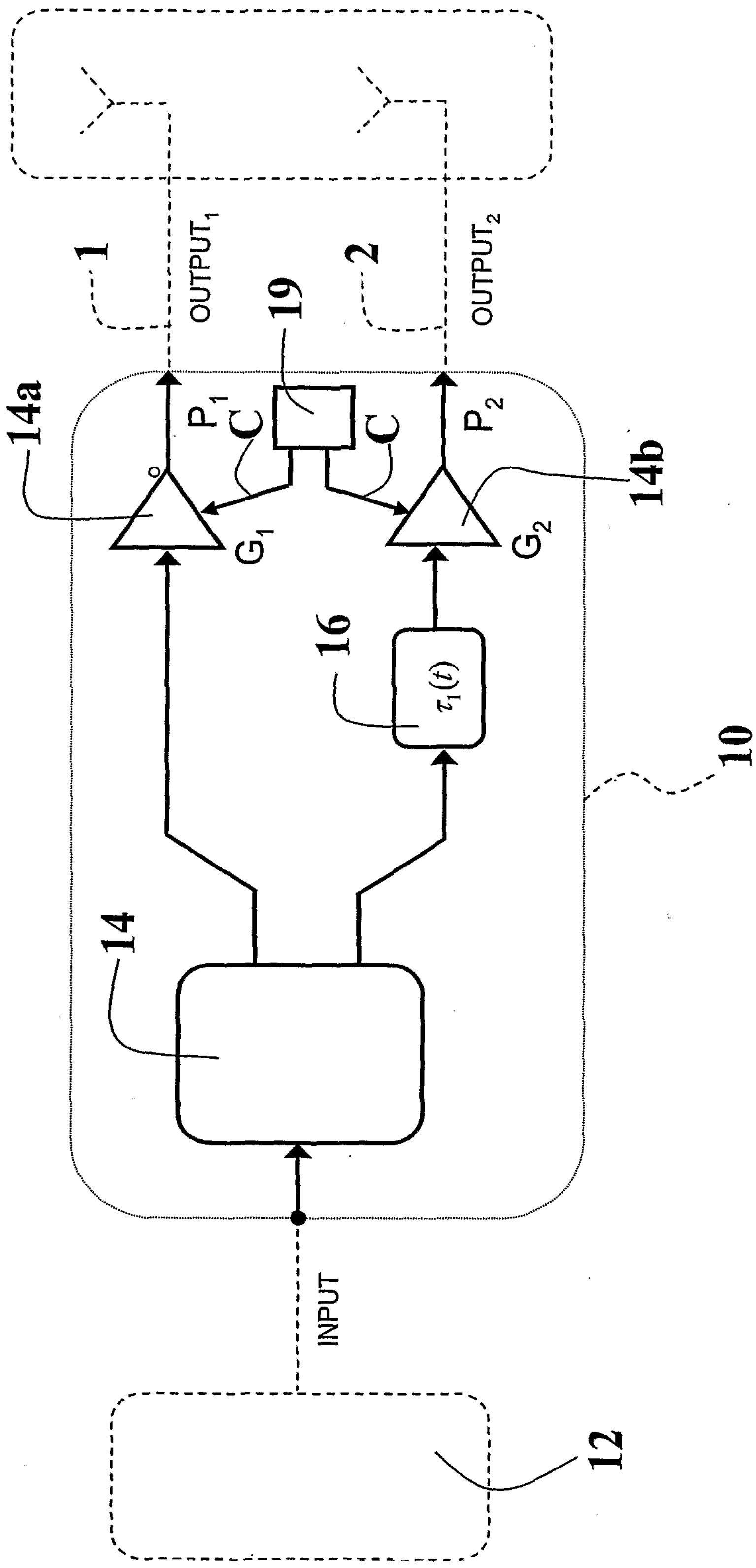

OUTPUT1
OUTPUT2
1
2
19
14a
14b
P1
P2
C
C
G1
G2
16
$\tau_1(t)$
10
14
INPUT
12

Fig. 7a

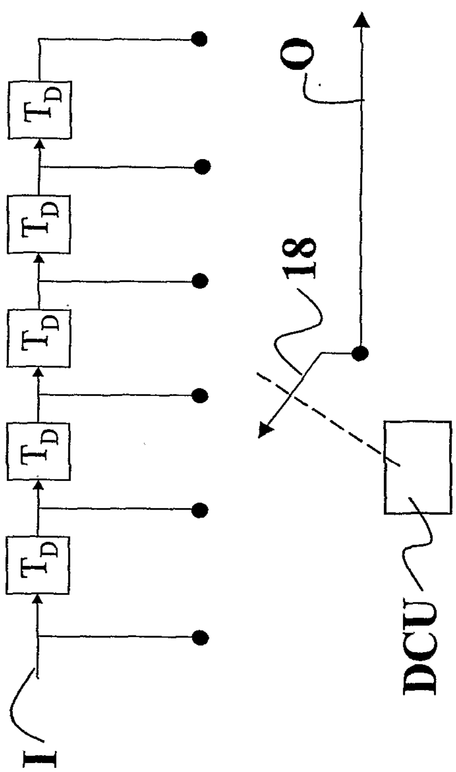


Fig. 7b

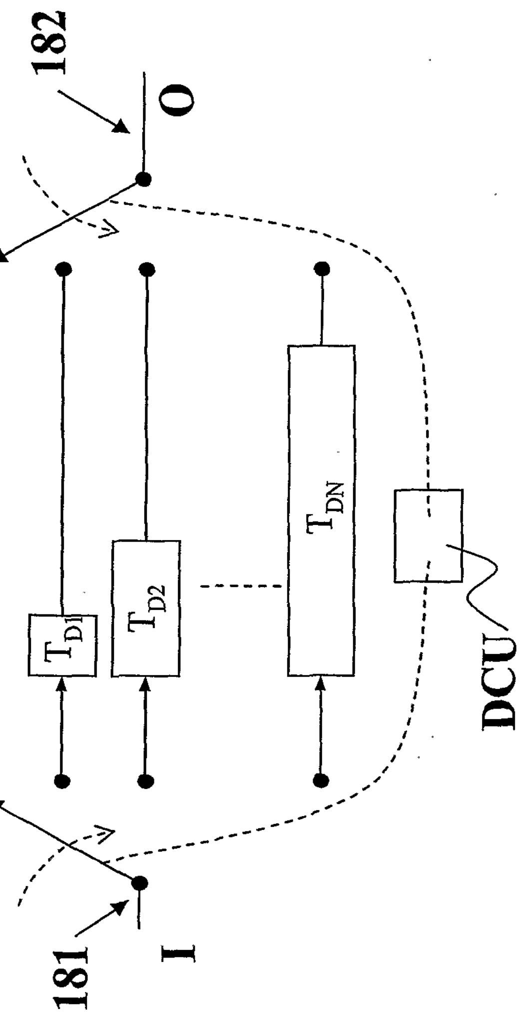


Fig. 8

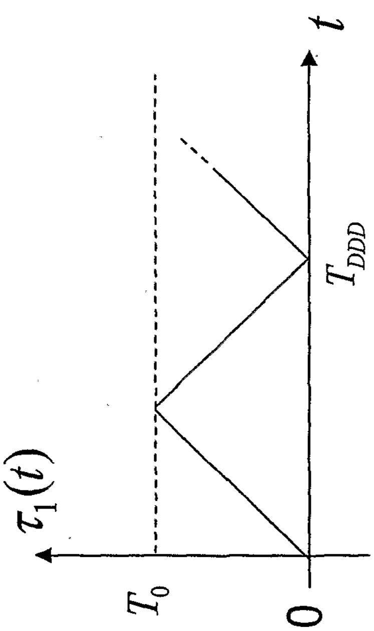


Fig. 9

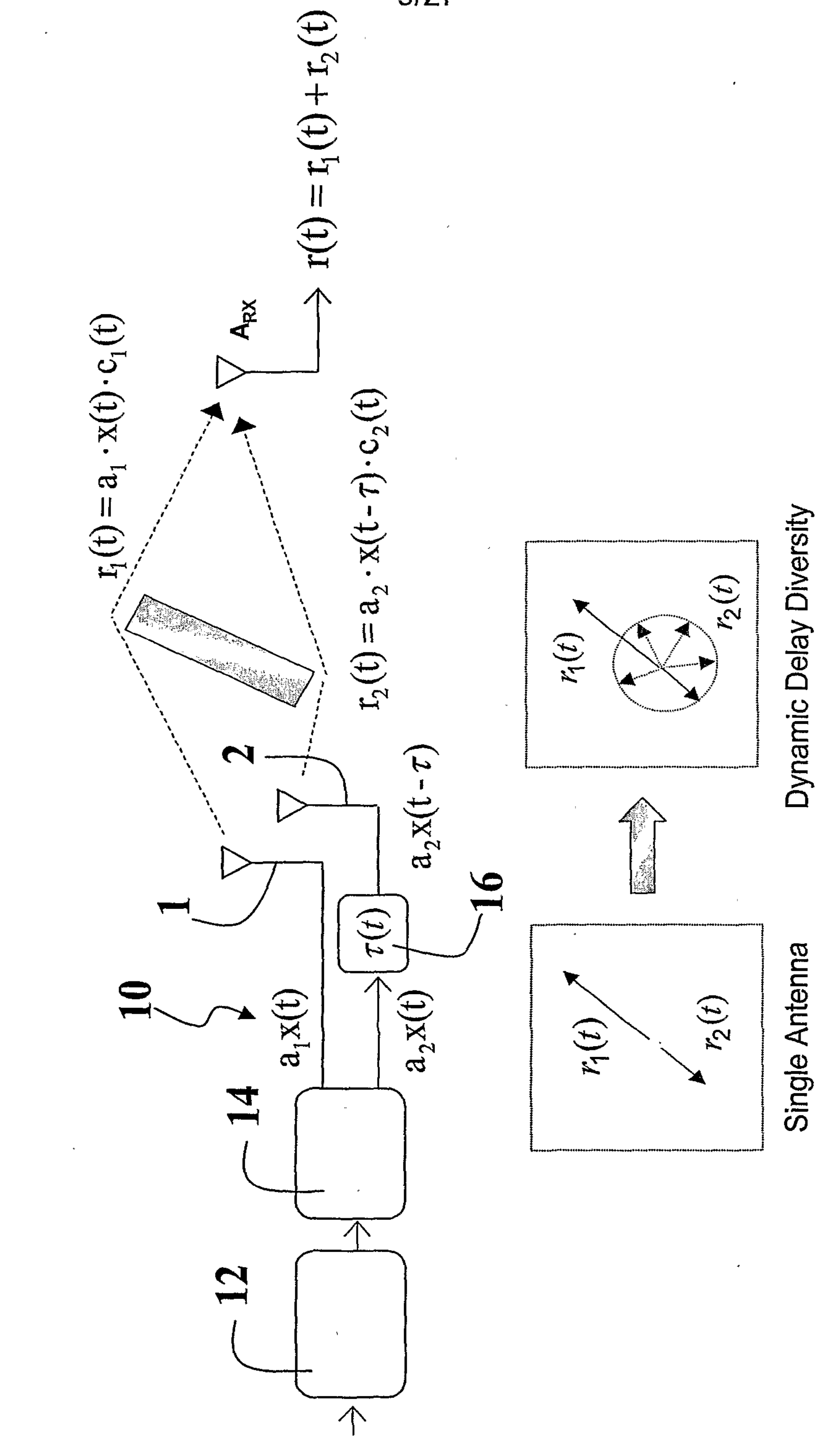

10
12
14
16
1
2
$a_1 x(t)$
$a_2 x(t)$
$\tau(t)$
$a_2 x(t-\tau)$
$r_1(t) = a_1 \cdot x(t) \cdot c_1(t)$
$r_2(t) = a_2 \cdot x(t-\tau) \cdot c_2(t)$
A_{RX}
$r(t) = r_1(t) + r_2(t)$
$r_1(t)$
$r_2(t)$
Single Antenna
Dynamic Delay Diversity

Fig. 10

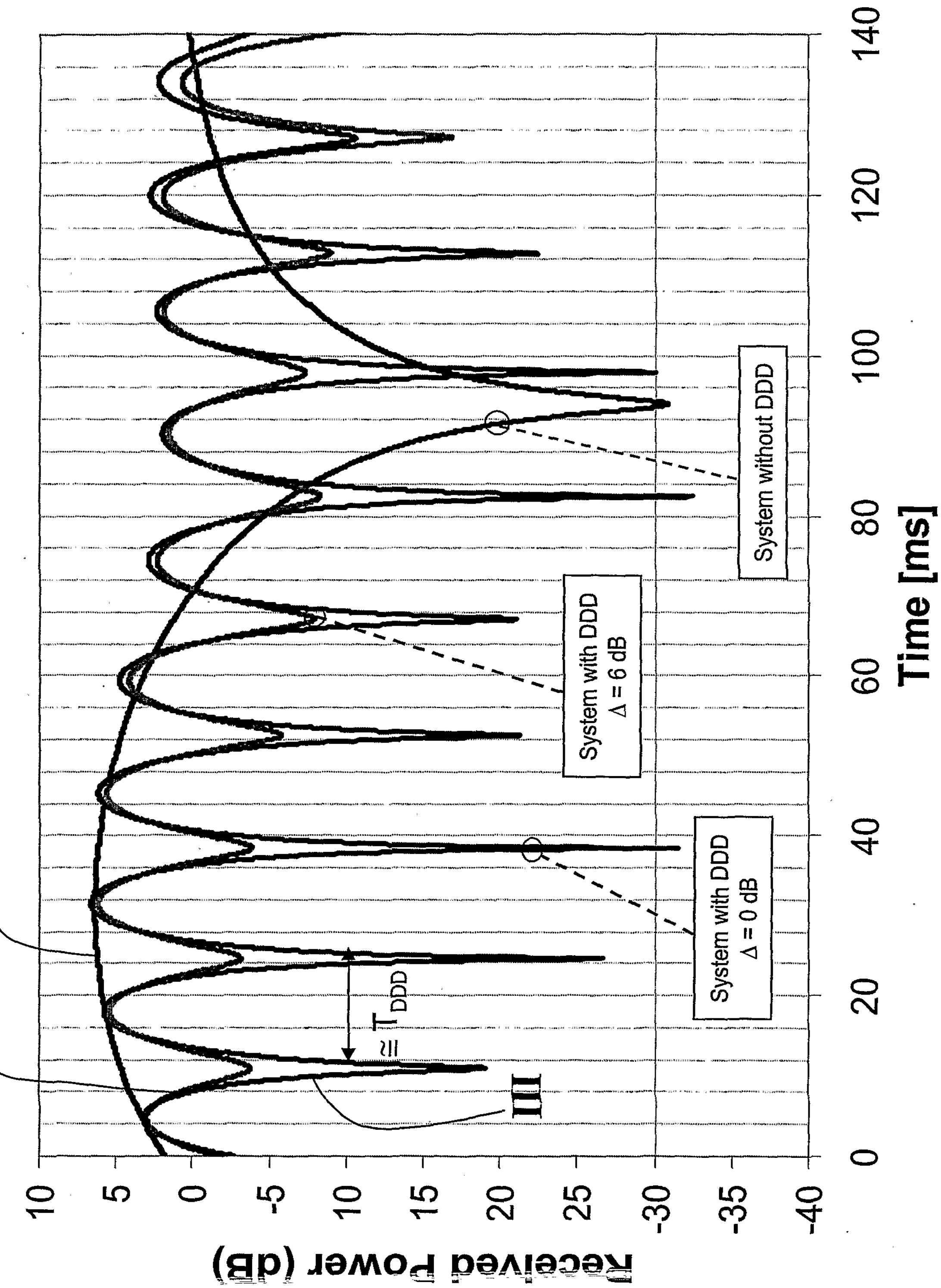

Received Power (dB)
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Time [ms]
0
20
40
60
80
100
120
140
I
II
III
≅ T_{DDD}
System with DDD
Δ = 0 dB
System with DDD
Δ = 6 dB
System without DDD

Fig. 11

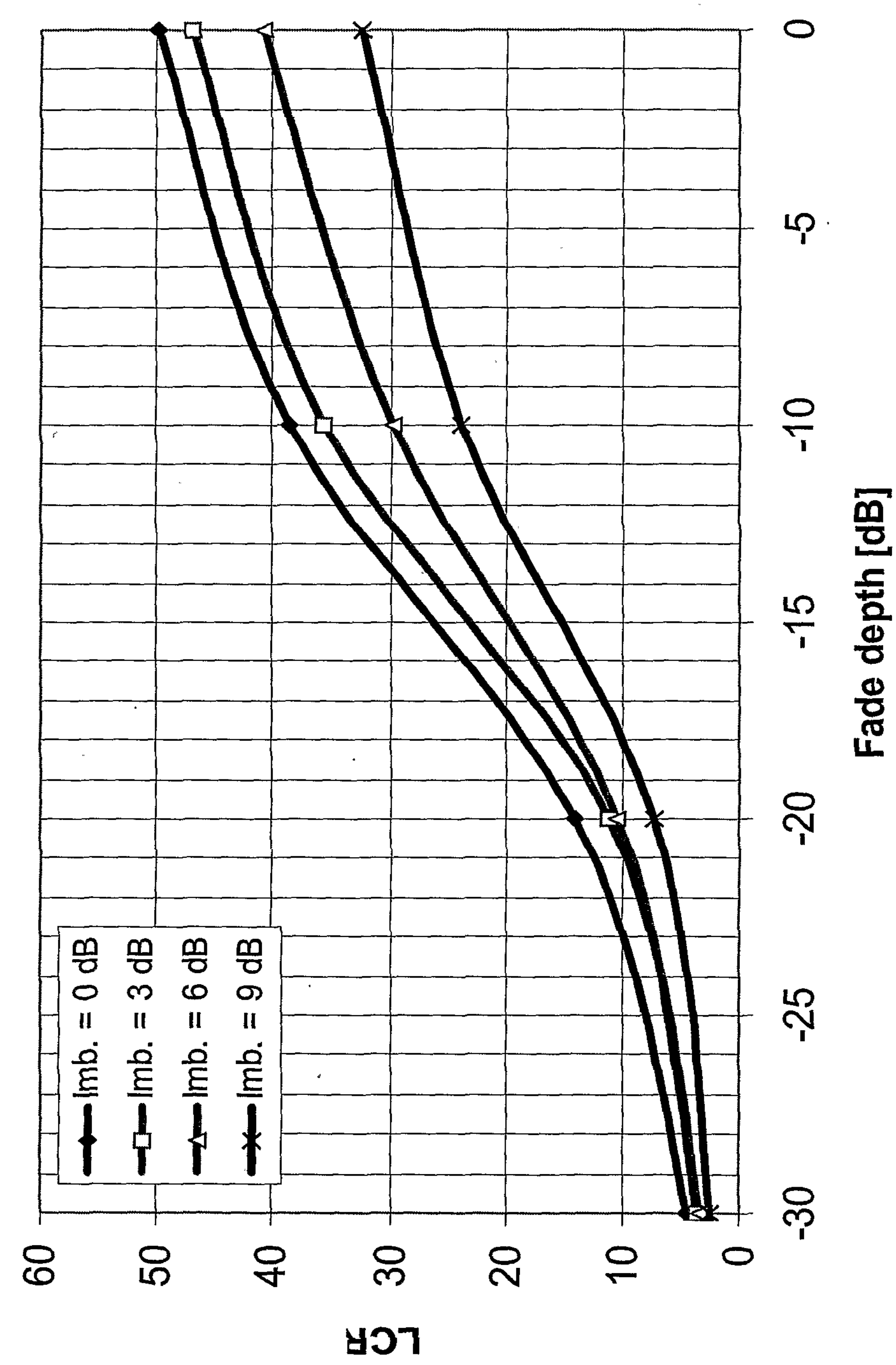

Imb. = 0 dB
Imb. = 3 dB
Imb. = 6 dB
Imb. = 9 dB
LCR
60
50
40
30
20
10
0
-30
-25
-20
-15
-10
-5
0
Fade depth [dB]

Fig. 12

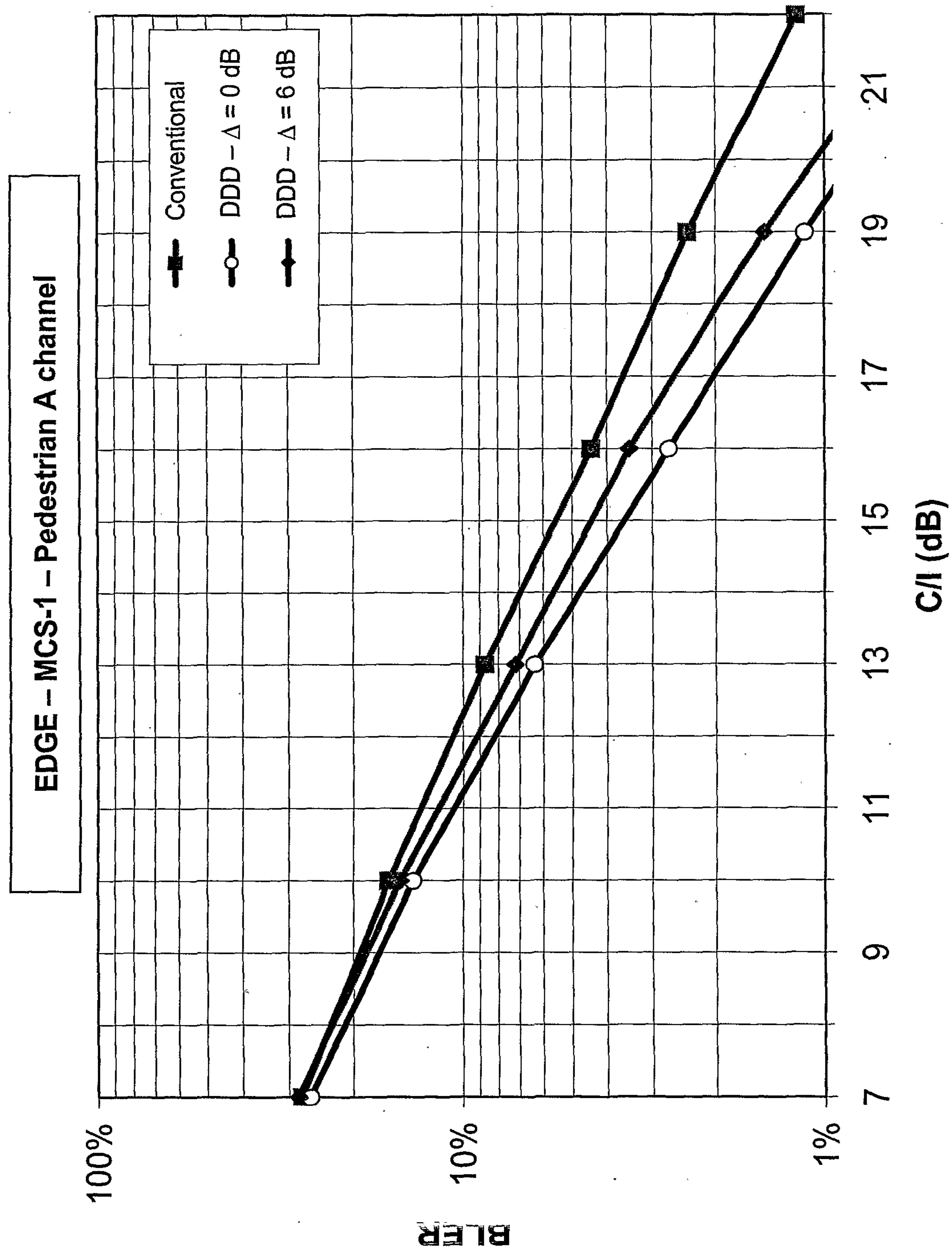

EDGE – MCS-1 – Pedestrian A channel
Conventional
DDD – Δ = 0 dB
DDD – Δ = 6 dB
100%
10%
1%
BLER
7
9
11
13
15
17
19
21
C/I (dB)

Fig. 13

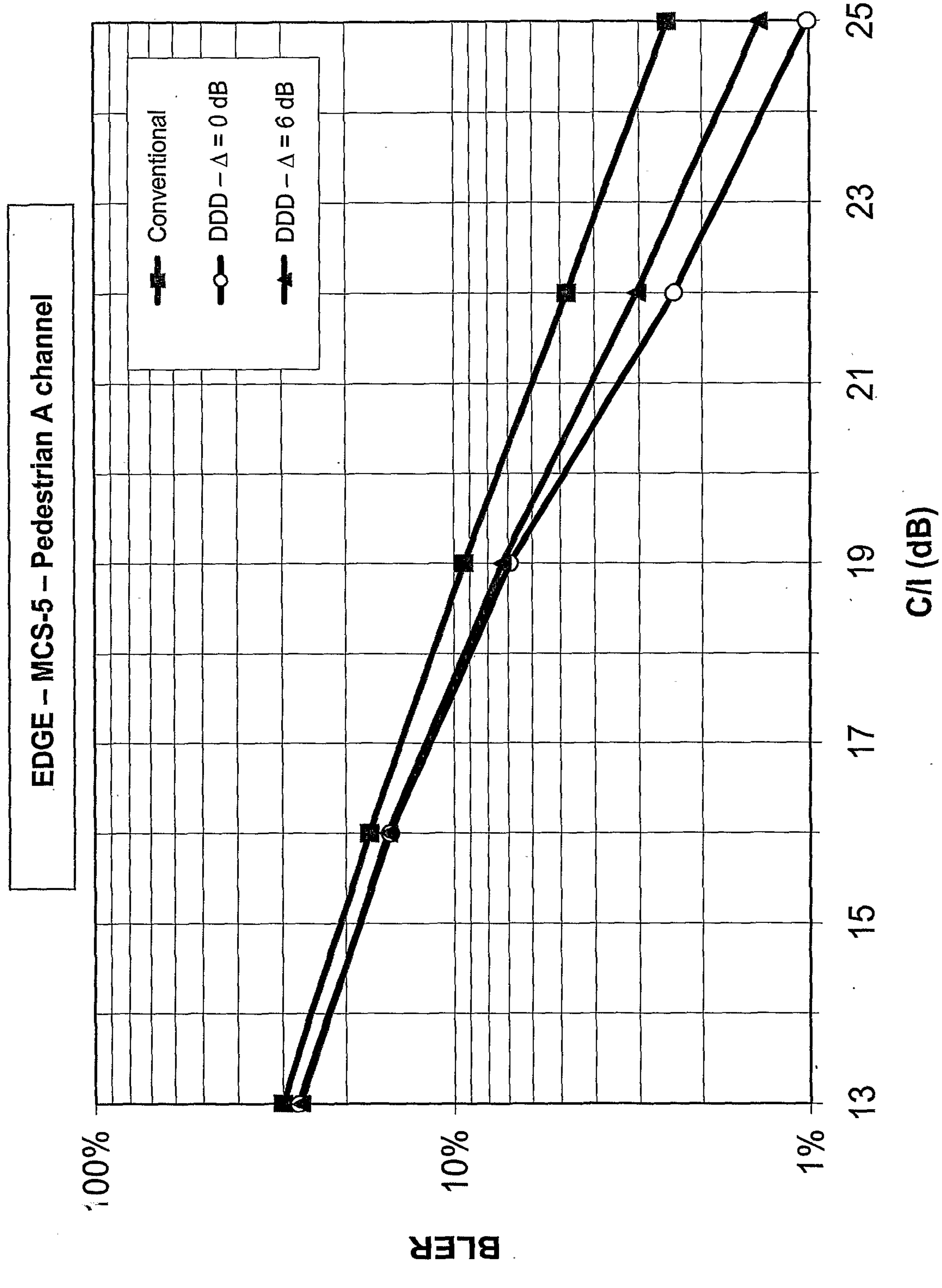
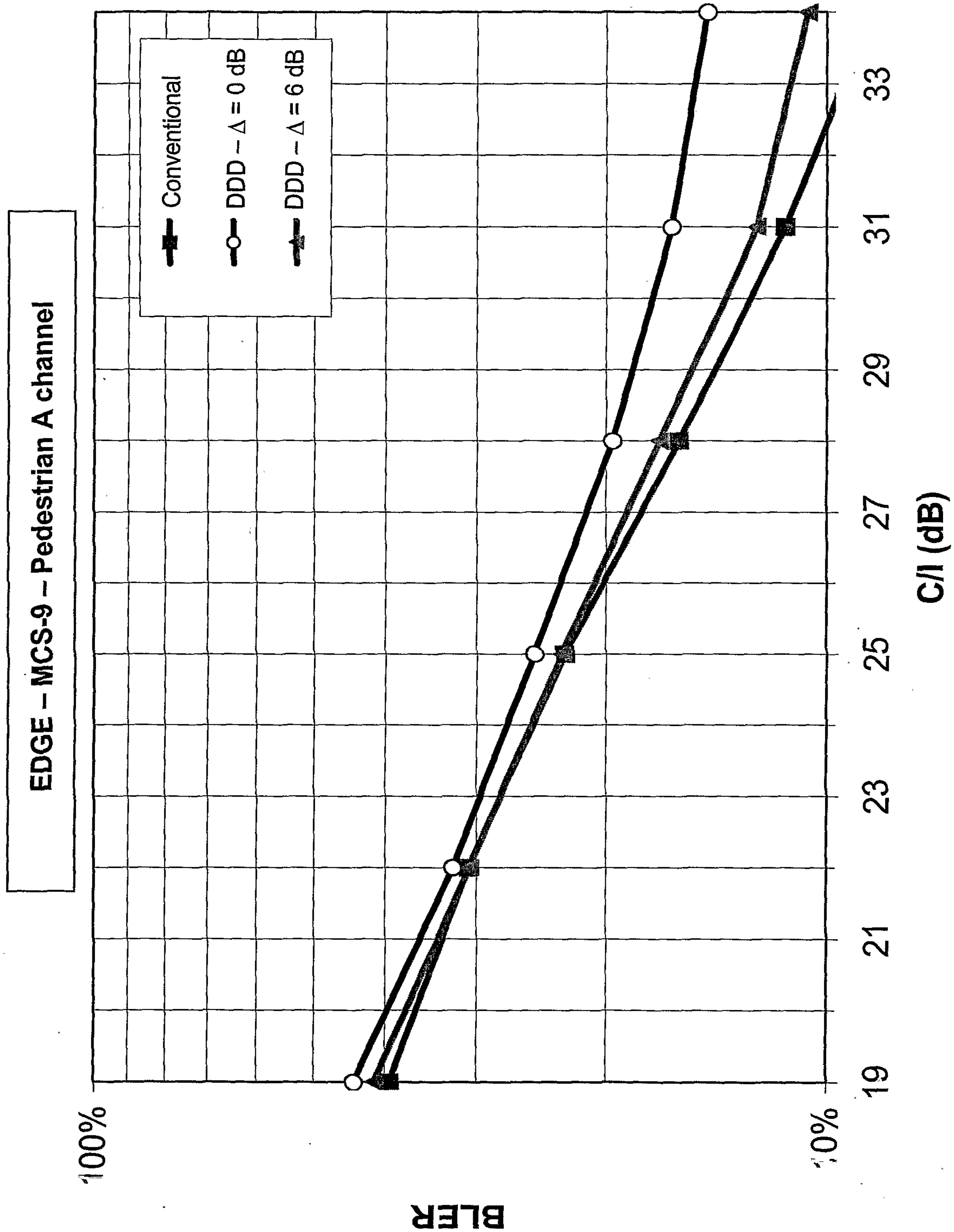

EDGE – MCS-5 – Pedestrian A channel
Conventional
DDD – Δ = 0 dB
DDD – Δ = 6 dB
100%
10%
1%
BLER
13
15
17
19
21
23
25
C/I (dB)

Fig. 14


EDGE – MCS-9 – Pedestrian A channel
Conventional
DDD – Δ = 0 dB
DDD – Δ = 6 dB
100%
10%
BLER
19
21
23
25
27
29
31
33
C/I (dB)

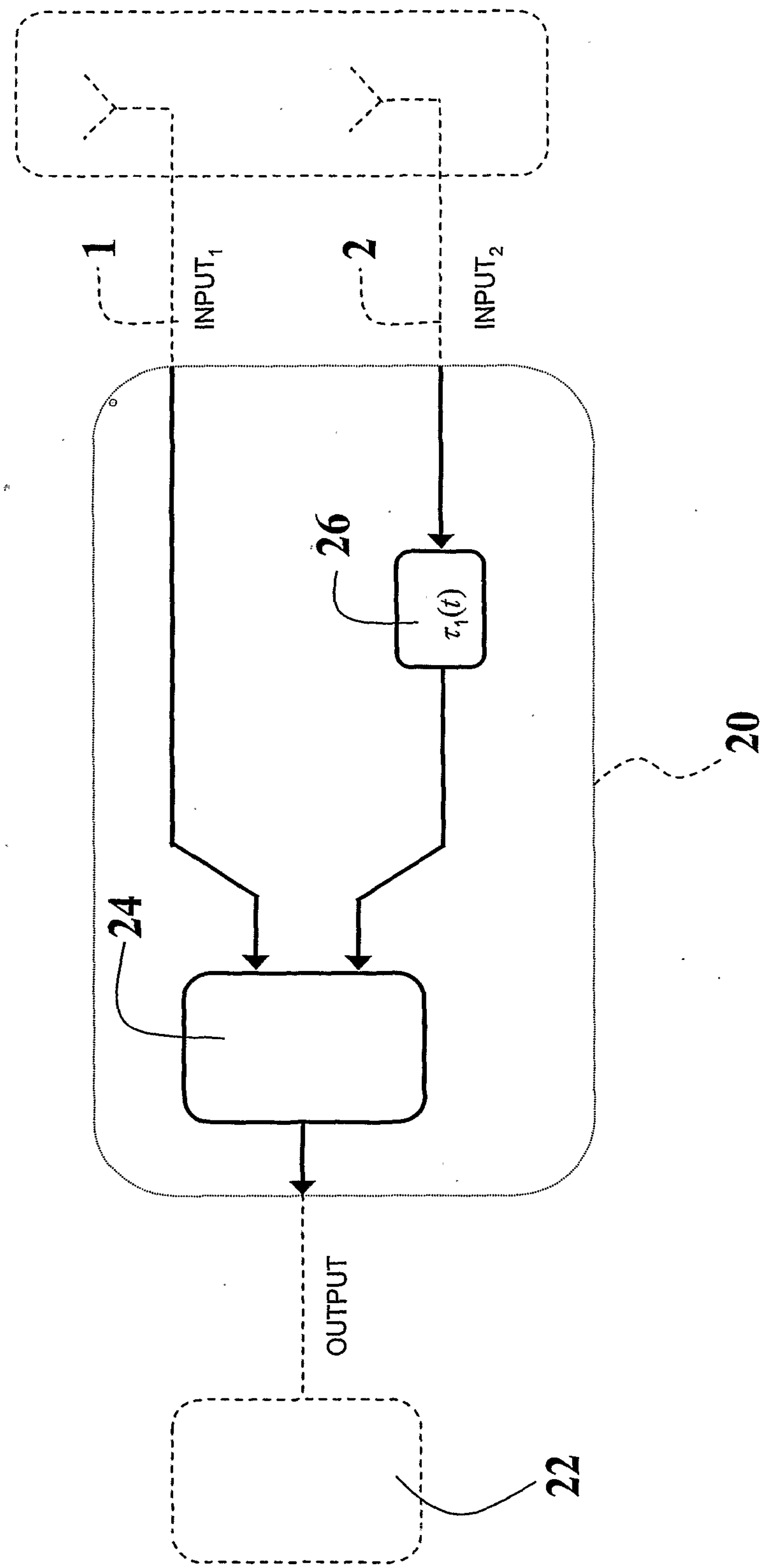
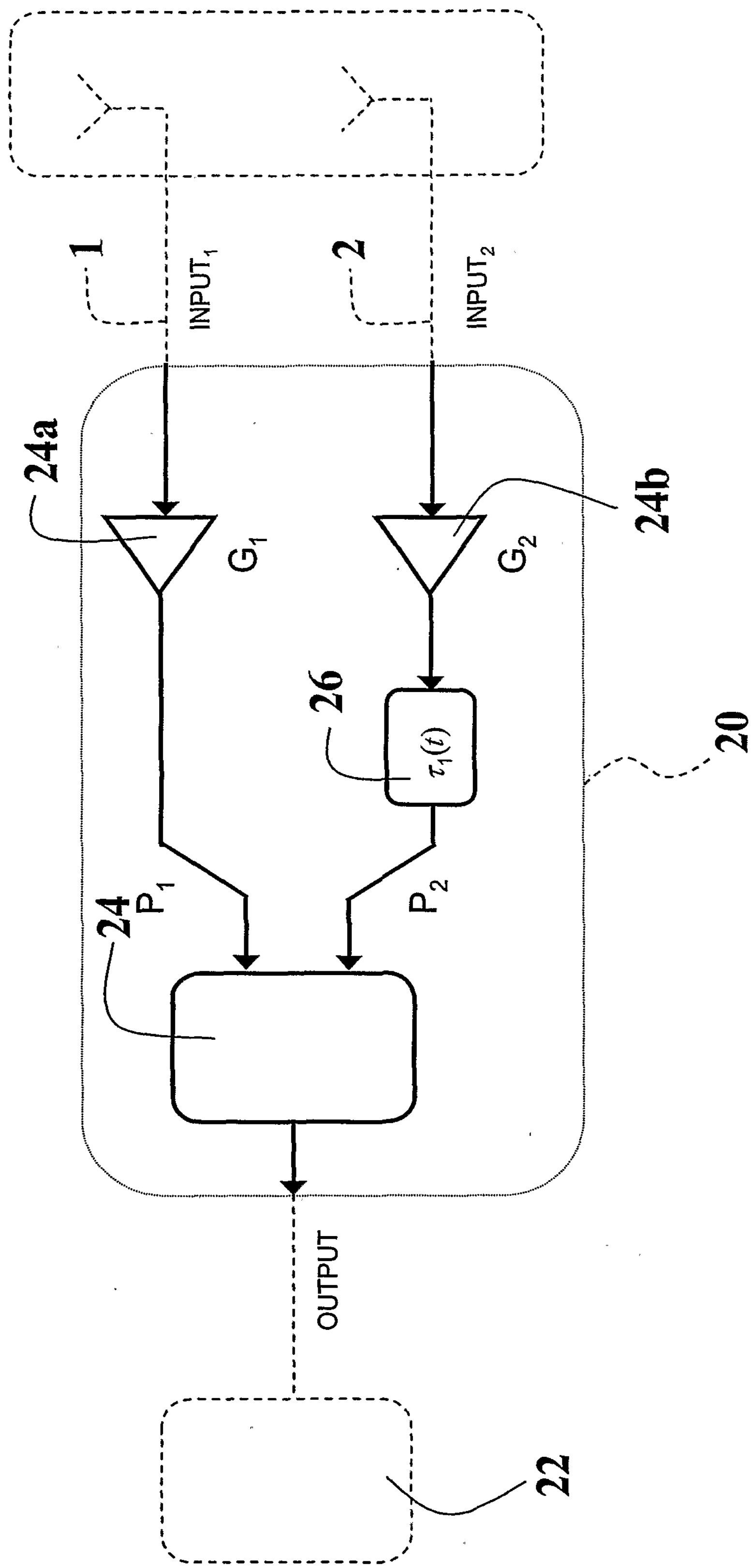


Fig. 15

Fig. 16



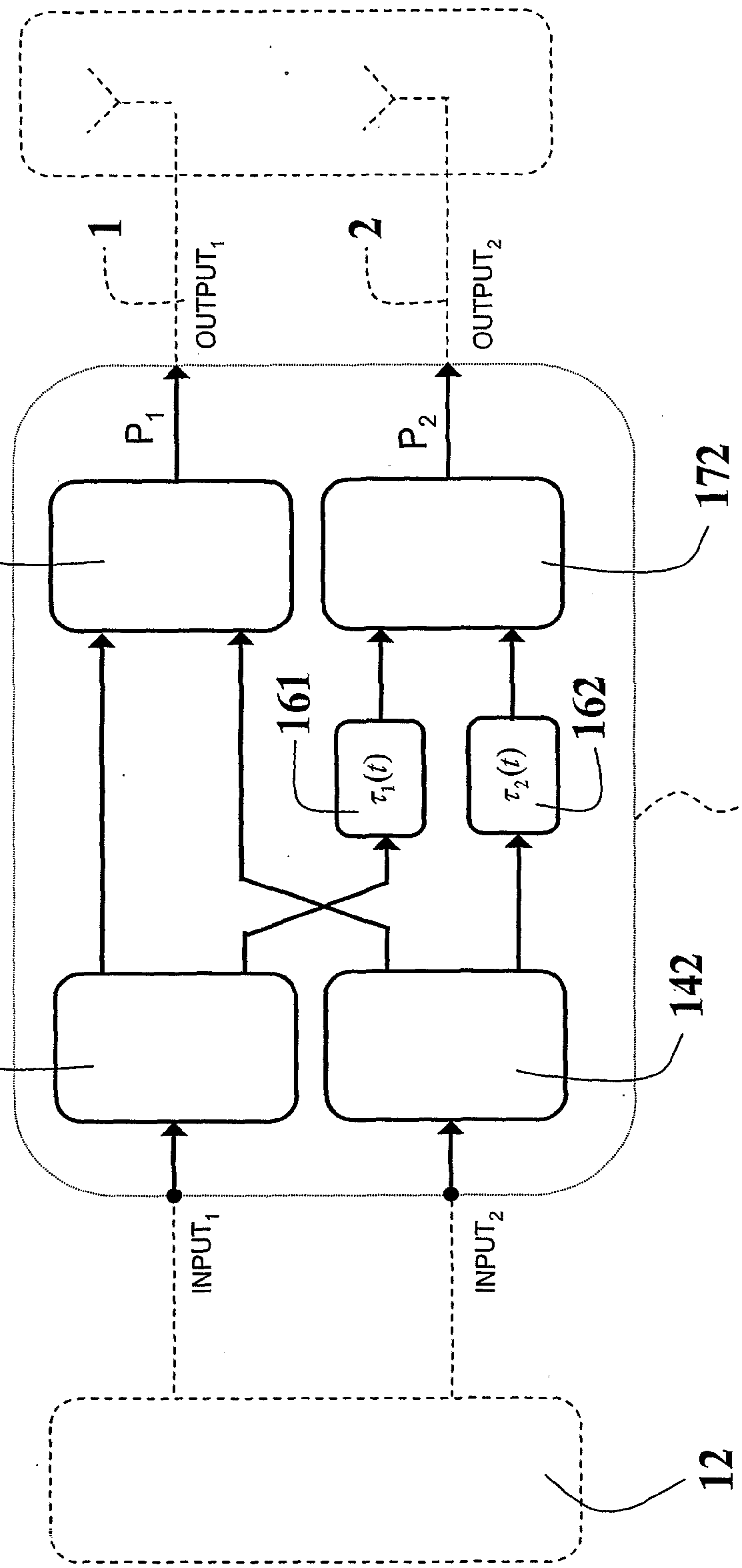

1
OUTPUT$_1$
2
OUTPUT$_2$
P$_1$
P$_2$
171
172
161
162
$\tau_1(t)$
$\tau_2(t)$
10
141
142
INPUT$_1$
INPUT$_2$
12

Fig. 17

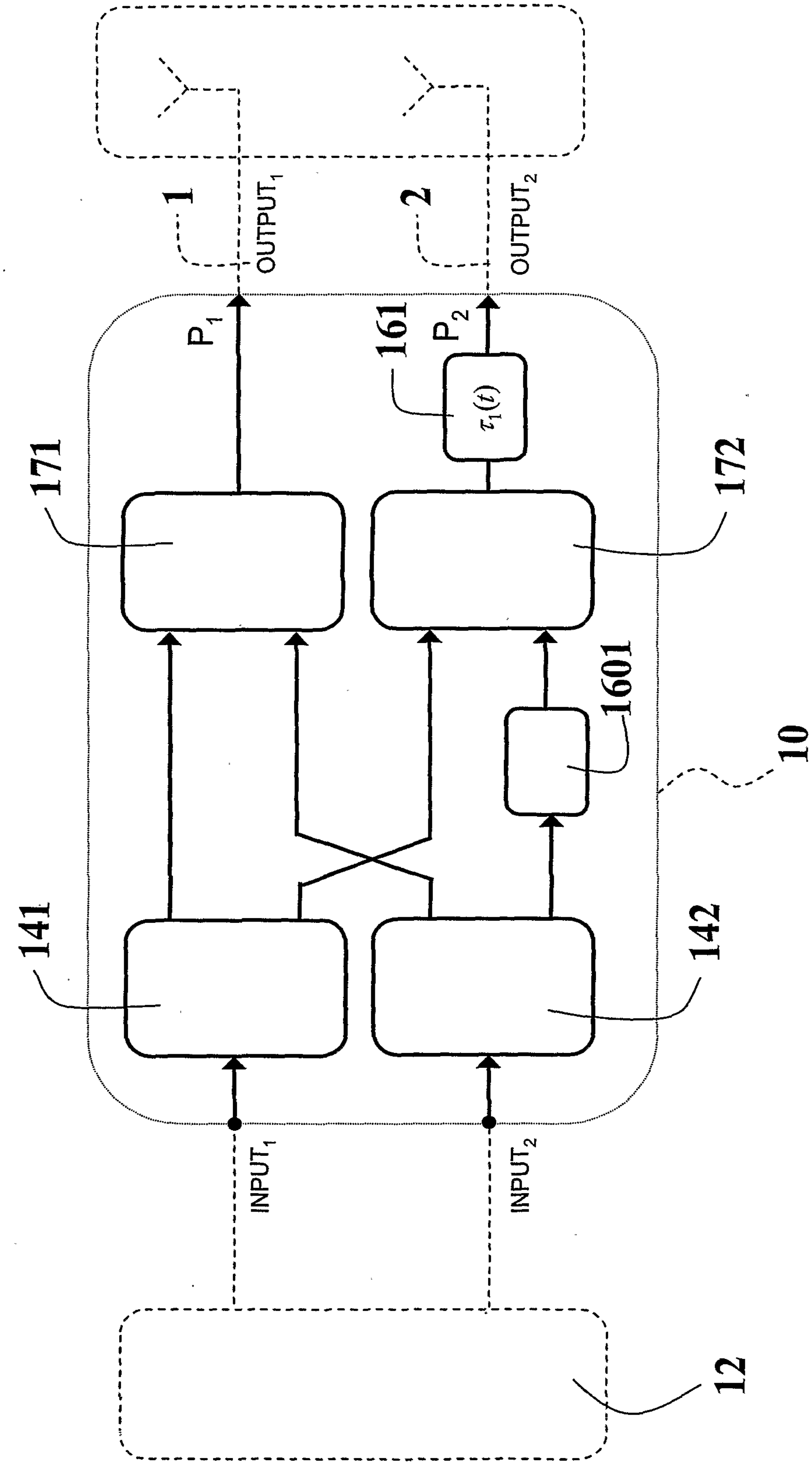
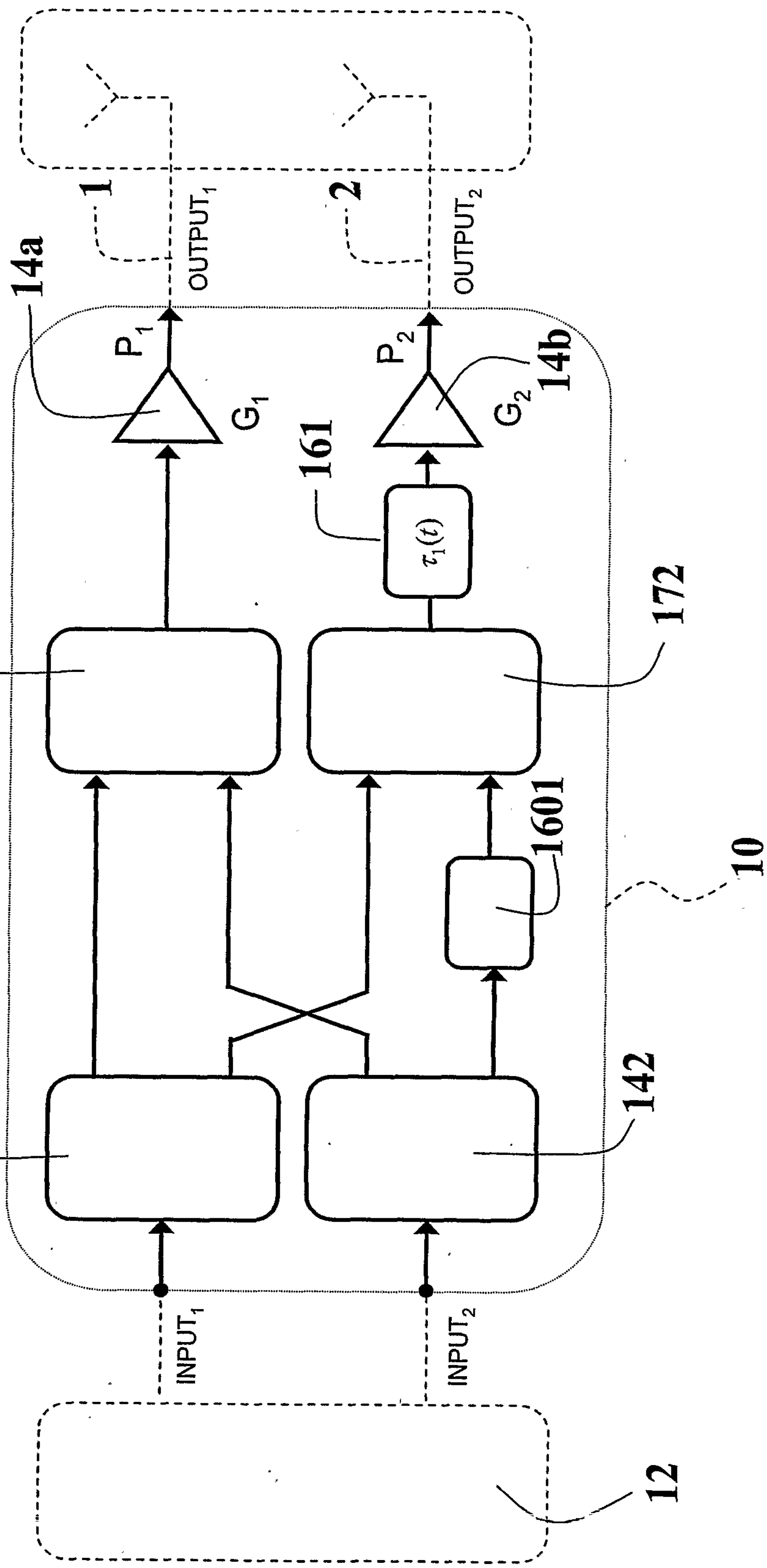

1
OUTPUT$_1$
2
OUTPUT$_2$
P$_1$
P$_2$
161
$\tau_1(t)$
171
172
1601
10
141
142
INPUT$_1$
INPUT$_2$
12

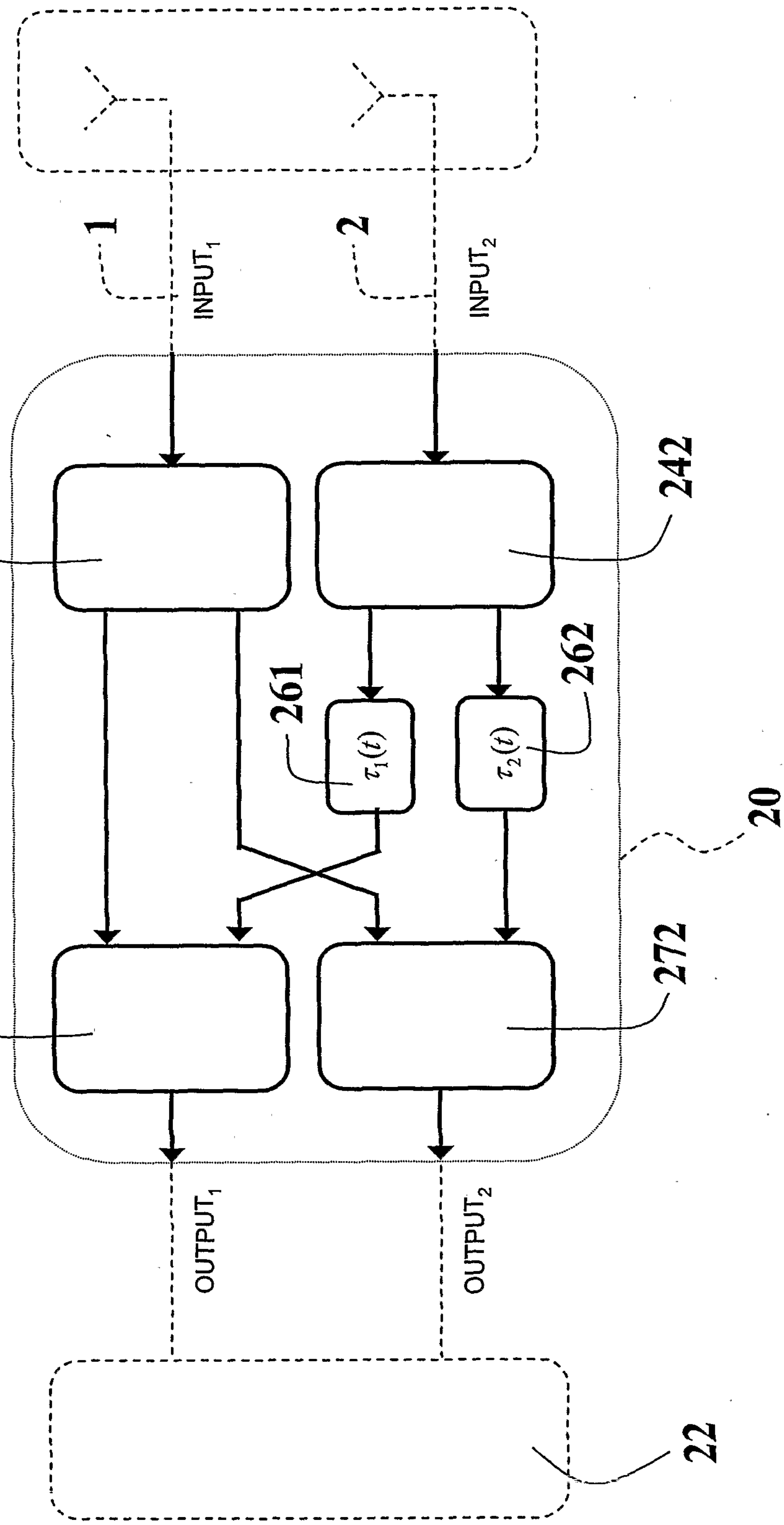
Fig. 18

Fig. 19



1
2
OUTPUT$_1$
OUTPUT$_2$
14a
14b
P$_1$
P$_2$
G$_1$
G$_2$
161
$\tau_1(t)$
171
172
1601
141
142
10
INPUT$_1$
INPUT$_2$
12

Fig. 20


1
2
INPUT$_1$
INPUT$_2$
241
242
261
262
$\tau_1(t)$
$\tau_2(t)$
271
272
20
OUTPUT$_1$
OUTPUT$_2$
22

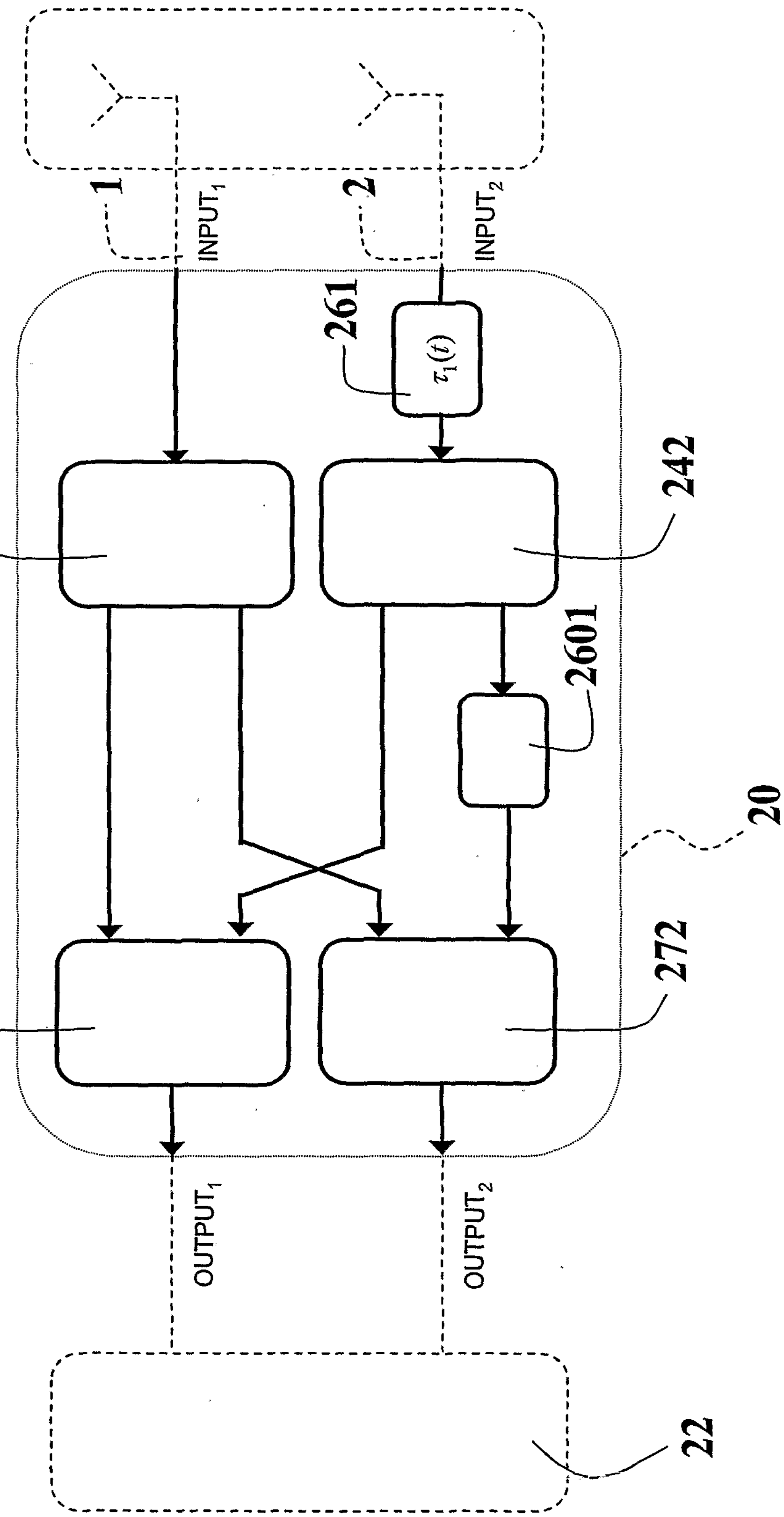

1
2
INPUT$_1$
INPUT$_2$
261
$\tau_1(t)$
241
242
2601
20
271
272
OUTPUT$_1$
OUTPUT$_2$
22

Fig. 21

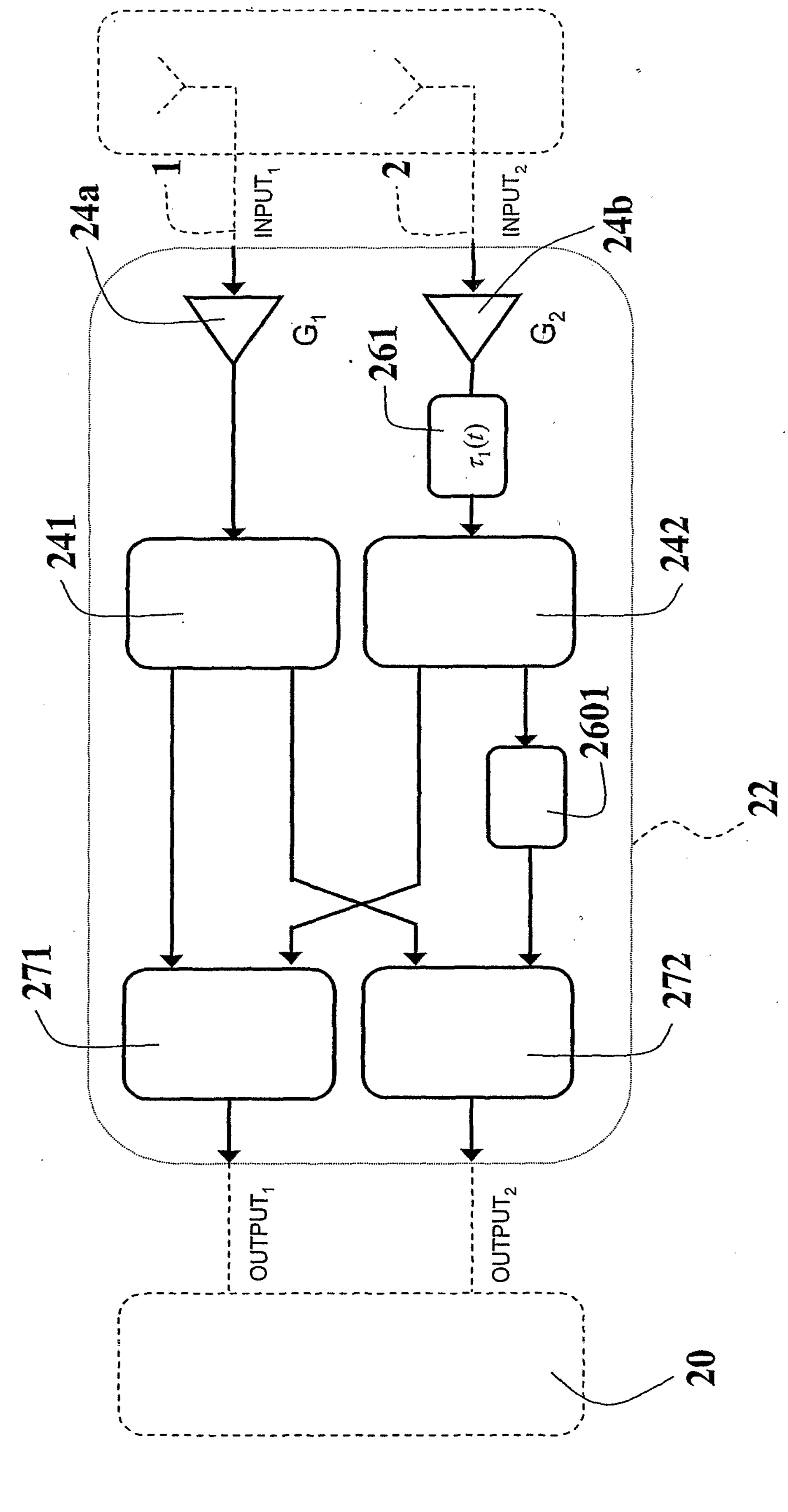

1
2
INPUT1
INPUT2
24a
24b
G1
G2
261
τ1(t)
241
242
2601
22
271
272
OUTPUT1
OUTPUT2
20

Fig. 22

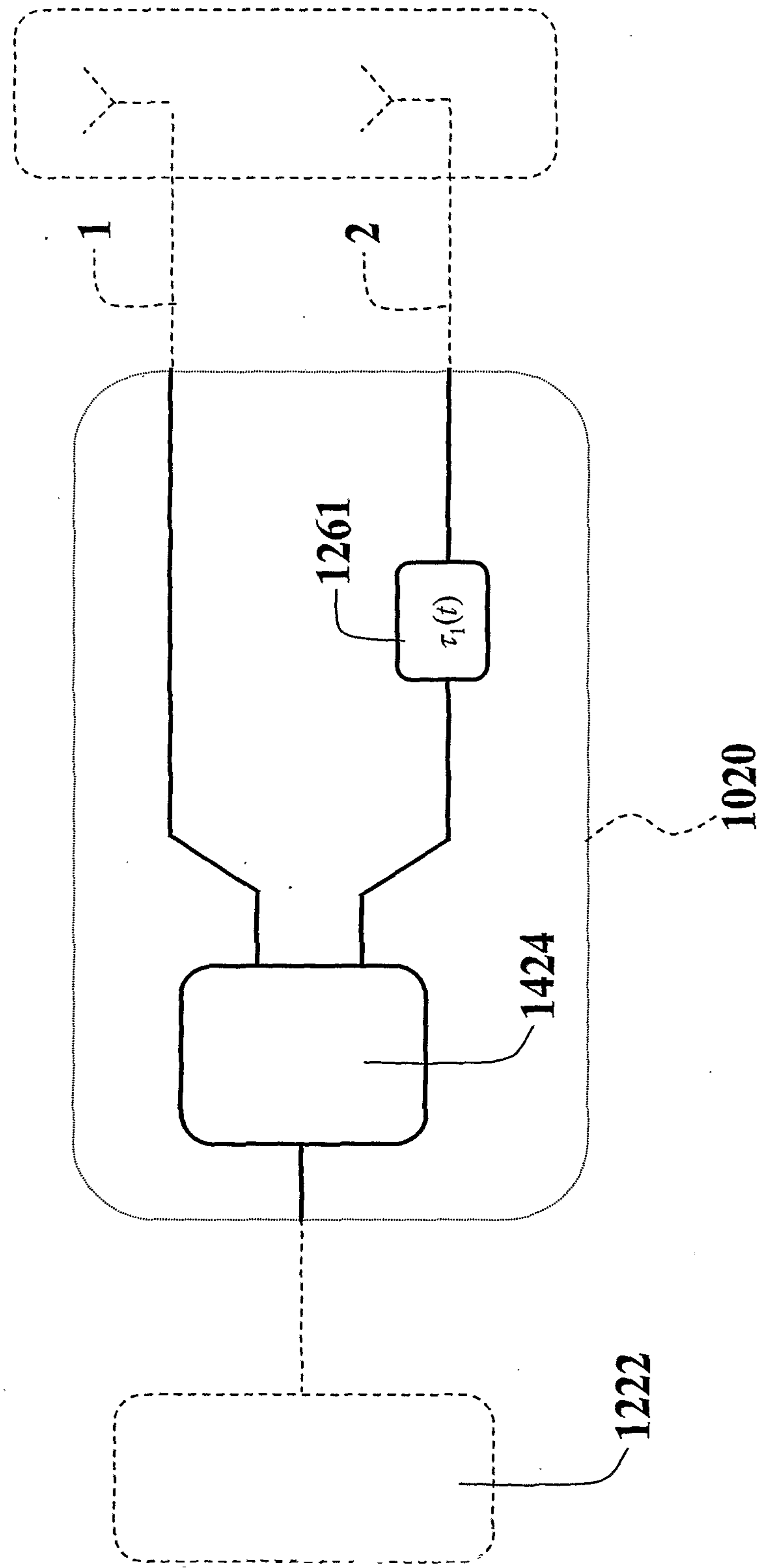


Fig. 23

Fig. 24

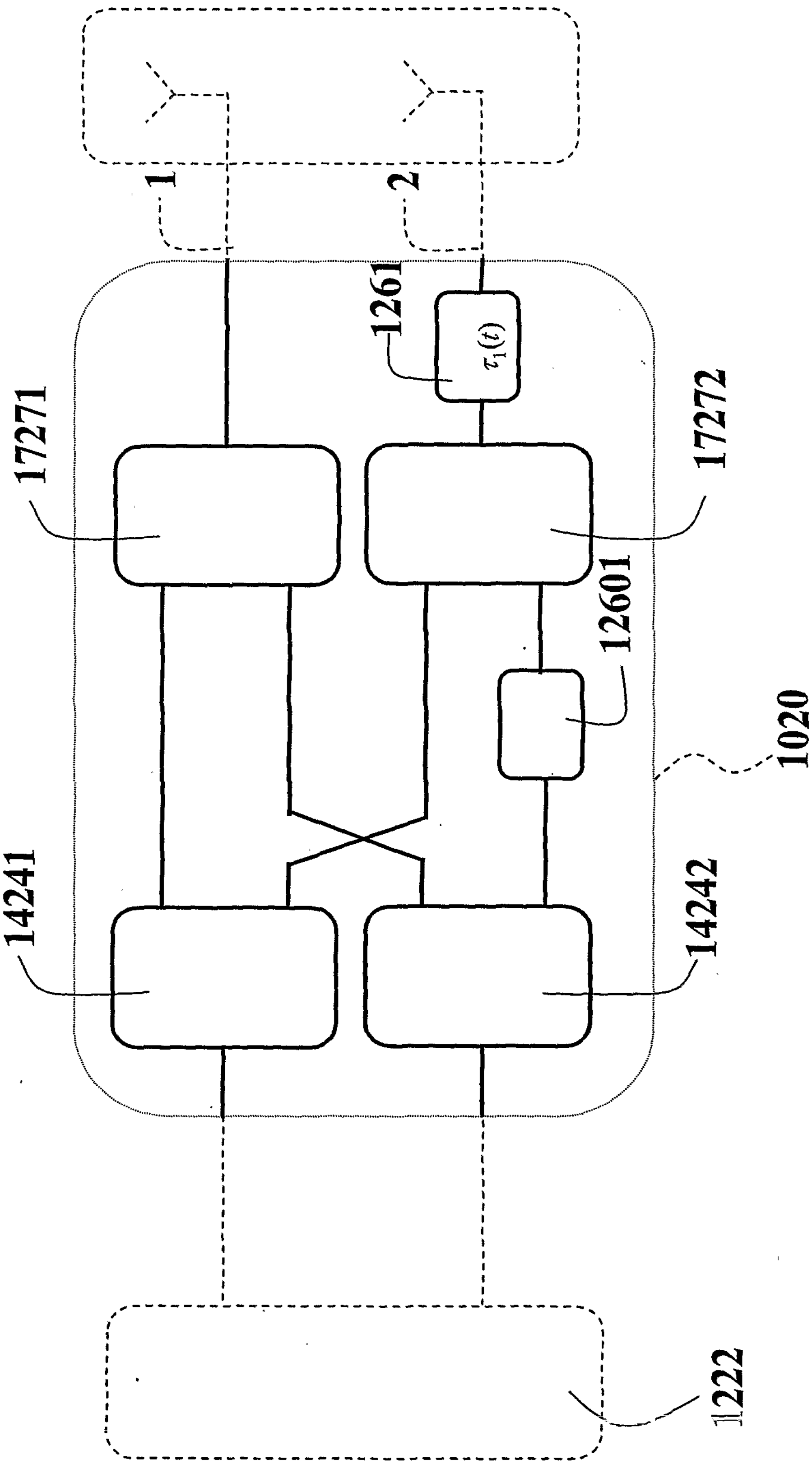
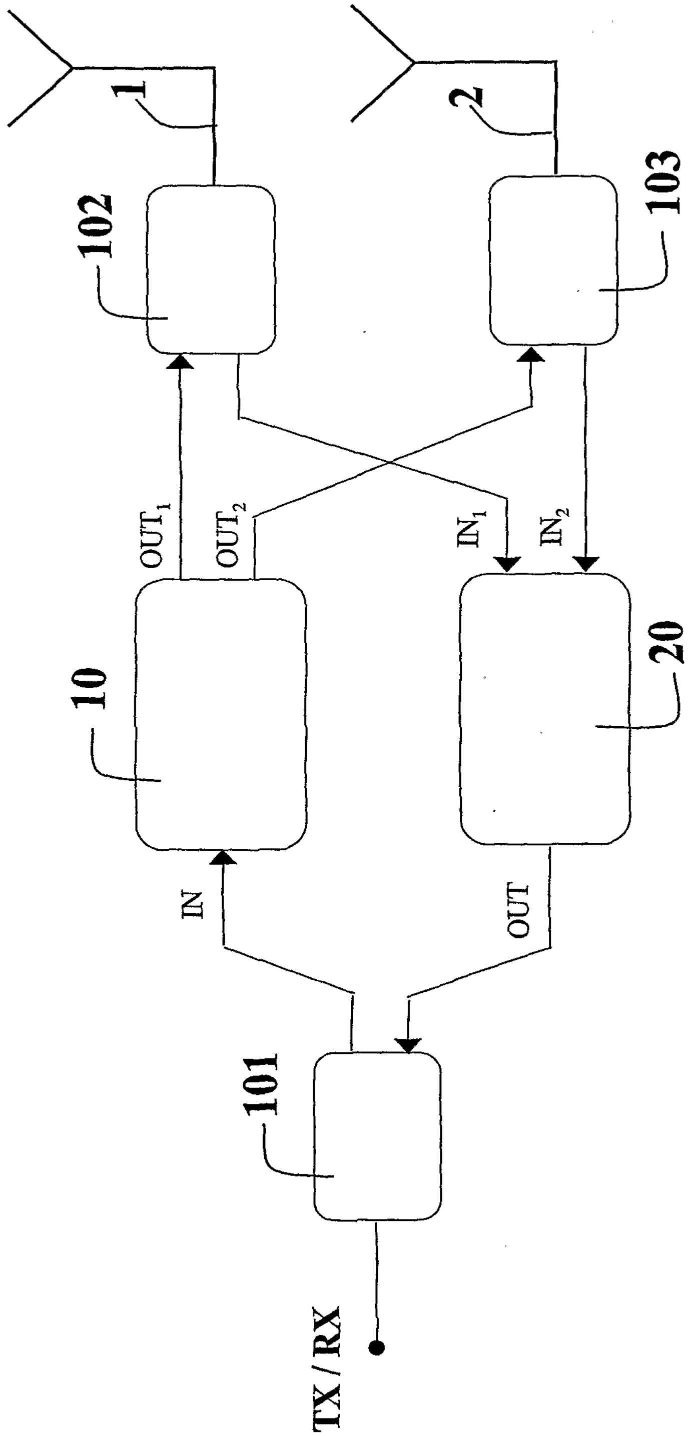


Fig. 25



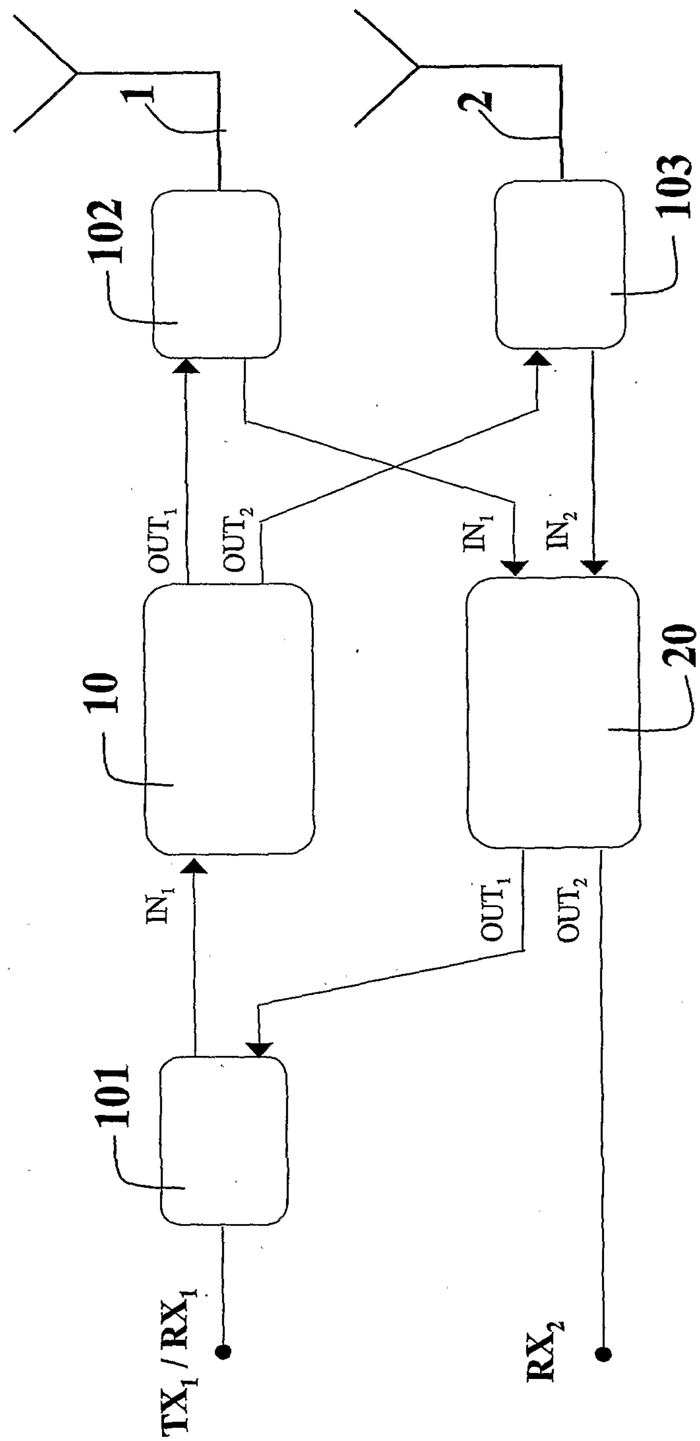
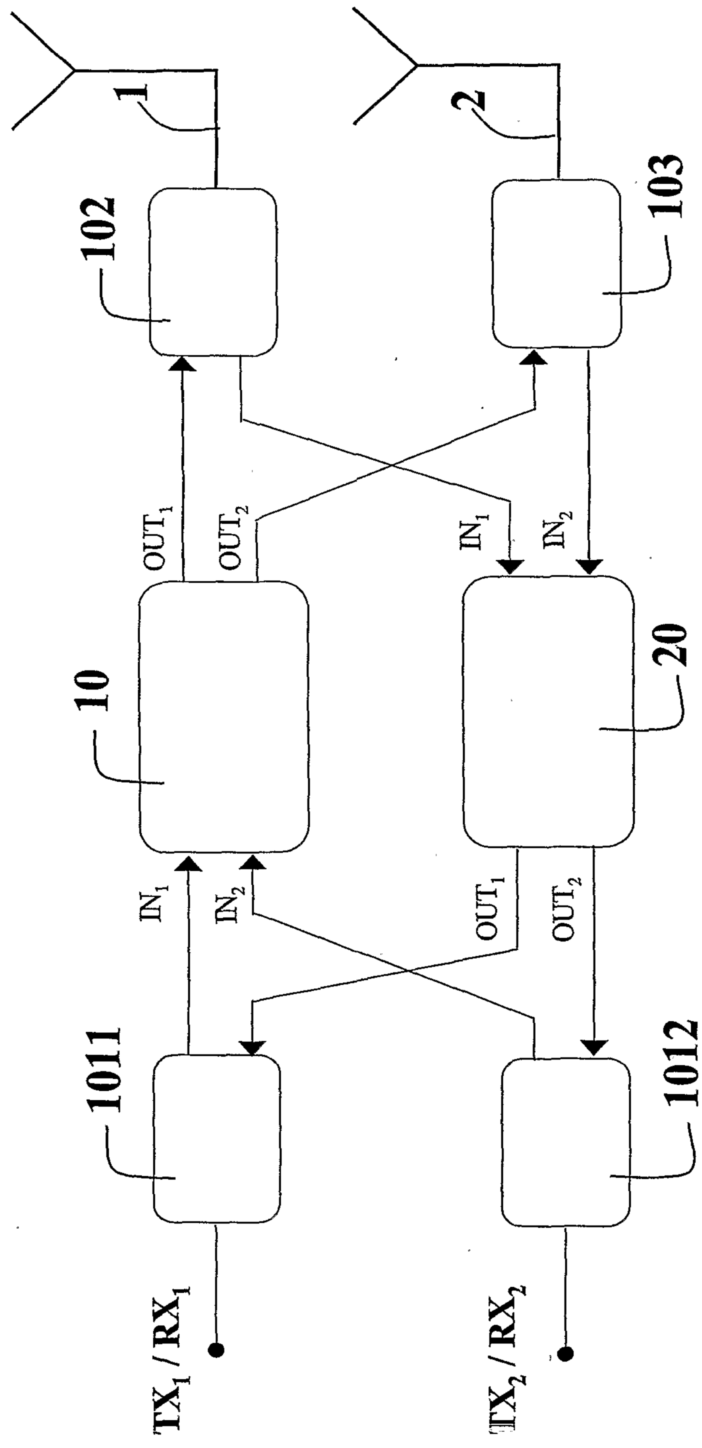


Fig. 26

Fig. 27


1
2
102
103
10
20
1011
1012
OUT_1
OUT_2
IN_1
IN_2
IN_1
IN_2
OUT_1
OUT_2
TX_1 / RX_1
TX_2 / RX_2