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(71) Applicant (for all designated States except US): **MOTOROLA, INC.** [US/US]; 1303 East Algonquin Road, Schaumburg, Illinois 60196 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **KODNER, Lionid** [IL/IL]; Meitav 6, 67899 Tel Aviv (IL). **BLAY, Genadi,** [IL/IL]; herzel 82/20, 59447 bat yam (IL). **KAUFMAN, Kalman** [IL/IL]; Y.L. Baruch 29, 46330 Hertzelia (IL). **YACOBI, Avishai A.,** [IL/IL]; Mendelson 8, 49310 Petah Tikva (IL).(74) Agents: **DAVIS, Valerie M.,** et al.; 1303 East Algonquin Road, Schaumburg, Illinois 60196 (US).

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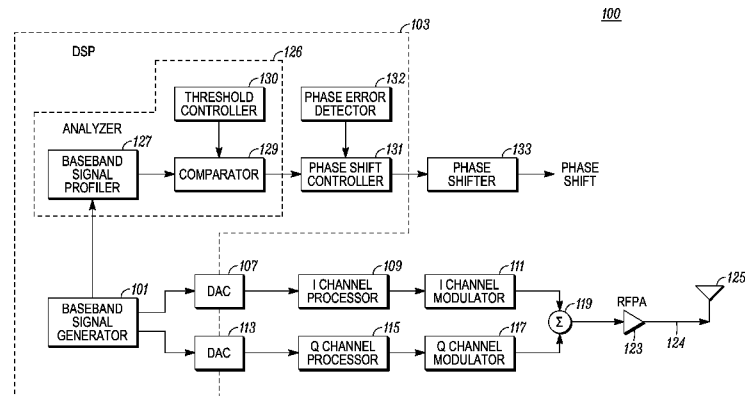


FIG. 1

(57) **Abstract:** An RF transmitter (100) for transmitting a QAM signal includes a baseband signal generator (101) to produce a baseband modulation signal, a phase shifter (133) to apply a change in phase affecting the baseband signal or a signal derived from it or to mixed with such a signal, a phase shift controller (131) to apply a control signal to control the phase shifter, and an analyzer (126) to analyze the baseband signal to detect low signal periods when a parameter which is a function of amplitude of the signal is not greater than a threshold, the phase shift controller being operable to receive from the analyzer an indication of the low signal periods and to apply the control signal so that the change in phase is applied by the phase shifter only during a selected period when the affected signal has a low power corresponding to a low signal period of the baseband signal.

TITLE: RF TRANSMITTER AND METHOD OF OPERATION

TECHNICAL FIELD

The technical field relates generally to an RF
5 (radio frequency) transmitter and a method of operation
of the transmitter. In particular, the technical field
relates to applying a phase adjustment in a transmitter
producing an RF signal modulated by QAM, especially for
use in mobile communications.

10

BACKGROUND

Various types of signal modulation are known for use
in RF transmitters employed in communications terminals,
such as digital mobile terminals. One such type of
15 modulation is the type known as 'QAM' ('Quadrature
Amplitude Modulation'). In this type of modulation, the
information to be transmitted for reception and
demodulation at a remote receiver comprises a modulation
signal having variations in both amplitude and phase. For
20 example, the transmitter may operate according to a
protocol defined by a communications standard such as the
TETRA (TErrestrial Trunked RAdio) standard defined by
ETSI (the European Telecommunications Standards
Institute) and may thereby use a defined version of QAM,
25 such as the version known as DQPSK (Differential
Quadrature Phase Shift Keying) as specified for use in
the TETRA standard.

Where the RF transmitter is used in mobile
communications, it is often necessary for the transmitter
30 to operate using a narrow modulation bandwidth in order
to avoid interference between neighbouring communication

channels. This normally requires the use of a linear transmitter in which the power of the transmitted signal, particularly after amplification by an RF power amplifier of the transmitter, is a linear function of the power of the applied modulation signal. In order to maintain acceptable operating efficiency, such linearity may be obtained by use of one or more linearity control loops, such as one or more of a Cartesian loop, a feed forward loop, or a pre-distortion loop.

One or more of the operational parameters of the transmitter may vary with time. Such variable parameters include an impedance of an antenna of the transmitter, a supply voltage employed to operate the RF power amplifier and other components of the transmitter, electromagnetic interference, and temperature. The effect of antenna impedance variation can be significant especially if the transmitter includes no device such as a circulator or isolator to isolate the RF power amplifier from the antenna. The variation in such parameters may affect operation of the linearity control loop. An error in phase of a signal or between component signals in the control loop may be developed and may lead to non-linearity. For example, the control loop may include 'I' (In-phase) and 'Q' (Quadrature phase) channels in which the respective component signals are intended to have a phase difference of exactly ninety degrees. The phase error developed may however cause a slight divergence of the phase difference from ninety degrees. In consequence, when the transmitted signal is received and demodulated, an unwanted distortion of the signal is obtained.

It is well known to apply a phase adjustment periodically which corrects for detected phase errors which occur as described above. The adjustment may be made during special intervals in which the transmitter periodically enters a phase test or training mode in which a test signal is applied to measure the phase error. In a TETRA transmitter, a training time slot is available once per frame of the TETRA timing sequence for the purpose of applying the phase training mode.

However, in some QAM transmitters it may not be suitable to rely for phase error detection and adjustment on the availability of special intervals, such as training time slots once per frame of the TETRA timing sequence, since such intervals do not occur frequently enough. Such transmitters include in particular those designed to include no isolating device, such as a circulator or isolator, between the RF power amplifier and the antenna of the transmitter. In such transmitters the phase error may develop rapidly, and detection and adjustment of phase may be required at very frequent intervals. The adjustment may be made during periods, e.g. time slots, when the transmitter is actively operational and is transmitting an information signal.

However, applying the phase adjustment whilst the transmitter is actively transmitting a QAM signal can cause an unwanted RF spectrum splatter to occur in the QAM signal, especially where the phase adjustment is applied as a step change under control of a digital signal obtained from a control processor. The spectrum splatter causes RF energy to be transmitted in unwanted side bands as well as in a main wanted band within the

desired modulation channel. The side bands reduce the inter-channel interference performance of the transmitter and may cause the transmitter to fail to meet stringent inter-channel interference performance specifications.

5 Thus, there exists a need for a transmitter, especially for use in narrow modulation band communications, which addresses at least some of the shortcomings of past and present techniques and/or procedures for use in such transmitters.

10

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

The accompanying drawings, in which like reference numerals refer to identical or functionally similar items throughout the separate drawings, which, together with
15 the detailed description below, are incorporated in and form part of this patent specification and serve to further illustrate various embodiments of concepts that include the claimed invention, and to explain various principles and advantages of those embodiments.

20 In the accompanying drawings:

FIG. 1 is a block schematic diagram of an illustrative RF transmitter.

FIG. 2 is a flow chart of an illustrative method of operation in the transmitter of FIG. 1.

25 FIG. 3 is a graph of baseband signal power measured in dB plotted against time measured in μsec (microseconds) for an illustrative power level profile for a TETRA 1 baseband modulation signal when generated in the transmitter of FIG. 1.

FIG. 4 is a block schematic diagram of an illustrative embodiment in which the transmitter of FIG. 1 includes a Cartesian feedback control loop.

FIG. 5 is a block schematic diagram of an illustrative embodiment in which the transmitter of FIG. 1 includes a feed forward control loop.

FIG. 6 is a block schematic diagram of an illustrative embodiment in which the transmitter of FIG. 1 includes a pre-distortion feedback control loop.

10 Skilled artisans will appreciate that items shown in the drawings are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the items may be exaggerated relative to other items to assist
15 understanding of various embodiments. In addition, the description and drawings do not necessarily require the order illustrated. Apparatus and method components have been represented where appropriate by conventional symbols in the drawings, showing only those specific
20 details that are pertinent to understanding the various embodiments so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein. Thus, it will be appreciated that
25 for simplicity and clarity of illustration, common and well-understood items that are useful or necessary in a commercially feasible embodiment may not be depicted in order to facilitate a less obstructed view of these various embodiments.

DETAILED DESCRIPTION

Generally speaking, pursuant to the various embodiments to be described, there is provided an RF transmitter, and a method for operating the transmitter, for transmitting a QAM (Quadrature amplitude modulated) signal. The transmitter includes a baseband signal generator operable to produce a baseband signal including information to be included as a QAM modulation of a transmitted RF signal, a phase shifter operable to apply a change in phase affecting a signal derived from the baseband signal, a phase shift controller operable to apply a control signal to the phase shifter to control a change in phase applied by the phase shifter, and an analyzer operable to analyze the baseband signal to detect low signal periods when the baseband signal has an amplitude or power not greater than a threshold level, the phase shift controller being operable to receive from the analyzer an indication of the low signal periods and to apply the control signal so that the change in phase is applied by the phase shifter only during a selected period when the affected signal has a low power corresponding to a low signal period of the baseband signal.

The transmitter of the embodiments may be one which operates according to a communications standard, especially a mobile communications standard, specifying use of linear digital QAM. The transmitter may for example operate according to one of the well known communications standards specified later. Illustrative examples will be given in which the transmitter operates according to the TETRA 1 (basic TETRA for voice and data

communication); and according to the TETRA 2 (enhanced TETRA for high speed data communication) standard.

The transmitter and the method of the embodiments allow a change in phase, especially one or more step
5 changes in phase, to be applied whilst a QAM modulated signal is being transmitted. Each change in phase may be applied in a manner such that RF spectrum splatter of the transmitted signal is significantly reduced. In particular, the transmitter may be one which has no
10 isolator, circulator or other isolating device normally located in a transmission path between an RF power amplifier and an antenna of the transmitter to provide substantial isolation of the RF power amplifier from reflected impedances from the antenna. Elimination of
15 such an isolating device has known benefits including simplicity and reduced cost of design, manufacture and operation of the transmitter.

Those skilled in the art will appreciate that these recognized advantages and other advantages described
20 herein are merely illustrative and are not meant to be a complete rendering of all of the advantages of the various embodiments.

Referring now to the accompanying drawings, and in particular to FIG. 1, there is shown a block schematic
25 diagram of an illustrative RF transmitter 100 for transmission of RF signals having a linear QAM modulation. The transmitter 100 includes a baseband signal generator 101 which is incorporated within a DSP (digital signal processor) 103 indicated by a dashed
30 line. The baseband signal generator 101 produces output digital signals to serve respectively as components of a

baseband QAM modulation signal. One of the output signals, an I (in phase) component signal, is applied to a DAC (digital to analog converter) 107 to convert the signal to analog form. Another of the output signals, a Q
5 (quadrature phase) component signal, is applied to a DAC 113 to convert the signal to analog form.

The DAC 107 thus produces an output signal which is an analog form of the I component signal. This output signal is applied to an I channel processor 109 which
10 processes the signal before it is applied to an I channel modulator 111. The I channel processor 109 produces a processed I component signal. The I channel modulator 111 upconverts the processed I component signal by modulating an RF carrier frequency signal with the processed I
15 component signal produced by the I channel processor 109. The RF carrier frequency signal is obtained from a local oscillator (not shown in FIG. 1).

The DAC 113 produces an output signal which is an analog form of the Q component signal. This output signal
20 is applied to a Q channel processor 115 which processes the signal before it is applied to a Q channel modulator 117. The Q channel processor 115 produces a processed Q component signal. The Q channel modulator 117 upconverts the processed Q component signal by modulating an RF
25 carrier frequency signal with the processed Q component signal produced by the Q channel processor 115. The RF carrier frequency signal is obtained from a local oscillator (not shown in FIG. 1). The RF carrier frequency signal may be obtained from the same local
30 oscillator (not shown in FIG. 1) as that which supplies the carrier frequency signal to the I channel modulator

111, although a phase shift of ninety degrees is applied to the phase of the carrier frequency signal applied to the modulator 117 relative to that of the carrier frequency applied to the modulator 111.

5 The I channel modulator 111 and the Q channel modulator 117 produce output signals which comprise RF carrier frequency signals modulated respectively by the processed I component signal produced by the I channel processor 109 and the processed Q component signal
10 produced by the Q channel processor 115. The output RF signals produced by the modulators 111 and 117 are combined by a combiner 119 to produce a combined QAM modulated RF signal. The combined QAM modulated RF signal produced by the combiner 119 is amplified by an RFPA
15 (radio frequency power amplifier) 123 which delivers an amplified RF signal to an antenna 125 via a transmission path 124. The antenna 125 transmits the amplified RF signal that it receives from the RFPA 123 as a radiated RF signal which is sent over-the-air to one or more
20 distant receivers (not shown).

 The transmitter 100 may be part of a transceiver which includes a receiver (not shown). The transmitter 100 may operate in a transmission mode of the transceiver and the receiver may operate in a reception mode of the
25 receiver. The mode may be selected by a controller, which may comprise a programmed processor, e.g. included in the DSP 103. The receiver may receive and process a signal obtained by the antenna 125 from a remote transmitter (not shown). The receiver may include one or more
30 processors incorporated within the DSP 103.

The transmission path 124 may include no circulator, isolator or like isolation device providing substantial isolation of the RFPA 123 from reflected impedances from the antenna 125.

5 The baseband QAM modulation signal processed by the baseband signal generator 101 to provide as its components the I component signal and the Q component signal delivered to the DAC 107 and the DAC 113 respectively, is also delivered to an analyzer 126 which
10 may be included within the DSP 103. The analyzer 126 includes a baseband signal profiler 127 which obtains a profile of the baseband modulation signal by estimating a series of consecutive levels of a parameter which is a function of the varying amplitude of the baseband signal,
15 e.g. the varying amplitude or the varying power of the baseband signal. The varying power is proportional to the varying amplitude squared. The profiler 127 may operate in a known manner. For example, the profiler 127 may operate by taking samples of the baseband modulation
20 signal at a rapid sampling rate. Illustratively, the sampling rate may be at least three times the channel bandwidth of the transmitter 100. For a TETRA 1 transmitter, the channel bandwidth is 25KHz; thus where the transmitter 100 is a TETRA 1 transmitter, the
25 sampling rate may be 75kHz or more, e.g. at least 80kHz. For a TETRA 2 transmitter, the channel bandwidth is a multiple of 25kHz, e.g. 50kHz; thus where the transmitter 100 is a TETRA 2 transmitter having a 50kHz channel bandwidth, the sampling rate may be 150kHz or more, e.g.
30 at least 160kHz.

Consecutive discrete samples of the baseband modulation signal are thereby formed by the profiler 127. Each sample may indicate an amplitude value (average amplitude value) of the signal for each sampling period
5 when the sample is taken. Alternatively, the amplitude value of each sample may be squared by the profiler 127 to obtain a corresponding power level value for each sample.

The profiler 127 produces an output signal
10 indicating a parameter value for each sampling period. The parameter value is the average value of the parameter, e.g. amplitude or power level value, estimated by the profiler 127 for each sampling period. The length of the sampling periods employed by the profiler 127
15 depends on the detailed implementation of the transmitter 100 and on the sampling rate, but may for example be in the illustrative range of from about 5 microseconds to about 20 microseconds, e.g. about 10 microseconds, for a TETRA 1 baseband modulation signal and may be in the
20 illustrative range of from about 2 microseconds to about 10 microseconds, e.g. about 5 microseconds, for a TETRA 2 baseband modulation signal.

The analyzer 126 includes a comparator 129 to which the output signal produced by the profiler 127 is
25 applied. The comparator 129 compares the parameter value, e.g. amplitude or power level value, indicated in each sampling period by the applied signal from the profiler 127 with a threshold level T of the parameter value. Thus, where the output signal produced by the profiler
30 127 indicates a profile of amplitude values, the threshold level T represents a suitable threshold

amplitude level. Where the output signal produced by the profiler 127 indicates a profile of power level values, the threshold level T represents a suitable threshold power level.

5 The threshold level T employed by the comparator 129 is set by a threshold controller 130. Where each parameter value of the baseband modulation signal produced for a sampling period by the profiler 127 is greater than the threshold T for the parameter, the value
10 is deemed to be a high value of the parameter. The sampling period in which the high value is obtained is deemed to be a high signal sampling period.

 On the other hand, where each parameter value of the baseband modulation signal produced for a sampling
15 period by the profiler 127 is not greater than the threshold T, the value is deemed to be a low value of the parameter. The sampling period in which the low value is obtained is deemed to be a low signal sampling period.

 The comparator 129 accordingly delivers an output
20 signal having a value which indicates for each sampling period whether the parameter value, e.g. amplitude level or power level value, estimated by the profiler 127 is either high or low thereby indicating whether the sampling period is either a high or low signal period.
25 The output signal produced by the comparator 129 is delivered to a phase shift controller 131 which controls a phase change or shift to be made by a phase shifter 133 by issue of one or more control signals to the phase shifter 133.

30 The phase shift controller 131 may be included within the DSP 103. The phase shift controller 131 also

receives an input phase error signal from a phase error detector 132, which may also be included within the DSP 103. The phase error detector 132 may be a processor which may operate in a known manner to detect and
5 estimate an error in phase of a signal in the transmitter 100 which can be (at least partially) corrected by operation of the phase shifter 133. For example, the phase error detector 132 may operate to estimate an error in phase difference between the phase of an I component
10 signal in an I channel of a control loop of the transmitter 100 and the phase of a corresponding Q component signal in a Q channel of the control loop. Alternatively, the phase error detector 132 may operate in a known manner to estimate an error in phase of a
15 carrier frequency signal applied in a mixer of a control loop of the transmitter 100.

In response to receiving the phase error detection signal from the phase error detector 132, the controller 131 determines that one or more changes in phase are
20 required to be made by the phase shifter 133. The controller 131 issues a control signal or signals to the phase shifter 133 during a period or periods selected using the output from the analyzer 126 as described below. Each output control signal produced by the phase
25 shift controller 131 indicates whether a required phase shift to be made by the phase shifter 133 is a positive or negative shift.

When the phase shifter 133 receives a control signal from the controller 131, the phase shifter 133 changes or
30 shifts the phase of an affected signal in the transmitter 100 accordingly. The affected signal is one whose phase

will at least partially corrected for the phase error indicated by the phase error detector 132. As will be appreciated by those skilled in the art, there are various signals whose phase may be changed by the phase shifter 133 depending on the phase error detected by the phase error detector 132. These affected signals include the baseband signal processed or produced by the generator 101 and baseband and RF signals derived from it in the transmitter 100. The affected signals also include signals, e.g. applied from local oscillators, to be mixed with the signal derived from the baseband signal processed or produced by the generator 101. Consequently, there are various possible locations in the transmitter 100 for the phase shifter 133. For example, the phase shifter 133 may be located so as to adjust a relative phase difference between signals in I and Q branches in a linearity control loop of the transmitter 100 or to adjust the phase of a carrier frequency signal applied in a mixer of a linearity control loop. Illustrative examples of such locations of the phase shifter 133 are described in more detail later.

The phase shifter 133 may apply a required change in phase as a single adjustment step or as a series of incremental adjustment steps. For example, where an overall phase change of ten degrees is detected to be required by the phase error detector 132, the phase shifter 133 may apply a series of phase adjustment steps each of which corrects the phase error by a fraction of ten degrees. The size of each incremental phase adjustment step made by the phase shifter 133 depends on the detailed implementation of the transmitter 100; an

illustrative example of an incremental phase adjustment step is one in which the phase of an affected signal is shifted by between about one and about two degrees, for example about 1.4 degrees.

5 The change in phase applied by the phase shifter 133 is intended to affect a signal derived from the baseband modulation signal, e.g. as in one of the examples described later. Each output control signal of the phase shift controller 131 is issued during the next selected
10 time period when the signal to be affected by the change has a low power. The selected low power period is determined by the phase shift controller 131 as corresponding to a low signal sampling period found by the profiler 127 and the comparator 129 of the analyzer
15 126 as described earlier. When receiving an output signal from the comparator 129 indicating such a low signal sampling period, the phase shift controller 131 may need to delay issue of a required output control signal to the phase shifter 133 by a known delay time so that, when the
20 phase shifter 133 applies a phase change, the affected signal is suitably in its selected low power period.

 Thus, in response to receiving an output control signal from the phase shift controller 131 during a selected period when the affected signal has low power,
25 the phase shifter 133 operates immediately during the selected period to make the required change in phase indicated by the output control signal.

 The threshold T applied by the threshold controller 130 may be a fixed or dynamically varied threshold value.
30 The threshold T may be dynamically varied by the threshold controller 130 depending for example on how

quickly a correction for a phase error detected by the phase error detector 132 needs to be applied by the phase shifter 133. For instance, a more rapid correction is likely to be needed when a reflected impedance of the antenna 123 is increased as a result of power reflections from the external environment in which the transmitter 100 is operating, especially where the transmitter 100 includes no isolating device in the path 124 between the antenna 125 and the RFPA 123. In such circumstances, the threshold T may thus be raised to a higher level, so that more sampling periods per unit time have a sampled parameter value, e.g. amplitude level or power level value, which is low during periods when the reflected impedance increases. The reflected impedance may be monitored by measuring the VSWR (voltage standing wave ratio) of the antenna 125 in a known way. The threshold T may for instance be set to a low level whenever the measured VSWR is below a given VSWR threshold and at a higher level whenever the measured VSWR is above the given VSWR threshold.

Where the threshold T applied by the threshold controller 130 is for indication of a suitable threshold power level, the value may be selected to be for example in the range of from about -3 dB to about -10 dB, such as a value of about -5 dB.

FIG. 2 is a flow chart summarizing an illustrative method 200 of operation in the transmitter 100 of FIG. 1. The baseband signal generator 101 generates a QAM baseband modulation signal at 201. Following processing (of I and Q components) of the baseband modulation signal in the processors 109 and 115, the baseband modulation

signal (in the analog form of its I and Q components) is upconverted to form a modulated RF signal at 203. The modulated RF signal so formed is amplified by the RFPA 123 at 205 and is then transmitted by the antenna 125 at 5 207.

An amplitude or power profile of the baseband modulation signal generated at 201 is obtained by the profiler 127 at 209. The profile is obtained by the profiler 127 estimating an average of the amplitude or 10 power of the baseband modulation signal in each of a series of consecutive sampling periods in the manner described earlier. The profile obtained at 209 is analyzed at 211. In the analysis, the level of the average amplitude or power level in each of the sampling 15 periods is compared with the threshold T in the comparator 129. Each sampling period in which the average amplitude or power level is determined to be low, i.e. each low signal sampling period when the level is not greater than the threshold T set by the threshold 20 controller 130, is indicated by the comparator 129 to the phase shift controller 131 at 213. Optionally, a delay is applied by the phase shift controller 131 at 215.

A phase error determination is applied at 217 by the phase error detector 132. The phase error determination 25 may be applied in a known manner in an early part of a transmission slot of the timing sequence of the transmitter 100. For example, a known phase error determination procedure may be initiated at a selected time which is in the first half of a transmission time 30 slot during which the transmitter 100 is to transmit a QAM modulated RF signal in the step 207. The procedure

may be initiated for example in a known test or training procedure applied at the start of such a transmission slot. The procedure may be initiated at the start of every transmission slot or at the start of selected transmission slots, e.g. during periods when a phase error is likely, such as when the VSWR of the antenna is detected to be above a threshold.

A phase error and a need for a change in phase is detected by the phase error detector 132 at 219. The change needed may be equivalent to one or more incremental step changes required to be made by the phase shifter 133. The change in phase needed is indicated to the phase shift controller 131 by the phase error detector 132 at 221. In response to receiving, at 221, the indication of the phase change needed, and at 213, the indication of the low signal sampling periods in relation to the baseband modulation signal, the phase shift controller 131 issues, optionally after the delay at 215, a control signal, at 223, to the phase shifter 133 for each change or increment of change in phase to be applied by the phase shifter 133. In response, at 225, the phase shifter 133 applies each change or increment of change in phase as a step change during a period when a signal affected by the phase change has a low power. The period of low power corresponds to the next low signal sampling period, determined by the comparator 129 and indicated by the phase shift controller 131, when the baseband modulation signal from which the signal to be affected by the phase change is derived has a low signal sampling period, i.e. when the average amplitude level or

power level (as appropriate) of the baseband modulation signal is deemed to be low.

Where a delay is applied at 215, the delay may be a pre-determined delay calculated to ensure that the step change in phase at 225 is applied at the correct instant in time so that the affected signal derived from the baseband modulation signal has low power. Illustrative examples of step changes in phase which may be applied at 225 are described later with reference to FIGS. 4 to 6.

FIG. 3 is a graph 300 of baseband signal power measured in dB (decibels) plotted against time measured in μsec (microseconds) in which an illustrative power profile 301 is plotted. The profile 301 is that of the varying power of a typical TETRA 1 baseband modulation signal which may be obtained from the baseband signal generator 101. In FIG. 3, an illustrative power threshold T at a power level of -5 dB is indicated by a dashed line 303. Three illustrative sampling periods 305, 309 and 313 each having a width along the time axis of 10 μsec are shown in FIG. 3. In the sampling period 305 the average power of the profile 301 has a level 307. In the sampling period 309 the average power of the profile 301 has a level 311. In the sampling period 313 the average power of the profile 301 has a level 315.

The power profile 301 can be converted into a histogram (not shown) in which each consecutive column of the histogram represents a sampling period in which an average level of the power in the profile 301 is obtained. Each consecutive column or sampling period may have the same width along the time axis. The width selected may illustratively be 10 μsec for a TETRA 1

signal. The periods 305, 309 and 313 are thus illustrative examples of columns of the histogram obtained in this manner. The average power of the profile 301 in each sampling period, or each column of the histogram, is compared in the comparator 129 with the threshold T, and sampling periods in which the average power is less than the threshold T may be selected and indicated as low signal sampling periods at 211 and 213 of the method 200.

10 The sampling period 305 shown in FIG. 3 coincides with a peak of the profile 301 in which the average power 307 of the baseband modulation signal is high, i.e. above about -1 dB. Thus, in the sampling period 305 the average power 307 of the baseband modulation signal is at a level above the threshold T indicated by the line 303. So the sampling period 305 is not selected as useful by the phase shift controller 131.

15 The sampling period 309 shown in FIG. 3 coincides with a steep trough of the profile 301 in which the average power 311 of the baseband modulation signal is low, i.e. below -10 dB. Thus, in the sampling period 309 the average power of the baseband modulation signal is below the threshold T indicated by the line 303. So the sampling period 309 is a low signal period and may be selected as useful by the phase shift controller 131. Any change in phase detected at 219 and indicated at 221 may be applied at 225 in a corresponding period suitably selected by the phase shift controller 131 so that the signal to be affected by the phase change has low power corresponding to the trough of the profile 301 in the sampling period 309.

The sampling period 313 shown in FIG. 3 also coincides with a steep trough of the profile 301 in which the average power 311 of the baseband modulation signal is low, i.e. below -10 dB. Thus, in the sampling period
5 313 the average power of the baseband modulation signal is below the threshold T indicated by the line 303. So the sampling period 313 may be selected as a useful low signal period by the phase shift controller 131. Any change in phase detected to be needed at 219 and
10 indicated at 221 may be applied at 225 in a corresponding period suitably selected by the phase shift controller 131 so that the signal to be affected by the phase change has low power corresponding to the trough of the profile 301 in the sampling period 313.

15 It can be seen from FIG. 3 that there are several other troughs of the profile 301 in which the average power is below the threshold T indicated by the line 303, and averaging periods coinciding with those other troughs may be indicated as low signal sampling periods
20 at 213.

FIG. 4 is a block schematic diagram of a circuit 400 which is an illustrative example in which a linearity control loop which is a Cartesian feedback control loop
401 is included in the transmitter 100 of FIG. 1. The
25 output signal produced by the DAC 107 (FIG. 1) is delivered as a first (baseband I channel) input signal to a combiner 403 included in the I channel processor 109. The combiner 403 may be a differential summer. The combiner 403 also receives a second input signal which is
30 an error control signal from an I feedback control channel 423. The combiner 403 produces an output signal

which is a differential sum of (difference between) its input signals. The output signal produced by the combiner 403 is applied to an amplifying/filtering processor 405 included in the I channel processor 109. The processor
5 405 provides filtering and gain of the output signal produced by the combiner 403.

The output signal produced by the DAC 113 (FIG. 1) is delivered as a first (baseband Q channel) input signal to a combiner 409 included in the Q channel processor
10 115. The combiner 409 may be a differential summer. The combiner 409 also receives a second input signal which is an error control signal from a Q feedback control channel 427. The combiner 409 produces an output signal which is a differential sum of (difference between) its input
15 signals. The output signal produced by the combiner 409 is applied to an amplifying/filtering processor 411 included in the Q channel processor 115. The processor 411 provides filtering and gain of the output signal produced by the combiner 409.

20 The I channel modulator 111 includes a mixer 407 which receives an output baseband signal produced by the processor 405. The mixer 407 upconverts the baseband signal to an RF frequency by mixing the baseband signal with a carrier frequency signal applied to the mixer 407.
25 The carrier frequency signal is produced by a local oscillator 415.

Similarly, the Q channel modulator 117 includes a mixer 413 which receives an output baseband signal produced by the processor 411. The mixer 413 upconverts
30 the baseband signal to an RF frequency by mixing the baseband signal with a carrier frequency signal applied

to the mixer 413. The carrier frequency signal is a signal produced by the local oscillator 415 and is delivered to the mixer 413 via a ninety degrees phase shifter 417 which shifts the phase of the signal by
5 ninety degrees.

The mixer 407 and the mixer 413 respectively produce RF output signals which are applied as input signals to the combiner 119. The combiner 119 combines the input component signals applied to it to produce a combined RF
10 output signal which is applied to the RFPA 123 and which is amplified by the RFPA 123 for transmission by the antenna 125.

A coupler 419, e.g. a directional coupler, at an output of the RFPA 123, in the path 124 between the RFPA
15 123 and the antenna 125, serves as an RF sampler to sample the amplified RF output signal produced by the RFPA 123. The RF signal sampled by the coupler 419 is applied as a first input signal to a mixer 421 in the I feedback control channel 423 and as a first input signal
20 to a mixer 425 in the Q feedback control channel 427. The mixer 421 also receives a second input which is the signal produced by the local oscillator 415 delivered via a phase shifter 133.1. The mixer 425 also receives a second input signal which is the signal produced by the
25 local oscillator 415 delivered to the mixer 425 via the phase shifter 133.1 and a ninety degrees phase shifter 431.

The phase shifter 431 shifts the phase of the signal applied to it by ninety degrees. The phase shifter 133.1
30 is an example of the phase shifter 133 shown in FIG. 1 and applies changes to the phase of the signal delivered

from the local oscillator 415 when required following a phase change determination procedure in which a need for the phase change is detected and indicated as at 219 and 221 of the method 200.

5 The mixer 421 produces, by downconverting the frequency of the RF signal applied to it from the coupler 419, a baseband I error control signal which is applied to the combiner 403. Similarly, the mixer 425 produces, by downconverting the frequency of the RF signal applied
10 to it from the coupler 419, a baseband Q error signal which is applied to the combiner 409.

 Thus, the Cartesian feedback control loop 401 of the transmitter 100 which provides linearity control of the RFPA 123 comprises: (a) a forward part having: (i) an I
15 channel extending from the combiner 403 to the combiner 119; (ii) a Q channel extending from the combiner 409 to the combiner 119; and (iii) a combined RF part extending from the combiner 119 to the coupler 419; and (b) a reverse or feedback part having: (i) a combined RF part
20 extending from the coupler 419 to the mixers 421 and 425; (ii) the I channel feedback control channel 423 extending from the mixer 421 to the combiner 403 and (iii) the Q channel feedback control channel 427 extending from the mixer 425 to the combiner 409.

25 By the phase shifter 133.1 applying a change in the phase of the signal from the local oscillator 415, the I and Q error signals derived from the baseband modulation signal, which are mixed with the signal in the mixers 421 and 425, are affected so that their phase is suitably
30 corrected relative to the I and Q component signals in the forward part of the loop 401.

The change in phase applied by the phase shifter 133.1 may be to correct for a phase error determined in a known manner during a known test or phase training procedure. During the known test procedure, a test signal
5 of known form, e.g. a sine wave, may be applied (as I and Q channel components as inputs to the combiners 403 and 409) and the I and Q feedback control channels 423 and 42 may be disconnected from the combiners 403 and 409. The test procedure may for example measure the relative phase
10 of error control signals produced by the mixers 421 and 425.

Although the phase error may be detected during a test or training procedure, at least part of the phase change required to correct for the error is applied, as
15 described earlier, whilst the live signal is being transmitted by the transmitter 100. Thus the test or training procedure may be carried out at the start of a time slot and the live signal transmission during which the phase change is applied may take place in the same
20 time slot following the test or training procedure.

In an alternative known test or training procedure a known test signal applied as inputs to the combiners 403 and 409 and eventually amplified by the RFPA 123 may be monitored by internal reception by a receiver (not shown)
25 of a transceiver of which the transmitter 100 is part. Processors used by the receiver may be part of the DSP 103. The phase of the received amplified test signal may thereby be monitored by the phase error detector 132 (FIG. 1) and an error between the phase of the test
30 signal as applied and as received by the receiver may thereby be found. The phase of a signal delivered to the

RFPA 123 for transmission may be changed accordingly by the phase shifter 133 located in the forward path leading to the RFPA 123.

FIG. 5 is a block schematic diagram of a circuit 500 which is an illustrative example of a linearity control loop which is a feed forward loop 501 included in the transmitter 100 of FIG. 1. An RF input signal (produced by the combiner 119 shown in FIG. 1) to be applied to the RFPA 123 is sampled by a coupler 503. The RF signal sampled by the coupler 503 is applied in the feed forward loop 501 via a phase shifter 133.2 and a gain adjuster 511 to a correction amplifier 513. An output RF signal produced by the correction amplifier 513 is delivered to a combiner 507. The RF input signal (produced by the combiner 119 shown in FIG. 1) is also applied via a delay 505 to the RFPA 123. The RFPA 123 produces an amplified RF signal which is delivered to the combiner 507. The combiner 507 combines the respective signals applied to it from the RFPA 123 and the correction amplifier 513 to produce an RF output signal that is delivered to the antenna 125 (not shown in FIG. 5). The RF output signal is sampled by a coupler 515. The signal sampled by the coupler 515 is delivered to a downconverter 517 which converts the signal to baseband form. The downconverter 517 is coupled to a gain and phase controller 519 which may be included in the DSP 103 (other components of the DSP 103 being omitted in FIG. 5). The gain and phase controller 519 applies control signals to the phase shifter 133.2 and to the gain adjuster 511.

In operation of the circuit 500, the feed forward loop 501 eliminates distortions of the RF signal

amplified by the RFPA 123 caused by non-linearity of the RFPA 123. The gain and phase controller 519 detects distortions in phase and amplitude of the RF output signal sampled by the coupler 515. The controller 519
5 produces control signals in response and delivers the control signals to the phase shifter 133.2 and the gain adjuster 511. The phase shifter 133.2 and the gain adjuster 511 thereby produce adjustments in phase and gain respectively to the RF signal sampled in the feed
10 forward loop 501. The correction amplifier 513 produces an amplification of the signal in the feed forward loop 501 which matches that produced by the RFPA 123. The delay 505 applies a time delay which matches a delay which occurs in the phase shifter 133.2 and the gain
15 adjuster 511.

Thus, in the circuit 500, the gain and phase controller 519 carries out the function of the phase error detector 132 and the phase shift controller 131 shown in FIG. 1, and the phase shifter 133.2 carries out
20 the function of the phase shifter 133 shown in FIG. 1.

FIG. 6 is a block schematic diagram of a circuit 600 which is an illustrative example of a linearity control loop which is a pre-distortion feedback control loop 601 included in the transmitter 100 of FIG. 1. The control
25 loop 601 is similar to the control loop 401 except that a baseband I error signal produced by the mixer 421 and a baseband Q error signal produced by the mixer 425 are delivered in the loop 601 to a pre-distortion analyzer 605 which may be included in the DSP 103. The pre-
30 distortion analyzer 605 also receives the I component signal and the Q component signal produced by the

baseband signal generator 101. The pre-distortion analyzer 605 analyzes the baseband I error signal and the baseband Q error signal to determine imbalances in phase and amplitude of the I and Q error signals relative to the I component signal and the Q component signal produced by the generator 101.

The pre-distortion analyzer 605 is coupled to a pre-distortion block 603, which may be within the DSP 103, located between the generator 101 and the DACs 107 and 113. The pre-distortion block 603 applies an adjustment in phase and amplitude to at least one of the I component signal and the Q component signal delivered to the DAC 107 and 113 respectively. The adjustments in phase and amplitude are computed so as to cancel the errors in phase and amplitude detected by the analyzer 605.

Thus, in the transmitter 600, the pre-distortion analyzer 605 carries out the function of the phase error detector 132 (FIG. 1) and the pre-distortion block 603 carries out the function of the phase shift controller 131 and the phase shifter 133.

Alternatively, or in addition, an adjustment in phase may also be made by the phase shifter 133.1 to the carrier frequency signal produced by the local oscillator 415. The remaining components numbered 109, 115, 111, 117, 119, 123, 125, 419 and 431 shown in FIG. 6 correspond to the identical components shown in FIG. 1 and FIG. 4 and, thus, have the same function functionality, the description of which is included above and not repeated here for the sake of brevity.

By the phase shifter 133 of the transmitter 100 applying a required change in phase, e.g. an incremental

step change, only during a selected period when the average power of the signal affected is known by the phase shift controller 131 to be low, the performance of the transmitter 100 may be improved. The amount of RF energy of an RF signal transmitted by the transmitter 100 which is wasted in side bands of unwanted RF spectrum splatter due to the change in phase can beneficially be reduced. This reduction is achieved because the amount of energy which is present in the side bands generally increases as a function of the average signal amplitude or power of a QAM transmitter when the phase change is made. The reduction in RF energy appearing in the side bands beneficially allows the inter-channel interference performance of the transmitter 100 to be improved, thereby allowing the transmitter 100 to meet stringent inter-channel interference performance specifications.

The transmitter 100 may suitably be any linear transmitter which produces QAM signals. The transmitter 100 may for example be a transmitter for use in a communication system operating according to one of the following known protocol standards: TETRA 1 (basic TETRA for voice and data communication); TETRA 2 (enhanced TETRA for high speed data communication); iDEN (Integrated Digital Enhanced Network); WiMAX (Worldwide Interoperability for Microwave Access, based on the IEEE 802.16 standard); and WiFi (defined by the WiFi Alliance and based on the IEEE 802.11 standard).

In the foregoing specification, specific embodiments have been described. However, one of ordinary skill in the art will appreciate that various modifications and

changes can be made without departing from the scope of the invention as set forth in the accompanying claims. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of present teachings. The benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential features or elements of any or all the claims. The invention is defined solely by the appended claims including any amendments made during the pendency of this patent application and all equivalents of those claims as issued.

Moreover in this document, relational terms such as 'first' and 'second', 'top' and 'bottom', and the like, may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions. The terms 'comprises', 'comprising', 'has', 'having', 'includes', 'including', 'contains', 'containing' or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises, has, includes or contains a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. An element preceded by 'comprises ...a', 'has ...a', 'includes ...a', or 'contains ...a' does not, without more

constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises, has, includes, contains the element. The terms 'a' and 'an' are defined as one or
5 more unless explicitly stated otherwise herein. The terms 'substantially', 'essentially', 'approximately', 'about' or any other version thereof, are defined as being close to as understood by one of ordinary skill in the art, and in one non-limiting embodiment the term is
10 defined to be within 10%, in another embodiment within 5%, in another embodiment within 1% and in another embodiment within 0.5%, of a stated value. The term 'coupled' as used herein is defined as connected, although not necessarily directly and not necessarily
15 mechanically. A device or structure that is 'configured' in a certain way is configured in at least that way, but may also be configured in ways that are not listed.

It will be appreciated that some embodiments may be comprised of one or more generic or specialized
20 processors (or "processing devices") such as microprocessors, digital signal processors, customized processors and field programmable gate arrays (FPGAs) and unique stored program instructions (including both software and firmware) that control the one or more
25 processors to implement, in conjunction with certain non-processor circuits, some, most, or all of the functions of the method and apparatus for synchronization in a digital mobile communication system as described herein. The non-processor circuits may include, but are not
30 limited to, a radio receiver, a radio transmitter, signal drivers, clock circuits, power source circuits, and user

input devices. As such, these functions may be interpreted as steps of a method to perform the synchronization in a digital mobile communication system as described herein. Alternatively, some or all functions could be implemented by a state machine that has no stored program instructions, or in one or more application specific integrated circuits (ASICs), in which each function or some combinations of certain of the functions are implemented as custom logic. Of course, a combination of the two approaches could be used. Both the state machine and ASIC are considered herein as a 'processing device' for purposes of the foregoing discussion and claim language.

Moreover, an embodiment including a memory can be implemented as a computer-readable storage element having computer readable code stored thereon for programming a computer (e.g., comprising a processing device) to perform a method as described and claimed herein. Examples of such computer-readable storage elements include, but are not limited to, a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a ROM (Read Only Memory), a PROM (Programmable Read Only Memory), an EPROM (Erasable Programmable Read Only Memory), an EEPROM (Electrically Erasable Programmable Read Only Memory) and a Flash memory.

Further, it is expected that one of ordinary skill, notwithstanding possibly significant effort and many design choices motivated by, for example, available time, current technology, and economic considerations, when guided by the concepts and principles disclosed herein will be readily capable of generating such software

instructions and programs and ICs with minimal experimentation.

In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together
5 in various embodiments for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims
10 reflect, inventive subject matter may lie in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separately claimed subject matter.

CLAIMS

1. An RF transmitter for transmitting a QAM (Quadrature Amplitude Modulated) signal, the transmitter including a
5 baseband signal generator operable to process or produce a baseband signal including information to be included as a QAM modulation of a transmitted RF signal, a phase shifter operable to apply a change in phase affecting the baseband signal or a signal derived from it, or a signal
10 to be mixed with the baseband signal or with a signal derived from it, a phase shift controller operable to apply a control signal to the phase shifter to control a change in phase applied by the phase shifter, and an analyzer operable to analyze the baseband signal to
15 detect low signal periods when the baseband signal has a value of a parameter, which is a function of amplitude, not greater than a threshold level, the phase shift controller being operable to receive from the analyzer an indication of the low signal periods and, in response, to
20 apply the control signal so that the change in phase is applied by the phase shifter only during a selected period when the affected signal has a low power corresponding to a low signal period of the baseband signal.

25

2. A transmitter according to claim 1 including a control loop wherein the phase shifter is operable to apply the change in phase to a signal in or to be delivered to the control loop.

3. A transmitter according to claim 2 wherein the control loop comprises a pre-distortion loop and wherein the phase shifter is operable to change the phase of the baseband signal delivered by the baseband signal generator or a baseband signal derived from it.
4. A transmitter according to claim 2 wherein the control loop comprises a feed forward loop and wherein the phase shifter is operable to apply the change in phase to an RF signal in the feed forward loop.
5. A transmitter according to claim 2 including a local oscillator and a mixer in the control loop operable to receive a signal produced by the local oscillator and to mix the signal with a signal in the control loop, wherein the phase shifter is operable to apply the change in phase to the signal produced by the local oscillator and received by the mixer.
6. A transmitter according to claim 5 wherein the control loop comprises a Cartesian control loop, and wherein the mixer is in a feedback control channel of the Cartesian control loop.
7. A transmitter according to claim 1 including a phase error detector operable to detect an error in phase of a signal in the transmitter to be at least partially corrected by the phase change applied by the phase shifter.

8. A transmitter according to claim 1 wherein the analyzer includes a profiler operable to sample the baseband signal and to estimate an average value of amplitude or power of the baseband signal in each of a series of consecutive sampling periods and a comparator operable to compare the average value estimated by the profiler for each sampling period with a threshold.
9. A transmitter according to claim 8 including a threshold controller operable to provide the threshold for use by the comparator, wherein the threshold is dynamically variable by the threshold controller according to operating conditions of the transmitter, and wherein the threshold controller is operable to vary the threshold according to variations in a voltage standing wave ratio of an antenna of the transmitter.
10. A transmitter according to claim 1 including an RF power amplifier operable to amplify an RF signal to be transmitted, an antenna operable to transmit the RF signal and a transmission path from the RF power amplifier to the antenna to deliver the signal amplified by the RF power amplifier to the antenna for transmission, the transmission path including no device for isolating the RF power amplifier from impedance reflections from the antenna.

11. A method of operation in an RF transmitter, the method including: producing by a baseband signal generator a baseband signal including information to be included as a QAM modulation of a transmitted RF signal,
5 analyzing the baseband signal by an analyzer to detect low signal periods when the baseband signal has an amplitude or power not greater than a threshold level, providing from the analyzer to a phase shift controller an indication of the low signal periods detected by the
10 analyzer, delivering from the phase shift controller to a phase shifter a control signal to control a change in phase applied by the phase shifter and, in response to receiving the control signal delivered by the phase shift controller, applying a change in phase by the phase
15 shifter to affect the baseband signal, a signal derived from the baseband signal or a signal to be mixed with the baseband signal, during a selected period corresponding to a low signal period of the baseband signal.

20 12. A method according to claim 11 including: detecting by a phase error detector an error in phase of a signal or between signals in the transmitter to be at least partially corrected by the phase change applied by the phase shifter; and indicating the error to the phase
25 shift controller.

13. A method according to claim 12 including detecting the error in phase during a period when the transmitter is not transmitting an RF signal.

14. A method according to claim 13 wherein the transmitter operates according to a time slotted timing sequence wherein signal transmission takes place during selected transmission time slots of the timing sequence and the method includes initiating a test procedure to
5 detect the error in phase in an early part of a transmission time slot and applying at least part of a change in phase needed to correct for the detected error during signal transmission.

10

15. A method according to claim 11 including applying by the phase shifter changes in phase which are step changes, each during a selected period corresponding to a low signal period of the baseband signal.

15

16. A method according to claim 15 including applying by the phase shifter incremental step changes in phase, wherein each of the phase shifter incremental step changes gives a phase angle change of between about one
20 degree and about two degrees.

20

17. A method according to claim 11 wherein the analyzing of the baseband signal includes sampling the baseband signal, estimating an average value of amplitude or power
25 of the baseband signal in each of a series of consecutive sampling periods and comparing by a comparator the average value estimated for each sampling period with a threshold, and wherein the estimating of the average value of amplitude or power is carried out for
30 consecutive sampling periods of between about 5 microseconds and about 20 microseconds.

30

18. A method according to claim 17 including providing
by a threshold controller a threshold for use by the
comparator wherein the threshold is dynamically variable
by the threshold controller according to operating
5 conditions of the transmitter.

19. A method according to claim 17 including the
comparator comparing average values of the power of the
baseband signal with a threshold power and the threshold
10 power is between about -3 dB and about -10 dB.

20. A method according to claim 11 including the phase
shift controller applying a pre-determined delay to issue
a control signal to the phase shifter following receipt
15 by the phase shift controller of an indication of a low
signal period from the analyzer.

100

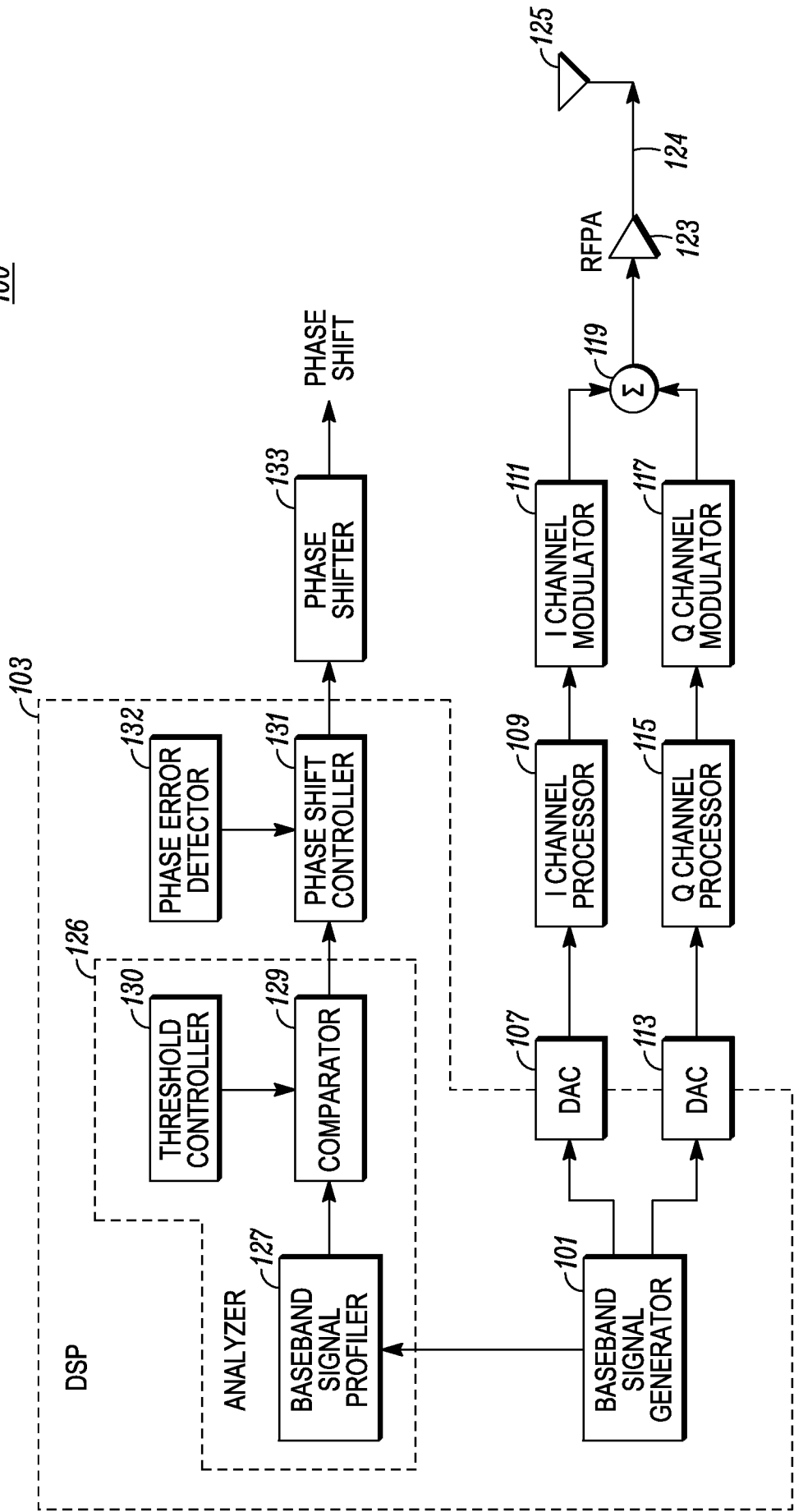


FIG. 1

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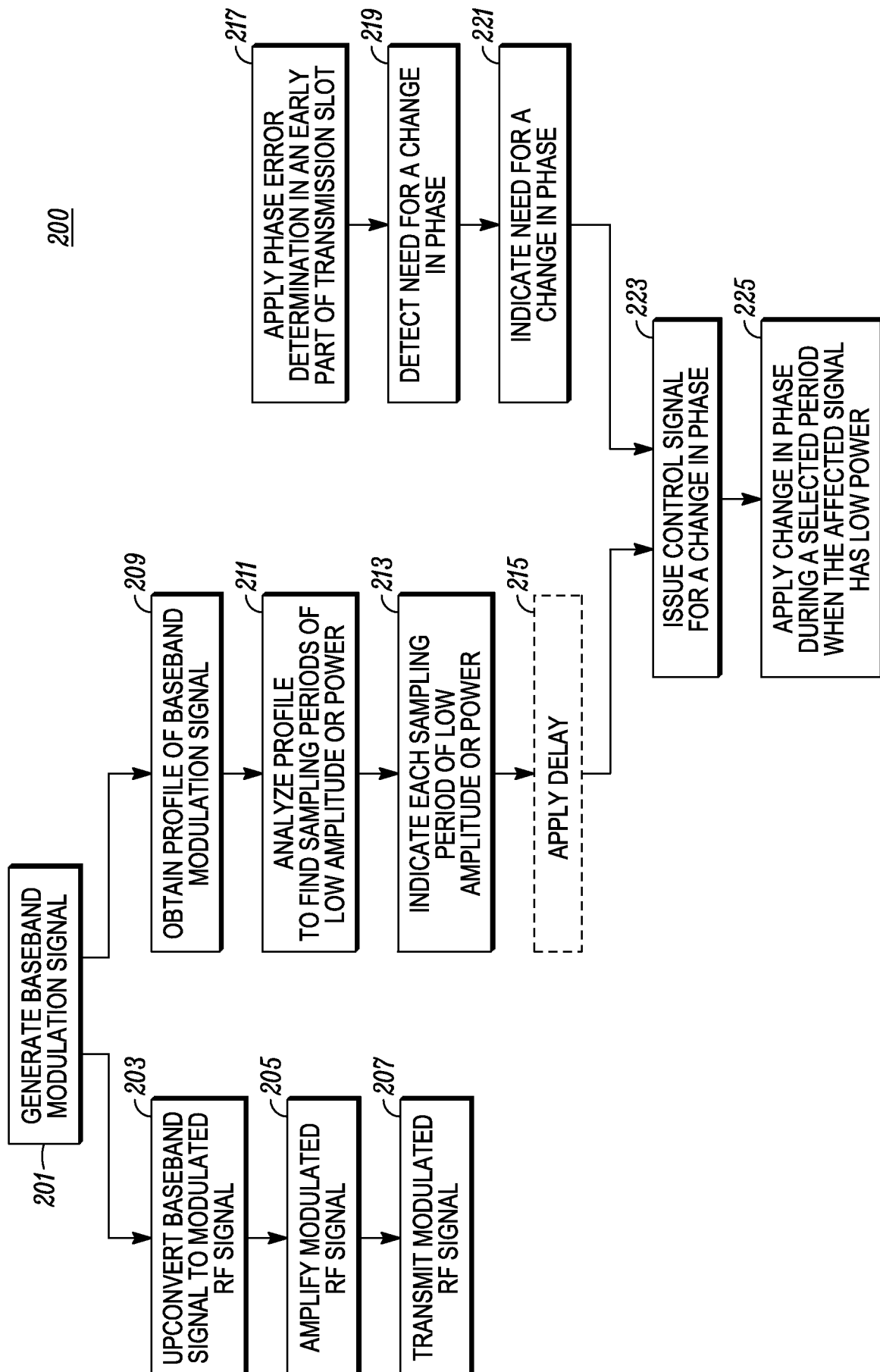


FIG. 2

300

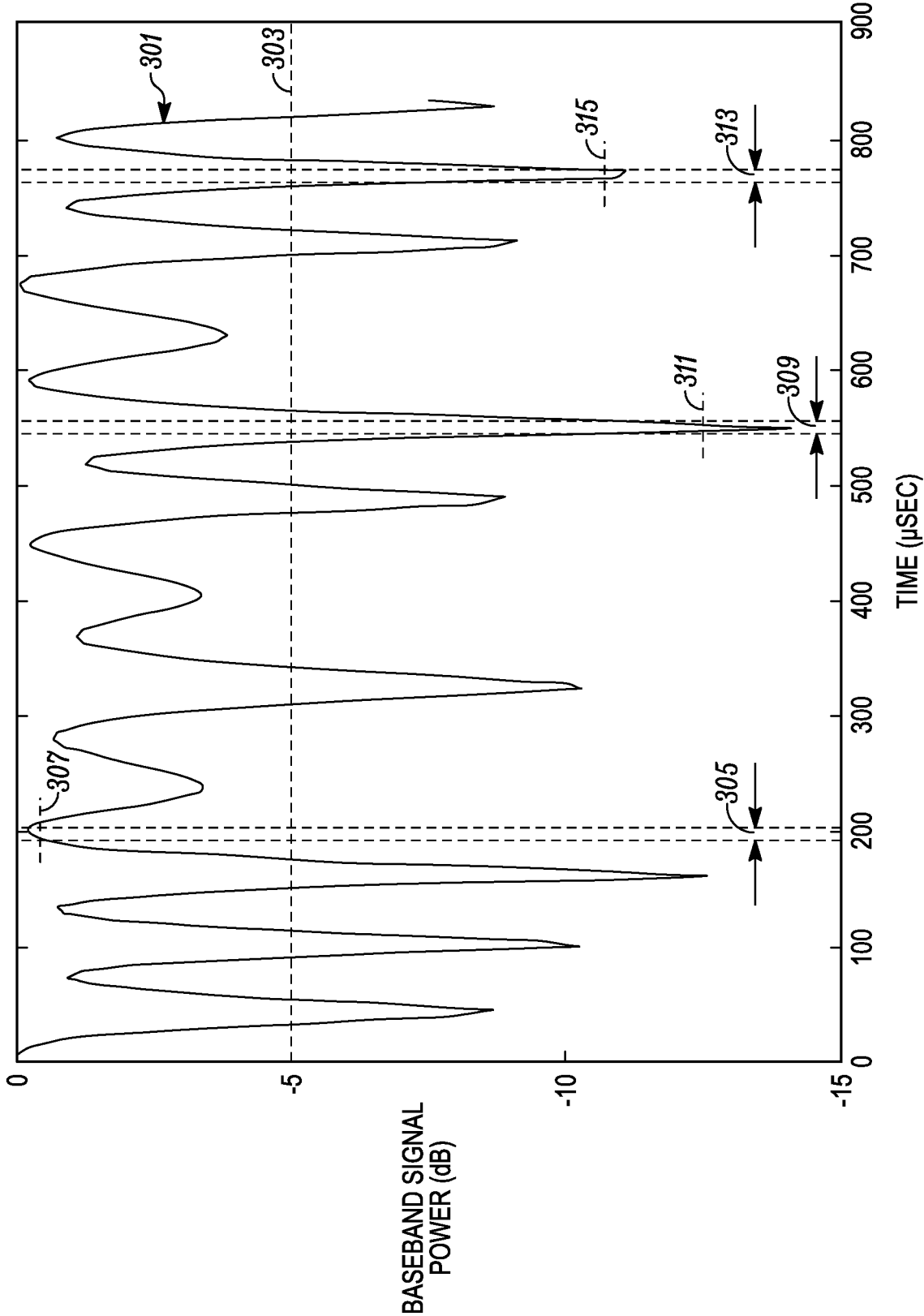
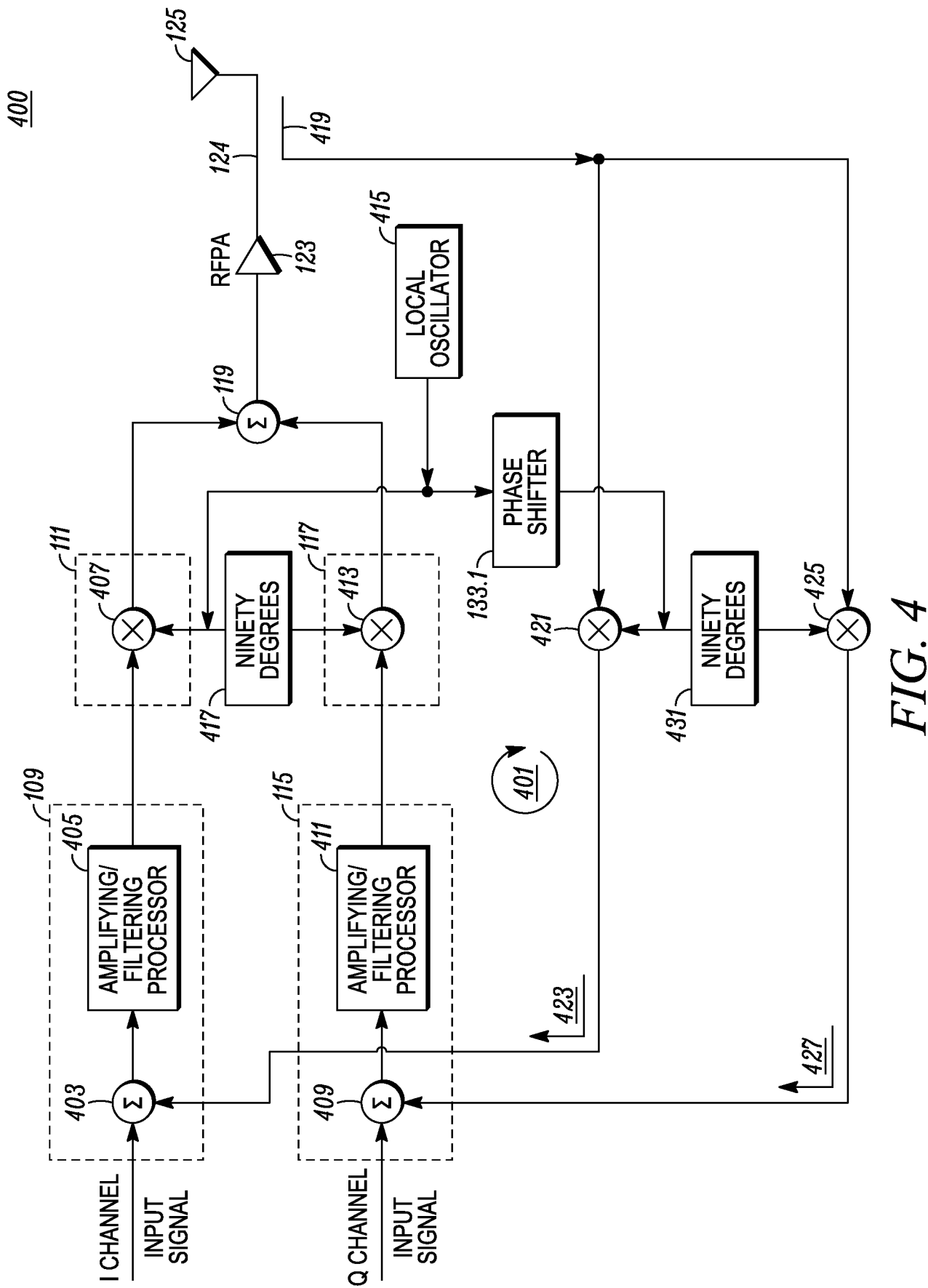


FIG. 3



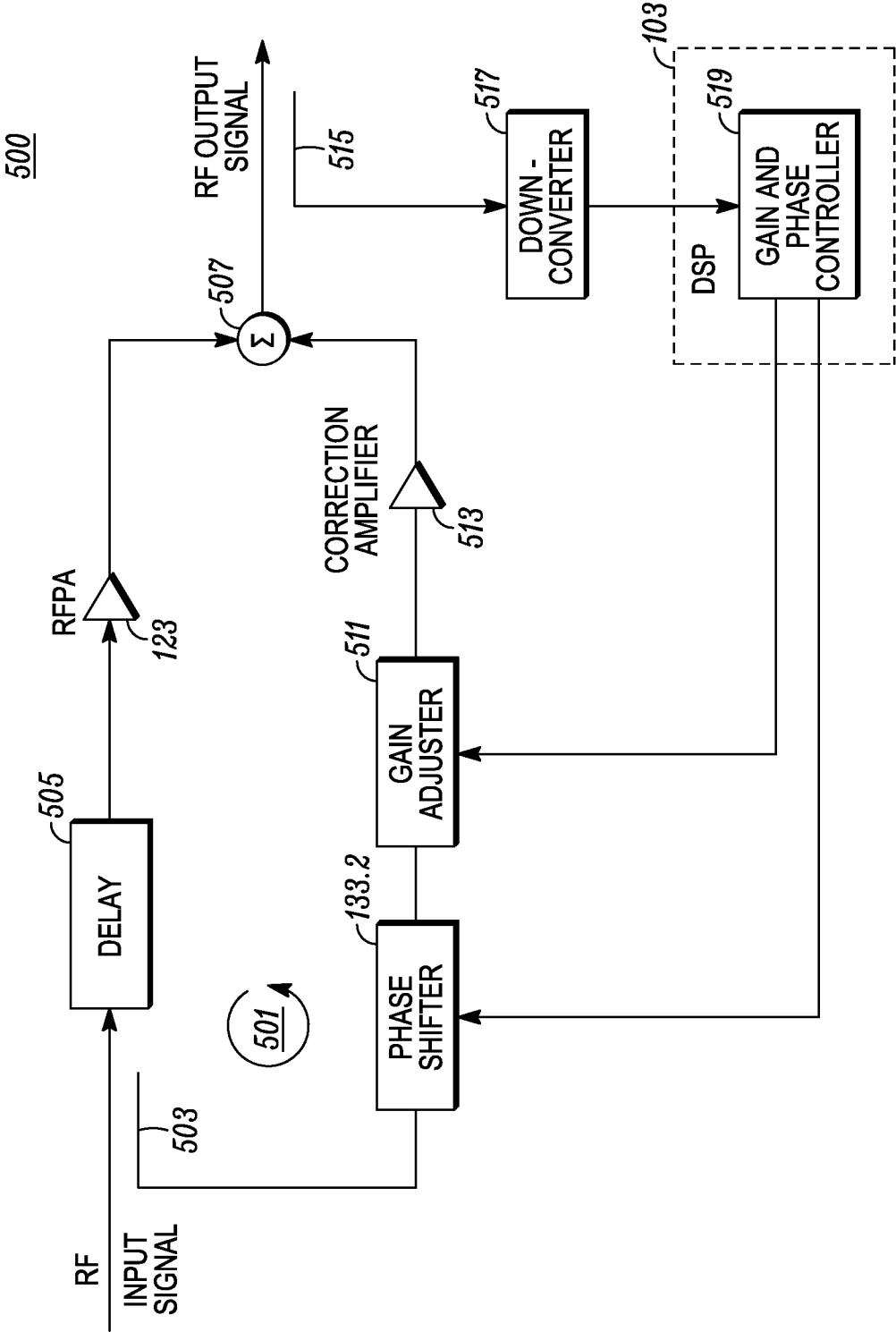


FIG. 5

600

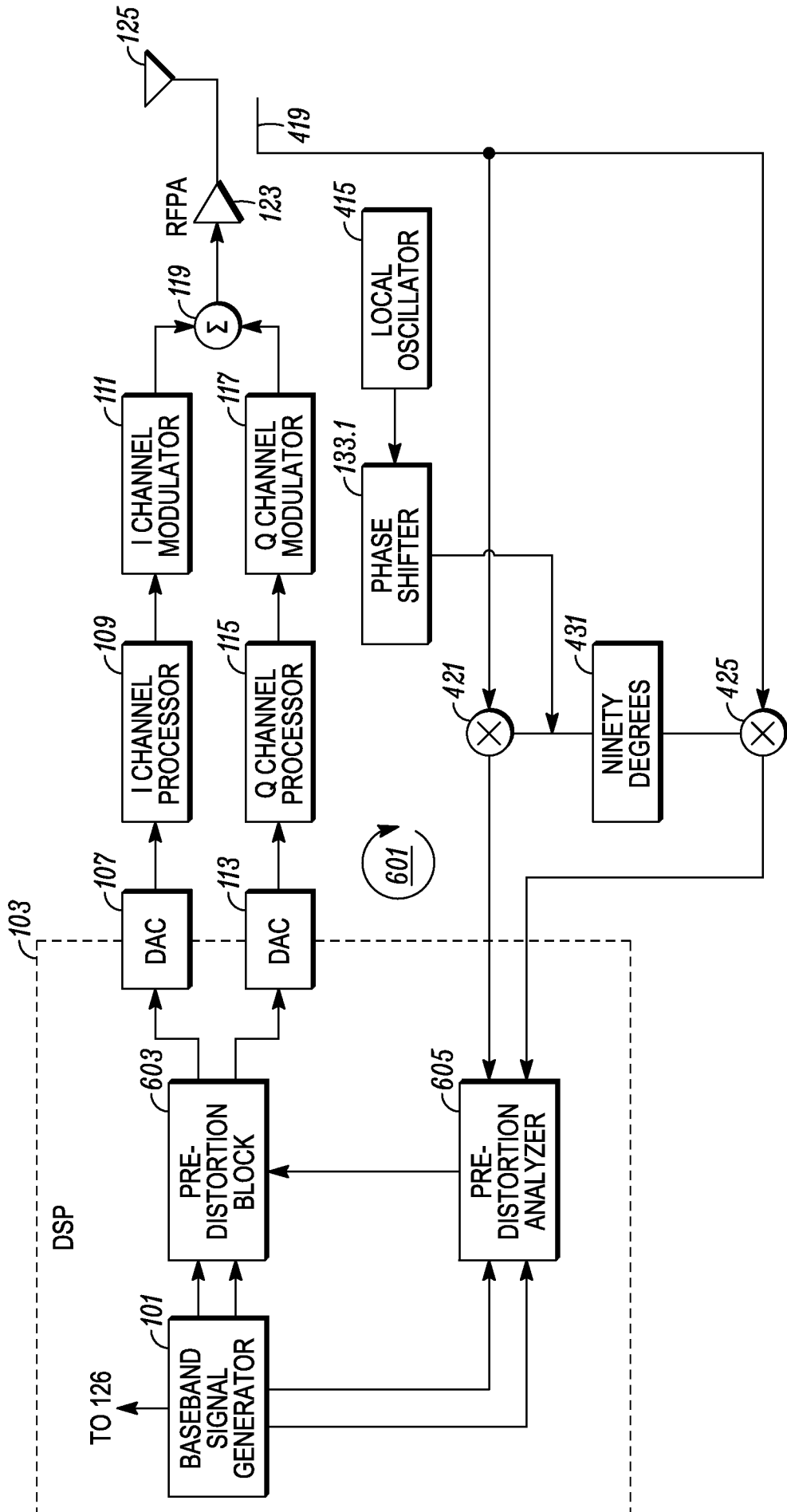


FIG. 6