PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : H04L 27/36, H03F 1/32

A1

(11) International Publication Number: WO 93/18602

(43) International Publication Date: 16 September 1993 (16.09.93)

(21) International Application Number: PCT/EP93/00429

(22) International Filing Date: 25 February 1993 (25.02.93)

(30) Priority data:
9204496.5 2 March 1992 (02.03.92) GB

(71) Applicant *(for all designated States except US):* MOTOROLA LIMITED [GB/GB]; Jays Close, Viables Industrial Estate, Basingstoke RG22 4PD (GB).

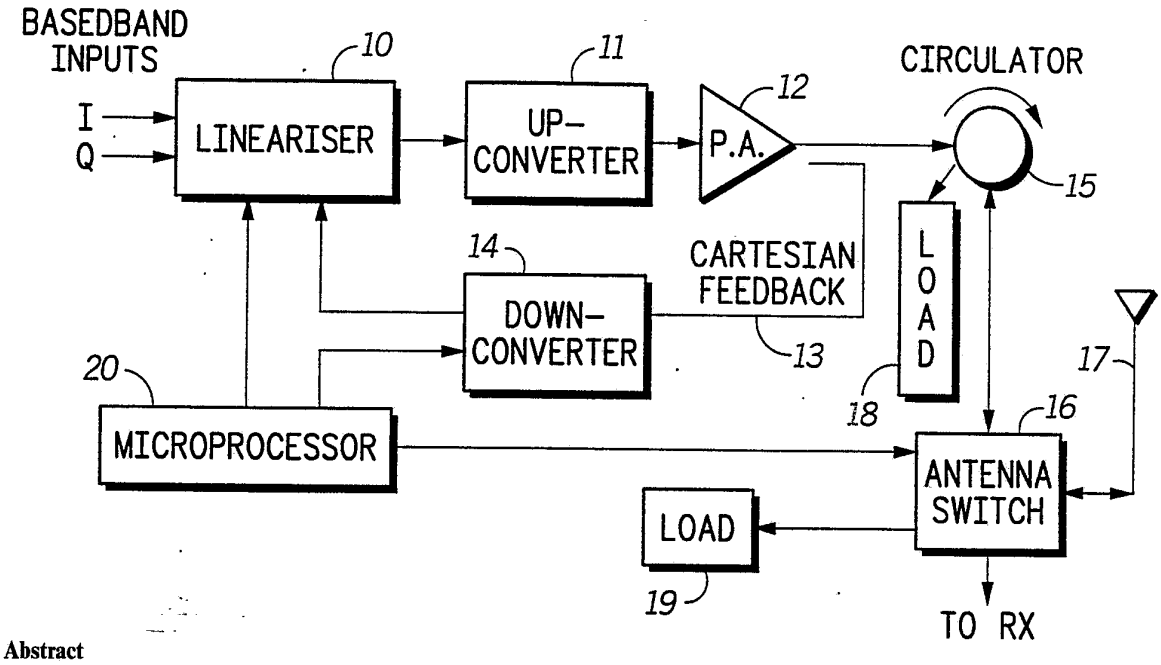
(72) Inventors; and
(75) Inventors/Applicants *(for US only) :* WRAY, Antony, John [GB/GB]; 33 Scarlatti Road, Hatch Warren, Basingstoke RG22 4LY (GB). VALENTINE, Stephen, Thomas [GB/GB]; 204 Birtten Road, Brighton Hill, Basingstoke RG22 4HR (GB).

(74) Agents: DUNLOP, Hugh, Christopher et al.; Motorola, European Intellectual Property Operations, Jays Close, Viables Ind. Est., Basingstoke, Hampshire RG22 4PD (GB).

(81) Designated States: AT, AU, BB, BG, BR, CA, CH, DE, DK, ES, FI, GB, HU, JP, KP, KR, LK, LU, MG, MN, MW, NL, NO, PL, RO, RU, SD, SE, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, SN, TD, TG).

Published
With international search report.

(54) Title: RADIO TRANSMITTER WITH LINEARIZATION TRAINING SEQUENCE



(57) Abstract

A radio transmitter circuit is provided comprising: a power amplifier coupled to an antenna for transmission of radio signals; linearizer means, such as a Cartesian feedback linearizer or a predistortion equalizer, for compensating for non-linearity in the power amplifier; means for inputting a training sequence to the linearizer means and outputting a training signal from the power amplifier resulting from the training sequence; and a feedback circuit for feeding the training signal output from the power amplifier back to the linearizer means to adjust the linearizer means and/or feedback circuit. Means are provided for inhibiting transmission of radio signals through the antenna while the training signal is being output from the power amplifier.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	**FR**	France	**MR**	Mauritania
AU	Australia	**GA**	Gabon	**MW**	Malawi
BB	Barbados	**GB**	United Kingdom	**NL**	Netherlands
BE	Belgium	**GN**	Guinea	**NO**	Norway
BF	Burkina Faso	**GR**	Greece	**NZ**	New Zealand
BG	Bulgaria	**HU**	Hungary	**PL**	Poland
BJ	Benin	**IE**	Ireland	**PT**	Portugal
BR	Brazil	**IT**	Italy	**RO**	Romania
CA	Canada	**JP**	Japan	**RU**	Russian Federation
CF	Central African Republic	**KP**	Democratic People's Republic of Korea	**SD**	Sudan
CG	Congo			**SE**	Sweden
CH	Switzerland	**KR**	Republic of Korea	**SK**	Slovak Republic
CI	Côte d'Ivoire	**KZ**	Kazakhstan	**SN**	Senegal
CM	Cameroon	**LI**	Liechtenstein	**SU**	Soviet Union
CS	Czechoslovakia	**LK**	Sri Lanka	**TD**	Chad
CZ	Czech Republic	**LU**	Luxembourg	**TG**	Togo
DE	Germany	**MC**	Monaco	**UA**	Ukraine
DK	Denmark	**MG**	Madagascar	**US**	United States of America
ES	Spain	**ML**	Mali	**VN**	Viet Nam
FI	Finland	**MN**	Mongolia		

Radio Transmitter with Linearization Training Sequence

Field of the Invention

This invention relates to a radio transmitter having a power amplifier incorporating linearization which uses a training sequence.

Background to the Invention

Continuing pressure on the limited radio spectrum available for radio communication systems is focusing attention on the development of spectrally efficient linear modulation schemes. Recent studies of digital mobile radio systems propose the use of linear modulation methods such as QPSK and $\pi/4$ QPSK which are considered to improve spectrum efficiency. The schemes, however, require a highly linear power amplifier or distortion will lead to intermodulation products, i.e. adjacent channel interference or "splatter". In the field of private mobile radio, stringent restrictions are placed on out-of-band emissions.

There is a demand for a strict linearity performance in power amplifiers.

Summary of the Prior Art

A known linearization method in power amplifiers particularly suitable in the private mobile radio environment is that of Cartesian feedback, the linearizing of the power amplifier requires the accurate setting of the phase and amplitude of a feedback signal. In such known systems, a training sequence is transmitted, during which time the operation of the Cartesian feedback loop, is measured and the gain and phase are adjusted. The pahse is adjusted to ensure stability and the gain is monitored and adjusted to optimise efficiency and avoid saturation. The training sequence is ignored at the receiver.

The problem with such known systems is that a finite amount of time is allocated to the training sequence to be transmitted. In time division multiple access systems, the allocating of a finite amount of air time for training is a particularly costly overhead which reduces overall system throughput.

It is also a problem that, during the training sequence, a search is made for the optimum amplitude setting of the amplifier for maximum efficiency of operation. During this search, the amplifier is pushed into a saturation or "clip" mode at which linearity is lost and out of band spectral emissions are generated.

Summary of the Invention

According to the present invention, a radio transmitter circuit is provided comprising: a power amplifier coupled to an antenna for transmission of radio signals; linearizer means for compensating for non-linearity in the power amplifier; means for inputting a training sequence to the linearizer means and outputting a training signal from the power amplifier resulting from the training sequence; and a feedback circuit for feeding the training signal output from the power amplifier back to the linearizer means to adjust the linearizer means and/or feedback circuit; characterized by means for inhibiting transmission of radio signals through the antenna while the training signal is being output from the power amplifier.

The means for inhibiting preferably comprise switching means and a load, for switching the signal from the power amplifier to the load when the training sequence is being output and for switching the signal to the antenna at the end of the training sequence.

A circulator may be provided coupled between the output of the power amplifier and the switching means and coupled to the load, for directing the output of the power amplifier to the switching means and for directing signals reflected from the switching means to the load. In another embodiment, the switching means is a multi-way switch coupled to the output

of the power amplifier and to the antenna and the load, for selectively switching the signal from the output of the power amplifier to the antenna and the load.

Receive circuitry may be provided coupled to the switching means and a multi-way switch coupled to the output of the power amplifier and to the receive circuitry, for selectively switching the output from the power amplifier to the antenna and a received signal from the antenna to the receive circuitry.

Switching means control means are preferably provided for causing the switching means to switch the signal to the antenna in a gradual manner to avoid splatter.

The linearizer means may be a Cartesian feedback linearizer or a predistortion linearizer.

The feedback circuit preferably provides open loop phase adjustment followed by closed loop gain adjustment.

A preferred embodiment of the invention will now be described, by way of example, with reference to the drawings.

Brief Description of the Drawings

Fig. 1 shows a block diagram of a transmitter in accordance with the preferred embodiment of the invention.

Fig. 2 shows the timing format of certain operations of the preferred embodiment of the invention in a time division multiple access scheme.

Fig. 3 shows a suitable training sequence for the operations represented in Fig. 2.

Detailed Description of Drawings

Referring to Fig 1 there is shown a RF power amplifier comprising a linearizer 10, an upconverter 11, a power amplifier 12, a feedback path 13, and a down converter 14. Connected to the output of the power amplifier 12 is a circulator 15 connected to an antenna switch 16 connected to an antenna 17. The first and second loads 18 and 19 are shown connected to the circulator 18 and the antenna switch 16 respectively. As is described below, it is not necessary

to include both loads 18 and 19, but these represent options. A microprocessor 20 controls the linearizer 10 and antenna switch 16 and the phase of the downconverter 14. Details of an appropriate linearizer are described in the paper "Transmitter Linearization using Cartesian Feedback for Linear TDMA Modulation" by M Johansson and T Mattsson 1991 IEEE.

The operation of the circuit will be described with reference to Fig 2, in which there is shown four transmit time slots (not to scale). The example will be described where transmit timeslot 2 is selected for transmission.

At a moment in time A in advance of the timeslot, microprocessor 20 causes antenna switch 16 to switch to the load 19. At point B, a training sequence is input to the linearizer 10 in the form of I and Q samples and is transmitted by the power amplifier 12. This training sequence is described in US Patent No. 5066923 of Motorola Inc. and illustrated in Fig. 3. The transmitted signal is fed directly to the load 19. The load is a matched resistor network with a heat sink if necessary. During this period, there is Cartesian feedback on feedback loop 17 which is downconverted in demodulator 14 and a phase comparison is made in the linearizer 10 between the input signal and the feedback signal. A phase shift adjustment is made in the downconvertor 14 in the feedback path so as to optimise the loop phase around the loop to ensure stable operation. When the phase is optimised, the feedback loop provided by feedback path 13 can be closed with the input to the linearizer to provide closed loop operation. Until the phase has been optimised, closed loop operation cannot commence, because of the likelihood of oscillation. Once the phase has been adjusted, the gain in the linearizer 10 can be adjusted for maximum efficiency of operation, by increasing the gain until the amplifier enters the "clip" mode. Once this threshold has been detected, the limit of operation of the overall amplifier is set and the amplifier is ready to transmit voice or data. The detecting of this threshold and backing off of the amplifier at the clip point is described

in US Patent Application No. 606679, attached hereto as Annex 1.

At point C, a signal is sent from the microprocessor 12 to the antenna switch 16 in the form of a raised cosine ramp or other suitable ramp signal to gradually open the antenna switch and allow the signal from the power amplifier to be transmitted to the antenna 17. At point D, the antenna switch is fully opened and the voice or data to be transmitted is transmitted on the time slot through the antenna.

As an alternative to using antenna switch 16 and load 19, circulator 15 and load 18 can be used in conjunction with antenna switch 16 and, when antenna switch 16 is closed to the antenna, the training sequence transmitted from the power amplifier 12 is reflected back from the antenna switch 16 to the circulator 15 from which it passes to the load 18.

As an alternative to using Cartesian feedback, a pre-distortion type of linearizer can be used as described in the paper "Linear Amplification Technique for Digital Mobile Communications" by Y Nagata 1989 IEEE. In this case the downconverter 14 includes a demodulator and instead of setting the gain and phase of the loop, the input signal to the linearizer is distorted.

Thus, there has been described an arrangement in which training is carried out in a TDMA timeslot prior to that allocated for transmission. Training of the power amplifier is performed "off-air" by dissipating the transmit energy into a load. Thus, no additional "on-air" time needs to be set aside for training. The transmitter is isolated from the antenna whilst training. This avoids spurious emissions into adjacent channels being transmitted on the transmitter.

The antenna switch 16 is opened at the end of the training sequence (which typically has a duration of 1.2ms), but the antenna switch can equally be opened as soon as the clip point has been determined and the gain has been backed off. It is of no consequence that the end of the training sequence may be transmitted, provided that there is no splatter onto the adjacent channel and provided that the transmission corresponds to the timeslot allocated.

In place of a training seqence as shown in Fig. 3, other training sequences can be devised and indeed, almost any sequence of data could be used, the important feature being that the data fed back can be compared with the data input to measure the loop phase and/or gain. User data or voice should not be used as it will be lost into the load 18 or 19.

Instead of a load 18 or 19, an adjacent channel receiver can be used to receive the training sequence, as described in copending patent application No ..... entitled "R.F. Power Amplifier with Linearization" filed on the same date as the present application.

Claims

1. A radio transmitter circuit comprising:

a power amplifier coupled to an antenna for transmission of radio signals;

linearizer means for compensating for non-linearity in the power amplifier;

means for inputting a training sequence to the linearizer means and outputting a training signal from the power amplifier resulting from the training sequence; and

a feedback circuit for feeding the training signal output from the power amplifier back to the linearizer means to adjust the linearizer means and/or feedback circuit; characterized by

means for inhibiting transmission of radio signals through the antenna while the training signal is being output from the power amplifier.

2. A radio transmitter according to claim 1, wherein the means for inhibiting comprises switching means and a load, for switching the signal from the power amplifier to the load when the training sequence is being output and for switching the signal to the antenna at the end of the training sequence.

3. A radio transmitter according to claim 2, further comprising a circulator coupled between the output of the power amplifier and the switching means and coupled to the load, for directing the output of the power amplifier to the switching means and for directing signals reflected from the switching means to the load.

4. A radio transmitter according to claim 2, wherein the switching means is a multi-way switch coupled to the output of the power amplifier and to the antenna and the load, for selectively switching the signal from the output of the power amplifier to the antenna and the load.

5. A radio transmitter according to claim 2, 3 or 4, further comprising receive circuitry coupled to the switching means is a multi-way switch coupled to the output of the power amplifier and to the receive circuitry, for selectively switching the output from the power amplifier to the antenna and a received signal from the antenna to the receive circuitry.

6. A radio transmitter according to any one of claims 2 to 5, comprising switching means control means for causing the switching means to switch the signal to the antenna in a gradual manner to avoid splatter.

7. A radio transmitter according to any one of the preceding claims wherein the linearizer means is a Cartesian feedback linearizer.

8. A radio transmitter according to any one of the preceding claims wherein the linearizer means is a predistortion linearizer.

9. A radio transmitter according to any one of the preceding claims wherein the feedback circuit provides open loop phase adjustment followed by closed loop gain adjustment.

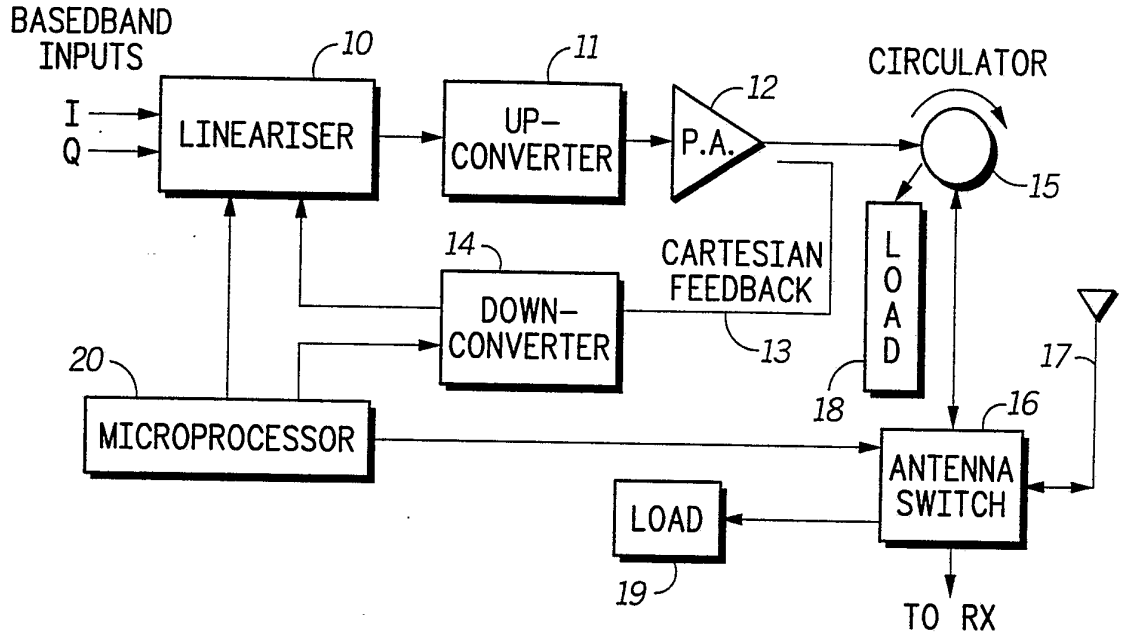

BASEDBAND INPUTS
I
Q
LINEARISER
10
UP-CONVERTER
11
P.A.
12
CIRCULATOR
15
DOWN-CONVERTER
14
CARTESIAN FEEDBACK
13
LOAD
18
17
20
MICROPROCESSOR
16
ANTENNA SWITCH
LOAD
19
TO RX

FIG.1

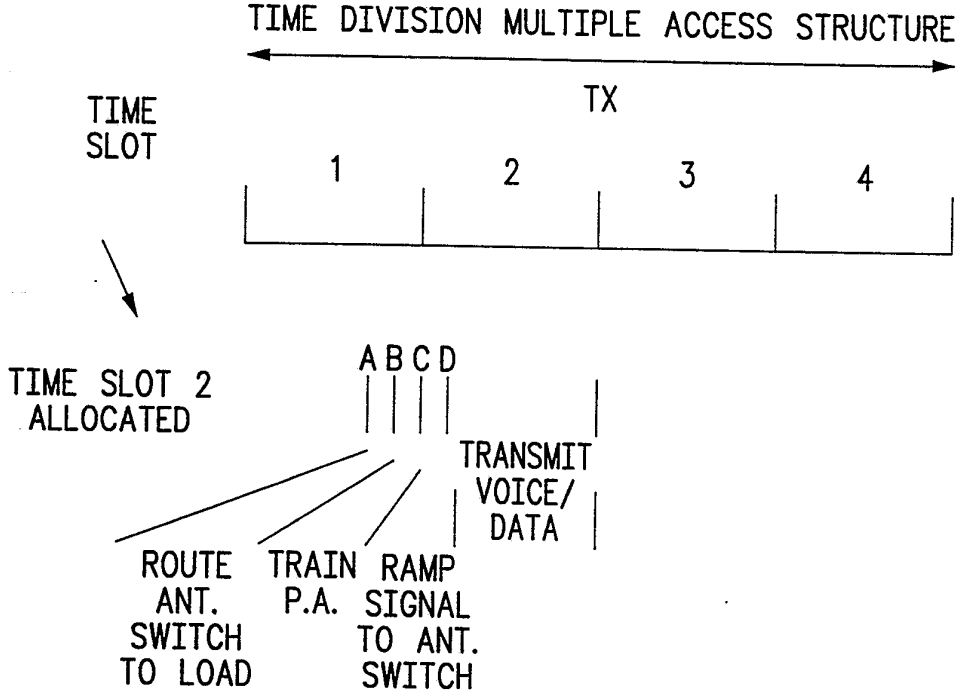

TIME DIVISION MULTIPLE ACCESS STRUCTURE
TX
TIME SLOT
1
2
3
4
TIME SLOT 2 ALLOCATED
A B C D
TRANSMIT VOICE/ DATA
ROUTE ANT. SWITCH TO LOAD
TRAIN P.A.
RAMP SIGNAL TO ANT. SWITCH

FIG.2

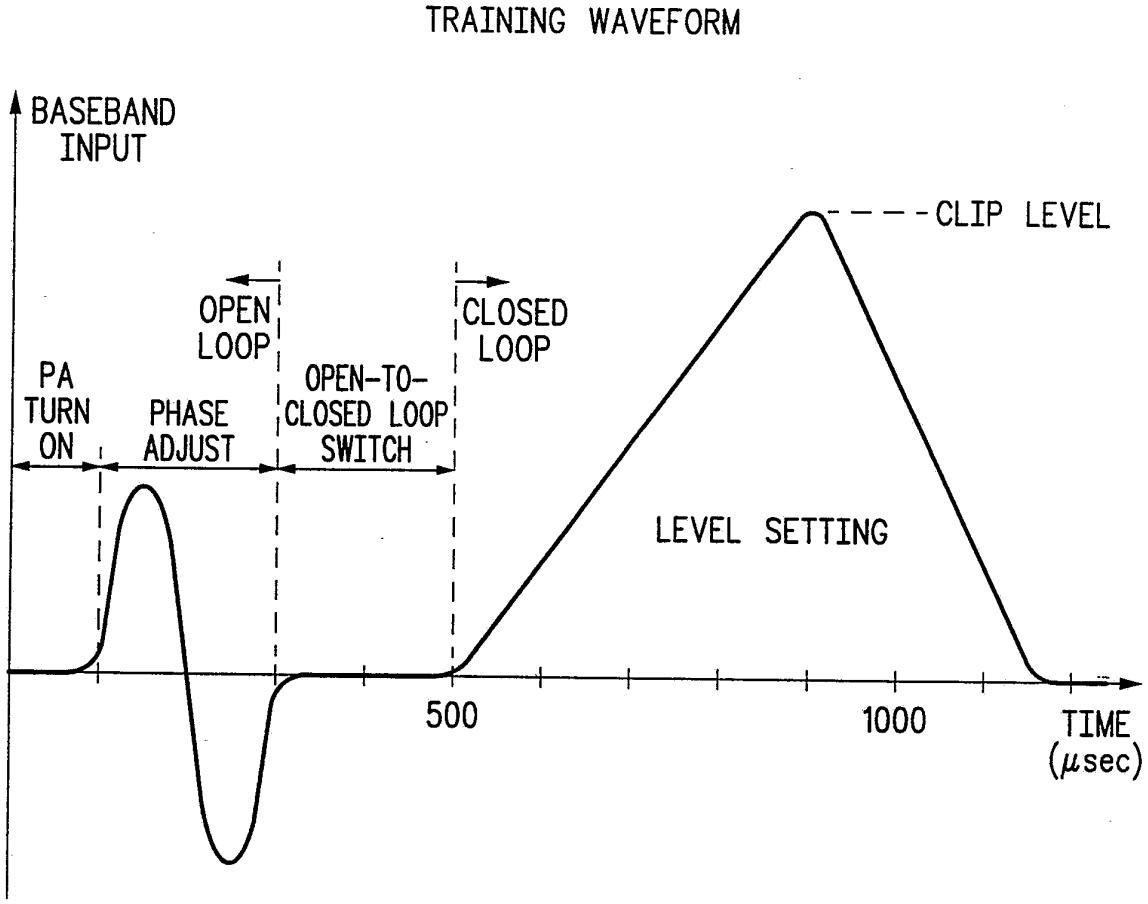

TRAINING WAVEFORM
BASEBAND INPUT
CLIP LEVEL
OPEN LOOP
CLOSED LOOP
PA TURN ON
PHASE ADJUST
OPEN-TO-CLOSED LOOP SWITCH
LEVEL SETTING
500
1000
TIME (μsec)

FIG.3

INTERNATIONAL SEARCH REPORT

International Application No PCT/EP 93/00429

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 H04L27/36; H03F1/32

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	H04L ; H04B ; H03F

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
A	US,A,5 066 923 (GAILUS ET AL.) 19 November 1991 see figures 1,3,4,6 see column 1, line 12 - line 55 see column 4, line 53 - column 5, line 25 ---	1,6-9
A	40th IEEE Vehicular Technology Conference, 6-9 May 1990, Orlando, US; IEEE, New York, US, 1990; pages 542 - 546, Minowa et al.: "Backoff improvement of an 800Mhz GaAs FET amplifier for a QPSK transmitter using an adaptive nonlinear distortion canceller" see page 542, left column, paragraph 4 --- -/--	1,7

° Special categories of cited documents : [10]

"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

"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

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
06 MAY 1993	18.06.93
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	SCRIVEN P.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	40th IEEE Vehicular Technology Conference, 6-9 May 1990, Orlando, US; IEEE, New York, US, 1990; pages 41 - 47, Cavers: "A linearizing predistorter with fast adaptation" see page 41, right column, paragraph 2 -paragraph 7 ---	1,8
A	EP,A,0 397 077 (FUJITSU) 14 November 1990 see abstract see column 4, line 47 - column 5, line 10 -----	1

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

EP 9300429
SA 70945

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 06/05/93

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A-5066923	19-11-91	AU-A-	8903391	26-05-92
		CN-A-	1061123	13-05-92
		EP-A-	0507926	14-10-92
		WO-A-	9208280	14-05-92
EP-A-0397077	14-11-90	JP-A-	2298139	10-12-90
		CA-A-	2016630	12-11-90
		US-A-	5193222	09-03-93