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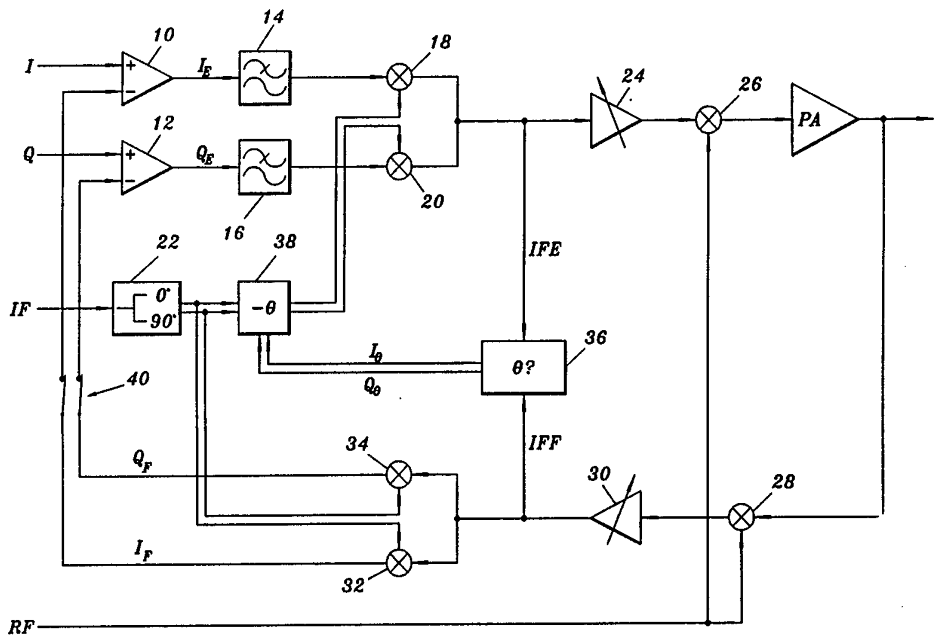

(57) Abstract

An apparatus for compensating the phase rotation (Θ) in the feedback loop of a cartesian feedback power amplifier (PA) in a final transmitter stage includes means (18, 20, 22) for quadrature modulation of the complex difference signal between a complex input signal (I, Q) and the corresponding complex feedback signal (I_F, Q_F) with a complex modulation signal for forming a modulated real valued first signal (IFE) and means (22, 32, 34) for quadrature modulation of the output signal (IFF) from the power amplifier (PA) with a complex demodulation signal for forming the complex feedback signal (I_F, Q_F). Means (36) are provided for detecting the phase shift between the first signal (IFE) and the second signal (IFF) and between the quadrature component of the first signal (IFE) and the second signal (IFF) for determining the phase rotation (Θ) of the feedback loop. Furthermore, means (38) are provided for phase rotation of the complex modulation signal with a compensating phase rotation defined by the determined phase rotation (Θ).

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APPARATUS FOR COMPENSATING OF PHASE ROTATION IN A FINAL AMPLIFIER STAGE

TECHNICAL FIELD

The present invention relates to an apparatus for compensating the phase rotation in a feedback loop of a cartesian feedback power amplifier in a final transmitter stage by utilizing incoming and feedback quadrature signals.

PRIOR ART

In cartesian feedback the incoming quadrature signals I and Q are compared to feedback quadrature signals. In order to obtain a stable feedback system it is required that the feedback quadrature signals are approximately in phase with the incoming quadrature signals when the feedback loop is closed. Due to the phase rotation generated by the feedback loop this condition is not always fulfilled. Therefore the incoming and feedback quadrature signals are usually brought into phase with each other with the aid of a compensating phase rotation in the feedback loop. A common method to determine the phase rotation generated by the feedback loop is to open the loop and to measure the incoming quadrature signals I, Q and the feedback quadrature signals, whereafter the measured values are A/D-converted, the phase error is calculated and a voltage controlled phase rotator is regulated after a D/A-conversion. In addition to A/D-conversion, D/A-conversion, computer calculation this method also requires electrical circuits to open and close the feedback loop.

SUMMARY OF THE INVENTION

An object of the invention is to provide an apparatus in which the phase rotation of the feedback loop can be measured and regulated and which can be easily implemented both in analog and digital form, preferably as a function in an integrated circuit.

In an apparatus for compensating phase rotation in the feedback loop of a cartesian feedback power amplifier in a final transmitter stage, said apparatus comprising means for quadrature modulation of a complex difference signal between a complex input signal and the corresponding complex feedback signal with a complex modulation signal for forming a modulated real-valued first signal, and means for quadrature modulation of an output signal from said power amplifier depending on a modulated real-valued second signal with a complex demodulation signal for forming said complex feedback signal, the above object is achieved by means for detecting a measure of the phase shift between said first signal and said second signal and between the quadrature component of said first/second signal and said second/first signal, for determining a measure of the phase rotation of said feedback loop, and means for phase rotation of one of said complex modulation, demodulation, difference and feedback signal with a phase rotation compensating said determined phase rotation.

A further solution comprises means for detecting a measure of the phase rotation between said complex difference signal and said complex feedback signal and means for phase rotation of one of said complex modulation, demodulation, and feedback signals with a phase rotation compensating said determined phase rotation.

SHORT DESCRIPTION OF THE DRAWINGS

The present invention, further objects and advantages obtained by the invention will be best understood with reference to the following specification and the enclosed drawing, in which:

Fig. 1 shows a cartesian feedback final stage in a radio transmitter provided with a preferred embodiment of an apparatus in accordance with the invention for compensating the phase rotation generated in the feedback loop of the final stage; and

Fig. 2 shows a more detailed block diagram of the phase detector and phase rotator in Figure 1.

PREFERRED EMBODIMENT

Fig. 1 shows a cartesian feedback final stage in a radio transmitter. In order to facilitate the description elements 36, 38 and 40 are initially ignored.

Quadrature signals I and Q are forwarded to comparators 10 and 12, respectively. The output signals I_E, Q_E from comparators 10, 12 over loop filters 14, 16 reach respective multipliers 18 and 20. In multiplier 18 the output signal from loop filter 14 is multiplied by an intermediate frequency signal IF, which for instance can have a frequency of the order of 10-500 MHz. In multiplier 20 the output signal from loop filter 16 is multiplied by an intermediate frequency signal IF which has been shifted 90° in a phase shifter 22. The output signal signals from multipliers 18, 20 are added and are over a possibly provided gain control 24 forwarded to a multiplier 26, in which a mixing to carrier frequency is performed with a high frequency signal RF, which can have a frequency of the order of 900 MHz. The output signal from multiplier 26 is thereafter forwarded to the power amplifier PA of the final transmitter stage. The output signal from amplifier PA is over a possibly provided filter forwarded to the antenna.

A part of the output signal from amplifier PA is used to form a feedback loop. This part of the output signal from amplifier PA is forwarded to a multiplier 28, in which it is mixed down to intermediate frequency with the high frequency signal RF. Over a second possibly provided gain control 30 this mixed down signal is forwarded to two multipliers 32, 34. In multiplier 32 the mixed down signal is multiplied by the intermediate frequency signal IF to form one feedback quadrature signal I_F. In multiplier 34 the mixed down signal is multiplied by the intermediate frequency signal IF phase shifted 90° in phase shifter 22 to form the second feedback quadrature signal Q_F. Signals I_F, Q_F are returned to the second input of respective comparators 10, 12.

In the circuit described so far the phase rotation θ of feedback quadrature signals IF, QF produced by the feedback loop has not been considered. This phase rotation θ is preferably detected by a phase detector 36 in the intermediate frequency section of the final stage. A suitable method of compensating for the phase rotation θ is to insert a phase rotator 38 that introduces a compensating phase rotation $-\theta$ before the modulation in multiplicators 18, 20.

The mixed output signal IFE from multipliers 18, 20 to phase detector 36 is defined as:

$$IFE = I_E \cdot \cos(\omega t) + Q_E \cdot \sin(\omega t)$$

where θ is the angular frequency of the intermediate frequency signal IF. The feedback input signal IFF to phase detector 36 is defined as:

$$IFF = I_E \cdot \cos(\omega t+\theta) + Q_E \cdot \sin(\omega t+\theta)$$

where θ is the phase rotation that is to be determined.

In order to calculate the phase rotation θ the quadrature signal to signal IFE is formed in phase detector 36. This signal can be defined as:

$$IFEQ = -I_E \cdot \sin(\omega t) + Q_E \cdot \cos(\omega t)$$

Thereafter each of signals IFE, IFEQ is multiplied by signal IFF in phase detector 34. For IFE·IFF one obtains:

$$IFE \cdot IFF =$$

$$= \{I_E \cdot \cos(\omega t) + Q_E \cdot \sin(\omega t)\} \cdot \{I_E \cdot \cos(\omega t+\theta) + Q_E \cdot \sin(\omega t+\theta)\}$$

$$= I_E^{2}\cdot \cos(\omega t+\theta)\cos(\omega t) + Q_E^{2}\cdot \sin(\omega t+\theta)\sin(\omega t)$$
$$+ I_E Q_E\cdot \sin(\omega t+\theta)\cos(\omega t) + I_E Q_E\cdot \cos(\omega t+\theta)\sin(\omega t)$$

$$= \tfrac{1}{2}I^{E}2\cdot \{\cos(2\omega t+\theta) + \cos(\theta)\} - \tfrac{1}{2}Q_E^{2}\cdot \{\cos(2\omega t+\theta) - \cos(\theta)\}$$
$$+ \tfrac{1}{2}I_E Q_E\cdot \{\sin(2\omega t+\theta) + \sin(\theta)\} + \tfrac{1}{2}I_E Q_E\cdot \{\sin(2\omega t+\theta) - \sin(\theta)\}$$

$$= \tfrac{1}{2}(I_E^{2}+Q_E^{2})\cdot \cos(\theta) + \tfrac{1}{2}(I_E^{2}-Q_E^{2})\cdot \cos(2\omega t+\theta) + \tfrac{1}{2}I_E Q_E\cdot \sin(2\omega t+\theta)$$

In a similar way one obtains for IFEQ·IFF:

IFEQ·IFF =

$$= \{-I_E\cdot \sin(\omega t) + Q_E\cdot \cos(\omega t)\}\cdot \{I_E\cdot \cos(\omega t+\theta) + Q_E\cdot \sin(\omega t+\theta)\}$$

$$= -I_E^{2}\cdot \cos(\omega t+\theta)\sin(\omega t) + Q_E^{2}\cdot \sin(\omega t+\theta)\cos(\omega t)$$
$$+ -I_E Q_E\cdot \sin(\omega t+\theta)\sin(\omega t) + I_E Q_E\cdot \cos(\omega t+\theta)\cos(\omega t)$$

$$= -\tfrac{1}{2}I_E^{2}\cdot \{\sin(2\omega t+\theta) - \sin(\theta)\} + \tfrac{1}{2}Q_E^{2}\cdot \{\sin(2\omega t+\theta) + \sin(\theta)\}$$
$$+ \tfrac{1}{2}I_E Q_E\cdot \{\cos(2\omega t+\theta) - \cos(\theta)\} + \tfrac{1}{2}I_E Q_E\cdot \{\cos(2\omega t+\theta) + \cos(\theta)\}$$

$$= \tfrac{1}{2}(I_E^{2}+Q_E^{2})\cdot \sin(\theta) - \tfrac{1}{2}(I_E^{2}-Q_E^{2})\cdot \sin(2\omega t+\theta) + \tfrac{1}{2}I_E Q_E\cdot \cos(2\omega t+\theta)$$

By lowpass filtering these two signals the t-dependent terms are eliminated and only the DC-components remain. These are:

$$I_\theta = \tfrac{1}{2}(I_E^{2}+Q_E^{2})\cdot \cos(\theta)$$
$$Q_\theta = \tfrac{1}{2}(I_E^{2}+Q_E^{2})\cdot \sin(\theta)$$

I_θ, Q_θ determine the phase error (through the equation: $\tan^{-1}(Q_\theta/I_\theta)$). The calculated phase rotation, represented by I_θ, Q_θ, is used in phase rotator 38 for complex phase rotation of the output signals from phase separator 22 with a phase angle minus θ. This principle is called feed-forward.

An embodiment of phase detector 36 and phase rotator 38 will now be described in detail with reference to Fig. 2.

In the embodiment of Fig. 2 signal IFE is forwarded to a phase separator 200, for instance a Hilbert-filter. In analog multipliers 202, 204 the separated signals are multiplied by signal IFF. The product signals are forwarded to respective lowpass filters 206, 208 for forming the phase error vector I_θ, Q_θ in accordance with the above equations. Multipliers 202, 204 can for instance comprise Gilbert-mixers. Error vector I_θ, Q_θ is forwarded to two further analog multipliers 210, 212, for example Gilbert-mixers, in which respective components are multiplied by the output signals from phase separator 22. Thereafter the product signals from multipliers 210, 212 are added, and the sum signal is separated in a further phase separator 214, for instance a Hilbert-filter. The output signal from phase separator 214 forms the phase corrected complex signal to multipliers 18, 20. The operation of the phase detector is such that it can be considered as hard limiting, that is the amplitude information is suppressed, while the phase information is emphasized.

When the system is started the loop is opened by opening switch 40 (see Fig. 1). Thereafter an initial value for θ is determined. During this measuring phase phase rotator 38 receives the initial values $I_\theta = 1$, $Q_\theta = 0$ (other values are also possible, the only condition is that $I_\theta^2+Q_\theta^2>>0$). During this initial phase the time constants of the phase detector can also be changed, so that the transient phase becomes very short. When the initial value for θ has been determined the loop is closed by reclosing switch 40. Thereby the input signals to phase rotator 38 are changed to the actually detected values. Simultaneously the time constants of phase detector 36 can return to their normal values. Thereafter the system operates in a stable mode without requiring reopening of the loop. This procedure is repeated every time transmission is started.

An advantage of the described embodiment of the invention is that the adjustment time is very short, approximately 50 ns for an accuracy in the phase angle determination of approximately 2 degrees. One reason for this is that $\theta=\tan^{-1}(Q_\theta/I_\theta)$, which gives the correct result also for small values of Q_θ/I_θ. For this reason it is in fact even possible to eliminate the above described starting procedure.

A variation of the preferred embodiment comprises a circuit in which phase rotator 38 corrects a complex signal to demodulator 32, 34 instead of the complex signal to modulator 18, 20. However, a drawback of this variation is among other things that the demodulator is more sensitive to phase errors and noise.

Further variations comprise letting phase rotator 38 correct signals I_E, Q_E and I_F, Q_F, respectively. However, this requires a cross connected phase rotator.

A further solution comprises performing both detection and correction on the base band. In such an embodiment the phase rotation between I_E, Q_E and I_F, Q_F is measured directly on the base band. This is accomplished by complex multiplication of these two signals and lowpass filtering of the complex output signal. The correction can then be performed in the base band with the aid of voltage controlled amplifiers, either directly after the loop filters or at the input of the comparator. A crossconnected phase rotator is required. A drawback of this embodiment, as compared to the preferred embodiment in accordance with Figs. 1 and 2, is that the adjustment time increases from approximately 50 nanoseconds to a few milliseconds, since the base band signals have significantly lower frequency than signal IF, so that the sum frequencies that are to be filtered away become significantly smaller.

An advantage of the described solutions is that they are suitable for implementation as a function in an integrated circuit.

The man skilled in the art realizes that different modifications and changes of the invention are possible without departure from the scope of the invention, which is defined by the attached patent claims. For instance the invention can be performed in the RF range if no intermediate frequency section is used.

CLAIMS

1. Apparatus for compensating the phase rotation (Θ) in the feedback loop of a cartesian feedback power amplifier (PA) in a transmitter final stage, comprising

means (18, 20, 22) for quadrature modulation of the complex difference signal (I_E, Q_E) between a complex input signal (I, Q) and the corresponding complex feedback signal (IF, QF) with a complex modulation signal for forming a modulated real valued first signal (IFE), and

means (22, 32, 34) for quadrature demodulation of a real valued second signal (IFF), which depends on the output signal from the power amplifier (PA) with a complex demodulation signal for forming the complex feedback signal (IF, QF),

characterized by

(a) means (36) for detecting a measure of the phase shift between the first signal (IFE) and the second signal (IFF) and between a quadrature component of the first/second signal (IFE, IFF) and the second/first signal (IFF/IFE), for determining a measure (I_θ, Q_θ) of the phase rotation (Θ) of the feedback loop,

(b) means (38) for phase rotation of one of said complex modulation, demodulation, difference and feedback signals with a phase rotation compensating said determined phase rotation (Θ).

2. Apparatus for compensating the phase rotation (Θ) in a feedback loop of a cartesian feedback power amplifier (PA) in a transmitter final stage, comprising

means (18, 20, 22) for quadrature modulation of the complex difference signal (I_E, Q_E) between a complex input signal (I,

Q) and the corresponding complex feedback signal (I_F, Q_F) with a complex modulation signal for forming a modulated real valued first signal (IFE), and

means (22, 32, 34) for quadrature demodulation of a modulated real valued second signal (IFF), which depends on the output signal from the power amplifier (PA), with a complex demodulation signal for forming the complex feedback signal (I_F, Q_F),

characterized by

(a) means (36) for detecting a measure (I_θ, Q_θ) of the phase rotation (θ) between the complex difference signal (I_E, Q_E) and the complex feedback signal (I_F, Q_F),

(b) means (38) for phase rotation of one of said complex modulation, demodulation, difference and feedback signals with a phase rotation compensating said determined phase rotation (θ).

3. The apparatus of claim 1 or 2, **characterized by** said phase rotating means (38) comprising two analog multipliers (210, 212) for multiplying the real and imaginary part of the complex output signal (I_θ, Q_θ) from said detecting means (36) with the real and imaginary part, respectively, of the modulation signal, and a Hilbert-filter (214) for separating the sum of the output signals from the multipliers (210, 212) in an I- and a Q-component.

4. The apparatus of claim 1 and 3, **characterized by** said detecting means (36) comprising a further Hilbert-filter (200) for separating the first/second signal (IFE, IFF) in an I- and a Q-component, two further analog multipliers (202, 204) for multiplying the I- and Q-components, respectively, with the second/first signal (IFF, IFE) and two lowpass filters (206, 208) for lowpass filtering of the output signals from said respective further multipliers for forming a complex output signal

comprising said measure (I_θ, Q_θ) of the phase rotation (Θ) of the feedback loop.

5. The apparatus in accordance with any of the preceeding claims, **characterized by** said modulation signal comprising an intermediate frequency (IF) signal.

6. The apparatus in accordance with any of claims 1-4, **characterized by** said modulation signal comprising a high frequency signal (RF).

7. The apparatus in accordance with any of the preceding claims, **characterized by** said apparatus being a function in an integrated circuit.

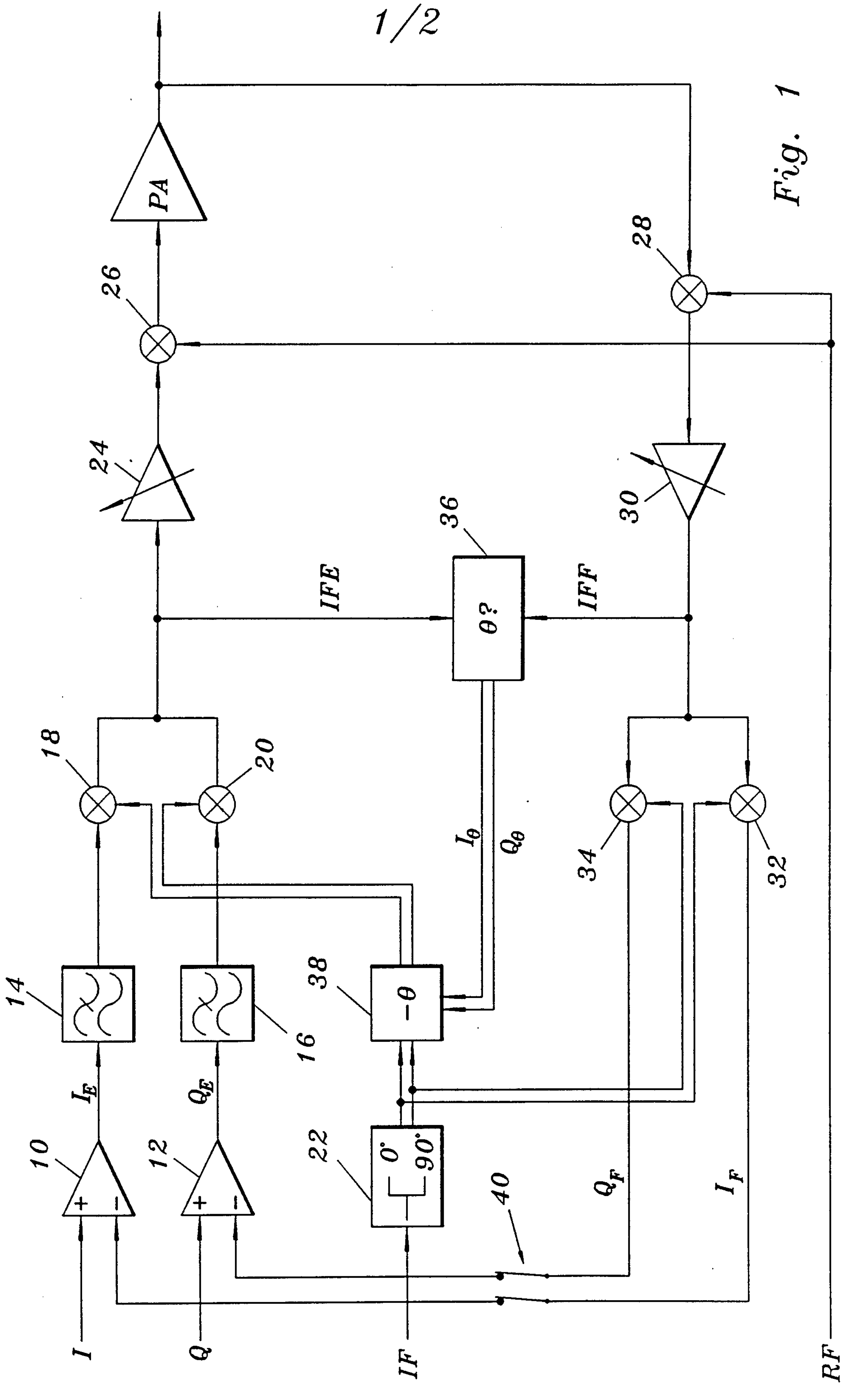
PA
26
24
28
30
36
θ?
IFE
IFF
18
20
34
32
I_θ
Q_θ
14
16
38
−θ
10
12
22
0°
90°
40
I_E
Q_E
Q_F
I_F
I
Q
IF
RF

Fig. 1

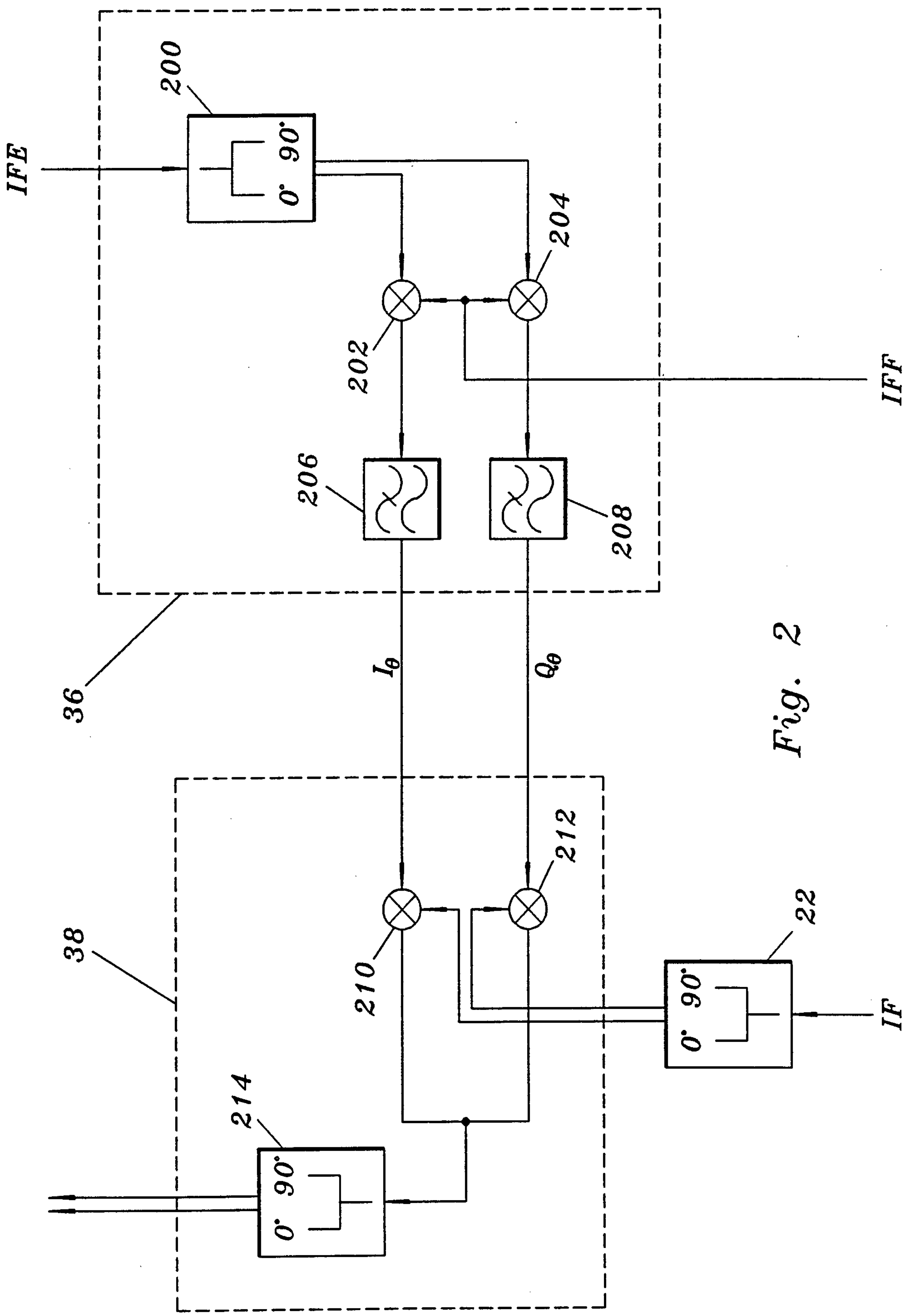
IFE
200
0° 90°
202
204
IFF
206
208
36
Iθ
Qθ
38
210
212
22
0° 90°
IF
214
0° 90°

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 93/00647

A. CLASSIFICATION OF SUBJECT MATTER

IPC5: H03F 1/26, H03F 1/34
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)

IPC5: H03F

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

SE,DK,FI,NO classes as above

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

USPM, WPAT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4291277 (ROBERT C. DAVIS ET AL), 22 Sept 1981 (22.09.81), figure 4 --	1-7
A	US, A, 4462001 (HENRI GIRARD), 24 July 1984 (24.07.84), figure 1 --	1-7
A	WO, A1, 9106149 (MOTOROLA INC.), 2 May 1991 (02.05.91), figure 1 -- --------	1-7

☐ Further documents are listed in the continuation of Box C. ☒ 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
30 November 1993	03 -12- 1993
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Bertil Ljungdahl Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

16/10/93

International application No.
PCT/SE 93/00647

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4291277	22/09/81	NONE	
US-A- 4462001	24/07/84	CA-A- 1184980	02/04/85
WO-A1- 9106149	02/05/91	EP-A- 0495921	29/07/92