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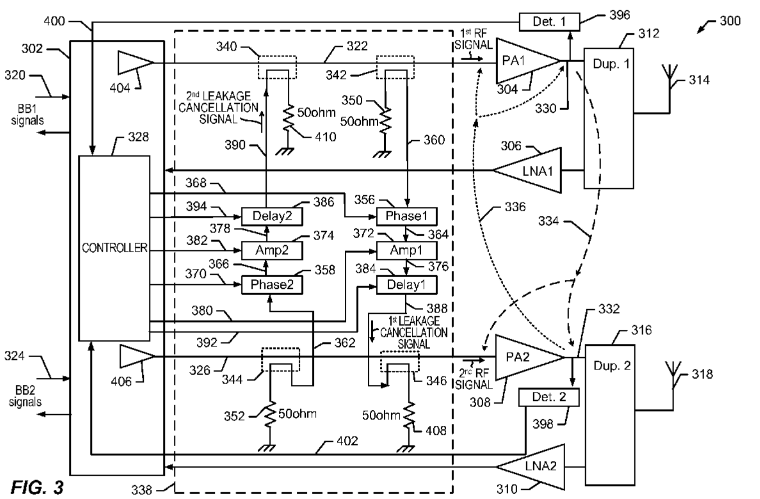

FIG. 3

(57) Abstract: An intermodulation distortion canceler for use in multi-carrier transmitters is disclosed. In an exemplary embodiment, an apparatus includes a first transmit chain that transmits a first RF signal, a second transmit chain that transmits a second RF signal, and a canceler that outputs a first leakage cancellation signal that is input to the second transmit chain, and outputs a second leakage cancellation signal that is input to the first transmit chain, the canceler generates the first and second leakage cancellation signals from the first and second RF signals or from first and second baseband signals used to generate the first and second RF signals.

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INTERMODULATION DISTORTION CANCELLER FOR USE IN MULTI-CARRIER TRANSMITTERS

BACKGROUND

I. Field

[0001] The present disclosure relates generally to electronics, and more specifically to multi-carrier transmitters.

II. Background

[0002] A wireless device (e.g., a cellular phone or a smartphone) in a wireless communication system may transmit and receive data for two-way communication. For example, the wireless device may operate in a frequency division duplexing (FDD) system or in a time division duplexing system (TDD). The wireless device may include a transmitter for data transmission and a receiver for data reception. For data transmission, the transmitter may modulate a radio frequency (RF) carrier signal with data to obtain a modulated RF signal, amplify and filter the modulated RF signal to obtain an amplified RF signal having the proper output power level, and transmit the amplified RF signal via an antenna to a base station. For data reception, the receiver may obtain a received RF signal via the antenna and may amplify, filter and process the received RF signal to recover data sent by the base station.

[0003] A wireless device may support operation over a wide frequency range. The wireless device may include a number of amplifiers, with each amplifier being designed to operate over a portion of the wide frequency range supported by the wireless device. For example, the wireless device may operate in a carrier aggregation (CA) communication system in which the device comprises multiple uplink (UL) transmitters transmitting at different carrier frequencies. However, simultaneous transmission by the transmitters might cause receiver desensitization due to intermodulation distortion (IMD).

[0004] Therefore, it is desirable to have a distortion canceler for use in a wireless device to support operation over a wide frequency range while reducing intermodulation distortion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] **FIG. 1** shows an exemplary embodiment of an IMD canceler in a wireless device configured to communicate in a wireless communication system.

[0006] **FIG. 2** shows exemplary frequency band groups in which the IMD canceler of **FIG. 1** is configured to operate.

[0007] **FIG. 3** shows a transmitter that includes an exemplary embodiment of an IMD canceler for use in a wireless device.

[0008] **FIG. 4** shows a transmitter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 3** for use in a wireless device.

[0009] **FIG. 5** shows a transmitter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 3** for use in a wireless device.

[0010] **FIG. 6** shows a transmitter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 3** for use in a wireless device.

[0011] **FIG. 7** shows a baseband to RF converter comprising an exemplary embodiment of an IMD canceler for use in a wireless device.

[0012] **FIG. 8** shows a transmitter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 7** for use in a wireless device.

[0013] **FIG. 9** shows a baseband to RF converter comprising an exemplary alternative embodiment of the IMD canceler of **FIG. 7** for use in a wireless device.

[0014] **FIG. 10** shows a baseband to RF converter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 9** for use in a wireless device.

[0015] **FIG. 11** shows a baseband to RF converter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 10** for use in a wireless device.

[0016] **FIG. 12** shows a transmitter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 11** for use in a wireless device.

[0017] **FIG. 13** shows an exemplary embodiment of a controller for use in an IMD canceler.

[0018] **FIG. 14** shows exemplary operations for performing IMD cancellation in a wireless device.

[0019] **FIG. 15** shows exemplary operations for performing IMD cancellation in a wireless device.

[0020] **FIG. 16** shows exemplary operations for performing dual IMD cancellation in a wireless device.

[0021] **FIG. 17** shows an exemplary apparatus configured for IMD cancellation in a wireless device.

[0022] **FIG. 18** shows a modified baseband to RF converter comprising an exemplary embodiment of an IMD canceler for use in a wireless device.

[0023] **FIG. 19** shows a modified baseband to RF converter comprising an exemplary alternative embodiment of an IMD canceler for use in a wireless device.

[0024] **FIG. 20** shows a modified baseband to RF converter comprising an exemplary alternative embodiment of an IMD canceler for use in a wireless device.

DETAILED DESCRIPTION

[0025] The detailed description set forth below is intended as a description of exemplary designs of the present disclosure and is not intended to represent the only designs in which the present disclosure can be practiced. The term "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any design described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other designs. The detailed description includes specific details for the purpose of providing a thorough understanding of the exemplary designs of the present disclosure. It will be apparent to those skilled in the art that the exemplary designs described herein may be practiced without these specific details. In some instances, well-known structures and devices are shown in block diagram form in order to avoid obscuring the novelty of the exemplary designs presented herein.

[0026] **FIG. 1** shows an exemplary embodiment of an IMD canceler **116** in a wireless device **110** configured to communicate in a wireless communication system **100**. Wireless system **100** may be a Long Term Evolution (LTE) system, a Code Division Multiple Access (CDMA) system, a Global System for Mobile Communications (GSM) system, a wireless local area network (WLAN) system, or some other wireless system. A CDMA system may implement Wideband CDMA (WCDMA), CDMA 1X, Evolution-Data Optimized (EVDO), Time Division Synchronous CDMA (TD-SCDMA), or some other version of CDMA. For simplicity, **FIG. 1** shows the wireless device **110** in communication with base stations **102** and **104** and one system controller **106**. In general, the wireless communication system **100** may include any number of base stations, Femto cells, Pico cells and/or any set of network entities.

[0027] The wireless device **110** may also be referred to as a user equipment (UE), a mobile station, a terminal, an access terminal, a subscriber unit, a station, etc. The wireless device **110** may be a cellular phone, a smartphone, a tablet, a wireless modem, a personal digital assistant (PDA), a handheld device, a laptop computer, a smartbook, a netbook, a cordless phone, a wireless local loop (WLL) station, a Bluetooth device, etc. The wireless device **110** may also receive signals from broadcast stations (e.g., a broadcast station **112**), and/or signals from satellites (e.g., a satellite **108**) in one or more global navigation satellite systems (GNSS). Wireless device **110** may support one or more radio technologies for wireless communication such as LTE, WCDMA, CDMA 1X, EVDO, TD-SCDMA, GSM, 802.11.

[0028] Wireless device **110** includes a transmitter **114** having an exemplary embodiment of the IMD canceler **116**. The transmitter **114** includes multiple transmit circuits that are configured to transmit over multiple transmit frequencies. Cross-leakage between two power amplifiers (PAs) may result in Tx intermodulation products IMD2, IMD3, IMD4, and/or IMD5, which might fall within the downlink (DL) frequency of one or both of the two operational bands. In various exemplary embodiments, the IMD canceler **116** comprises a first adaptive canceler coupled from band-1 to band-2 to cancel any band-1 leaking products at the input of the band-2 PA. The IMD canceler also comprises a second adaptive canceller coupled from band-2 to band-1 to cancel any band-2 leaking products at the input of the band-1 PA. In an exemplary embodiment, PA output detectors are utilized to obtain the level of the leaking signals so that they can be canceled to optimize performance (EVM, BER, etc.). Thus, by adjusting the IMD canceler **116** it is possible to obtain minimal or reduced IMD leading to lower EVM and BER. In exemplary embodiments, the IMD canceler **116** operates to reduce, minimize, or eliminate distortion associated with operation of the multiple simultaneous transmit circuits.

[0029] **FIG. 2** shows exemplary frequency band groups in which the IMD canceler **116** of **FIG. 1** is configured to operate. Wireless device **110** may be able to operate in a low-band (LB) covering frequencies lower than approximately 1000 megahertz (MHz), a mid-band (MB) covering frequencies from approximately 1000 MHz to 2300 MHz, and/or a high-band (HB) covering frequencies higher than 2300 MHz. For example, the low-band may cover 698 to 960 MHz, the mid-band may cover 1427.9 to 2170 MHz, and the high-band may cover 2300 to 2690 MHz and 3400 to 3800 MHz, as shown in

FIG. 2. The low-band, mid-band, and high-band refer to three groups of bands (or band groups), with each band group including any number of frequency bands (or simply, "bands"). Each band may cover up to 200 MHz. LTE Release 11 supports 35 bands, which are referred to as LTE/UMTS bands and are listed in 3GPP TS 36.101.

[0030] In general, any number of band groups may be defined. Each band group may cover any range of frequencies, which may or may not match any of the frequency ranges shown in **FIG. 2**. Each band group may also include any number of bands.

[0031] **FIG. 3** shows a transmitter **300** that includes an exemplary embodiment of an IMD canceler **338** for use in a wireless device, such as the wireless device **110** shown in **FIG. 1**. The transmitter **300** comprises a baseband (BB) to radio frequency (RF) converter **302**, a first power amplifier (PA1) **304**, a first low noise amplifier (LNA1) **306**, a second power amplifier (PA2) **308**, and a second low noise amplifier (LNA2) **310**. PA1 **304** and LNA1 **306** transmit and receive RF signals in a first band through first duplexer **312** using first antenna **314**. PA2 **308** and LNA2 **310** transmit and receive RF signals in a second band through second duplexer **316** using second antenna **318**. It should be noted that the first and second bands may be any of the bands shown in **FIG. 2**. For example, in a first exemplary embodiment, the first band is the high band and the second band is the low band. In a second exemplary embodiment, the first band is the mid band and the second band is the low band. In a third exemplary embodiment, the first band is the mid band and the second band is the low band.

[0032] During operation, the baseband to RF converter **302** operates to receive a first baseband transmit signal **320** and converts this signal to a first RF transmit signal **322** that is output from a first driver amplifier (DA) **404**. The baseband to RF converter **302** also receives a second BB transmit signal **324** and converts this signal to a second RF transmit signal **326** that is output from a second DA **406**. A controller **328** controls the operation of the baseband to RF converter **302** to convert the BB signals to RF signals. A first transmit chain comprises the DA **404**, PA1 **304**, and duplexer **312** and operates to transmit the first baseband signal **320** from the antenna **314**. A second transmit chain comprises the DA **406**, PA1 **308**, and duplexer **316** and operates to transmit the baseband signal **324** from the antenna **318**.

[0033] The first RF transmit signal **322** is input to PA1 **304** for amplification to generate a first amplified RF transmit signal **330** that is input to the first duplexer **312** and thereafter transmitted by the first antenna **314**. The second RF transmit signal **326**

is input to PA2 **308** for amplification to generate a second amplified RF transmit signal **332** that is input to the second duplexer **316** and thereafter transmitted by the second antenna **318**.

[0034] Intermodulation distortion occurs when two transmit (Tx) channels transmit signals simultaneously and one transmit signal couples into another transmit signal. This coupling may appear as distortion in a receive signal band that results in degraded receiver performance. For example, the first amplified RF transmit signal **330** may couple (or leak) to the input or output of PA2 **308**, as shown by path **334.** As a result, an IMD product frequency may fall in the Rx2 range and this IMD product may leak into the Rx2 signal path and be amplified by LNA2 **310,** thereby degrading the second receiver performance. The second amplified RF transmit signal **332** may couple (or leak) to the input or output of PA1 **304**, as shown by path **336**. As a result an IMD product frequency may fall in the Rx1 range and this IMD product may leak into the Rx1 path and be amplified by LNA1 **306,** thereby degrading the first receiver performance.

[0035] The transmitter **300** also comprises distortion canceler **338**, which operates to reduce, minimize, or eliminate distortion caused by leakage of the first amplified RF signal **330** to PA2 **308** or leakage of the second amplified RF signal **332** to PA1 **304**. The canceler **338** comprises signal couplers **342** and **344,** which are coupled to the signal lines carrying the first RF signal **322** and the second RF signal **326**, respectively. The couplers **342** and **344** comprise any suitable type of signal couplers (directional or non-directional) and have first terminals connected to a signal ground via resistors **350** and **352**, respectively. The coupler **342** has a second terminal connected to a first phase adjustment circuit **356** and the coupler **344** has a second terminal connected to a second phase adjustment circuit **358**. The couplers **342** and **344** operate to generate coupled signals **360** and **362** from the first and second RF signals **322** and **326** and these coupled signals are input to the first and second phase adjustment circuits **356** and **358**, respectively. For example, the coupled signals **360** and **362** represent versions of the first and second RF signals **322** and **326**.

[0036] The phase adjustment circuits **356** and **358** operate to adjust phase characteristics of the coupled signals **360** and **362** that are receive from the couplers **342** and **344** to generate phase adjusted signals **364** and **366**. The phase adjustment circuits **356** and **358** comprise any suitable type of phase adjustment circuits operable to adjust phase characteristics of a received signal based on a control input to generate a phase adjusted output signal. The phase adjustments circuits **356** and **358** operate to adjust the phase characteristics of the coupled signals **360** and **362** based on phase control inputs **368** and **370** received from the controller **328** to generate phase adjusted output signals **364** and **366**. The phase adjusted output signals **364** and **366** are input to amplitude adjustment circuits **372** and **374**.

[0037] The amplitude adjustment circuits **372** and **374** operate to adjust amplitude characteristics of the phase adjusted signals **364** and **366** received from the phase adjustment circuits **356** and **358** to generate amplitude adjusted signals **376** and **378**. The amplitude adjustment circuits **372** and **374** comprise any suitable amplitude adjustment circuit operable to adjust amplitude characteristics of a received signal based on a control input to generate an amplitude adjusted output signal. The amplitude adjustment circuits **372** and **374** operate to adjust the amplitude characteristics of the phase adjusted signals **364** and **366** based on amplitude control inputs **380** and **382** received from the controller **328** to generate the amplitude adjusted output signals **376** and **378**. The amplitude adjusted output signals **376** and **378** are input to delay adjustment circuits **384** and **386**.

[0038] The delay adjustment circuits **384** and **386** operate to adjust delay characteristics of the amplitude adjusted signals **376** and **378** received from the amplitude adjustment circuits **372** and **374** to generate first and second cancellation signals **388** and **390**. The delay adjustment circuits **384** and **386** comprise any suitable delay adjustment circuit operable to adjust delay characteristics of a received signal based on a control input to generate a delay adjusted output signal. The delay adjustment circuits **384** and **386** operate to adjust the delay characteristics of the amplitude adjusted signals **376** and **378** based on delay control inputs **392** and **394** received from the controller **328** to generate the first and second cancellation signals **388** and **390**. The first and second cancellation signals **388** and **390** are input to couplers **346** and **340**.

[0039] The couplers **346** and **340** have first terminals coupled to a signal ground through resistors **408** and **410**. The couplers have second terminals coupled to receive the first and second cancellation signals **388** and **390** and operate to couple the first **388** and second **390** cancellation signals to the signal lines carrying the second **326** and first **322** RF transmit signals, respectively, to cancel distortion caused by leakage of the first amplified RF transmit signal **330** to PA2 **308** and leakage of the second amplified RF transmit signal **332** to PA1 **304**. It should be noted that the arrangement and/or order of the phase, amplitude, and delay adjustment circuits can be changed or rearranged such that other configurations are possible within the scope of the exemplary embodiments.

[0040] As described in greater detail below, calibration operations are performed to determine an amount of leakage associated with the path **334** to control the cancellation circuit **338** to generate the first cancellation signal **388** to cancel this leakage at the input of PA2 **308**. In an exemplary embodiment, a second detector **398** operates to detect a power level at the output of PA2 **308** and provides a second detected power level **402** to the controller **328**. The controller **328** uses the second detected power level **402** to adjust the cancellation circuit **338** to generate the first cancellation signal **388** so as to cancel detected leakage. Additionally, the calibration operations operate to determine an amount of leakage associated with the path **336** to control the cancellation circuit **338** to generate the second cancellation signal **390** to cancel this leakage due to path **336** at the input of PA1 **304**. In an exemplary embodiment, a first detector **396** operates to detect a power level at the output of PA1 **304** and provides a first detected power level **400** to the controller **328**. The controller uses the first detected power level **400** to adjust the cancellation circuit **338** to generate the second cancellation signal **390**. Once the calibration operations are performed, the cancellation circuit **338** operates to maintain the first **388** and second **390** cancellation signals to cancel leakage during operation of the transceiver.

[0041] **FIG. 4** shows a transmitter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 3** for use in a wireless device. In this exemplary alternative embodiment, the detectors **396** and **398** shown in **FIG. 3** are replaced with a coupler module **402**. The coupler module **402** comprises a first directional coupler **404**, a second directional coupler **406**, and a switch **408**. The directional couplers **404**, **406** are configured to generate a coupled signal that represents a version of signals flowing in a selected direction in a coupled signal line and to output the coupled signal at an output terminal. Signals flowing in a direction other than the selected direction are suppressed from appearing in the coupled signal.

[0042] The first directional coupler **404** is coupled to the signal line carrying the first amplified RF signal **330** between the output of PA1 **304** and the first duplexer **312**. The second directional coupler **406** is coupled to the signal line carrying the second amplified RF transmit signal **332** between the output of PA2 **308** and the second duplexer **316**.

[0043] The first directional coupler **404** has an output terminal **410** that outputs a first coupled signal **412** that is input to the switch **408** at a first switch terminal **414**. The second directional coupler **406** has an output terminal **416** that outputs a second coupled signal **418** that is input to the switch **408** at a second switch terminal **420**.

[0044] The switch **408** includes a switch control terminal **422** that receives a switch control signal **424** to determine which of the first **414** and second **420** switch terminals will be connected to a switch output terminal **426**. The switch output terminal **426** and the switch control terminal **422** are connected to the controller **328** by signal lines **428** and **424**.

[0045] During operation, the controller **328** outputs the switch control signal on the signal line **424** to control the switch **408** to connect the switch output terminal **426** to one of the switch input terminals **414**, **420**. Based on the selected terminal, one of the first **412** and second **418** coupled signals is passed to the controller **328** by the signal line **428**. Once received at the controller **328**, the selected coupled signal is used during the cancellation calibration operations. For example, the coupled signals are used by the controller **328** to adjust the components of the IMD canceler **338** to reduce or eliminate IMD distortion between the first and second transmit chains.

[0046] **FIG. 5** shows a transmitter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 3** for use in a wireless device. In this exemplary alternative embodiment, the canceler **338** is moved and integrated within the integrated circuit (IC) of the BB to RF converter **302**. By integrating the canceler **338** within the IC of the BB to RF converter **302**, circuit board area is saved.

[0047] The switch **408** of the coupler module **402** is also modified to include an additional input terminal **502**. The input terminal **502** is connected to an output terminal **504** of a directional coupler **506**. The directional coupler **506** is coupled to the signal line between a diplexer **508** and the antenna **314**. The directional coupler **506** outputs from the output terminal **504** a coupled signal on the signal line **510** that represents a coupled version of the signal to be transmitted from the antenna **314**. This signal is referred to as a Tx main feedback signal.

[0048] The controller **328** operates to control the switch **408** through switch control line **424** to connect its output terminal **426** to one of its input terminals **414**, **420**, or **502** so that the coupled signal on the selected input terminal flows to the controller **328** through the signal line **428.** Thus, the controller **328** can receive any of the coupled signals generated by the couplers **404**, **406**, and **506**. These coupled signals are used by the controller **328** to perform distortion cancellation operations.

[0049] **FIG. 6** shows a transmitter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 3** for use in a wireless device. In this exemplary alternative embodiment, the canceler **338** is moved and integrated within the BB to RF converter **302** and the canceler **338** is split such that a first canceler portion **602** is coupled to inputs of the DAs **404**, **406**, and a second canceler portion **604** is coupled to outputs of the DAs **404**, **406**. It should be noted that the components of the canceler portions are the same as those of the canceler **338** shown in **FIG. 3,** and these canceler portions operate under the control of the controller **328.**

[0050] The first canceler portion **602** provides an IMD cancellation path at the inputs to the DAs **404** and **406**. For example, a coupled version of the signal at the input to the DA **404** is input to the adjustment circuit **606** and the output of the adjustment circuit **606** is coupled to the input of the DA **406**. It should be noted that for clarity only one cancellation path is shown connected to the inputs of the DAs **404**, **406**. There is also another path (not shown) that couples a version of the signal input to the DA **406** through another adjustment circuit (not shown) to the input of the DA **404**.

[0051] The second canceler portion **604** provides an IMD cancellation path at the inputs to the PAs **304** and **308**. For example, a coupled version of the signal at the input to the PA **304** is input to the adjustment circuit **608** and the output of the adjustment circuit **608** is coupled to the input of the PA **308**. It should be noted that for clarity only one cancellation path is shown connected to the inputs of the PAs **304**, **308**. There is also another path (not shown) that couples a version of the signal input to the PA **308** through another adjustment circuit (not shown) to the input of the PA **404**.

[0052] Thus, multiple versions of the IMD canceler can be used to reduce or elimination IMD either at the inputs to the DAs **404**, **406** or the inputs to the PAs **304**, **308**.

[0053] **FIG. 7** shows a baseband to RF converter **700** comprising an exemplary embodiment of an IMD canceler for use in a wireless device. In this exemplary embodiment, distortion cancelling signals are generated from received baseband signals and applied to the generated RF signals that are output from the baseband to RF converter **700**.

[0054] The distortion canceler comprises a first canceler module **702** and a second canceler module **704**. The distortion canceler also comprises a first directional coupler **706** and a second directional coupler **708**. The first canceler module **702** comprises a first delay circuit **710**, a first phase shifter **712**, and a first adjustable driver amplifier **714**. The second canceler module **704** comprises a second delay circuit **716**, a second phase shifter **718**, and a second adjustable driver amplifier **720**.

[0055] The first adjustable delay circuit **710** comprises a switched capacitor delay circuit that operates to receive first baseband signals I and Q and delay these signals by a selectable delay amount determined from a delay control signal on signal line **392** that is generated by the controller **328**. Delayed I and Q signals are output from the first adjustable delay circuit **710** and input to the first phase shifter **712**. In other exemplary embodiments, the first adjustable delay circuit **710** comprises any other suitable delay circuit to delay the first I and Q signals in response to the delay control signal.

[0056] The phase shifter **712** operate to phase shift the delayed signals at its inputs to generate phase shifted signals **722**. The amount of phase shift provide by the phase shifter **712** is determined by phase shift control signals on signal lines **368** that are generated by the controller **328**.

[0057] The phase shifted signals **722**, which are still baseband signals, are input to a mixer circuit **724** that includes two mixers to mix the phase shifted signals with local oscillator signals that also are used to modulate the baseband I and Q signals. The RF outputs of the mixer circuit **724** are combined by resistor **726** and the combined signal **728** is input to the driver amplifier (DA) **714**. The DA **714** amplifies the signal **728** received at its input and outputs first cancellation signal **730** that is input to directional coupler **708**. The amount of amplification provided by the DA **714** is determined by a received amplitude control signal on signal line **380** that is generated by the controller **328**. In an exemplary embodiment, an optional phase shifter **732** provides phase shift to the amplified signal **730** that is output from the DA **714** to generate the first cancellation signal **730** that is input to the directional coupler **708**. The phase shifter **732** receives a phase shift control signal on signal line **734** to determine the amount of phase shift to be applied to the output of the DA **730**. The phase shift control signal on signal line **734** is generated by the controller **328**.

[0058] As illustrated in **FIG. 7**, the second cancellation module **704** is configured similarly to the first cancellation module **702**. For example, the second cancellation module **704** comprises the second delay circuit **716**, the second phase shifter **718**, and the second DA **720**, which are all configured to operate as described with reference to their counterparts in the first cancellation module **702**. The second cancellation module **704** operates to generate a second cancellation signal **736** that is connected to the first coupler **706**.

[0059] During operation, the controller **328** uses received feedback signals (not shown in **FIG. 7** but shown in **FIG. 8**) to adjust the cancellation modules **702**, **704** to generate the first and second cancellation signals **730**, **736**. The couplers **706** and **708** operate to couple the first **730** and second **736** cancellation signals to the first and second RF transmit signals that are output from the baseband to RF converter **700**. As a result, IMD products between the first and second channels can be reduced, minimized or eliminated. As will be shown in **FIG. 8**, the controller **328** receives the feedback signals from couplers coupled to RF signals further down the transmit chains.

[0060] **FIG. 8** shows a transmitter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 7** for use in a wireless device. In this exemplary embodiment, the IMD canceler shown in **FIG. 7** is incorporated within the IC of the baseband to RF converter **700**. **FIG. 8** also shows the generation of the feedback signals used by the controller **328**.

[0061] As shown in **FIG. 8**, the coupler circuit **402** operates to provide a feedback signal **410** to the controller **328**. The feedback signal is selected from signals input to the switch **408**. In an exemplary embodiment, the switch **408** receives a first coupled signal from the directional coupler **404** that is couple to the signal line **802** carrying the first amplified RF transmit signal. The switch **408** also receives a second coupled signal from the directional coupler **406** that is couple to the signal line **804** carrying the second amplified RF transmit signal. The switch **408** also receives a third coupled signal from the directional coupler **506** that is couple to the signal line **806** carrying the signal to be transmitted by the antenna **314**. The switch **408** receives a switch control signal on the signal line **424** that controls the switch **408** to connect one of its input terminals to its output terminal. The switch output terminal is connected to the controller **328** by the signal line **410**.

[0062] The controller **328** also generates the control signals **808** that control the operation of the IMD canceler as discussed in the exemplary embodiments above. Thus, the controller **328** operates to obtain one or more of the coupled signals by controlling the operation of the switch **408**. The controller **328** uses the coupled signals to control the operation of the IMD canceler to reduce, minimize, or elimination IM distortion.

[0063] **FIG. 9** shows a baseband to RF converter **900** comprising an exemplary alternative embodiment of the IMD canceler in **FIG. 7** for use in a wireless device. In this embodiment, the canceler modules **702**, **704** are modified to generate either IM distortion canceling signals or harmonic canceling signals. To cancel IM distortion, the generated IM distortion canceling signals are cross-coupled to the first and second RF transmit signals **322**, **326** using the couplers **706**, **708**. To cancel harmonic distortion, harmonic distortion canceling signals generated from each canceler module are coupled back to the RF transmit signal used to generate the cancellation signal associated with each canceler module.

[0064] In an exemplary embodiment, the first canceler module **702** is modified to include a first switch **902** and a second switch **904**. The first switch **902** has an input terminal **926** that is connected to receive the delay and phase adjusted cancellation signal **728**. The first switch **902** has a first output terminal **906** and a second output terminal **908**. The first output terminal **906** is connected to a first input terminal **910** of the second switch **904**. The second output terminal **908** is connected to an input of an amplifier **912**. An output of the amplifier **912** is connected to an input of a filter **914**. An output of the filter **914** is connected to a second input terminal **916** of the second switch **904**. An output terminal **918** of the second switch **904** is connected to an input of the DA **714**.

[0065] During operation, the first **902** and second **904** switches are controlled by switch control signals (SC1) generated by the controller **328**. In a filter bypass mode, the first switch **902** is set so that the input terminal **926** is connected to the first output terminal **906**. The second switch **904** is set so that its first input terminal **910** is connected to its output terminal **918**. In this mode, the amplifier **912** and filter **914** are bypassed so that the cancellation module **702** operates to generate IM distortion canceling signals at the output of the DA **714** as described with respect to **FIG. 7**. The second canceler module **704** is configured similarly to the first canceler module **702**.

[0066] In a non-bypass mode of operation, the first switch **902** is set so that its input terminal **926** is connected to the second output terminal **908**. The second switch **904** is set so that the second input terminal **916** is connected to the output terminal **918**. In this mode, the amplifier **912** and filter **914** are not bypassed but instead connected to receive the delay and phase adjusted cancellation signal **728** and output an amplified and filtered signal to the input of the DA **714**. In this non-bypassed mode, signals to cancel harmonic distortion are generated at the output of the DA **714**. For example, the amplifier **912** operates to amplify the delay and phase adjusted cancellation signal **728** and output an amplified signal that is input to the filter **914**. In an exemplary embodiment, the amplifier **912** functions as a low IP3 amplifier. The filter **914** operates to filter this amplified signal such that harmonic signals remain that can be canceled from first amplified RF signal **322**. The second canceler module **704** is modified to operate the same as the first canceler module **702**. Thus, the two canceler modules **702** and **704** operate to generate the canceling signals **730**, **736**. These canceling signals **730**, **736** are generated to be either IM distortion canceling signals or harmonic distortion canceling signals depending on the settings of the switches **902** and **904** in module **702** and similar switches in module **704**.

[0067] In addition to the modifications to the canceler modules **702**, **704**, an output switch **920** is added to switch the cancellation signals **730**, **736** to the couplers **706**, **708** associated with the first **322** and second **326** RF transmit signals.

[0068] The output switch **920** is configured as two switches with each switch have two inputs and one output. The output **922** of the first switch is connected to the directional coupler **706** and the output **924** of the second switch is connected to the directional coupler **708**. When in by-pass mode, IM distortion cancellation is performed. In this mode, the switch **920** cross couples the cancellation signals **730**, **736** to the output couplers **706**, **708**. When in non-by-pass mode, the switch **920** connects the cancellation signals **730**, **736**, which represent harmonic cancellation signals, to the coupler associated with its respective transmit signal. For example, the harmonic cancellation signal **730** is connected to the coupler **706**, and the harmonic cancellation signal **736** is connected to the coupler **708**

[0069] **FIG. 10** shows a baseband to RF converter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 9** for use in a wireless device. In this embodiment, the canceler modules **702**, **704** are modified to generate IM distortion canceling signals and harmonic canceling signals at the same time. The generated IM distortion canceling signals are cross-coupled to the first and second RF transmit signals. The harmonic distortion canceling signals are coupled back to the RF transmit signal associated with each canceler module.

[0070] As illustrated in the first canceler module **702** of **FIG. 10**, the delayed and phase adjusted cancellation signal **728** is input to two signal paths. A first signal path comprises DA **714** and optional phase shifter **732**. The output of the DA **714** is an IM distortion canceling signal **730** that is connected to the directional coupler **708** to cancel any leakage of the first RF transmit signal **322** into the second RF transmit signal **326**.

[0071] The second signal path that receives the delayed and phase adjusted cancellation signal **728** comprises the amplifier **912**, the filter **914**, DA **1002** and optional phase shifter **1004**. The output of the DA **1002** is a harmonic canceling signal **1006** that is connected to the directional coupler **1008** to cancel harmonic distortion from the first RF transmit signal **322**. The second canceler module **704** is configured identically to the first cancellation module **702**. Thus, the canceler modules **702**, **704** operate to generate both IM distortion canceling signals **730**, **736** and harmonic distortion canceling signals **1006**, **1010** and these signals are coupled to cancel leaking signals and harmonic distortion from the first RF transmit signal **322** and the second RF transmit signal **326** through the use of the couplers **706**, **708**, **1008**, and **1012**.

[0072] **FIG. 11** shows a baseband to RF converter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 10** for use in a wireless device. In this exemplary embodiment, the canceler modules **702**, **704** operate to generate IM distortion canceling signals **730**, **736** and harmonic canceling signals **1006**, **1010**. The generated IM distortion canceling signals **730**, **736** are cross-coupled to the first **322** and second **326** RF transmit signals. The harmonic distortion canceling signals generated from the canceler modules **702**, **704** are output from the baseband to RF converter and coupled further down the transmission chain to cancel harmonic distortion.

[0073] **FIG. 12** shows a transmitter that includes an exemplary alternative embodiment of the IMD canceler of **FIG. 11** for use in a wireless device. In this exemplary alternative embodiment, the canceler modules **702**, **704** shown in **FIG. 11** are located within the IC of the baseband to RF converter **900**. **FIG. 12** also shows the coupling of the harmonic canceling signals **1006**, **1010** to cancel harmonic distortion further down the transmission chain.

[0074] As shown in **FIG. 12**, the harmonic cancellation signals **1006**, **1010**, are output from the first and second canceler modules **702**, **704** as shown in detail in **FIG. 11** and are input to directional couplers **1202** and **1204**. The directional couplers **1202**, **1204** are coupled to signal paths that extend between the outputs of the duplexers **312**, **316** and the inputs to the diplexer **508**. By coupling the harmonic cancellation signals **1006**, **1010** to the signal paths at this point in the transmission chain, the harmonic cancellation signals **1006**, **1010** operate to cancel harmonic distortion at the inputs to the diplexer **508** just before transmission of the signals from the antenna **314**.

[0075] The controller **328** operates to obtain one or more of the coupled signals obtained by the coupler **402** by controlling the operation of the switch **408**. The controller **328** uses the coupled signals to control the operation of the cancellation module to generate the IMD canceling signals **730**, **736** and the harmonic canceling signals **1006**, **1010**, which operate to reduce, minimize, or eliminate IMD and harmonic distortion from the transmitted RF signals.

[0076] **FIG. 13** shows an exemplary embodiment of a controller **1300** for use in an IMD canceler. For example, the controller **1300** is suitable for use as the controller **328** shown in **FIG. 3**. The controller **1300** comprises processor **1302**, memory **1304**, feedback receiver **1306**, amplitude adjuster **1308**, phase adjuster **1310**, delay adjuster **1312,** and switch controller **1314** all coupled to communicate over communication bus **1316**.

[0077] The processor **1302** comprises at least one of a CPU, processor, gate array, hardware logic, discrete circuits, memory elements, and/or hardware executing software. The processor **1302** operates to control the other functional elements of the controller **1300** using the communication bus **1316**. The processor **1302** is also configured to communicate with other entities at the wireless device using the communication line **1318**. For example, the processor **1302** may receive instructions, control information, configuration information, data, measurements or other information over the communication line **1318**.

[0078] The memory **1304** comprises any suitable memory or storage device that allows for storing, retrieving, and maintaining instructions and/or data associated with the operation of the controller **1300**. In an exemplary embodiment, the memory **1304** stores algorithm instructions that can be executed by the processor **1302** to perform the functions of IMD and harmonic canceling as described herein.

[0079] The feedback receiver **1306** comprises hardware, such as amplifiers, buffers, registers, gates, analog to digital converters, digital to analog converters, or any other suitable hardware or discreet components and/or hardware executing software that operates to receive feedback signals from the signal couplers and power detectors in the various exemplary embodiments described above. The information received from the signal couplers and power detectors is input to the processor **1302** for processing and/or the memory **1304** for storage. For example, the feedback receiver **1306** operates to receive power detection signals from the detectors **396**, **398** shown in **FIG. 3** and converts these power detection signals to digital values that can be processed by the processor **1302** and/or stored in the memory **1304**. In another example, the feedback receiver **1306** operates to receive coupled signals from the signal couplers **404**, **406** shown in **FIG. 4** and converts these coupled signals to digital values that can be processed by the processor **1302** and/or stored in the memory **1304**. In an exemplary embodiment, the feedback receiver **1306** is configured to receive and process both analog and digital signals.

[0080] The amplitude adjustor **1308** comprises hardware, such as amplifiers, buffers, registers, gates, analog to digital converters, digital to analog converters or any other suitable hardware or discrete components and/or hardware executing software that operates to output amplitude adjustment signals to the adjustable amplifiers in the various exemplary embodiments described above. For example, the processor **1302** operates to determine amplitude adjustments to one or more of the adjustable amplifiers used in the various embodiments and passes these adjustments to the amplitude adjuster **1308**. The amplitude adjuster **1308** outputs adjustment signals to the designated adjustable amplifiers to adjust their amplification factors according to the determinations made by the processor **1302**. In an exemplary embodiment, the processor **1302** determines that the amplification factor of the first amplitude adjustment circuit **372** shown in **FIG. 3** is to be changed to a new amplification factor. The processor **1302** sends the new amplification factor to the amplitude adjuster **1308** which outputs an amplitude adjustments signal through the signal line **380** to the first amplitude adjustment circuit **372** to set the new amplification factor. In an exemplary embodiment, the amplitude adjuster **1306** is configured to output both analog and digital adjustment signals.

[0081] The phase adjustor **1310** comprises hardware, such as amplifiers, buffers, registers, gates, analog to digital converters, digital to analog converters or any other suitable hardware or discrete components and/or hardware executing software that operates to output phase adjustment signals to the adjustable phase shifters in the various exemplary embodiments described above. For example, the processor **1302** operates to determine phase adjustments to one or more of the adjustable phase shifters used in the various embodiments and passes these adjustments to the phase adjuster **1310**. The phase adjuster **1310** outputs phase adjustment signals to the designated adjustable phase shifters to adjust their phase shift according to the determinations made by the processor **1302**. In an exemplary embodiment, the processor **1302** determines that the phase shift being provided by the first adjustable phase circuit **356** in **FIG. 3** is to be changed to a new phase shift. The processor **1302** sends the new phase shift information to the phase adjuster **1310** which outputs a phase adjustment signal to the phase shifter **356** on line **368** to set the new phase shift. In an exemplary embodiment, the phase adjuster **1310** is configured to output both analog and digital phase adjustment signals.

[0082] The delay adjustor **1312** comprises hardware, such as amplifiers, buffers, registers, gates, analog to digital converters, digital to analog converters or any other suitable hardware or discrete components and/or hardware executing software that operates to output delay adjustment signals to the adjustable delay circuits in the various exemplary embodiments described above. For example, the processor **1302** operates to determine delay adjustments to one or more of the adjustable delay circuits used in the various embodiments and passes these adjustments to the delay adjuster **1312**. The delay adjuster **1312** outputs delay adjustment signals to the designated adjustable delay circuits to adjust their delay setting according to the determinations made by the processor **1302**. In an exemplary embodiment, the processor **1302** determines that the delay being provided by the first adjustable delay circuit **386** in **FIG. 3** is to be changed to a new delay value. The processor **1302** sends the new delay value to the delay adjuster **1312** which outputs a delay adjustment signal to the delay circuit **386** through the line **392** to set the new delay value for that delay circuit. In an exemplary embodiment, the delay adjuster **1312** is configured to output both analog and digital delay adjustment signals.

[0083] The switch controller **1314** comprises hardware, such as amplifiers, buffers, registers, gates, analog to digital converters, digital to analog converters or any other suitable hardware or discrete components and/or hardware executing software that operates to output switch control signals to the switches used in the various exemplary embodiments described above. For example, the processor **1302** operates to determine switch settings for one or more of the switches used in the various embodiments and passes these switch settings to the switch controller **1314**. The switch controller **1314** outputs switch control signals to the designated switches to adjust their switch settings according to the determinations made by the processor **1302**. In an exemplary embodiment, the processor **1302** determines that the switch settings of the switch **408** in **FIG. 4** are to be changed to a new switch setting. The processor **1302** sends the new switch setting to the switch controller **1314** which outputs a switch control signal to the switch **408** using the line **424** to set the new switch settings for that switch. In an exemplary embodiment, the switch controller **1312** is configured to output both analog and digital switch adjustment signals.

[0084] It should be noted that the controller **1300** represents just one implementation and that other implementations are possible. For example, the controller **1300** may be implemented in discrete logic that eliminates the need for a processor or memory devices. In another implementation, the functions and/or implementations of the controller **1300** are incorporated or integrated into the IC of the BB to RF converter **302**.

[0085] **FIG. 14** shows exemplary operations **1400** performed by an apparatus to provide calibration of leakage cancellation in a wireless device. For example, the operations **1400** are suitably performed by the canceler **338** shown in **FIG. 3** to reduce, minimize, or eliminate leakage associated with the first (TxA) and second (TxB) transmit chains. In an exemplary embodiment, the processor **1302** executes instructions stored in the memory **1304** to control the components of the controller **1300** and the canceler **338** to perform the operations describe below.

[0086] At block **1402**, measurement of a leakage signal level is taken while the first transmit chain TxA is on but not transmitting a specific signal (e.g., no signal input to DA **404**). For example, an original signal (x(t)) is input to the second transmit chain TxB and appears on signal line **326** for transmission by PA2 **308**. The detector **396** measures a signal at the output of the PA1 **304** while no signal being input for transmission by the first transmit chain TxA (e.g., no signal output by DA **404**). Thus, the measured signal represents leakage from the second transmit chain (e.g., PA2 of TxB) into the first transmit chain (e.g., PA1 of TxA). In an exemplary embodiment, the feedback receiver **1306** at the controller **328** receives the measurement output from the detector **396** while disabling the operation of the canceler **338** by outputting the appropriate control signals to control the amplitude **1308**, phase **1310**, and delay **1312** adjusters to disable the operation of the canceler **338**.

[0087] At block **1404**, a signal (x'(t)) is injected into the first transmit chain TxA. The signal (x'(t)) is a coupled version of the original signal (x(t)) from the second transmit chain TxB and is injected into the first transmit chain TxA with no delay. In an exemplary embodiment, the controller **328** controls the phase **358**, amplitude **374**, and delay **386** adjustment circuits to obtain the coupled signal (x'(t)) from the second transmit chain TxB using coupler **344** and to couple that signal (without added delay) into the first transmit chain TxA using coupler **340**. In an exemplary embodiment, the controller **328** uses the amplitude **1308**, phase **1310**, and delay **1312** adjusters to output the appropriate control signals to control the phase **358**, amplitude **374**, and delay **386** adjustment circuits to pass the coupled signal (x'(t)) without adding any delay so that it can be injected into the first transmit chain TxA by the coupler **340**.

[0088] At block **1406**, a delay sweep is performed to change a delay parameter (τ) to find maximum correlation between the original signal (x(t)) and a delayed version of the injected signal $x'(t-\tau)$ as detected by the detector **396**. For example, the controller processor **1302** controls the delay adjuster **1312** to output control signals to control the delay adjustment circuit **386** to sweep a delay associated with the injected coupled signal $x'(t-\tau)$. The detector **396** then feedbacks the detected signal to the feedback receiver **1306**. Knowing the original signal (x(t)), the processor **1302** is able to find the maximum correlation by performing a convolution between the original signal x(t) and the injected signal $x'(t-\tau)$, which is [max $(\int x(t)*x'(t-\tau))$]. The delay value τ' is then determined that provides the maximum correlation.

[0089] At block **1408**, a phase difference is determined that can be used for cancellation of the leakage signal. For example, the phase difference $\Delta(\varphi)$ between the phase of the original signal $\varphi(x(t))$ and the phase of the appropriately delayed injected signal $\varphi(x'(t-\tau'))$ is determined. [e.g., $\Delta(\varphi) = \varphi(x(t)) - \varphi(x'(t-\tau'))$] In an exemplary embodiment, the processor **1302** determines this phase difference. Once $\Delta(\varphi)$ is determined, it is possible to add 180° find the phase setting for cancellation [e.g., $\Delta(\varphi)' = \Delta(\varphi) + 180$].

[0090] At block **1410**, the injected signal is adjusted for the determined delay and phase. In an exemplary embodiment, the processor **1302** controls the delay **1312** and phase **1310** adjusters to output control signals to the delay **386** and phase **358** adjustment circuits to set the delay and phase of the injected signal to the determined values. The signal injected into the TxA chain then becomes $[x'(t-\tau')\angle\Delta(\varphi)']$.

[0091] At block **1412**, the amplitude of the injected signal is adjusted for maximum cancellation. In an exemplary embodiment, the processor **1302** controls the amplitude adjuster **1308** to output control signals to control the amplitude adjustment circuit **374** to set the amplitude (A') of the injected signal to obtain maximum cancellation. The signal injected into the TxA chain then becomes $[A'(x'(t-\tau')\angle\Delta(\varphi)')]$.

[0092] Thus, the controller **1300** and the canceler **338** are configured to perform the operations **1400** to calibrate the cancellation of a leakage signal from a first transmit chain to a second transmit chain. The controller **1300** and the canceler **338** are also configured to perform operations **1400** in a similar fashion to calibrate the cancellation of a leakage signal from the second transmit chain to the first transmit chain. It should be noted that that operations **1400** are just one implementation and that changes, additions, modifications, and/or rearrangements of the operations are within the scope of the exemplary embodiments.

[0093] **FIG. 15** shows exemplary operations **1500** performed by an apparatus to provide calibration of IMD cancellation in a wireless device. For example, the operations **1500** are suitably performed by the canceler **338** shown in **FIG. 3**. In an exemplary embodiment, the processor **1302** execute instructions stored in the memory **1304** to control the components of the controller **1300** and the canceler **338** to perform the operations describe below.

[0094] At block **1502**, IMD is measured with respect to the first and second transmit chains. In an exemplary embodiment, IMD is measured by a device processor, such as a modem, that computes the IMD and provides the measurements to the controller **1300** using the communication line **1318**. The canceler **338** is turned off and both Tx chains are turned on. Assuming that IMD appears in the RxA band, it can be detected in the RxA receive band by the baseband to RF converter **302** and the IMD level is fed into the processor **1302** of the controller **1300** using the communication line **1318**.

[0095] At block **1504**, the IMD canceler **338** is turned on. In an exemplary embodiment, the controller **1300** enables the IMD canceler **338** with the calibrated parameters for phase delay and amplitude determined by the operations **1400**.

[0096] At block **1506**, adjustments are made to the delay, phase and amplitude of the IMD to obtain reduced or minimum IMD. In an exemplary embodiment, the processor **1302** controls the amplitude **1308**, phase **1310** and delay **1312** adjusters to output control signals to fine tune the delay, phase and amplitude adjustment circuits of the IMD **338**, if needed, in order to obtain reduced or minimum IMD. Measurements of IMD are input to the processor **1302** from the baseband to RF converter **302** to make this determination.

[0097] At block **1508**, measurement of additional Rx performance characteristics are made. For example, measurements of one or more of signal strength (RSSI), error rate (BER) and/or error vector magnitude (EVM) are made in order to measure the Rx channel desense.

[0098] At block **1510**, adjustments are made to the delay, phase and amplitude of the canceler **338** to obtain the best performance characteristics with minimum Rx desense. In an exemplary embodiment, the processor **1302** controls the amplitude **1308**, phase **1310** and delay **1312** adjusters to output control signals to fine tune the delay, phase and amplitude adjustment circuits of the canceler **338**, if needed, in order to reach the best or desired performance characteristics with minimum Rx desense. Measurements are input to the processor **1302** from the baseband to RF converter **302** to make this determination.

[0099] Thus, the controller **1300** and the canceler **338** are configured to perform the operations **1500** to calibrate the canceler **338** to obtain the best receiver performance. It should be noted that that operations **1500** are just one implementation and that changes, additions, modifications, and/or rearrangements of the operations are within the scope of the exemplary embodiments.

[00100] **FIG. 16** shows exemplary operations **1600** performed by an apparatus to provide a dual interference canceler calibration procedure in a wireless device. For example, the operations **1600** are suitable performed by canceler **338** shown in **FIG. 3**. In an exemplary embodiment, the processor **1302** execute instructions stored in the memory **1304** to control the components of the controller **1300** and the canceler **338** to perform the operations describe below.

[00101] At block **1602**, a Tx chain is chosen for calibration. In this example, the first Tx1 chain having PA1 **304** is chosen.

[00102] At block **1604**, the power amplifier on the chosen Tx path is turned on. In this example, the PA1 **304** is turned on so the leakage from the other Tx chain (Tx2) can pass through when Tx1 is not transmitting. In an exemplary embodiment, the baseband to RF converter **302** controls the operation of the transmit chains and the power amplifiers on those chains to perform this operation.

[00103] At block **1606**, the second Tx chain is turned on. In this example, Tx2 and PA2 are turned on in order to measure the leakage passing through PA1.

[00104] At block **1608**, a signal is transmitted on the Tx2 chain. For example, a LTE 1RB signal (or any other signal) is transmitted on the Tx2 chain for calibrating the Tx2 canceler.

[00105] At block **1610**, the Tx2 chain canceler is turned on for calibration. For example, the controller **1300** controls the amplitude **1308**, phase **1310**, and delay **1312** adjusters to output control signals to enable the amplitude **374**, phase **358**, and delay **386** adjustment circuits so that a 2^{nd} cancellation signal **390** can be generated.

[00106] At block **1612**, the calibration operations **1400** disclosed above are performed. By performing the operations **1400**, calibrated amplitude, phase and delay parameters can be determined which allow the 2^{nd} cancellation signal **390** to be generated to reduce, minimize or eliminate leakage of Tx2 signals into Tx1.

[00107] At block **1614**, the Tx1 chain is turned on to allow signals to be transmitted by the Tx1 chain. Turning on the Tx1 chain allows IMD products to be seen at the PA1 **304** output.

[00108] At block **1616**, a signal is transmitted on the Tx1 chain. For example, a LTE 1RB signal (or any other signal) is transmitted on the Tx1 chain so that IMD products will be generated at PA1 output.

[00109] At block **1618**, the calibration operations **1500** disclosed above are performed. By performing the operations **1500**, calibrated amplitude, phase and delay parameters can be determined to generate the 2^{nd} cancellation signal **390** in order to reach the best or desired performance characteristics (e.g., RSSI, BER, EVM, etc.) with minimum Rx desense.

[00110] At block **1620**, the amplitude, phase, and delay values determined from the operations **1400** and **1500** are saved. For example, the processor **1302** saves the

amplitude, phase, and delay values in the memory **1304**. The processor **1302** also controls the amplitude **1308**, phase **1310**, and delay **1312** adjusters to use the saved values to generate the appropriate cancellation signal during operation of the transmitter.

[00111] At block **1622**, the operations as performed in blocks **1604-1620** are performed to calibrate the other Tx channel. Those calibrated amplitude, phase, and delay values associated with the other Tx channel are then saved.

[00112] Thus, the controller **1300** and the canceler **338** are configured to perform the operations **1600** to perform a dual interference canceller calibration procedure to obtain improved receiver performance. It should be noted that that operations **1600** are just one implementation and that changes, additions, modifications, and/or rearrangements of the operations are within the scope of the exemplary embodiments.

[00113] It should also be noted that the operations **1400**, **1500** and **1600** can be performed by any of the exemplary embodiments shown. For example, the operation of the detectors **396** and **398** shown in **FIG. 3** can be performed by the various signal couplers shown in **FIGS 4-12**. Thus, the operations **1400**, **1500**, and **1600** performed by the controller **1300** and the canceler **338** perform canceler calibration procedures utilizing the canceler **338** to obtain the best or improved receiver performance. It should also be noted that the operations **1400**, **1500**, and **1600** can be performed in the digital domain by the apparatus shown and described with reference to **FIGS. 19-20.**

[00114] **FIG. 17** shows an exemplary apparatus **1700** configured for IMD cancellation in a wireless device. For example, the apparatus **1700** is suitable for use as the canceler **338** shown in **FIG. 3**. The apparatus **1700** comprises a first means (**1702**) for transmitting a first RF signal, which in an exemplary embodiment comprises the first transmit chain shown in **FIG. 3**. The apparatus **1700** comprises a second means (**1704**) for transmitting a second RF signal, which in an exemplary embodiment comprises the second transmit chain shown in **FIG. 3**. The apparatus **1700** comprises a third means (**1706**) for canceling configured to output a first leakage cancellation signal that is input to the means for transmitting the second RF signal, and to output a second leakage cancellation signal that is input to the means for transmitting the first RF signal, the means for canceling generates the first and second leakage cancellation signals from the first and second RF signals or from first and second baseband signals used to generate

the first and second RF signals, which in an exemplary embodiment comprises the canceler **338** shown in **FIG. 3**.

[00115] **FIG. 18** shows a modified baseband to RF converter **1800** comprising an exemplary embodiment of an IMD canceler for use in a wireless device. For example, the modified baseband to RF converter **1800** is a modified version of the baseband to RF converter **700** shown in **FIG. 7.** In this exemplary embodiment, distortion cancelling signals are generated from received baseband signals and applied to the generated RF signals that are output from the modified baseband to RF converter **1800**.

[00116] As illustrated in **FIG. 18**, the first **702** and second **704** cancellation modules are configured as shown in **FIG. 7** and operate as described above. For example, the first cancellation module **702** outputs cancellation signal **730** and the second cancellation module **704** outputs cancellation signal **736**, as described with reference to **FIG. 7**.

[00117] As shown in **FIG. 18**, the modified baseband to RF converter **1800** includes signal combiners **1802** and **1804** that operate to combine signals at their inputs to generate combined signals at their outputs.

[00118] During operation, the controller **328** uses received feedback signals (not shown in **FIG. 18** but shown in **FIG. 8**) to adjust the cancellation modules **702**, **704** to generate the first and second cancellation signals **730**, **736**. The signal combiners **1802** and **1804** operate to combine the cancellation signals **730** and **736** with the first and second RF transmit signals prior to the DAs **404** and **406**. The DAs **404** and **406** then receive, as inputs, the RF transmit signals that have been adjusted to reduce, minimize or eliminate IMD. The DAs **404** and **406** then output the amplified adjusted RF transmit signals **322** and **326**. As a result of the operation of the modified baseband to RF converter **1800**, IMD products between the first and second channels are reduced, minimized or eliminated.

[00119] **FIG. 19** shows a modified baseband to RF converter **1900** comprising an exemplary embodiment of an IMD canceler for use in a wireless device. For example, the modified baseband to RF converter **1900** is a modified version of the baseband to RF converter shown in **FIG. 11.** In this exemplary embodiment, a digital leakage canceler **1901** operates to generate digital distortion cancelling signals **1906** and **1908** from digital baseband signals (I_1,Q_1 / I_2,Q_2). The digital distortion cancelling signals **1906** and **1908** are used to generate RF transmit signals that are output from the modified baseband to RF converter **1900**.

[00120] As illustrated in **FIG. 19**, the digital leakage canceler **1901** comprises a first digital canceler **1902** and a second digital canceler **1904**. In an exemplary embodiment, the digital leakage canceler **1901** is located in a baseband processor, modem, or other entity in the wireless device where digital baseband signals can be processed. The first digital canceler **1902** receives the first (I_1.Q_1) signals and performs the operations described above (e.g., See **FIG. 7**) in a digital domain to generate the digital cancellation signals **1906**. The digital calibration signals **1906** are converted to analog signals that are analogous to the analog signals **722** shown in **FIG. 7**. In an exemplary embodiment, the controller **328** outputs digital control signals (D1) which control the operation of the canceler **1902** to adjust digital phase (A), digital delay (B) and digital amplitude (C) adjustors to generate the digital cancellation signals **1906**. In an exemplary embodiment, the controller **328** outputs the digital controls signals D1 based on feedback received from further down the transmit chain during the operation of a calibration procedure, such as described in the operations **1400**, **1500**, and **1600**. The second digital canceler **1904** operates similarly to the first digital canceler **1902** to generate the second cancellation signals **1908** based on control signal D2.

[00121] The first **702** and second **704** cancellation modules are configured as shown in **FIG. 11** and operate as described above. For example, the first cancellation module **702** outputs cancellation signal **730** and the second cancellation module **704** outputs cancellation signal **736**, as described with reference to **FIG. 11**.

[00122] As shown in **FIG. 19**, the modified baseband to RF converter **1900** includes signal combiners **1910** and **1912** that operate to combine signals at their inputs to generate combined signals at their outputs.

[00123] During operation, the controller **328** uses received feedback signals (not shown in **FIG. 19** but shown in **FIG. 8**) to adjust the cancellation modules **702**, **704** to generate the first and second cancellation signals **730**, **736**. The signal combiners **1910** and **1912** operate to combine the cancellation signals **730** and **736** with the first and second RF transmit signals prior to the DAs **404** and **406**. The DAs **404** and **406** then receive, as inputs, the RF transmit signals that have been adjusted to reduce, minimize or eliminate IMD. The DAs **404** and **406** then output the adjusted amplified RF transmit signals **322** and **326**. As a result of the operation of the modified baseband to RF converter **1900**, IMD products between the first and second channels are reduced, minimized or eliminated. The modified baseband to RF converter **1900** also provides the generation

of the cancellation signals in a digital process with can be integrated into a baseband processor, modem, or other device to save circuit area.

[00124] **FIG. 20** shows a modified baseband to RF converter **2000** comprising an exemplary embodiment of an IMD canceler for use in a wireless device. For example, the modified baseband to RF converter **2000** is a modified version of the baseband to RF converter shown in **FIG. 19.** In this exemplary embodiment, the digital leakage canceler **1901** operates to generate digital distortion cancelling signals **1906** and **1908** from digital baseband signals (I_1,Q_1 / I_2,Q_2). The digital distortion cancelling signals **1906** and **1908** are used to generate RF transmit signals that are output from the modified baseband to RF converter **2000**.

[00125] As illustrated in **FIG. 20**, a switching circuit **2001** is provided that operates to switch between the cancellation signals **1906** and **1908** to save circuit area. For example the switching circuit **2001** comprises switch **2002**, switch **2004** and switch **2006**. The controller **328** outputs switch control signals (sel1, sel2, and sel3) which control the operation of the switches **2002**, **2004**, **2006** to connect various input terminals to various output terminals of the switches. For example, the switch **2002** switches its output between the first **1906** and second **1908** cancellation signals received by the switch **2002** based on the (sel1) control signal. The switch **2004** switches its output between the first and second LO signals based on the (sel2) control signal. The outputs of the switches **2002** and **2004** are input to the oscillators shown generally at **2010**. The switch **2006** switches its input terminal to one of two output terminals based on the (sel3) control signal. Thus, when the cancellation signal **736** is being generated, the switches **2002** and **2004** are controlled to select the second cancellation signals **1908** and second LO, and the switch **2006** is controlled to connect its input terminal to the output terminal that is connected to the signal combiner **1910**. When the cancellation signal **730** is being generated, the switches **2002** and **2004** are controlled to select the first cancellation signals **1906** and first LO, and the switch **2006** is controlled to connect its input terminal to the output terminal that is connected to the signal combiner **1912**.

[00126] As shown in **FIG. 20**, the modified baseband to RF converter **2000** includes signal combiners **1910** and **1912** that operate to combine signals at their inputs to generate combined signals at their outputs.

[00127] During operation, the signal combiners **1910** and **1912** operate to selectively combine one of the cancellation signals **730** and **736** with the first or second RF

transmit signals prior to the DAs **404** and **406** based on the operation of the switches **2002**, **2004**, and **2006**. The DAs **404** and **406** then receive, as inputs, the RF transmit signals that have been adjusted to reduce, minimize or eliminate IMD. The DAs **404** and **406** then output the adjusted amplified RF transmit signals **322** and **326**. As a result of the operation of the modified baseband to RF converter **2000**, IMD products between the first and second channels are reduced, minimized or eliminated. The modified baseband to RF converter **2000** also provides the generation of the cancellation signals in a digital process with can be integrated into a baseband processor, modem, or other device to save circuit area.

[00128] The exemplary embodiments of an IMD canceler described herein may be implemented on an IC, an analog IC, an RFIC, a mixed-signal IC, an ASIC, a printed circuit board (PCB), an electronic device, etc. The IMD canceler may also be fabricated with various IC process technologies such as complementary metal oxide semiconductor (CMOS), N-channel MOS (NMOS), P-channel MOS (PMOS), bipolar junction transistor (BJT), bipolar-CMOS (BiCMOS), silicon germanium (SiGe), gallium arsenide (GaAs), heterojunction bipolar transistors (HBTs), high electron mobility transistors (HEMTs), silicon-on-insulator (SOI), etc.

[00129] An apparatus implementing an IMD canceler described herein may be a stand-alone device or may be part of a larger device. A device may be (i) a stand-alone IC, (ii) a set of one or more ICs that may include memory ICs for storing data and/or instructions, (iii) an RFIC such as an RF receiver (RFR) or an RF transmitter/receiver (RTR), (iv) an ASIC such as a mobile station modem (MSM), (v) a module that may be embedded within other devices, (vi) a receiver, cellular phone, wireless device, handset, or mobile unit, (vii) etc.

[00130] In one or more exemplary designs, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other

magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where *disks* usually reproduce data magnetically, while *discs* reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

[00131] The previous description of the disclosure is provided to enable any person skilled in the art to make or use the disclosure. Various modifications to the disclosure will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other variations without departing from the scope of the disclosure. Thus, the disclosure is not intended to be limited to the examples and designs described herein the disclosure is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

CLAIMS

What is claimed is:

1. An apparatus comprising:

a first transmit chain configured to transmit a first RF signal;

a second transmit chain configured to transmit a second RF signal; and

a canceler configured to output a first leakage cancellation signal that is input to the second transmit chain, and to output a second leakage cancellation signal that is input to the first transmit chain, the canceler generates the first and second leakage cancellation signals from the first and second RF signals or from first and second baseband signals used to generate the first and second RF signals.

2. The apparatus of Claim 1, the first transmit chain includes a first amplifier and the second cancellation signal is input to the first amplifier, and the second transmit chain includes a second amplifier and the first cancellation signal is input to the second amplifier.

3. The apparatus of Claim 1, further comprising a feedback receiver that receives first and second feedback signals, the first feedback signal indicates a level of leakage of the second RF signal to the first transmit chain and the second feedback signal indicates a level of leakage of the first RF signal to the second transmit chain.

4. The apparatus of Claim 3, the first and second feedback signals determined from at least one of a power amplifier input, a power amplifier output, a diplexer input and an antenna input associated with the first and second transmit chains.

5. The apparatus of Claim 3, further comprising a controller configured to adjust at least one of amplitude, phase, and time delay of the first and second leakage cancellation signals.

6. The apparatus of Claim 5, the controller configured to adjust at least one of the amplitude, phase, and time delay of at least one of the first and second leakage cancellation signals based on the indicated levels of leakage.

7. The apparatus of Claim 5, the controller configured to adjust at least one of the amplitude, phase, and time delay of at least one of the first and second leakage cancellation signals based on a measure of intermodulation distortion (IMD).

8. The apparatus of Claim 5, the controller configured to adjust at least one of the amplitude, phase, and time delay of at least one of the first and second leakage cancellation signals based on a transceiver performance measurement.

9. The apparatus of Claim 1, the canceler configured to output a first harmonic distortion cancellation signal that is coupled to the first transmit chain, and to output a second harmonic distortion cancellation signal that is coupled to the second transmit chain.

10. The apparatus of Claim 1, the apparatus integrated within a baseband to RF integrated circuit (IC) of a transmitter.

11. The apparatus of Claim 1, further comprising:

first and second signal combiners that combine the first and second cancellation signals with first and second up-converted RF signals to produce first and second adjusted RF signals, respectively; and

first and second driver amplifiers that amplify the first and second adjusted RF signals to produce the first and second RF signals.

12. The apparatus of Claim 11, further comprising a switching circuit configured to selectively connect the first cancellation signal to one of the first and second signal combiners and to selectively connect the second cancellation signal to one of the first and second signal combiners.

13. The apparatus of Claim 11, the canceler configured to output first digital cancellation signals that are converted to the first leakage cancellation signal, to output second digital cancellation signals that are converted to the second leakage cancellation

signal, and to generate the first and second digital cancellation signals from first and second digital baseband signals used to produce the first and second RF signals.

14. The apparatus of Claim 13, the further comprising a controller configured to output control signals to digitally adjust at least one of amplitude, phase, and time delay of the first and second digital cancellation signals based on at least one feedback signal.

15. The apparatus of Claim 1, further comprising a controller coupled to the canceler, the controller configured to measure a leakage signal in the first transmit chain, the leakage signal associated with the second RF signal flowing in the second transmit chain, and to control the canceler to inject a coupled signal into the first transmit chain, the coupled signal being a coupled version of the second RF signal.

16. The apparatus of Claim 15, the controller configured to sweep a delay parameter to find a delay value that yields a selected correlation between the second RF signal and the injected coupled signal delayed by the delay value, to determine a phase difference between the second RF signal and the injected coupled signal delayed by the delay value, and to determine a phase adjustment based on the phase difference.

17. The apparatus of Claim 16, the controller configured to adjust the injected signal using the delay value and the phase adjustment to produce a phase and delay adjusted injected signal, and to adjust an amplitude level of the phase and delay adjusted injected signal to produce the second leakage cancellation signal.

18. The apparatus of Claim 1, further comprising a controller coupled to the canceler, the controller configured to determine an intermodulation distortion (IMD) level with respect to first and second transmit chains, and to control the canceler to adjust at least one of delay, phase, and amplitude of at least one of the first and second leakage cancelation signals to reduce the IMD level.

19. The apparatus of Claim 18, the controller configured to determine at least one receiver (Rx) performance characteristic selected from a set that includes signal strength (RSSI), bit error rate (BER) and error vector magnitude (EVM) levels, and to adjust at

least one of the delay, the phase, and the amplitude of the at least one of the first and second leakage cancelation signals to obtain a desired level of the at least one Rx performance characteristic.

20. An apparatus comprising:

means for transmitting a first RF signal;

means for transmitting a second RF signal; and

means for canceling configured to output a first leakage cancellation signal that is input to the means for transmitting the second RF signal, and to output a second leakage cancellation signal that is input to the means for transmitting the first RF signal, the means for canceling generates the first and second leakage cancellation signals from the first and second RF signals or from first and second baseband signals used to generate the first and second RF signals.

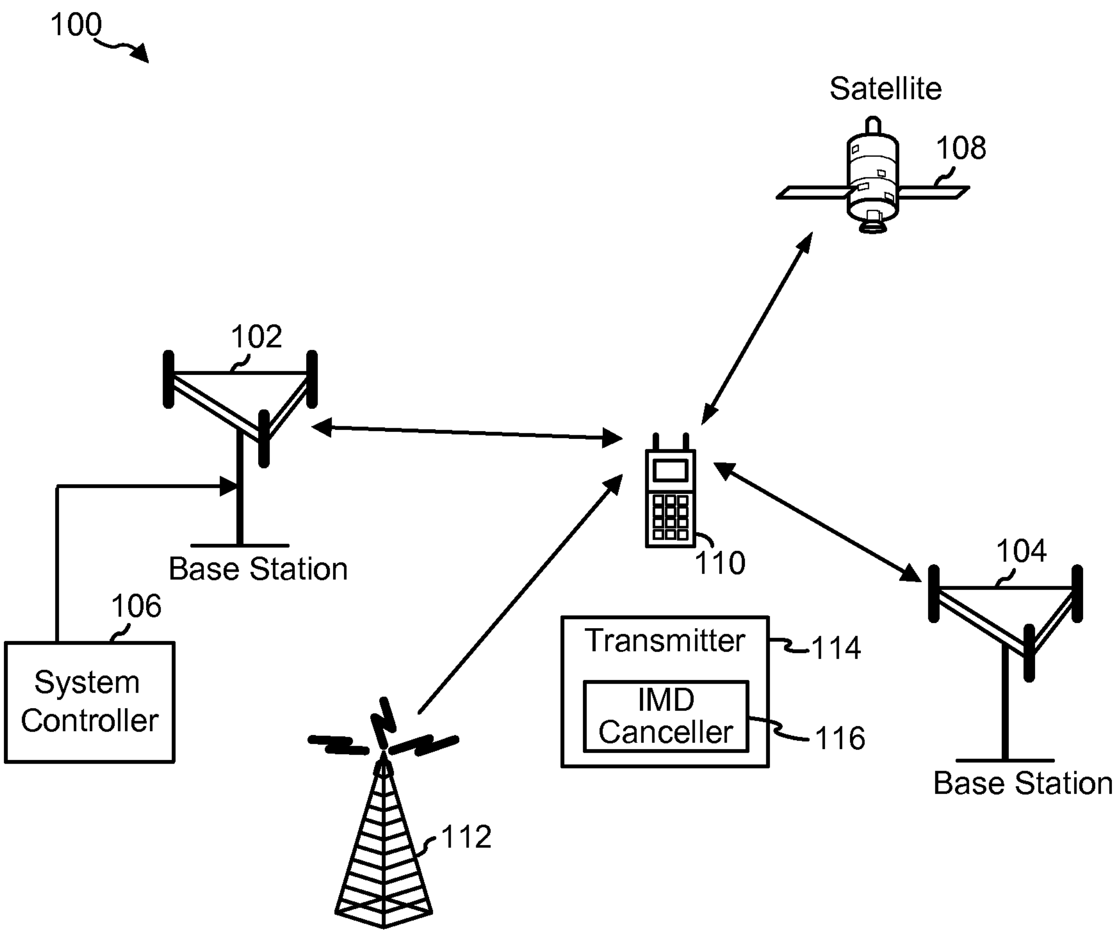

100
Satellite
108
102
Base Station
110
104
106
System Controller
Transmitter
114
IMD Canceller
116
Base Station
112

FIG. 1

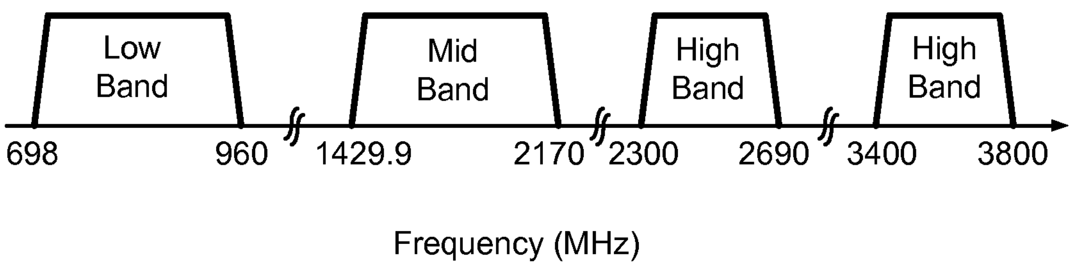

Low Band
Mid Band
High Band
High Band
698
960
1429.9
2170
2300
2690
3400
3800
Frequency (MHz)

FIG. 2

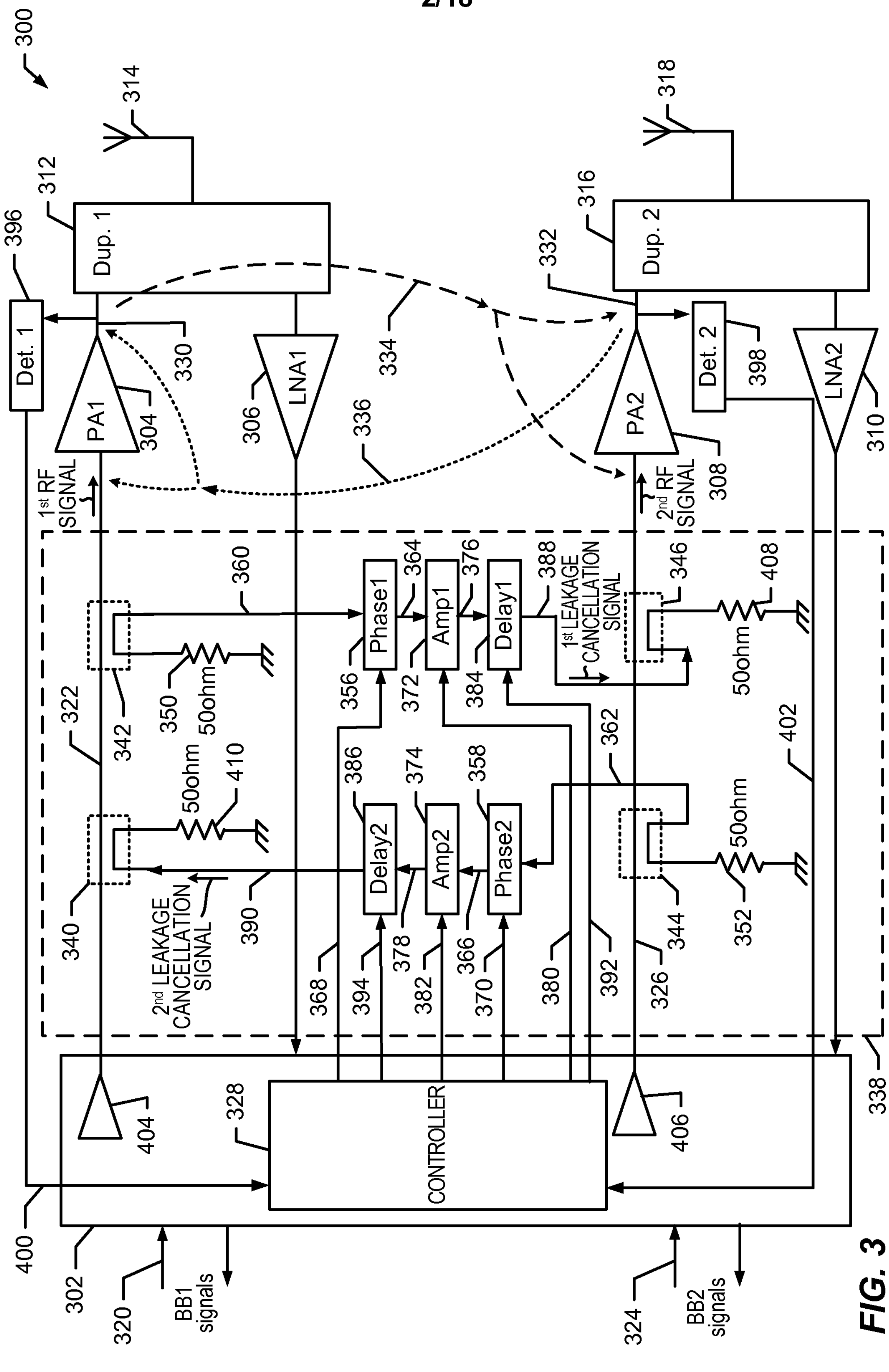

300
314
318
312
316
Dup. 1
Dup. 2
396
332
Det. 1
Det. 2
330
334
398
PA1
LNA1
PA2
LNA2
304
306
336
308
310
1st RF SIGNAL
2nd RF SIGNAL
360
364
376
388
346
408
Phase1
Amp1
Delay1
1st LEAKAGE CANCELLATION SIGNAL
50ohm
322
342
350
356
372
384
386
374
358
362
402
410
Delay2
Amp2
Phase2
340
390
378
366
344
352
2nd LEAKAGE CANCELLATION SIGNAL
368
394
382
370
380
392
326
338
328
CONTROLLER
404
406
400
302
320
324
BB1 signals
BB2 signals

FIG. 3

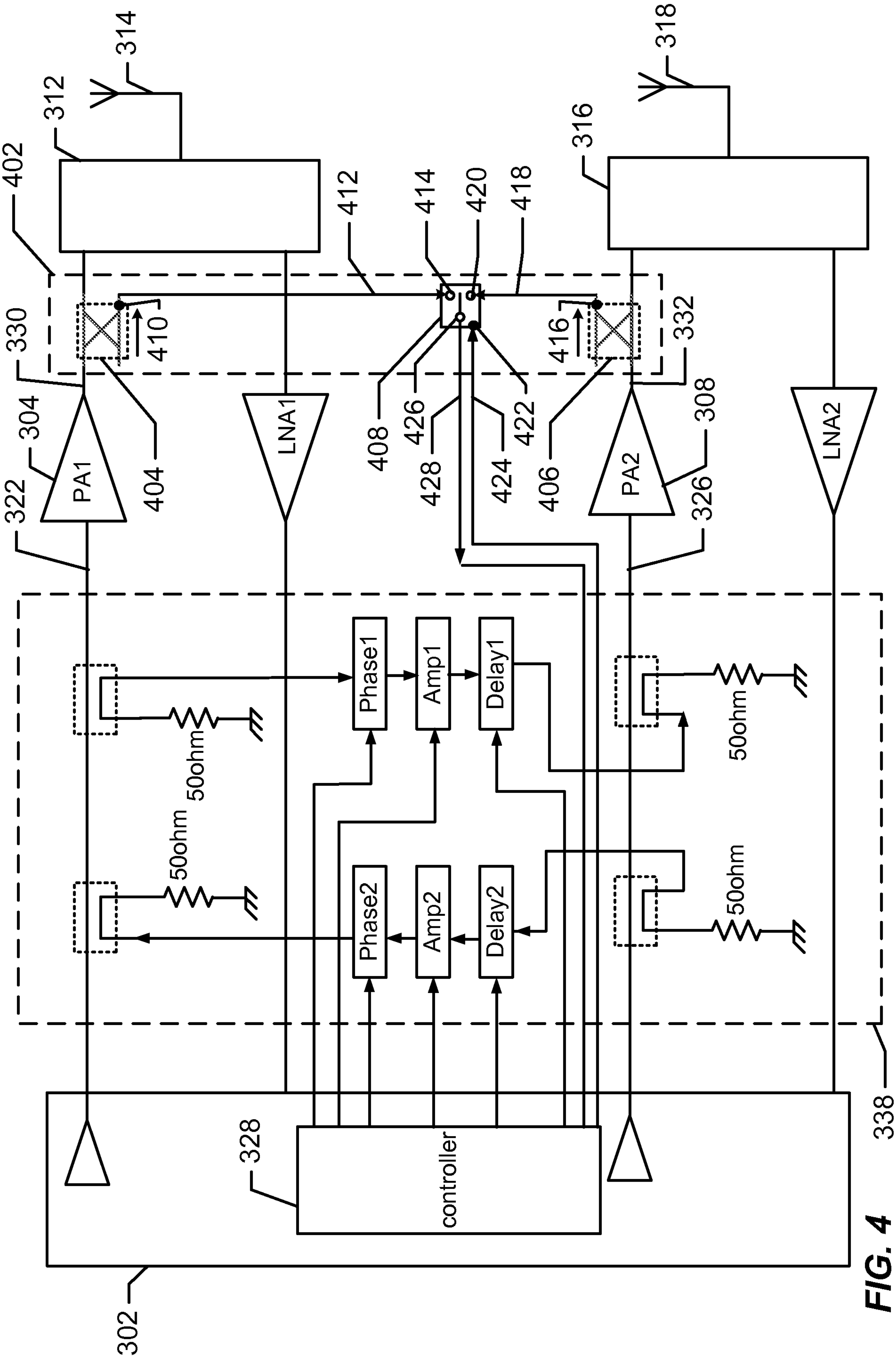

314
312
402
318
316
412
414
420
418
330
410
416
332
404
408
426
422
406
308
304
PA1
LNA1
428
424
PA2
LNA2
322
326
Phase1
Amp1
Delay1
50ohm
50ohm
50ohm
Phase2
Amp2
Delay2
50ohm
338
328
controller
302

FIG. 4

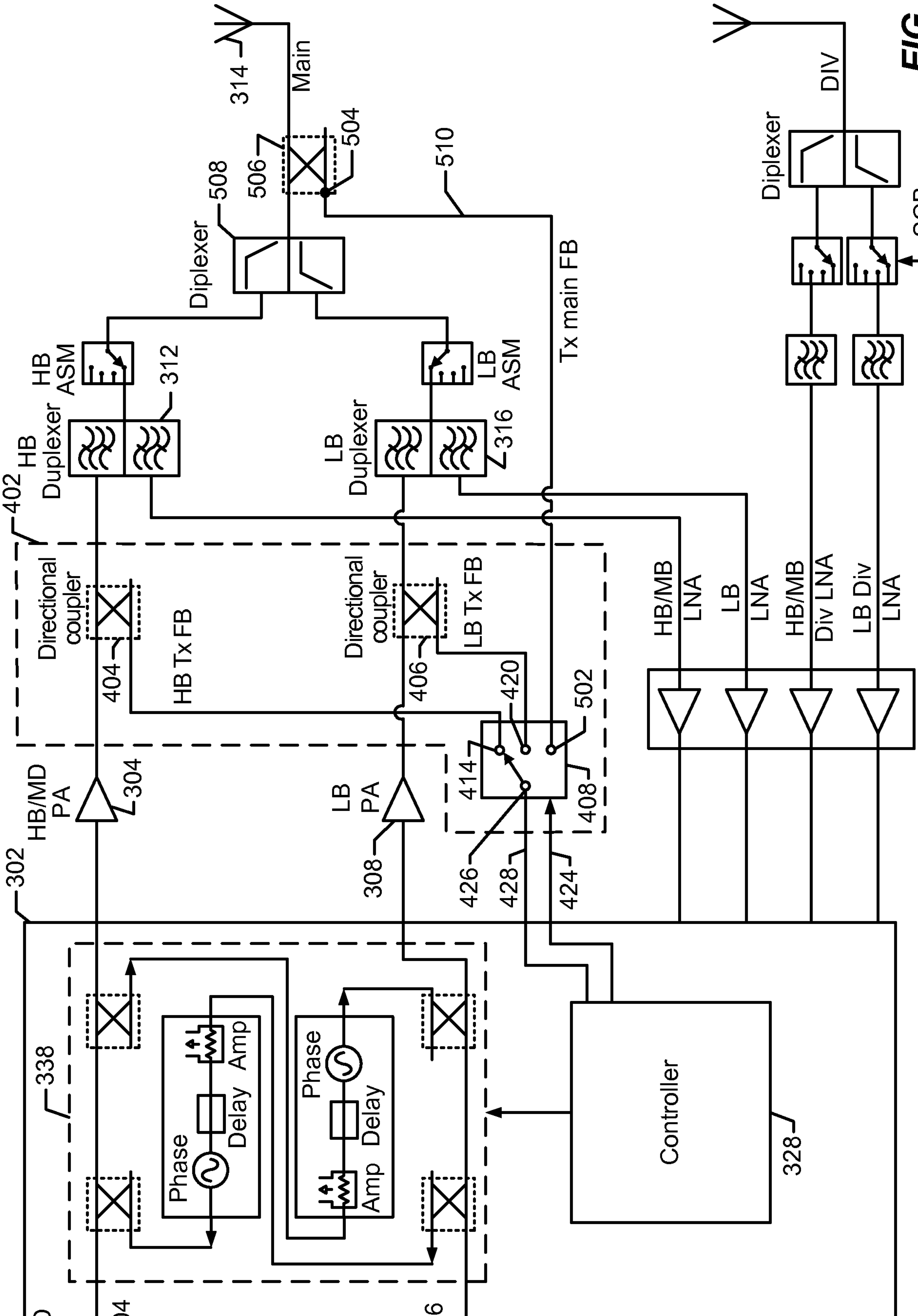

314
Main
504
506
508
510
Diplexer
Tx main FB
HB ASM
312
LB ASM
HB Duplexer
LB Duplexer
316
402
Directional coupler
404
HB Tx FB
Directional coupler
406
LB Tx FB
420
502
414
408
HB/MD PA
304
LB PA
308
426
428
424
302
HB/MB LNA
LB LNA
HB/MB Div LNA
LB Div LNA
DIV
Diplexer
SCB
338
Phase
Delay
Amp
Controller
328
HB/MD DA
404
406
LB DA

FIG. 5

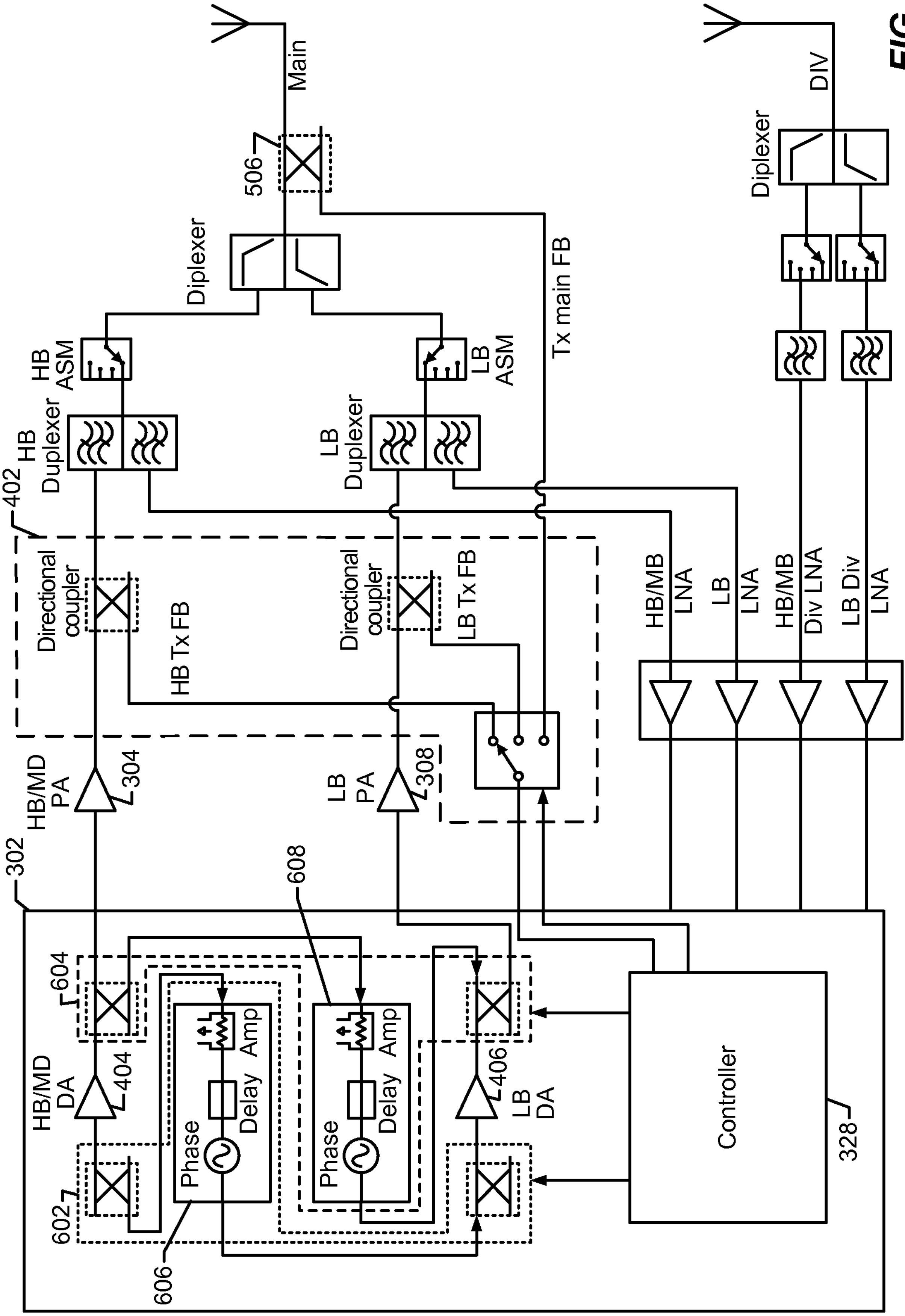

Main
506
Diplexer
HB ASM
LB ASM
Tx main FB
HB Duplexer
LB Duplexer
402
Directional coupler
HB Tx FB
Directional coupler
LB Tx FB
HB/MB LNA
LB LNA
HB/MB Div LNA
LB Div LNA
DIV
Diplexer
HB/MD PA
304
LB PA
308
302
608
604
Amp
Delay
Phase
HB/MD DA
404
406
LB DA
Controller
328
602
606

FIG. 6

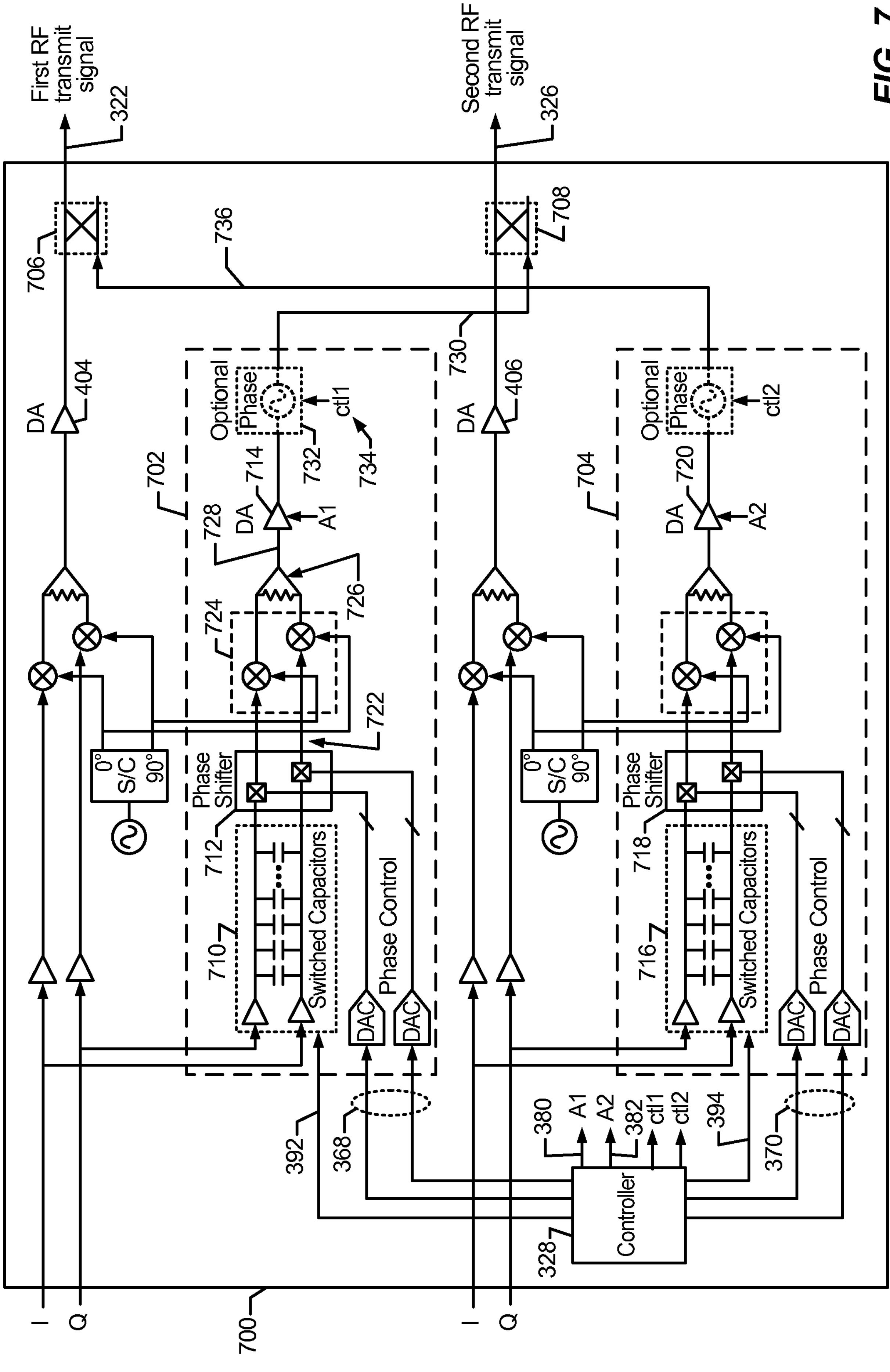

First RF transmit signal
322
Second RF transmit signal
326
706
708
736
DA
404
406
Optional Phase
ctl1
ctl2
730
702
704
714
720
732
734
728
A1
A2
726
724
722
Phase Shifter
S/C
0°
90°
712
718
710
716
Switched Capacitors
Phase Control
DAC
I
Q
700
392
368
380
382
394
370
ctl1
ctl2
Controller
328

FIG. 7

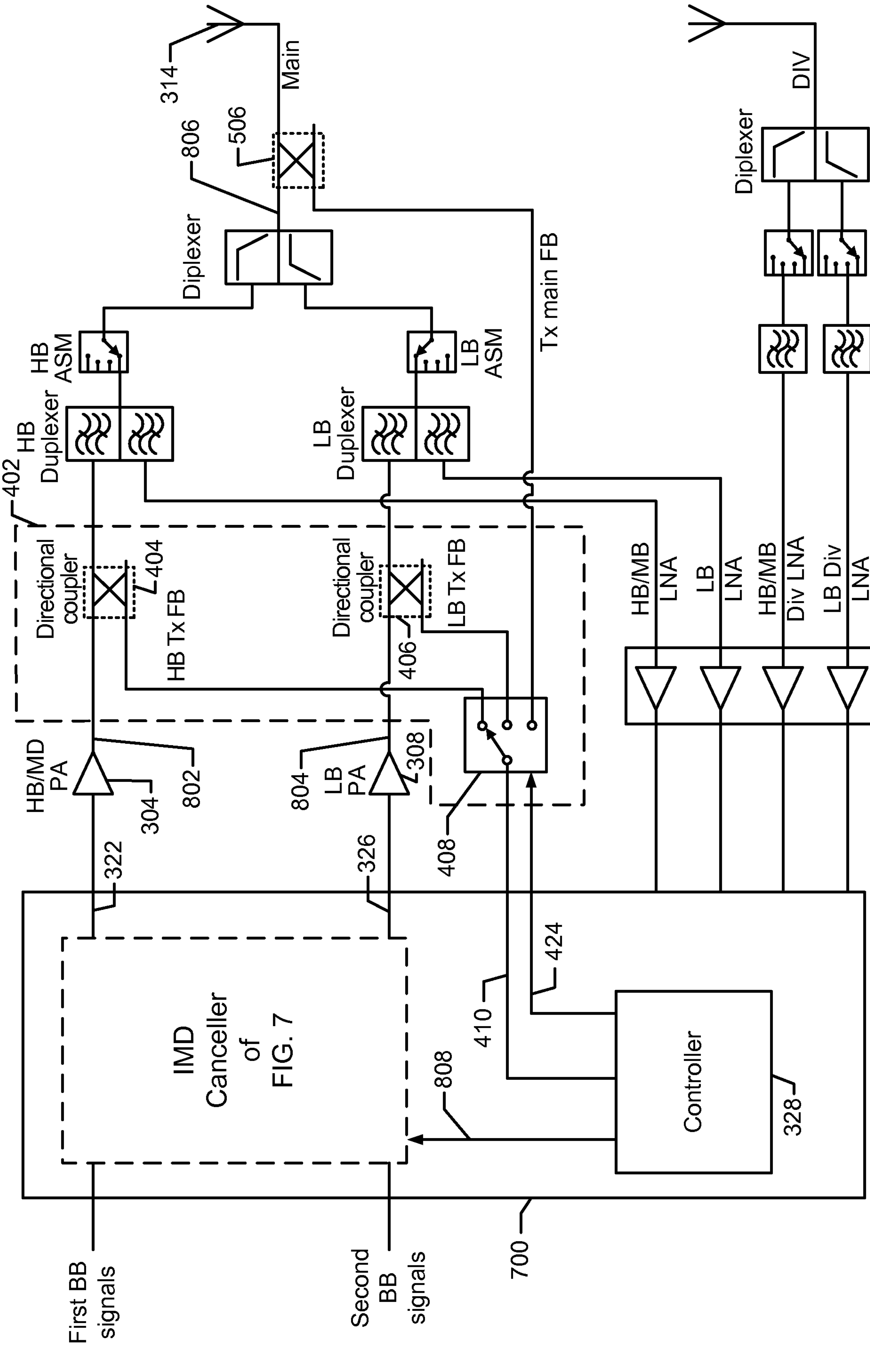
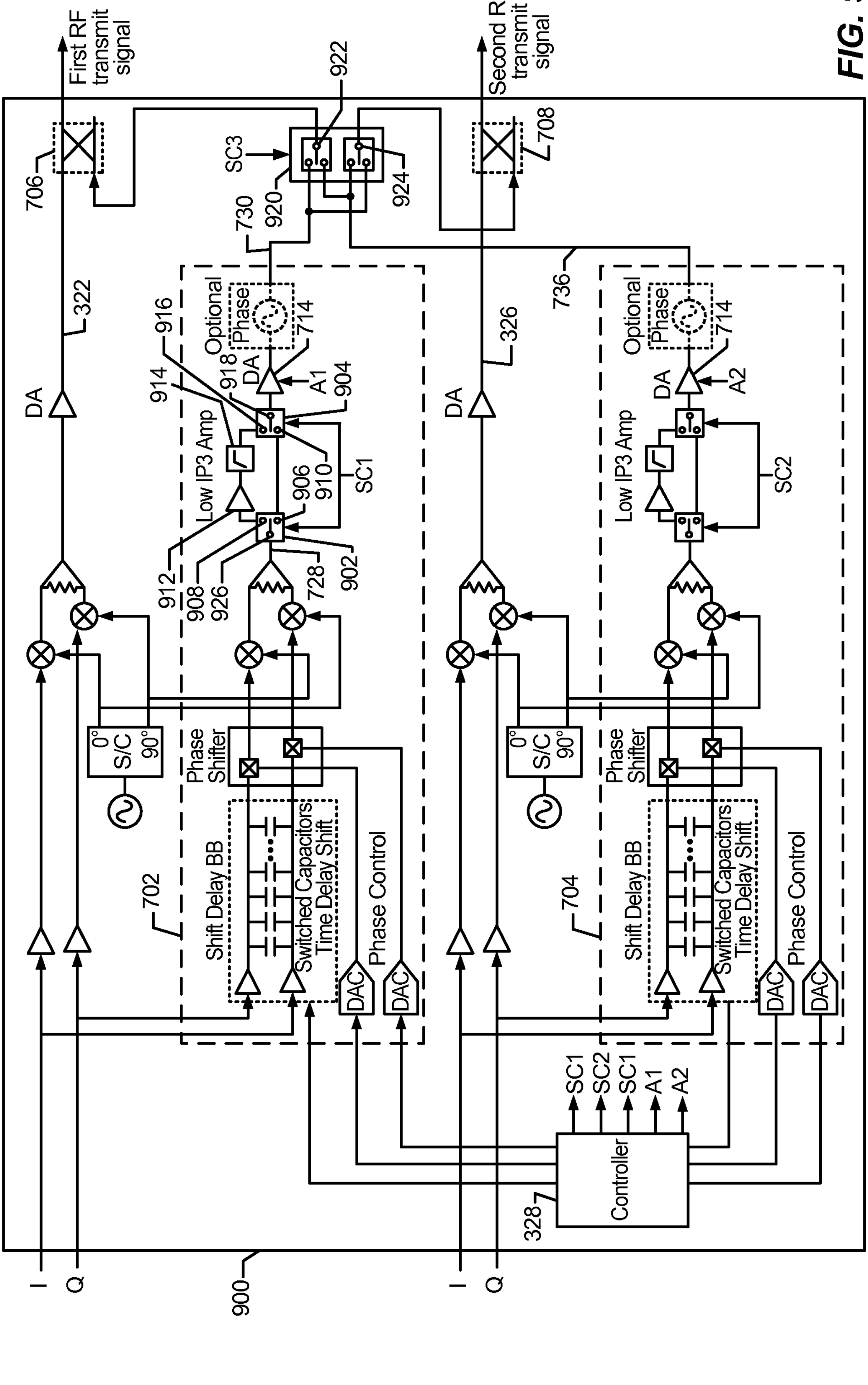

314
Main
506
806
Diplexer
HB ASM
LB ASM
Tx main FB
HB Duplexer
LB Duplexer
402
Directional coupler
404
HB Tx FB
Directional coupler
LB Tx FB
406
HB/MD PA
304
802
804
LB PA
308
408
322
326
HB/MB LNA
LB LNA
HB/MB Div LNA
LB Div LNA
DIV
Diplexer
IMD Canceller of FIG. 7
410
424
808
Controller
328
700
First BB signals
Second BB signals

FIG. 8



First RF transmit signal
Second RF transmit signal
706
708
922
SC3
920
924
730
736
322
326
916
914
918
Optional Phase
714
DA
A1
A2
904
Low IP3 Amp
906
910
SC1
SC2
912
908
926
728
902
Phase Shifter
0°
S/C
90°
Shift Delay BB
Switched Capacitors Time Delay Shift
Phase Control
702
704
DAC
Controller
328
SC1
SC2
SC1
A1
A2
900
I
Q

FIG. 9

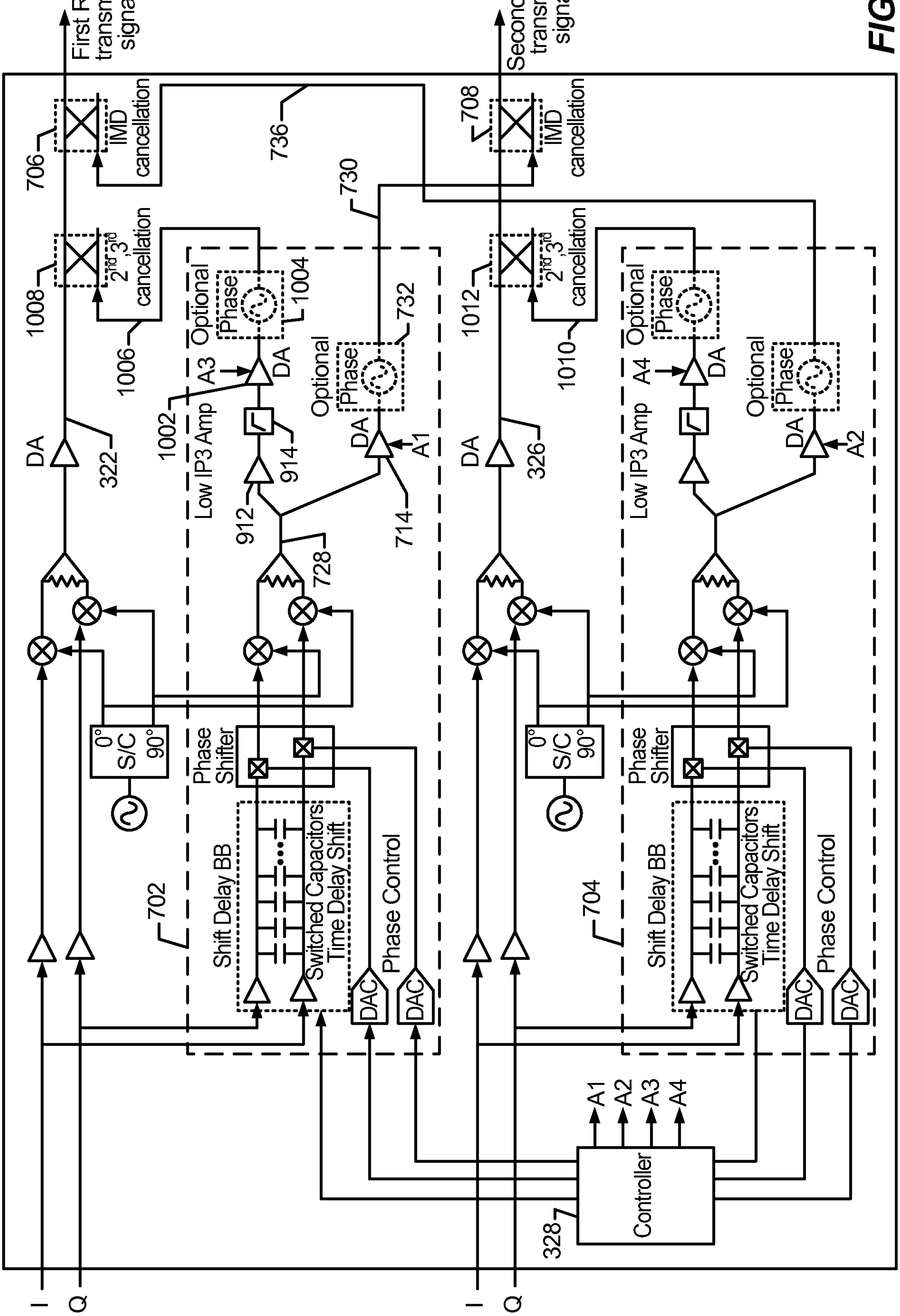
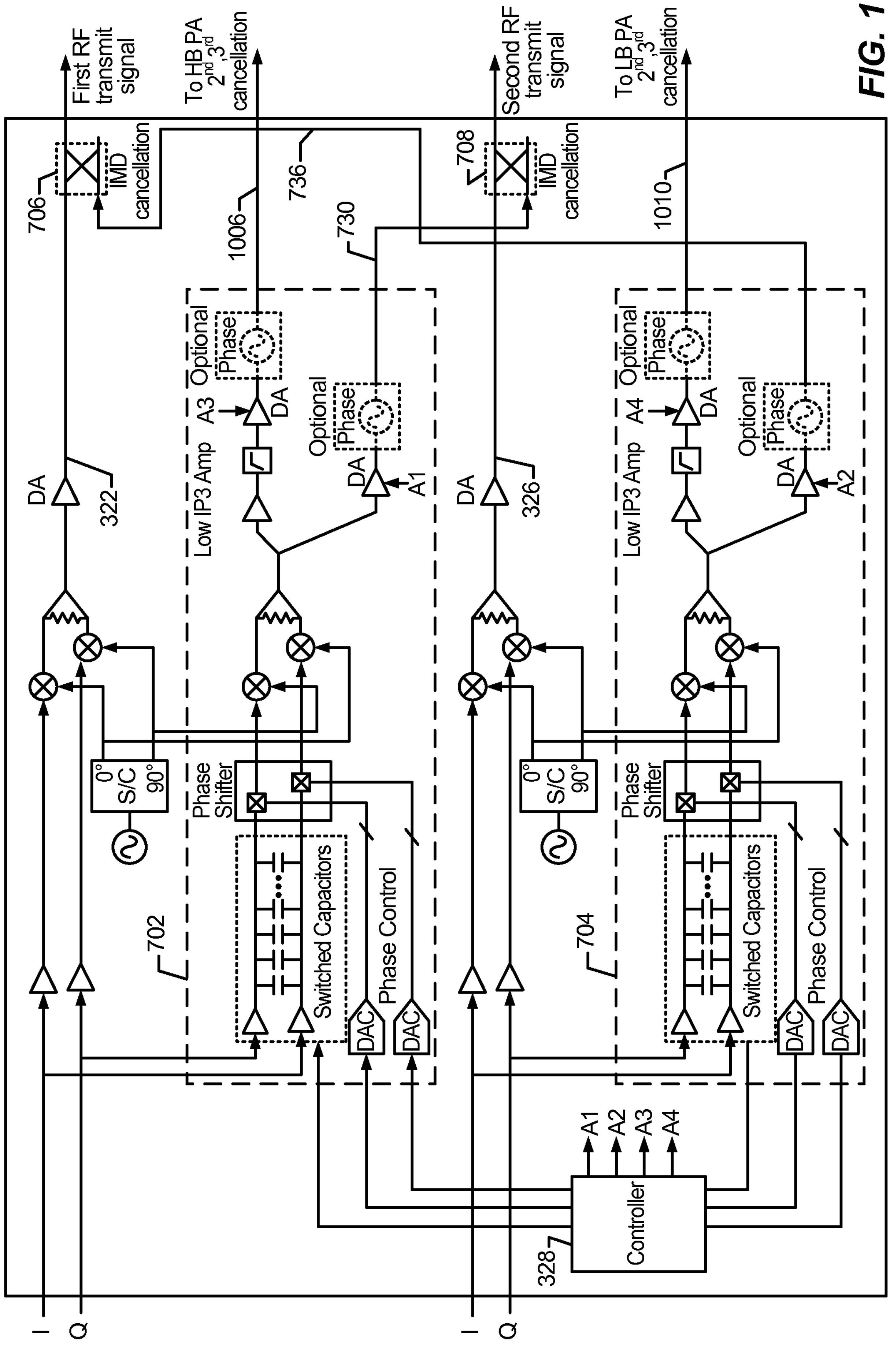
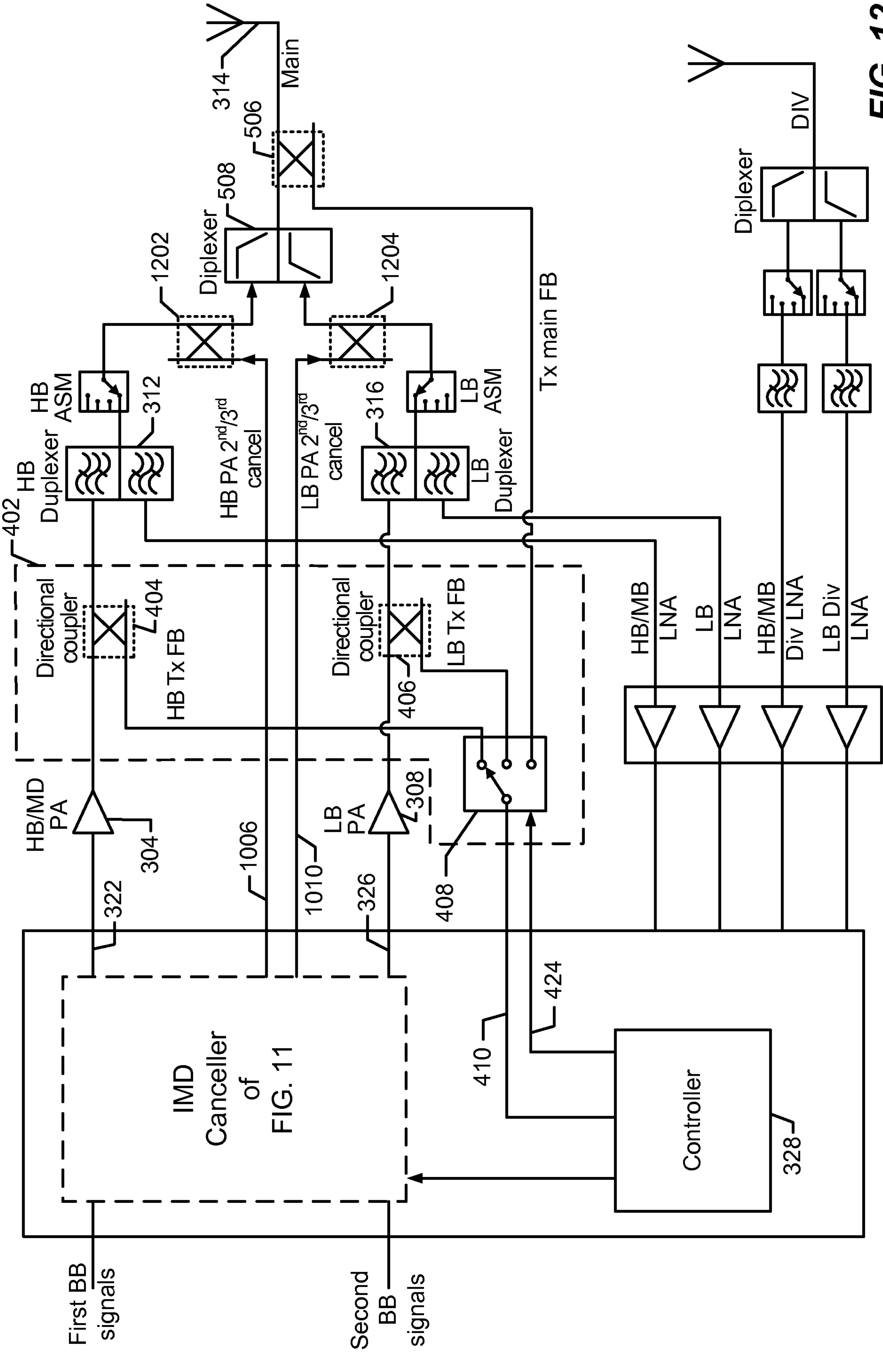

First RF transmit signal
Second RF transmit signal
706
708
IMD cancellation
IMD cancellation
736
730
1008
1012
2nd, 3rd cancellation
2nd, 3rd cancellation
1006
1010
Optional Phase
1004
732
Optional Phase
A3
A4
DA
1002
Low IP3 Amp
914
912
A1
A2
714
322
326
728
Phase Shifter
S/C
0°
90°
Shift Delay BB
Switched Capacitors Time Delay Shift
Phase Control
DAC
702
704
Controller
328
I
Q

FIG. 10



First RF transmit signal
To HB PA 2nd,3rd cancellation
Second RF transmit signal
To LB PA 2nd,3rd cancellation
706
IMD cancellation
708
IMD cancellation
1006
736
730
1010
Optional Phase
A3
DA
Low IP3 Amp
Optional Phase
DA
A1
A4
DA
A2
DA
322
326
S/C
0°
90°
Phase Shifter
Switched Capacitors
Phase Control
DAC
DAC
702
704
A1
A2
A3
A4
Controller
328
I
Q
I
Q

FIG. 11



314
Main
506
508
Diplexer
1202
1204
Tx main FB
HB ASM
312
LB ASM
316
HB Duplexer
LB Duplexer
HB PA 2nd/3rd cancel
LB PA 2nd/3rd cancel
402
Directional coupler
404
HB Tx FB
Directional coupler
LB Tx FB
406
HB/MB LNA
LB LNA
HB/MB Div LNA
LB Div LNA
DIV
Diplexer
HB/MD PA
304
LB PA
308
408
322
1006
1010
326
424
410
IMD Canceller of FIG. 11
Controller
328
First BB signals
Second BB signals

FIG. 12

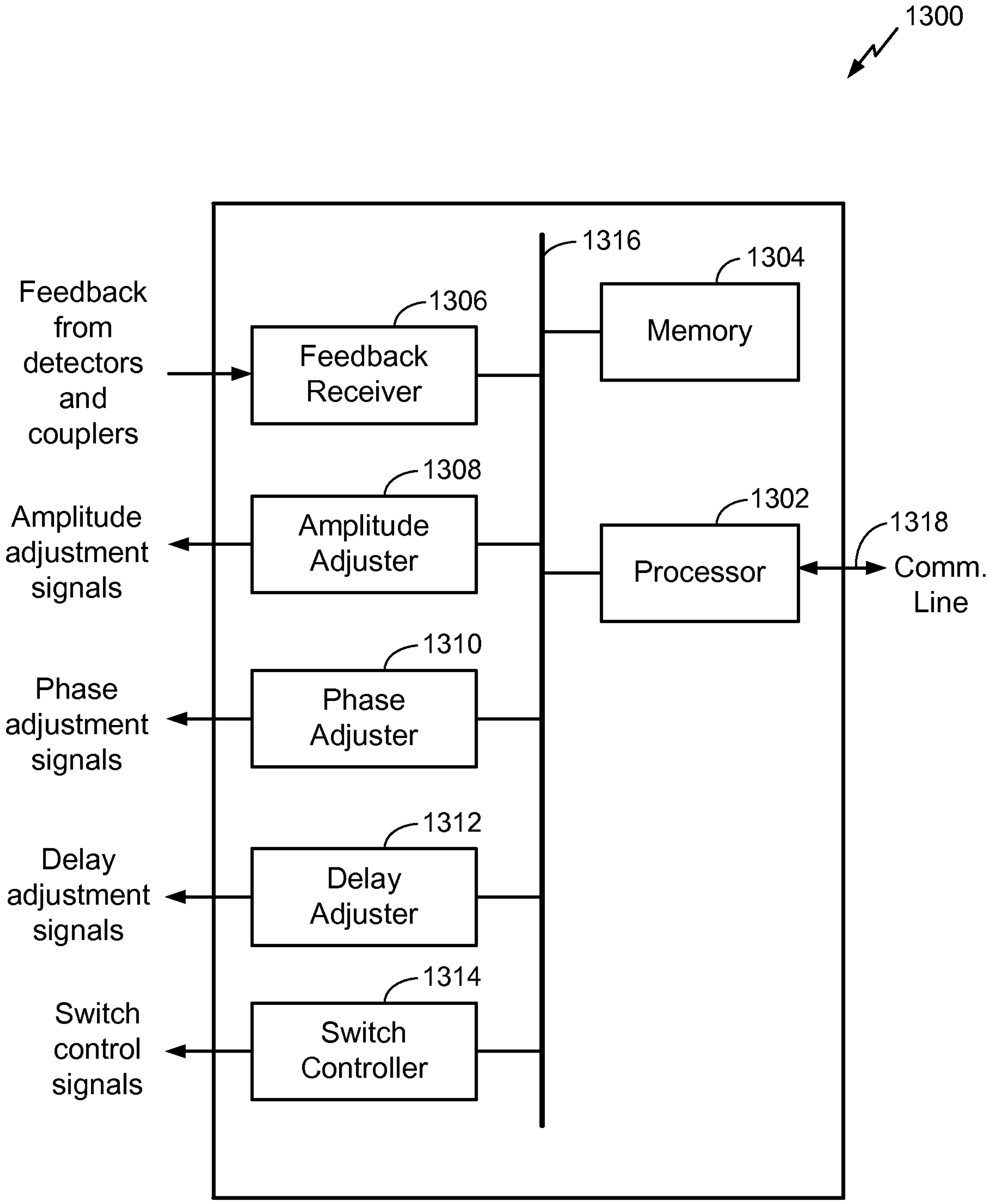

1300
1316
1304
Memory
1306
Feedback
from
detectors
and
couplers
Feedback
Receiver
1308
1302
1318
Amplitude
adjustment
signals
Amplitude
Adjuster
Processor
Comm.
Line
1310
Phase
adjustment
signals
Phase
Adjuster
1312
Delay
adjustment
signals
Delay
Adjuster
1314
Switch
control
signals
Switch
Controller

FIG. 13

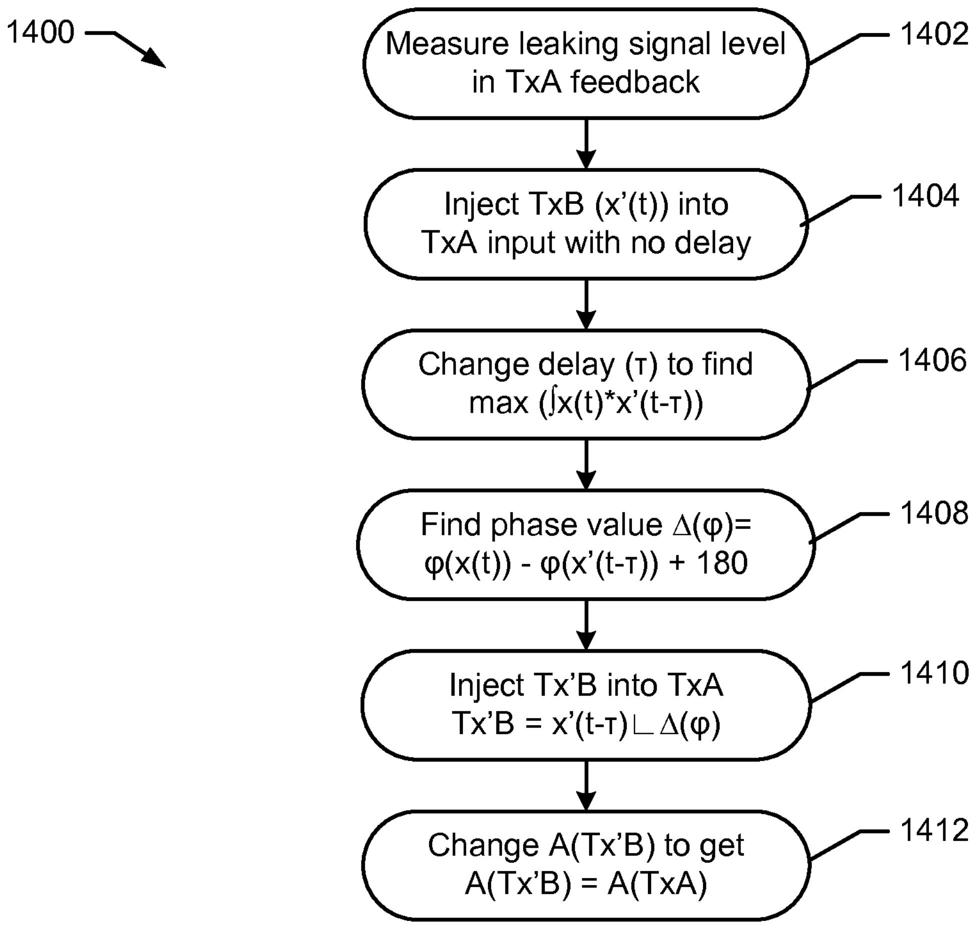

1400
Measure leaking signal level in TxA feedback
1402
Inject TxB (x'(t)) into TxA input with no delay
1404
Change delay (τ) to find max (∫x(t)*x'(t-τ))
1406
Find phase value Δ(φ)= φ(x(t)) - φ(x'(t-τ)) + 180
1408
Inject Tx'B into TxA Tx'B = x'(t-τ)∟Δ(φ)
1410
Change A(Tx'B) to get A(Tx'B) = A(TxA)
1412

FIG. 14

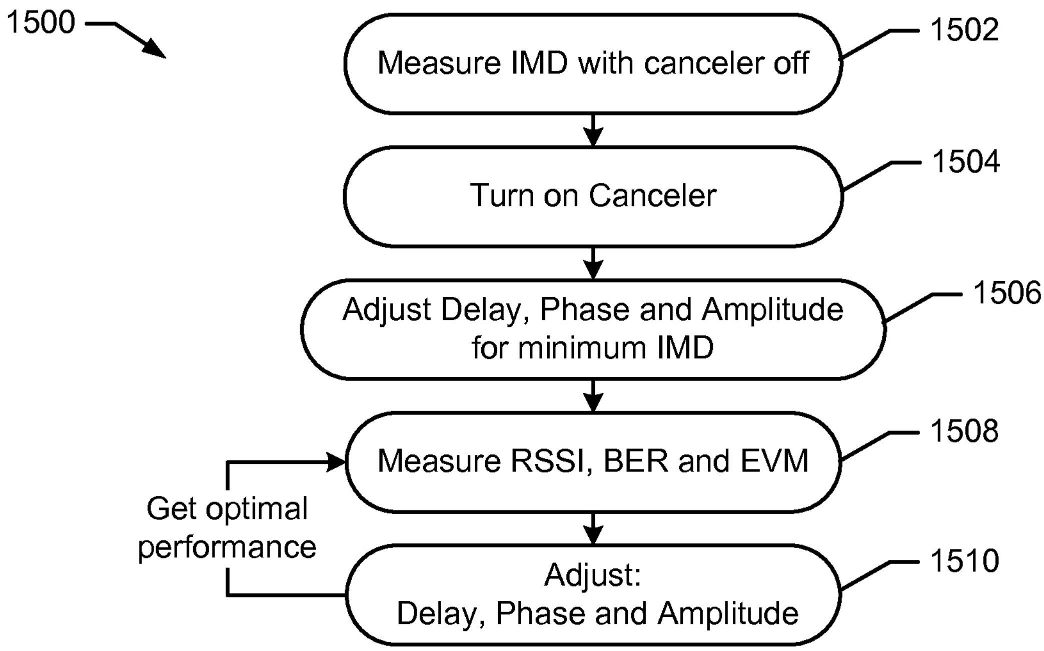

1500
Measure IMD with canceler off
1502
Turn on Canceler
1504
Adjust Delay, Phase and Amplitude for minimum IMD
1506
Measure RSSI, BER and EVM
1508
Get optimal performance
Adjust: Delay, Phase and Amplitude
1510

FIG. 15

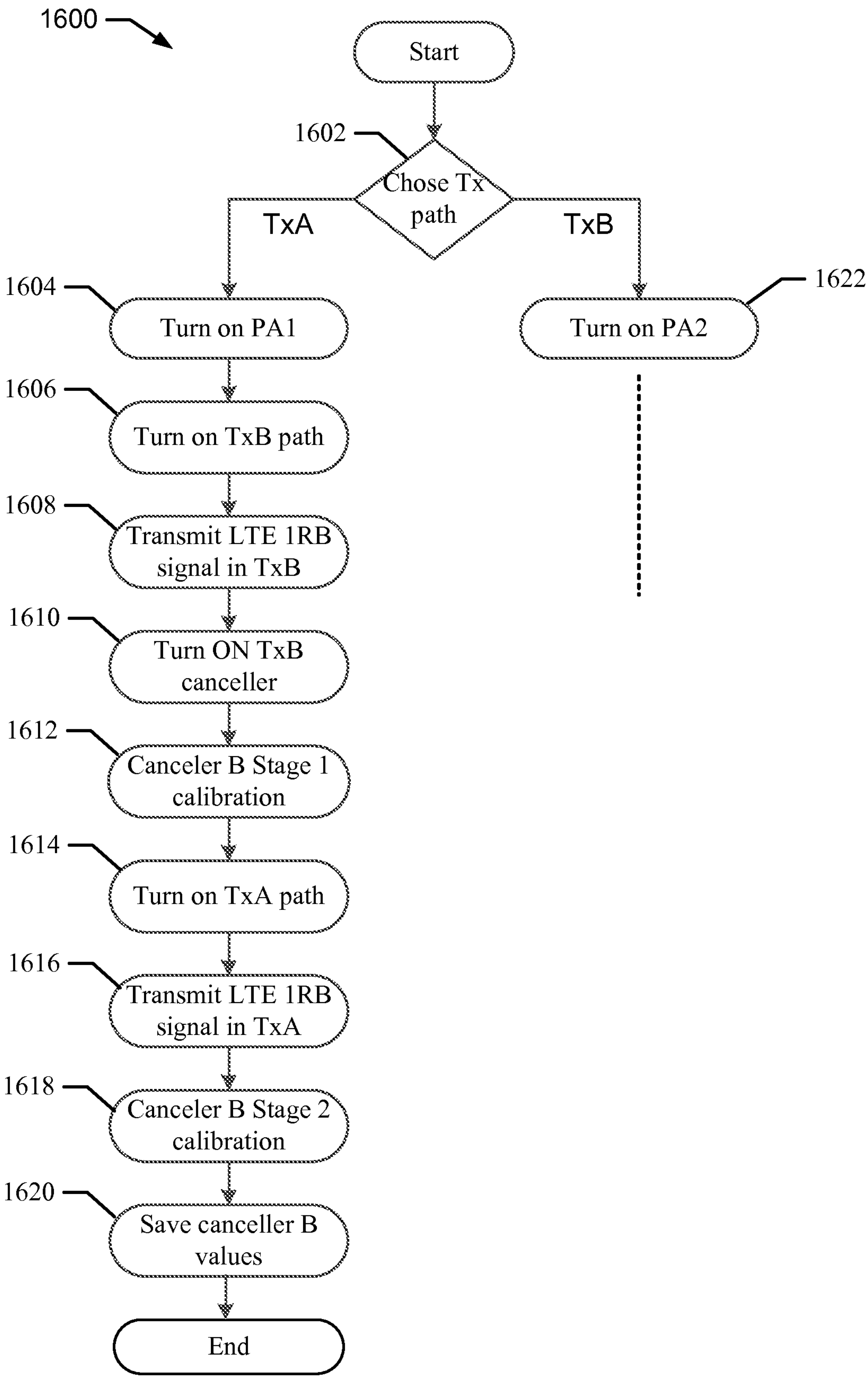

1600
Start
1602
Chose Tx path
TxA
TxB
1604
Turn on PA1
1622
Turn on PA2
1606
Turn on TxB path
1608
Transmit LTE 1RB signal in TxB
1610
Turn ON TxB canceller
1612
Canceler B Stage 1 calibration
1614
Turn on TxA path
1616
Transmit LTE 1RB signal in TxA
1618
Canceler B Stage 2 calibration
1620
Save canceller B values
End

FIG. 16

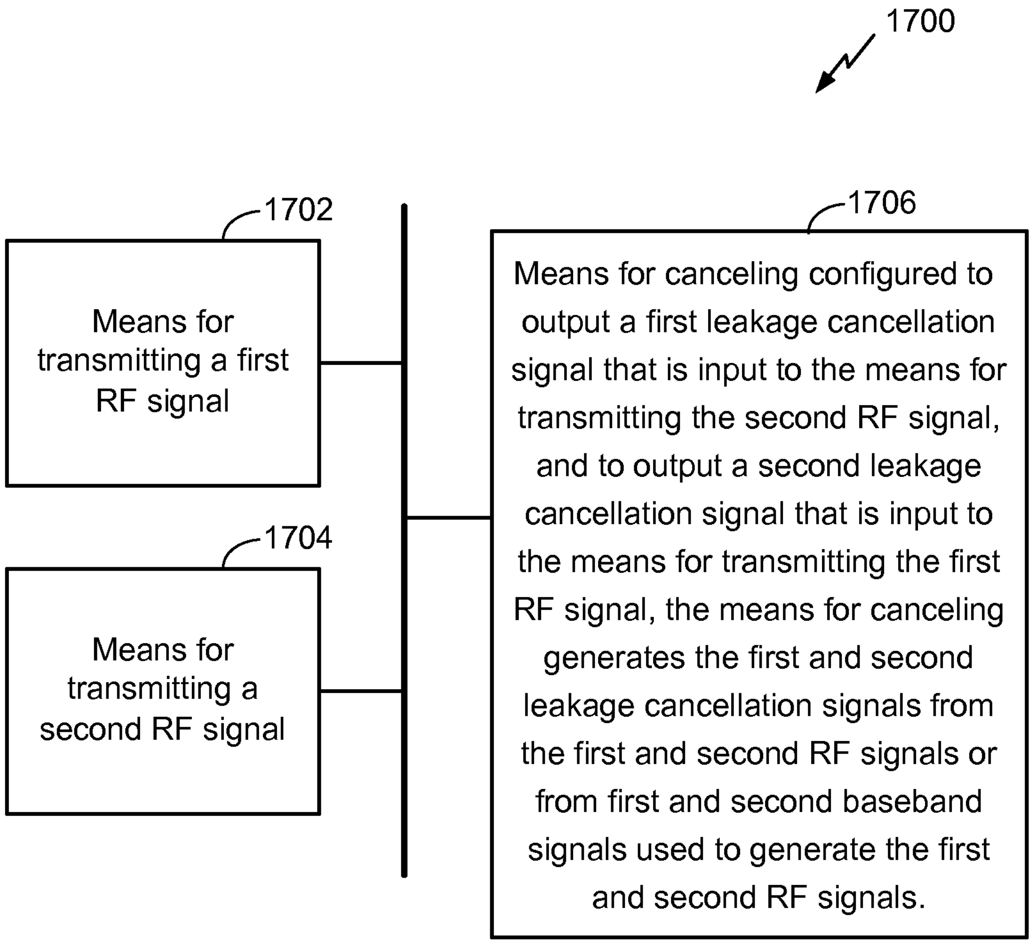

1700
1702
Means for transmitting a first RF signal
1704
Means for transmitting a second RF signal
1706
Means for canceling configured to output a first leakage cancellation signal that is input to the means for transmitting the second RF signal, and to output a second leakage cancellation signal that is input to the means for transmitting the first RF signal, the means for canceling generates the first and second leakage cancellation signals from the first and second RF signals or from first and second baseband signals used to generate the first and second RF signals.

FIG. 17

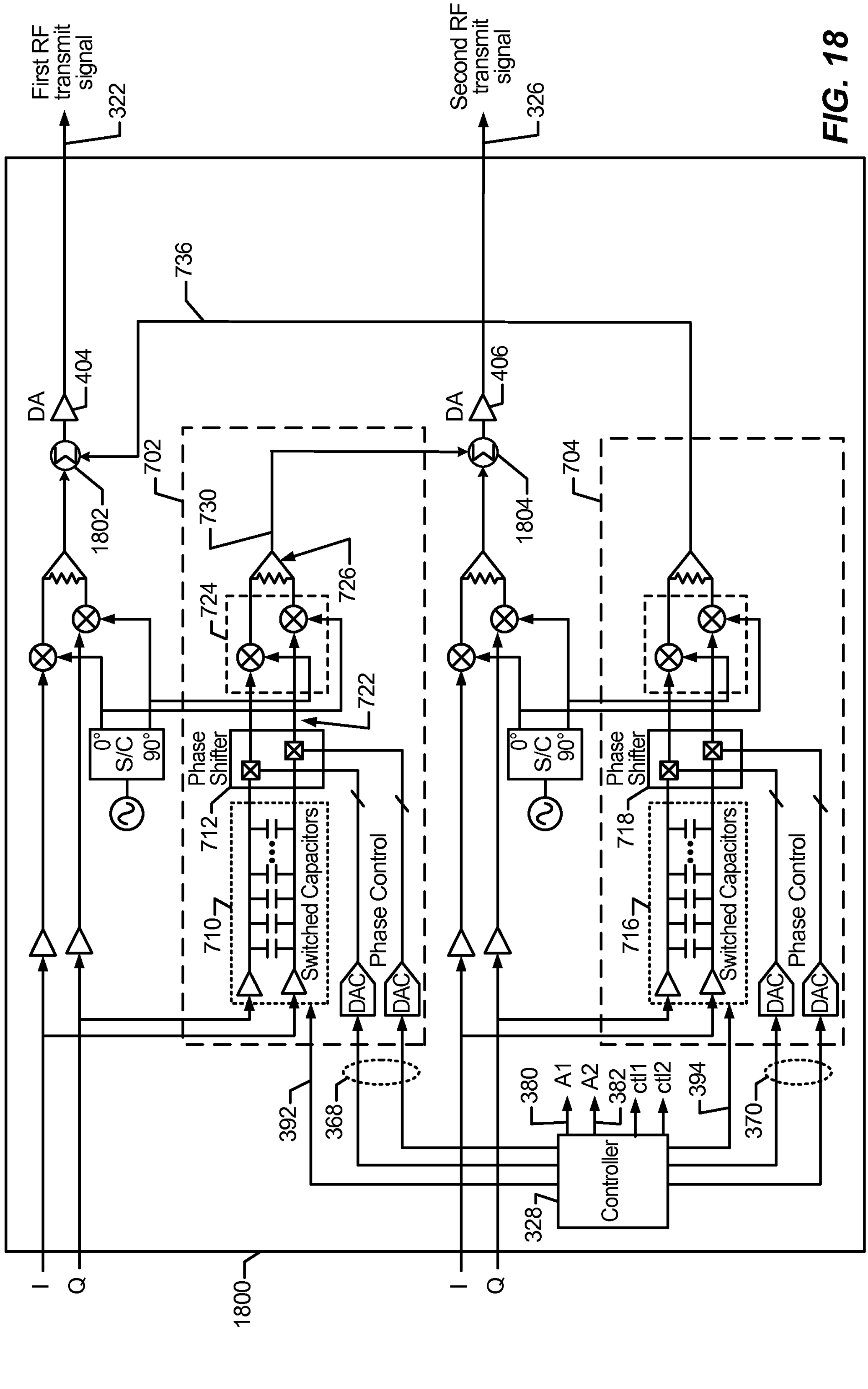

First RF transmit signal
322
Second RF transmit signal
326
736
DA
404
DA
406
702
704
730
1802
1804
724
726
722
0°
S/C
90°
Phase Shifter
712
718
710
716
Switched Capacitors
Phase Control
DAC
DAC
380
A1
A2
382
ctl1
ctl2
394
392
368
370
Controller
328
I
Q
1800

FIG. 18

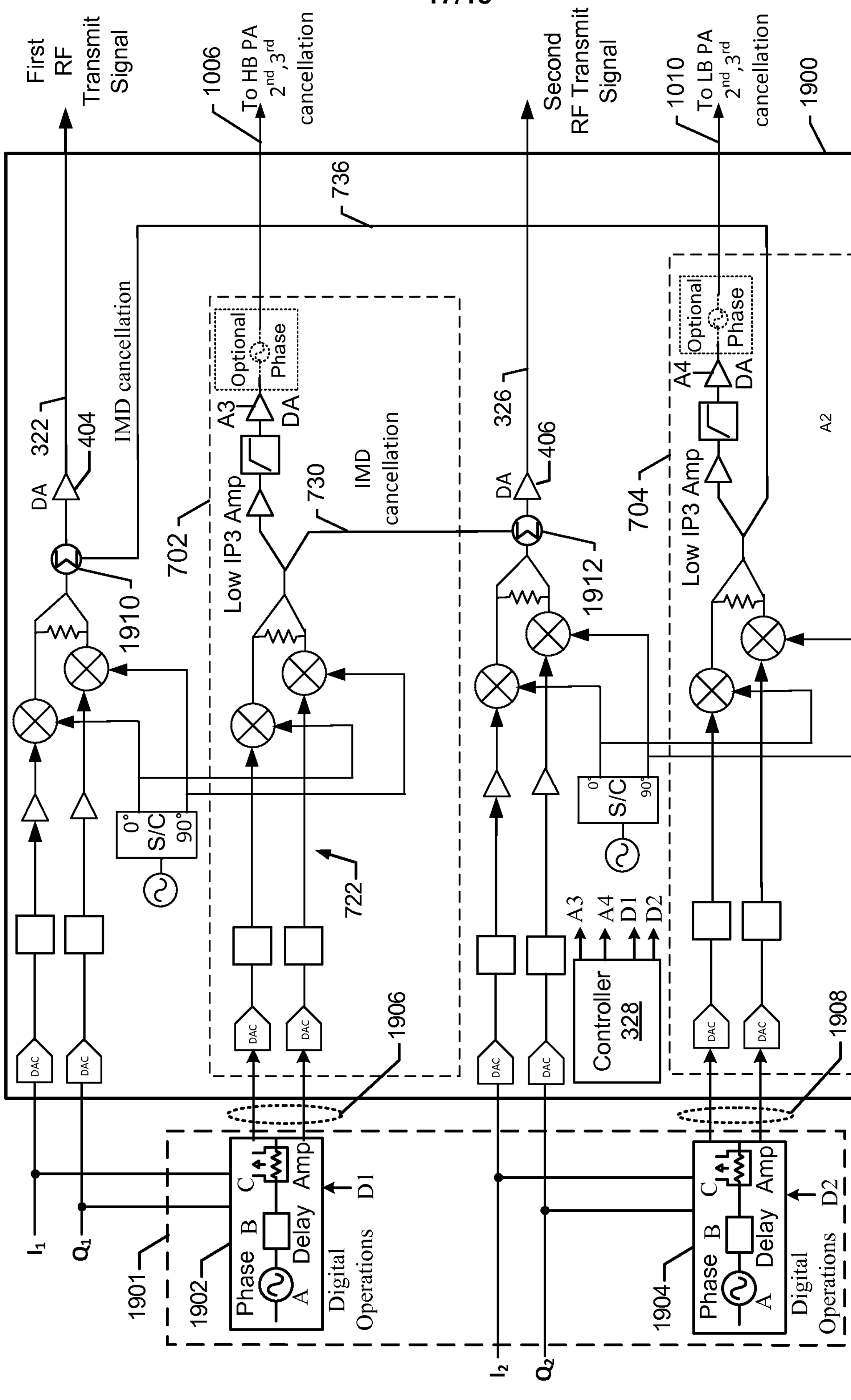

First RF Transmit Signal
1006
To HB PA 2nd, 3rd cancellation
Second RF Transmit Signal
1010
To LB PA 2nd, 3rd cancellation
1900
736
IMD cancellation
Optional Phase
A3
DA
322
404
DA
326
406
DA
A4
DA
Optional Phase
A2
730
IMD cancellation
Low IP3 Amp
702
704
Low IP3 Amp
1910
1912
S/C
0°
90°
722
A3
A4
D1
D2
Controller
328
DAC
1906
1908
I1
Q1
1901
1902
Phase A
Delay B
C
Amp
D1
Digital Operations
I2
Q2
1904
D2

FIG. 19

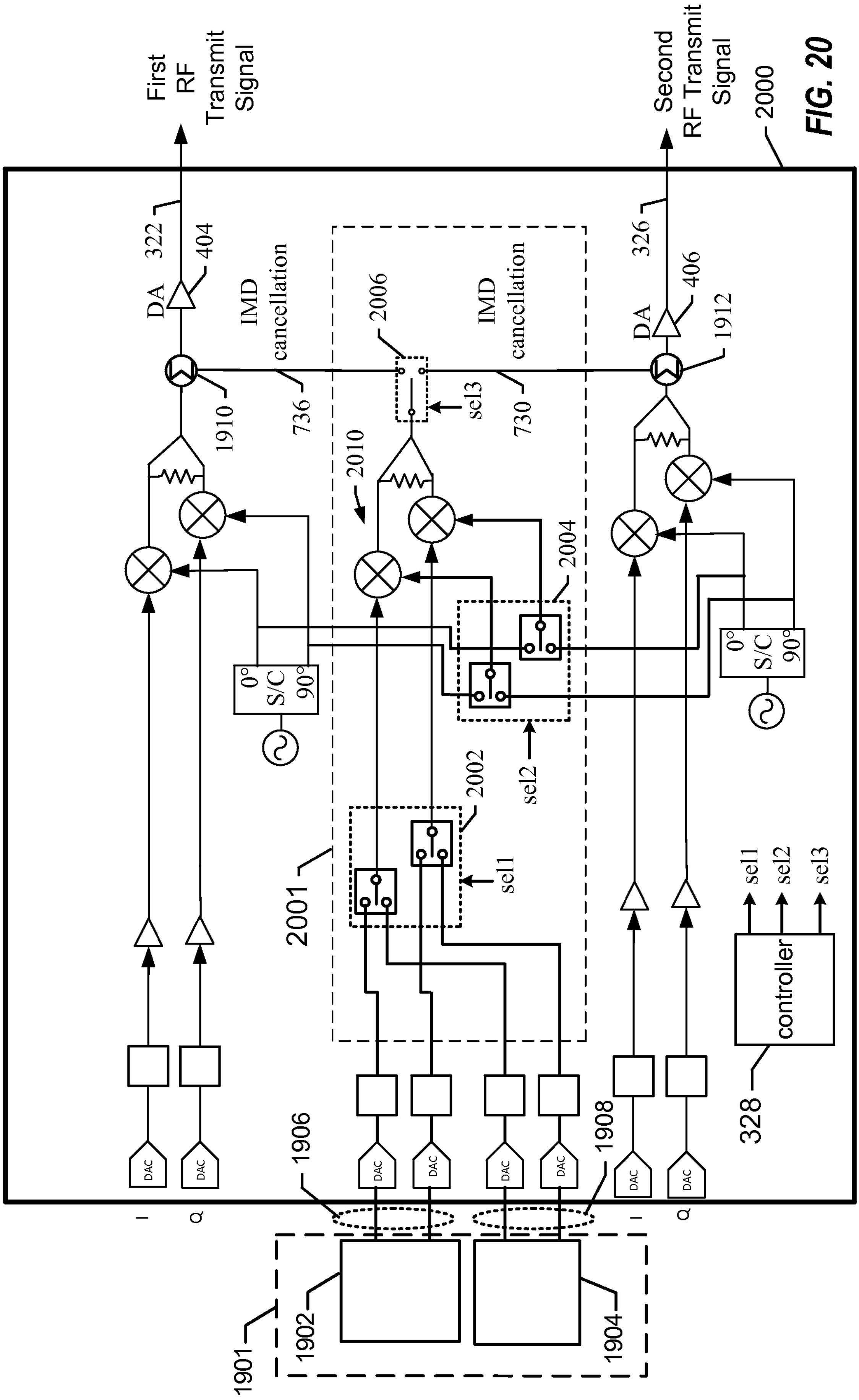

First RF Transmit Signal
Second RF Transmit Signal
2000
322
404
DA
IMD cancellation
2006
326
406
1912
1910
736
sel3
730
2010
2004
0°
S/C
90°
sel2
2002
2001
sel1
sel1
sel2
sel3
controller
328
DAC
1906
1908
I
Q
1901
1902
1904

FIG. 20

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/054032

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B1/00 H04B17/19 H04B15/04
ADD. H04B1/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 704 318 A1 (NTT DOCOMO INC [JP]) 5 March 2014 (2014-03-05) paragraphs [0017], [0060] - [0066]; figures 8,9	1-20
X	US 2014/051373 A1 (KLOMSDORF ARMIN W [US] ET AL) 20 February 2014 (2014-02-20) paragraph [0031]; figures 1,2	1-20
A	US 2014/269857 A1 (RIMINI ROBERTO [US] ET AL) 18 September 2014 (2014-09-18) abstract	1-20
A	US 2013/044621 A1 (JUNG HYEJUNG [US] ET AL) 21 February 2013 (2013-02-21) abstract	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 December 2015	11/12/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Marques, Gabriela

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2015/054032

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2704318 A1	05-03-2014	CN 103718456 A	09-04-2014
		EP 2704318 A1	05-03-2014
		JP 5620590 B2	05-11-2014
		JP WO2013084778 A1	27-04-2015
		US 2014191799 A1	10-07-2014
		WO 2013084778 A1	13-06-2013
US 2014051373 A1	20-02-2014	DE 212013000183 U1	24-04-2015
		US 2014051373 A1	20-02-2014
		WO 2014028239 A2	20-02-2014
US 2014269857 A1	18-09-2014	NONE	
US 2013044621 A1	21-02-2013	NONE	