



## **CARRIER AGGREGATION DIVERSITY ANTENNA MODULE WITH INTEGRATED LNA BANKS**

### **CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] The present application claims priority from commonly owned U.S. Provisional Patent Application No. 62/015,951 filed on June 23, 2014, and U.S. Non-Provisional Patent Application No. 14/676,639 filed on April 1, 2015, the contents of which are expressly incorporated herein by reference in their entirety.

### **FIELD**

[0002] The present disclosure relates generally to transceivers, and more specifically to a diversity antenna module for use in carrier aggregation transceivers.

### **BACKGROUND**

[0003] In a radio frequency (RF) transceiver, a communication signal is developed, upconverted, amplified and transmitted by a transmitter and is received, amplified, downconverted and recovered by a receiver. In the receiver, the communication signal is typically received and downconverted by receive circuitry to recover the information contained in the communication signal. A single transmitter or receiver can be configured to operate using multiple transmit frequencies and/or multiple receive frequencies. For a receiver to be able to simultaneously receive two or more receive signals, the concurrent operation of two or more receive paths is used. Such systems are sometimes referred to as "carrier-aggregation" (CA) systems. The term "carrier-aggregation" may refer to systems that include inter-band carrier aggregation (Inter-CA) and intra-band carrier aggregation (Intra-CA). Inter-CA refers to the processing of two or more separate (either contiguous or non-contiguous) carrier signals that occur in different communication bands. Intra-CA refers to the processing of two or more separate (either contiguous or non-contiguous) carrier signals that occur in the same communication band. The carrier aggregated RF signal is typically down-converted using one or more distinct local oscillator (LO) frequencies, which generally employ one or more low noise amplifiers (LNA) to process the multiple carriers present in the RF signal. The amplified signal is typically processed by downconversion and demodulation circuitry to extract the information contained in the received signal.

[0004] In a conventional multi-antenna transceiver design, there is typically a primary antenna and several secondary antennas. The secondary antennas constitute an array of

- 2 -

diversity antennas. Baseband electronics (e.g., modem, signal conditioners, etc.) produce signals for transmission and also operate to process received signals. The baseband electronics interface with a transceiver that connects to RF front end electronics. The RF front end electronics includes amplifiers, duplexer, or other filters to amplify and route signals to and from the antennas. The signals may be in various communication bands, such as low band (LB), mid band (MB), and/or high band (HB) signals.

[0005] The RF front end electronics typically includes a receiver module for routing diversity signals received from the secondary antennas to the transceiver.

Unfortunately, conventional receiver modules may be complex with many switches and filters thereby requiring large circuit area. Furthermore, conventional receiver modules may have limitations as to how many diversity signals can be simultaneously received and/or how various receive and transmit modes are performed in combination.

[0006] It is therefore desirable to have a diversity receiver module that reduces or eliminates the number switches and filters that are utilized to reduce costs and space requirements, and that provides a wide range of transmit and receive combinations when compared to conventional designs.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0007] **FIG. 1** shows an exemplary embodiment of a diversity antenna module that efficiently routes received RF signals from multiple antennas to a receiver in a wireless device communicating within a wireless system.

[0008] **FIG. 2** shows diagrams that illustrate signal carrier configurations in a carrier aggregation communication system.

[0009] **FIG. 3** shows a block diagram of a receiver front end that includes an exemplary embodiment of a diversity antenna module.

[0010] **FIG. 4** shows a detailed exemplary embodiment of the diversity receiver shown in **FIG. 3**.

[0011] **FIG. 5** shows a detailed exemplary embodiment of the diversity antenna module shown in **FIG. 3**.

[0012] **FIG. 6** shows antenna configurations for use with the front end shown in **FIG. 3**.

[0013] FIG. 7 shows a diagram that illustrates diversity receive signal paths of the front end.

[0014] FIG. 8 shows an exemplary embodiment of diversity receiver apparatus.

#### **DETAILED DESCRIPTION**

[0015] 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.

[0016] FIG. 1 shows an exemplary embodiment of a diversity antenna module 114 that efficiently routes received RF signals from multiple antennas to a receiver in a wireless device 102 communicating within a wireless 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 wireless system 100 including two base stations 104 and 106 and one system controller 108. In general, wireless system 100 may include any number of base stations and any set of network entities.

[0017] Wireless device 102 may also be referred to as a user equipment (UE), a mobile station, a terminal, an access terminal, a subscriber unit, or a station. Wireless device 102 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, or other communicating device. Wireless device 102 may communicate with devices in the

- 4 -

wireless system **100**. Wireless device **102** may also receive signals from broadcast stations (e.g., a broadcast station **110**), or signals from satellites (e.g., a satellite **112**) in one or more global navigation satellite systems (GNSS). Wireless device **102** may support one or more radio technologies for wireless communication such as LTE, WCDMA, CDMA 1X, EVDO, TD-SCDMA, GSM, 802.11. In various exemplary embodiments, the diversity antenna module **114** efficiently routes received RF signals from multiple antennas to a receiver in the device **102**. In an exemplary embodiment, the diversity antenna module **114** operates with a reduced the number of switches and filters typically used in conventional systems to reduce circuit area and increase the functionality, thereby allowing more combinations of primary and diversity signals to be simultaneously transmitted and received.

[0018] FIG. 2 shows diagrams **200** that illustrate signal carriers in a carrier aggregation communication system. For example, the signal configurations show carriers that may be transmitted or received in the communication system **100** shown in FIG. 1. For example, the diagrams **200** show low-band, mid-band and high-band groups and each band group may have one or more carrier signals. In diagram **206**, the low-band group is divided into two bands.

[0019] Diagram **202** shows an illustration of contiguous intra-band carriers. For example, there are multiple contiguous carriers in one band (e.g., four contiguous carriers in the low-band). Wireless device **100** may send and/or receive transmissions on the four contiguous carriers within the same band.

[0020] Diagram **204**, shows an illustration of non-contiguous intra-band carriers. For example, there are multiple non-contiguous carriers in one band (e.g., four non-contiguous carriers in the low-band). The carriers may be separated by 5 MHz, 10 MHz, or some other amount. Wireless device **100** may send and/or receive transmissions on the four non-contiguous carriers within the same band.

[0021] Diagram **206** shows an illustration of inter-band carriers in the same band group. For example, there are multiple carriers in two bands (e.g., two contiguous carriers in low band 1 and two contiguous carriers in low-band 2). Wireless device **100** may send and/or receive transmissions on the four carriers in different bands in the same band group.

- 5 -

[0022] Diagram **208** shows an illustration of inter-band carriers in different band groups. For example, there are multiple carriers in two bands of different band groups (e.g., two carriers in the low-band group and two carriers in the mid-band group. Wireless device **100** may send and/or receive transmissions on the four carriers in the different band groups. It should also be noted that other carrier configurations in a carrier aggregation system having other combinations of bands and band groups may also be supported.

[0023] **FIG. 3** shows a block diagram of a receiver front end **300** that includes an exemplary embodiment of a diversity antenna module **114**. For example, the receiver front end **300** is suitable for use to transmit and receive RF signals at the device **102** shown in **FIG. 1**. In an exemplary embodiment, a baseband (BB) processor **302** processes baseband signals that are communicated to and from a transceiver **304**. Baseband signals to be transmitted from the device **102** are up-converted to RF signals by the transceiver **304** and output to the front end **300** for transmission by one or more antennas. For example, the RF signals may comprise carrier signals that are in any of the band groups illustrated in **FIG. 2**. However, the RF signals for transmission are not limited to any specific band group configuration. RF signals received by the front end **300** are passed to the transceiver **304** where they are down-converted to baseband and then passed to the baseband processor **302** for further processing.

[0024] The front end **300** transmits and receives RF signals using an antenna group comprising a primary antenna **314** and secondary (or diversity) antennas **332** and **336**. Filter **312** is coupled to a low band cross switch **310** and a mid/high band cross switch **320** and filters signals communicated between the primary antenna **314** and the cross switches **310** and **320**. In an exemplary embodiment, the filter **312** is set so that the primary antenna **314** can transmit and receive signals in low, mid, and high bands. For example, in an exemplary embodiment, the low, mid, and high bands are those shown in **FIG. 2**.

[0025] Filter **330** is coupled to the diversity antenna module **114** and filters signals communicated between the secondary antenna **332** and the diversity antenna module **114**. In an exemplary embodiment, the filter **330** is set so that the secondary antenna **332** can transmit and receive signals in the low, mid, and high bands. Filter **334** is coupled to the diversity antenna module **114** and filters signals communicated between

- 6 -

the secondary antenna **336** and the diversity antenna module **114**. In an exemplary embodiment, the filter **334** is set so that the secondary antenna **336** can transmit and receive signals in an ultra high band. A WiFi modem **338** communicates using either of the secondary antennas **332** and **336**. In an exemplary embodiment, the modem **338** communicates signals to and from the filter **330** so that the secondary antenna **332** can transmit and receive signals in a 2.4 GHz WiFi band. In an exemplary embodiment, the modem **338** communicates signals to and from the filter **334** so that the secondary antenna **336** can transmit and receive signals in a 5 GHz WiFi band.

[0026] RF signals to be transmitted in the low band are amplified by power amplifier (PAL) **306** and passed to duplexer **308**. The duplexer **308** passes the signals to be transmitted to the low band cross switch **310** that routes the signals to the primary antenna **314** or through the diversity antenna module **114** to the secondary antenna **332** for transmission. Low band signals received from the primary antenna **314** or the secondary antenna **332** flow through either of the same paths in the reverse direction to the cross switch **310** and then are input to the duplexer **308** and passed back to transceiver **304** for processing.

[0027] RF signals to be transmitted in the mid band are amplified by PAM **316** and passed to duplexer **318**. The duplexer **318** passes the signals to the mid/high band cross switch **320** that routes the signals to the primary antenna **314** or the diversity antenna module **114**. The diversity antenna module **114** routes the mid band signals to the antenna **332** for transmission. Mid band signals received from the primary antenna **314** or the secondary antenna **332** flow back through the diversity antenna module **114** in the reverse direction to the cross switch **320** and then are input to the duplexer **318** where they are filtered and passed back to transceiver **304** for processing.

[0028] RF signals to be transmitted in the high band are amplified by PA<sub>H</sub> **322** and passed to duplexer **324**. The duplexer **324** passes the signals to the mid/high band cross switch **320** that routes the signals to the primary antenna **314** or the diversity antenna modules **114**. The diversity antenna module **114** routes the high band signals to the antenna **332** for transmission. High band signals received from the primary antenna **314** or the secondary antenna **332** flow back through the diversity antenna module **114** in the reverse direction to the cross switch **320** and then are input to the duplexer **324** and passed back to transceiver **304** for processing.

- 7 -

[0029] The front end **300** comprises a diversity receiver (DRx) **326** that receives a low band diversity signal ( $D_L$ ) from the cross switch **310** and selectively filters this signal to input selected low band diversity signals to the transceiver **304**. The diversity receiver (DRx) **326** also receives mid, high, and ultra high (M/H/UH) band diversity signals ( $D_M/D_H/D_{UH}$ ) from the cross switch **320** and selectively filters these signals to input selected mid, high, and ultra high band diversity signals to the transceiver **304**.

[0030] In an exemplary embodiment, the diversity antenna module **114** receives and selectively filters mid and high band signals from the antenna **332** to generate mid and high band diversity signals ( $D_{MB}/D_{HB}$ ) that are output from the module **114** and input to the DRx **326**. In an exemplary embodiment, the diversity antenna module **114** receives and selectively filters high band signals from the antenna **332** and ultra high band signals from the antenna **336** to generate high and ultra high band diversity signals ( $D_{HB}/D_{UHB}$ ) that are output from the module **114** and input to the DRx **326**. In an exemplary embodiment, the diversity antenna module **114** outputs all or selected diversity signals directly to the transceiver **304** using optional signal path **340** thereby bypassing the DRx **326**.

[0031] The DRx module **326** operates to filter and selectively switch the low, mid, high and ultra high band diversity signals received from the cross switches **310** and **320** to input selected low, mid, high and high band diversity signals to the transceiver **304**. The DRx module **326** also operates to selectively switch the mid ( $D_{MB}$ ), high ( $D_{HB}$ ) and ultra high ( $D_{UHB}$ ) signals received from the diversity antenna module **114** to input one or more of these signals directly into the transceiver **304** without additional filtering.

[0032] The diversity antenna module **114** is configured to efficiently filter and route diversity signals to the transceiver **304** through the DRx **326** with fewer components (e.g., fewer switches and filters) and with greater flexibility (e.g., more diversity signal combinations) than conventional circuits. For example, in an exemplary embodiment, the DRx module **326** can simultaneously input up to four diversity signals into the transceiver **304**.

#### Low Band Communications Using Primary Antenna

[0033] The front end **300** provides low band communication to transmit and receive signals in the low band. In an exemplary embodiment, the front end **300** includes the low band power amplifier ( $PA_L$ ) **306** that receives low band RF signals from the



- 8 -

transceiver **304**. The PA<sub>L</sub> **306** outputs amplified signals to a duplexer **308** that filters the signals and passes amplified signals in the low band to the low band cross switch **310**. The low band cross switch **310** outputs signals to the filter **312**, which provides filtering after which the low band signals are transmitted by the primary antenna **314**. Low band signals received by the primary antenna **314** are filtered by filter **312** and input to the low band cross switch **310**. The low band signals output from the low band cross switch **310** are input back to the duplexer **308** where they are filtered and passed back to the transceiver **304**.

#### Low Band Communications Using Secondary Antenna

[0034] The low band cross switch **310** also communicates with the diversity antenna module **114** to transmit and receive signals in the low band using the secondary antenna **332**. For example, low band signals output from the low band cross switch **310** are input to the diversity antenna module **114** which passes the low band signals to the filter **330**. The signals are filtered and then transmitted using the secondary antenna **332**. Low band signals received by the secondary antenna **332** are filtered by the filter **330** and input to the diversity antenna module **114**. The diversity antenna module **114** outputs low band signals to the cross switch **310**. From the cross switch **310** the low band signals received by the secondary antenna **332** are input to the duplexer **308** and flow back to the transceiver **304**.

#### Diversity Reception of Low Band Signals

[0035] The front end **300** performs diversity reception of low band signals using the cross switch **310**. For example, both the primary antenna **314** and the secondary antenna **332** receive low band signals that are routed to the low band cross switch **310**. The low band cross switch **310** selects one of its low band inputs to output as the low band diversity signal (DL) that is input to the DRx **326**. The DRx **326** filters and selects bands of the low band diversity signal to be input to the transceiver **304**.

#### Mid Band Communications Using Primary Antenna

[0036] The front end **300** provides mid band communication to transmit and receive signals in the mid band. In an exemplary embodiment, the front end **300** includes the mid band power amplifier PA<sub>M</sub> **316** that receives mid band RF signals from the transceiver **304**. The PA<sub>M</sub> **316** outputs amplified signals to a duplexer **318** that filters the signals and passes amplified signals in the mid band to a mid/high band cross switch

- 9 -

**320**. The cross switch **320** outputs signals in the mid band signals to the filter **312**, which provides mid band filtering after which the mid band signals are transmitted by the primary antenna **314**. Mid band signals received by the primary antenna **314** are filtered by filter **312** and input to the cross switch **320**. The mid band signals output from the cross switch **320** are input back to the duplexer **318** where they are filtered and passed back to the transceiver **304**.

#### Mid Band Communications Using Secondary Antenna

[0037] The mid band cross switch **320** also communicates with the diversity antenna module **114** to transmit and receive signals in the mid band using the secondary antenna **332**. For example, mid band signals output from the mid band cross switch **320** are passed to the diversity antenna module **114**, passed to the filter **330** and transmitted using the secondary antenna **332**. Mid band signals received by the secondary antenna **332** are filtered by the filter **330**, input to the diversity antenna module **114** and then passed to the mid band cross switch **320**. From the cross switch **320** the mid band signals received by the secondary antenna **332** are input to the duplexer **318** and flow back to the transceiver **304**.

#### Diversity Reception of Mid Band Signals

[0038] The front end **300** provides for diversity reception of mid band signals using the primary antenna **314** or the secondary antenna **332**. For example, diversity mid band signals received by the primary antenna **314** are filtered by filter **312** and input to the cross switch **320**. The diversity mid band signals ( $D_M$ ) output from the cross switch **320** are input to the DRx **326** where they are filtered and switched to generate selected diversity mid band signals that are input to the transceiver **304**.

[0039] In another embodiment, the secondary antenna **332** receives diversity mid band signals that are routed to the diversity antenna module **114**. The diversity antenna module **114** filters and selects one or more of the mid bands to generate the mid band diversity signals ( $D_{MB}$ ) that are input to the DRx **326**, which selectively inputs these signals to the transceiver **304** without additional filtering.

#### High Band Communications Using Primary Antenna

[0040] The front end **300** provides high band communication to transmit and receive signals in the high band. In an exemplary embodiment, the front end **300** includes the

- 10 -

high band power amplifier (PA<sub>H</sub>) **322** that receives high band RF signals from the transceiver **304**. The PA<sub>H</sub> **322** outputs amplified signals to a duplexer **324** that filters the signals and passes amplified signals in the high band to the cross switch **320**. The cross switch **320** outputs signals in the high band signals to the filter **312**, which provides filtering after which the high band signals are transmitted by the primary antenna **314**. High band signals received by the primary antenna **314** are filtered by filter **312** and input to the cross switch **320**. The high band signals output from the cross switch **320** are input back to the duplexer **324** where they are filtered and passed back to the transceiver **304**.

#### High Band Communications Using Secondary Antenna

[0041] The cross switch **320** also communicates with the diversity antenna module **114** to transmit and receive signals in the high band using the secondary antenna **332**. For example, high band signals output from the cross switch **320** are passed to the diversity antenna module **114**, passed to the filter **330** and transmitted using the secondary antenna **332**. High band signals received by the secondary antenna **332** are filtered by the filter **330**, input to the diversity antenna module **114** and then passed to the cross switch **320**. From the cross switch **320** the high band signals are input to the duplexer **324** and flow back to the transceiver **304**.

#### Diversity Reception of High Band Signals

[0042] The front end **300** provides for diversity reception of high band signals using the primary antenna **314** and the secondary antenna **332**. For example, high band signals received by the primary antenna **314** are filtered by filter **312** and input to the cross switch **320**. The high band signals output from the cross switch **320** are input to the DRx **326** as high band diversity signals (D<sub>H</sub>), where they are filtered and switched before being passed to the transceiver **304**.

[0043] In another embodiment, the secondary antenna **332** receives high band signals that are routed to the diversity antenna module **114**. The diversity antenna module **114** selects one or more bands of the high band diversity signals and outputs the selected high band diversity signals (D<sub>HB</sub>) to the DRx **326**. The DRx **326** selectively outputs the high band diversity signals to the transceiver **304** without additional filtering.

Diversity Reception of Ultra High Band Signals

[0044] The front end **300** provides for transmission and reception of ultra high band signals using the diversity antenna module **114** that works in conjunction with the secondary antenna **336**. For example, the secondary antenna **336** receives ultra high band signals that are routed to the diversity antenna module **114**. The diversity antenna module **114** selects one or more bands of the ultra high band diversity signals and outputs selected high band diversity signals ( $D_{UHB}$ ) to the DRx **326**. The DRx **326** outputs the ultra high band diversity signals to the transceiver **304** without additional filtering.

[0045] The following table provides band assignments, uplink frequencies, downlink frequencies and band groups for FDD LTE communication bands.

| band | uplink (MHz)  | downlink (MHz) | band group |
|------|---------------|----------------|------------|
| 5    | 824 - 849     | 869 - 894      | LOW        |
| 6    | 830 - 840     | 875 - 885      | LOW        |
| 8    | 880 - 915     | 925 - 960      | LOW        |
| 12   | 698 - 716     | 728 - 746      | LOW        |
| 13   | 777 - 787     | 746 - 756      | LOW        |
| 14   | 788 - 798     | 758 - 768      | LOW        |
| 17   | 704 - 716     | 734 - 746      | LOW        |
| 18   | 815 - 830     | 860 - 875      | LOW        |
| 19   | 830 - 845     | 875 - 890      | LOW        |
| 20   | 832 - 862     | 791 - 821      | LOW        |
| 26   | 814 - 849     | 859 - 894      | LOW        |
| 27   | 807 - 824     | 852 - 869      | LOW        |
| 28   | 703 - 748     | 758 - 803      | LOW        |
| 29   | n/a           | 717 - 728      | LOW        |
| 31   | 452.5 - 457.5 | 462.5 - 467.5  | LOW        |
| 1    | 1920 - 1980   | 2110 - 2170    | MID        |
| 2    | 1850 - 1910   | 1930 - 1990    | MID        |
| 3    | 1710 - 1785   | 1805 - 1880    | MID        |
| 4    | 1710 - 1755   | 2110 - 2155    | MID        |

- 12 -

|    |                 |                 |            |
|----|-----------------|-----------------|------------|
| 9  | 1749.9 - 1784.9 | 1844.9 - 1879.9 | MID        |
| 10 | 1710 - 1770     | 2110 - 2170     | MID        |
| 11 | 1427.9 - 1452.9 | 1475.9 - 1500.9 | MID        |
| 15 | 1900 - 1920     | 2600 - 2620     | MID        |
| 21 | 1447.9 - 1462.9 | 1495.5 - 1510.9 | MID        |
| 23 | 2000 - 2020     | 2180 - 2200     | MID        |
| 24 | 1625.5 - 1660.5 | 1525 - 1559     | MID        |
| 25 | 1850 - 1915     | 1930 - 1995     | MID        |
| 7  | 2500 - 2570     | 2620 - 2690     | HIGH       |
| 16 | 2010 - 2025     | 2585 - 2600     | MID/HIGH   |
| 30 | 2305 - 2315     | 2350 - 2360     | HIGH       |
| 22 | 3410 - 3500     | 3510 - 3600     | ULTRA HIGH |

[0046] The following table provides band assignments, frequency allocations, band widths, and band groups for TDD LTE communication bands.

| band | allocation (MHz) | width (MHz) | band group |
|------|------------------|-------------|------------|
| 44   | 703 - 803        | 100         | LOW        |
| 33   | 1900 - 1920      | 20          | MID        |
| 34   | 2010 - 2025      | 15          | MID        |
| 35   | 1850 - 1910      | 60          | MID        |
| 36   | 1930 - 1990      | 60          | MID        |
| 37   | 1910 - 1930      | 20          | MID        |
| 39   | 1880 - 1920      | 40          | MID        |
| 38   | 2570 - 2620      | 50          | HIGH       |
| 40   | 2300 - 2400      | 100         | HIGH       |
| 41   | 2496 - 2690      | 194         | HIGH       |
| 42   | 3400 - 3600      | 200         | ULTRA HIGH |
| 43   | 3600 - 3800      | 200         | ULTRA HIGH |

[0047] FIG. 4 shows a detailed exemplary embodiment of the DRx 326 shown in FIG. 3. The DRx 326 communicates diversity signals to the transceiver 304. For example, the diversity signals comprise a low band output (LBO) signal at input terminal 404,

- 13 -

low/mid band output (LMBO) signal at input terminal **406**, mid band output (MBO) signal at input terminal **408**, first high band output (HBO1) signal at input terminal **410**, second high band output (HBO2) at input terminal **412**, first ultra high band output (UHBO1) at input terminal **414**, and second ultra high band output (UHBO2) signal at input terminal **416**, which are communicated between the DRx **326** and the transceiver **304**.

[0048] In an exemplary embodiment, the DRx **326** receives low band input **432**, mid/high/ultra high band input **436**, high/ultra high band input **438** and mid/high band input **440** as shown. In an exemplary embodiment, the received signals flow to a switch group **452** that includes switch **442**, switch **444** and switch **446**. The switch group **452** switches the received signals to selected switch outputs, which either pass the switched signals to band pass filters or pass the switched signals directly to the DRx **326**.

[0049] The switch **442** comprises a single pole nine throw switch that includes a single input that receives the low band input signal **432** and selectively connects this signal to one of nine output terminals. A first output terminal of the switch **442** is directly connected to the LBO at terminal **404**. A second output terminal of the switch **442** is connected to a separate switch of a multiplexing LNA **418** and the output of that switch is connected to the LMBO at terminal **406**.

[0050] The third through eighth output terminals of the switch **452** are connected to signal paths that include filters, shown generally at **454**. The filters operate to filter the low band input signal **432** to pass selected low bands to the multiplexing LNA **418**. For example, the filter **456** filters the low band input signal **432** to pass band 27 “B27” to the multiplexing LNA **418**. Thus, the filters **454** filter the low band input signal at terminal **432** to pass bands B12/B13, B26, B20, B8, B27, and B28 to the multiplexing LNA **418**. The ninth output terminal of the switch **442** is connected to the signal ground through impedance “Z.”

[0051] The switch **444** comprises a double pole seven throw switch that includes a first input terminal that receives the mid/high/ultra high band input signal **436** and a second input terminal that is connected to an output terminal of the switch **446**. The first and second input terminals of the switch **444** can be connected to any of the output terminals but not the same output terminal.

- 14 -

[0052] The first two output terminals of the switch **444** are connected to filters shown generally at **458**. The filters **458** operate to filter the signals output from the first two output terminals of the switch **444** to pass selected mid and high bands to the multiplexing LNA **418**. Thus, the filters **458** filter the signals output from the first two output terminals of the switch **444** to pass mid bands B1, B3+DGSM, B25+PGSM, and B4 and high bands B7 and B30 to the multiplexing LNA **418**.

[0053] The switch **444** includes a third output terminal that is unused and a seventh output terminal that is connected to a signal ground through impedance “Z.” The third, fourth, and fifth output terminals of the switch **444** are connected directly to the output terminals of the DRx **326**. For example, the fourth output terminal is directly connected to the LMBO terminal **406** to pass a mid band (MB-B) signal directly to the transceiver **304**. The fifth output terminal is directly connected to the HBO2 terminal **412** to pass a high band (HB-B) signal directly to the transceiver **304**. The sixth output terminal is directly connected to the UHBO2 terminal **416** to pass an ultra high band signal (UHB-B) directly to the transceiver **304**.

[0054] The switch **446** comprises a double pole five throw switch that includes two input terminals that receive high/ultra high band input signal **438** and the mid/high band input signal **440**. The switch **446** selectively connects the input signals **438** and **440** at its input terminals to any of five output terminals to pass selected signals directly to selected output terminals of the DRx **326**. For example, a first output terminal of the switch **446** is connected to the second input terminal of the switch **444**. Thus, the switch **444** can receive the HUHB signal at terminal **438** or the MHB signal at terminal **440** as an input to the switch **444**. The second output terminal of the switch **446** is directly connected to the MBO terminal **408** to pass a mid band (MB-A) signal directly to the transceiver **304**. The third output terminal of the switch **446** is directly connected to the HBO2 terminal **412** to pass a high band (HB-A) signal directly to the transceiver **304**. The fourth output terminal of the switch **446** is directly connected to the UHBO1 terminal **414** to pass an ultra high band (UHB-A) signal directly to the transceiver **304**. The sixth output terminal of the switch **446** is connected to the signal ground through impedance “Z.”

[0055] In an exemplary embodiment, a mobile industry processor interface (MIPI) **448** operates to control the operation of the switches **442**, **444** and **446** of the switch group

- 15 -

**452.** For example, the MIPI **448** controls the operation of the switches **442**, **444** and **446** to connect their input terminals to selected output terminals based on received command and control information from another entity at the device, such as the baseband processor **302**.

[**0056**] The multiplexing LNA **418** includes amplifiers (A1-A13). Selected amplifiers of the multiplexing LNA **418** have their outputs connected together to generate a combined signal. For example, the outputs of a first group of amplifiers (A1-A4) have their outputs connected together to provide a signal comprising a selected low band at node **420**, which is connected to the LBO terminal **404**. A second group of amplifiers (A1-A10) have their outputs connected together to provide a signal comprising a selected low or mid band at node **422**, which is connected to the LMBO terminal **406**. A third group of amplifiers (A5-A10) have their outputs connected together to provide a signal comprising a selected mid band at node **424**, which is connected to the MBO terminal **408**. A fourth group of amplifiers (A12-A13) have their outputs connected together to provide a signal comprising a selected high band at node **426**, which is connected to the HBO1 terminal **410**. A fifth group of amplifiers (A12-A13) have their outputs connected together to provide a signal comprising a selected high band at node **428**, which is connected to the HBO2 terminal **412**.

[**0057**] Enabling and disabling the amplifiers (A1-A13) controls which of the input signal bands are amplified and passed to the output nodes. In an exemplary embodiment, MIPI **430** operates to enable and disable the amplifiers (A1-A13) to control the operation of the multiplexing LNA **418** to amplify and pass selected signal bands to the output terminals **404**, **406**, **408**, **410**, and **412**. Accordingly, the DRx **326** receives diversity signals obtained from one or more of the primary and secondary antennas, filters selected signals to pass selected bands, amplifies the selected bands and inputs the amplified bands to the transceiver **304**. In an exemplary embodiment, selected diversity signals received by the DRx **326** are input directly to the transceiver **304** after flowing through one or more of the switches in the switch group **452**. For example, the signals MB-A, MB-B, HB-A, HB-B, UHB-A, and UHB-B flow from the switches **444** and **446** directly to the transceiver **304** without additional filtering or amplification.



- 16 -

[0058] FIG. 5 shows a detailed exemplary embodiment of the diversity antenna module 114 shown in FIG. 3. In an exemplary embodiment, the diversity antenna module 114 receives signals from the secondary antennas and outputs selected received signals for input to the transceiver 304 as diversity signals. For example, the module 114 receives a low band input from antenna 332 at terminal 502, mid/high band input from antenna 332 at terminal 504, mid/low band input from antenna 332 at terminal 506, and ultra high band input from antenna 336 at terminal 508.

[0059] The low band input signal at terminal 502 is input to an input terminal of switch 520 of low band module 530. The switch 520 connects its input terminal to one of six output terminals to pass the low band signal to associated signal paths. A filter bank 560 filters the outputs of the switch 520 to pass selected low band signals to switches 522 and 524. For example, in an exemplary embodiment, the filter bank 560 filters the low band input signal to pass signal bands B12/B13, B26, B20, B8, B29, B27, and B28Full to the switches 522 and 524.

[0060] The outputs of the filters flow to corresponding input terminals of switches 522 and 524. The switch 522 connects one of its input terminals to an output terminal to pass a selected band of the low band signal as a first low band input (LB1) to a multiplexing LNA 532. The switch 524 also receives various bands of the low band signal at its input terminals and connects one of its input terminals to one output terminal to pass a selected low band signal to the multiplexing LNA 532 as a second low band input (LB2).

[0061] A switch 526 has an input terminal that is connected to the terminal 558 to send and receive low band signals with the cross switch 310. For example, when receiving a low band transmit signal from the cross switch 310, the switch 526 connects its input terminal to a first output terminal to pass the low band transmit signal to the fifth terminal of the switch 520. The switch 520 is controlled to connect the fifth terminal to its input terminal to pass the low band transmit signal to the terminal 502 and thus to the antenna 332 for transmission. When receiving a low band signal from the antenna 332, the switch 526 connects its input terminal to a second output terminal to receive a low band signal output from the node 544 of the multiplexing LNA 532. This signal then flows to the terminal 558 and thereafter to the cross switch 310.

[0062] A switch group **510** includes switch **512** and switch **514**. The switch **512** receives, at an input terminal, the mid/high band signal at terminal **504** and selectively connects this input terminal to one of 10 output terminals. The output terminals of the switch **512** are connected to signal paths that include filters, shown generally at **518**. The filters operate to filter the MHB input signal at terminal **504** to pass selected bands to the multiplexing LNA **532**. For example, the filters **518** filter the mid/high band input signal to pass mid bands B1, B3, B4, B25, B34 and B39 to the multiplexing LNA **532**. The filters **518** also filter the mid/high band input signal to pass high bands B7, B30, B40A, and B41b/B38 to the multiplexing LNA **532**.

[0063] During a transmission mode, a first terminal of a switch **548** is connected to a first terminal of the switch **512** to pass a mid/high band Tx bypass signal that can be selectively connected to a terminal of the switch **512** to pass the mid/high Tx bypass signal to the antenna **332**. A second terminal of the switch **548** is connected to a first switch section of the switches **568** to pass a mid band Tx bypass signal, which flows through the filters **566** and into a fourth terminal of the switch **512**. A fifth terminal of the switch **548** is connected to a second switch portion of the switches **568** to pass a high band Tx signal, which flows through the filters **566** and into the fourth terminal of the switch **512**. A seventh terminal of the switch **548** is connected to a second terminal of switch **514** to pass an ultra high band Tx bypass signal to the switch **514**.

[0064] The switch **514** communicates the ultra high band signal **508** between the module **114** and the secondary antenna **336**. When receiving the ultra high band signal at terminal **508** from the secondary antenna **336**, the switch **514** connects its input terminal to a first output terminal to pass the ultra high band signal to a filter that filters this signal to output an ultra high band “B42” that is input to the multiplexing LNA **532**. When transmitting the ultra high band signal, the switch **514** connects its input terminal to a second output terminal to receive an ultra high band transmit signal that is passed to the secondary antenna **336**. A MIPI **516** controls the operation of the switches **512**, **570**, and **514** of the switch group **510**, and the operation of the switches **568**.

[0065] The switch **570** has an input terminal connected to receive a mid/low band signal at terminal **506**. The switch **570** has first and second terminals that can be selectively connected to the input terminal to pass the mid/low band signal to filters **518** that filter

- 18 -

this signal to output mid band signal bands (B11+B21) and B32 to the multiplexing LNA **532**.

[0066] The multiplexing LNA **532** includes amplifiers (D1-D17). Selected amplifiers of the multiplexing LNA **532** have their outputs connected together to generate a signal comprising a selected band. For example, the outputs of a first group of amplifiers (D1-D4, D7-D11 and D13) have their outputs connected together to provide a signal comprising a selected low/mid band output (LMBO) signal at node **546**. A second group of amplifiers (D1-D2) have their outputs connected together to provide a selected low band (LBO) signal at node **544**. A third group of amplifiers (D3-D8) have their outputs connected together to provide a selected first mid/high band (MHBO1) signal at node **542**. A fourth group of amplifiers (D3-D13) have their outputs connected together to provide a selected second mid/high band (MHBO2) signal at node **540**. A fifth group of amplifiers (D5, D6, D12, D14, D15, and D17) have their outputs connected together to provide a selected first high/ultra high band (HUHBO1) signal at node **538**. A sixth group of amplifiers (D5, D6, D12, D14, D15, and D17) have their outputs connected together to provide a selected second high/ultra high band (HUHBO2) signal at node **536**.

[0067] Enabling and disabling the amplifiers (D1-D17) controls which of the input band signals are amplified and passed to the output nodes. In an exemplary embodiment, MIPI **534** operates to enable and disable the amplifiers (D1-D17) to control the operation of the multiplexing LNA **532** to output selected signal bands. Accordingly, the diversity antenna module **114** receives diversity signals obtained from one or more of the secondary antennas (**332**, **336**) and filters these signals to pass selected bands, which are amplified and output to the cross switch **310** (e.g., LB-out-CS), the cross switch **320**, or directly to the DRx **326** for input to the transceiver **304**.

[0068] FIG. 6 shows antenna configurations for use with the front end **300** shown in FIG. 3 and more specifically with the diversity module **114** shown in FIG. 5. The primary antenna **314** communicates receive and transmit signals with the filter **312**. The filter **312** includes a first stage **602** that filters low band transmit and receive signals. For example, the first stage **602** communicates low band signals between the antenna **314** and the cross switch **310** using the signal path **618**. The filter **312** includes a second stage **604** that filters mid and high band transmit and receive signals. For example, the

- 19 -

second stage **604** communicates mid and high band signals between the antenna **314** and the cross switch **320** using the signal path.

[0069] The secondary antenna **332** communicates receive and transmit signals with the filter **330**. The filter **330** includes a first stage **606** that filters low band transmit and receive signals. For example, the first stage **606** communicates low band signals between the antenna **332** and the diversity antenna module **114** using the signal path **622** that connects to the terminal **502**. The filter **330** includes a second stage **608** that filters mid band transmit and receive signals. For example, the second stage **608** communicates mid band signals between the antenna **332** and the diversity antenna module **114** using signal path **624** that connects to the terminal **504**. The filter **330** includes a third stage **610** that filters high band transmit and receive signals. For example, the third stage **610** communicates high band signals between the antenna **332** and the diversity antenna module **114** using signal path **626** that connects to the terminal **506**. The filter **330** includes a fourth stage **612** that filters WiFi transmit and receive signals. For example, the fourth stage **612** communicates 2.4 GHz WiFi signals between the antenna **332** and the WiFi modem **338** using signal path **628**.

[0070] The secondary antenna **336** communicates receive and transmit signals with the filter **334**. The filter **334** includes a first stage **614** that filters WiFi transmit and receive signals. For example, the first stage **614** communicates 5 GHz WiFi signals between the antenna **336** and the WiFi modem **338** using the signal path **630**. The filter **334** includes a second stage **616** that filters ultra high band transmit and receive signals. For example, the second stage **616** communicates ultra high band signals between the antenna **336** and the diversity antenna module **114** using the signal path **632** that connects to the terminal **508**.

[0071] **FIG. 7** shows a diagram that illustrates diversity receive signal paths of the front end **300**. In an exemplary embodiment, the diversity antenna module **114** processes secondary antenna signals to output mid, high and ultra high band diversity signals that are input directly to the transceiver **304**. For example, the mid, high, and ultra high signals flow to the transceiver **304** through closed switches of the switch group **452** of the DRx **326**.

[0072] Low band signals received by the primary antenna **314** flow along path **618** to a band selector **702** of the cross switch **310**. Low band signals received by the secondary

- 20 -

antenna **332** flow through the low band circuit **530** and are output (LB-out) to the band selector **702** that outputs selected low bands (LB-in) that are received at terminal **432** of the DRx **326**. The band selector **702** of the cross switch **310** selects from the low bands it receives and outputs low band diversity signals (LB-in) to the DRx **326**.

[0073] Mid and high band signals received by the primary antenna **314** flow along path **620** to a band selector **704** of the cross switch **320**. Mid, high and ultra high band signals received by the secondary antennas **332** and **336** flow through the multiplexing LNA **532** along path **706** to the band selector **704** of the cross switch **320**. The band selector **704** outputs selected mid, high, and ultra high band diversity signals (MHUHB-in) that are received at terminal **436** of the DRx **326**.

[0074] The diversity receiver **326** includes the switch group **452**, band selection filters **454** and **458** and the multiplexing LNA **418**. The switch group **452** outputs selected received signals to the band selection filters **454** and **458** that filter the signals to select bands for input to the multiplexing LNA **418**. The multiplexing LNA **418** combines and amplifies the signal bands to generate the signals LBO, LMBO, MBO, HBO1, and HBO2 signals that are input the transceiver **304**.

[0075] Mid and high band signals received by the secondary antenna **332** flow to the switch group **510** of the diversity antenna module **114**. Ultra-high band signals received by the secondary antenna **336** also flow to the switch group **510** of the diversity antenna module **114**. The switch group **510** outputs selected mid, high, and ultra-high band signals to the filters **518**, which filter selected bands from the received signals and inputs these bands into the multiplexing LNA **532**. The multiplexing LNA **532** combines selected signal bands it receives and outputs the mid/high/ultra high band signals (MHUHB-out) at terminal **556** along path **706** ( $D_M/D_H/D_{UH}$ ) to the cross switch **320**. The selector **704** of the cross switch **320** outputs selected mid/high/ultra high bands from the signals it receives and outputs the MHUHB-in signal to the DRx **326**, which is received at the terminal **436**.

[0076] The multiplexing LNA **532** also outputs a high/ultra high band diversity signal (HUHB-out) at terminal **564**, and a mid/high band diversity signals (MHB-out) at terminal **554**. These signals are received by the DRx **326** at terminals **438** and **440**, respectively. These signals are input to the switch group **452** of the DRx **326**, which selects one or more of these signals to be input directly into the transceiver **304**. Thus,

- 21 -

these signals are input to the transceiver **304** without any additional filtering, such as that provided by the selection filters **454** and **458**.

[0077] In an exemplary embodiment, the diversity antenna module **114** provides greater flexibility and the ability to process a greater number of diversity signal combinations when compared to conventional systems. For example, in an exemplary embodiment, the diversity antenna module **114** is configured to provide a transmit signal path to transmit a high band TDD signal using the diversity antennas **332**. For example, a HB Tx signals flows through the switch **556** and onto the HB TX Bypass signal path to the switch **568**, which is configured to enable the high band Tx signal to flow to the duplexer **566**. The duplexer **566** is connected to the fourth terminal of the switch **512**, which is configured by the MIPI **516** to be connected to the input/output terminal of the switch **504**, thereby inputting the high band Tx signal to the filter **330** for transmission by the secondary antenna **332**.

[0078] Simultaneously with the transmission of the high band signal, the secondary antenna **332** receives FDD mid band and low band signals that are input to the diversity antenna module **114**. For example, low band signals are input to the terminal **502** and mid band signals are input to the terminals **504** and **506**. The received low band diversity signals are routed from terminal **502** through module **530**, such that selected low band signals are output from terminal **558**. The mid band diversity signals received at terminal **504** are routed back through the duplexer **566** and input to the band selection filters **518**. For example, the output of the duplexer **566** is input to the switch **568**, which is configured to output the received diversity signals to selected band selection filters. The mid band diversity signals received at terminal **506** are input to the switch **570**, which is configured to pass the received diversity signals to the band selection filters **518**.

[0079] The band selection filters **518** filter the receive diversity signals to generate mid band signals that are input to the multiplexing LNA **532**. For example, the mid band signals may include signal bands (B1, B3, B4, B25, B11+B21, and B32). The multiplexing LNA **532** amplifies selected mid band signals by enabling selected ones of the amplifiers (D1-D17) and outputs amplified mid band signals at port **540** that is connected to terminal **554**. The terminal **554** is connected to input ports **440** of the DRx **326**. The amplified mid band signals received at input ports **440** of the DRx **326** are

- 22 -

routed by the switch **446** to the transceiver **304**. Also, the low band diversity signals are received by the DRx **326** at terminal **432** and routed to the transceiver **304**. Thus, in this example, the diversity antenna module **114** is configured to establish a transmit signal path to transmit one high band TDD signal. The diversity antenna module **114** is also configured to receive three downlink FDD diversity signals (e.g., one low band and two mid band signals). The three downlink diversity signals are input to the transceiver **304** using the switching functions of the DRx **326**. It should be noted that the DRx **326** provides no additional filtering of the mid band signals it receives and therefore these signals are input to the transceiver **304** as received from the diversity antenna module **114** without additional filtering. It should also be noted that in an exemplary embodiment, the mid band signals output from the diversity antenna module **114** can be input directly to the transceiver **304** using the optional signal path **340** shown in **FIG. 3** and in **FIG. 7**.

[0080] In another exemplary embodiment, the diversity antenna module **114** is configured to provide a transmit signal path to transmit a mid band FDD signal using the diversity antennas **332**. For example, a mid band Tx signal flows through the switch **556** and onto the MB TX Bypass signal path to the switch **568**, which is configured to enable the mid band Tx signal to flow to the duplexer **566**. The duplexer **566** is connected to the fourth terminal of the switch **512**, which is configured by the MIPI **516** to be connected to the input/output terminal of the switch **504**, thereby inputting the mid band Tx signal to the filter **330** for transmission by the secondary antenna **332**.

[0081] Simultaneously with the transmission of the FDD mid band signal, the secondary antenna **332** receives two TDD high band signals and FDD low and mid band signals that are input to the diversity antenna module **114**. For example, low band signals are input to the terminal **502** and the high and mid band signals are input to the terminals **504** and **506**. The received low band diversity signals are routed from terminal **502** through module **530**, such that selected low band signals are output from terminal **558**. The mid and high band diversity signals received at terminal **504** are routed back through the duplexer **566** and input to the band selection filters **518**. For example, the output of the duplexer **566** is input to the switch **568**, which is configured to output the received diversity signals to selected band selection filters. The mid band diversity signals received at terminal **506** are input to the switch **570**, which is configured to pass the received diversity signals to the band selection filters **518**.

- 23 -

[0082] The band selection filters **518** filter the receive diversity signals to generate high mid band signals that are input to the multiplexing LNA **532**. For example, the mid band signals may include signal bands (B1, B3, B4, B25, B11+B21, and B32) and the high band signals may include (B7, B30). The multiplexing LNA **532** amplifies selected high and mid band signals by enabling selected ones of the amplifiers (D1-D17) and outputs amplified high and mid band signals at ports **540** and port **538** that are connected to terminals **554** and **564**. The terminal **554** is connected to input ports **440** of the DRx **326** and the terminal **564** is connected to terminal **438** of the DRx **326**. The amplified mid band signals received at input ports **440** of the DRx **326** are routed by the switch **446** to the transceiver **304**. The amplified high band signals received at input port **438** also are routed by switch **446** to the transceiver **304**. In addition, the low band diversity signals are received by the DRx **326** at terminal **432** and routed to the transceiver **304**. Thus, in this example, the diversity antenna module **114** is configured to establish a transmit signal path to transmit one mid band FDD signal. The diversity antenna module **114** is also configured to receive four downlink FDD diversity signals (e.g., one low band, two high band (intra CA), and one mid band signal). The four downlink diversity signals are input to the transceiver **304** using the switching functions of the DRx **326**. It should be noted that the DRx **326** provides no additional filtering of the high and mid band signals it receives and therefore these signals are input to the transceiver **304** as received from the diversity antenna module **114** without additional filtering. It should also be noted that in an exemplary embodiment, the high and mid band signals output from the diversity antenna module **114** can be input directly to the transceiver **304** using the optional signal path **340** shown in FIG. 3 and in FIG. 7.

[0083] Therefore, low band diversity signals received by the diversity antenna **332** can be input to the DRx **326** at terminal **432** and selectively input to the transceiver **304**. In addition to receiving the low band diversity signals, the diversity antenna module **114** simultaneously receives mid, high, and ultra high band diversity signals from the antennas **332** and **336**. The multiplexing LNA **532** of the diversity antenna module **114** then outputs (at terminal **556**) selected mid, high, and ultra high band signal to the cross switch **320** and outputs (at terminals **564**, **554**) selected mid, high, and ultra high signal bands to the DRx **326**. The DRx **326** can select from the signal bands received at the terminals **432**, **436**, **438**, and **440** to determine the low, mid, high, and ultra high band diversity signals to input to the transceiver **304**.



- 24 -

[0084] Additionally, in an exemplary embodiment, mid, high, and ultra high signal bands output from the multiplexing LNA 532 are input directly to the DRx 326 and received at the switch group 452. The switch group 452 selects from these received signals to determine which will be input directly to the transceiver 304 without additional filtering. Thus, it is possible that the transceiver 304 simultaneously receives up to four diversity signals. For example, the transceiver 304 can receive a low band diversity signal from the primary antenna 314 and three additional diversity signals from the secondary antennas 332 and 336. For example, the three additional diversity signals can be selected from the mid, high and ultra high bands. Thus, the band group combinations of diversity signals that can be simultaneously received by the transceiver 304 include (L/M/M/H, L/M/H/H, L/M/H/UH, L/L/M/H, L/L/M/UH, M/M/H/H, and M/M/UH/UH). It should also be noted that other band group combinations are possible and can be determined from the switch selections of the various modules and switches illustrated in the drawings.

[0085] Accordingly, the diversity antenna module 114 processes diversity signals received from the secondary antennas (332 and 336) and provides selected diversity signals directly to the diversity receiver 326 and/or to the cross switches 310, 320. The diversity signals provided to the DRx 326 are input directly to the transceiver 304 without additional amplification and/or filtering. In an exemplary embodiment, the signals flow through closed switches of the switch group 452 but additional filtering is avoided. In an exemplary embodiment, the optional signal path 340 can be used to input diversity signals directly to the transceiver 304. The various embodiments provide greater flexible and diversity signal reception combinations while reducing parts, space and costs over conventional front ends.

[0086] FIG. 8 shows an exemplary embodiment of diversity receiver apparatus 800. In an exemplary embodiment, the apparatus 800 is suitable for use as the diversity receiver module 114 shown in FIG. 5.

[0087] The apparatus 800 includes a first means (802) for switching configured to establish a transmit signal path to transmit an uplink signal from at least one diversity antenna and configured to establish a receive signal path to receive downlink diversity signals from the at least one diversity antenna, which in an exemplary embodiment comprises the switch group 510. The apparatus 800 also comprises a second means

- 25 -

(804) for band selection configured to filter the downlink diversity signals to generate at least three diversity band signals, which in an exemplary embodiment comprises the filters 518. The apparatus 800 also comprises a third means (806) for amplifying configured to amplify the diversity band signals to generate at least three amplified diversity band signals that are output to a transceiver, which in an exemplary embodiment comprises the multiplexing LNA 532.

[0088] The exemplary embodiments 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 exemplary embodiments 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.

[0089] An apparatus implementing an exemplary embodiment 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.

[0090] 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 but the disclosure is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

**CLAIMS:**

1. An apparatus comprising:  
at least one switch configured to establish a transmit signal path to transmit an uplink signal from at least one diversity antenna and to establish a receive signal path to receive downlink diversity signals from the at least one diversity antenna;  
band selection filters configured to filter the downlink diversity signals to generate at least three diversity band signals; and  
a multiplexing amplifier configured to amplify the diversity band signals to generate at least three amplified diversity band signals that are output to a transceiver.
2. The apparatus of Claim 1, the transmit signal path configured to transmit an uplink time division duplex (TDD) signal and the band selection filters configured to filter the received downlink diversity signals to generate at least three downlink frequency division duplex (FDD) diversity band signals.
3. The apparatus of Claim 2, the uplink TDD signal resides in a high band group and the at least three downlink FDD diversity band signals reside in at least one of low and mid band groups.
4. The apparatus of Claim 3, the multiplexing amplifier amplifies the at least three downlink FDD diversity band signals to generate amplified versions of the at least three downlink FDD diversity band signals, the amplified versions of the at least three downlink FDD diversity band signals that are in the mid band group are output to the transceiver.
5. The apparatus of Claim 1, the transmit signal path configured to transmit an uplink FDD signal and the band selection filters configured to filter the received diversity signals to generate four downlink diversity band signals.
6. The apparatus of Claim 5, the uplink FDD signal resides in the mid band group, first and second downlink diversity band signals comprise TDD signals that reside in the high band, and third and fourth downlink diversity band signals comprise FDD signals that reside in at least one of the low and mid bands.
7. The apparatus of Claim 6, the multiplexing amplifier amplifies the four downlink diversity band signals to generate amplified versions of the four downlink

- 27 -

diversity band signals, the amplified versions of the four downlink diversity band signals that are in the high band and the mid band are output to the transceiver.

8. The apparatus of Claim 1, the multiplexing amplifier comprising a plurality of amplifiers that receive the diversity band signals and selectively amplify the diversity band signals to generate the amplified diversity band signals, each amplifier has an output that is connected to an output port of the multiplexing amplifier based on a frequency band of the amplified diversity band signal output from that amplifier.

9. The apparatus of Claim 8, the output ports comprising a first output port to output amplified diversity band signals that are in mid and high bands, a second output port to output a second portion of the amplified diversity band signals that are in mid and high bands, a third output port to output a third portion of the amplified diversity band signals that are in high and ultra high bands, and a fourth output port to output a fourth portion of the amplified diversity band signals that are in high and ultra high bands.

10. The apparatus of Claim 9, at least one of the first, second, third, and fourth output ports are directly connected to the transceiver.

11. The apparatus of Claim 9, at least one of the first, second, third, and fourth output ports are connected to at least one intermediate component that outputs selected amplified diversity band signals to the transceiver.

12. The apparatus of Claim 1, further comprising a first controller configured to control the at least one switch to selectively output the received diversity signals to one or more of the band selection filters.

13. The apparatus of Claim 8, further comprising a controller configured to control the multiplexing amplifier to output selected amplified diversity band signals from the first, second, third, and fourth output ports.

14. The apparatus of Claim 1, the apparatus configured in a front end of a wireless device to route the amplifier diversity band signals to the transceiver.

- 28 -

15. An apparatus comprising:

means for switching configured to establish a transmit signal path to transmit an uplink signal from at least one diversity antenna and configured to establish a receive signal path to receive downlink diversity signals from the at least one diversity antenna;

means for band selection configured to filter the downlink diversity signals to generate at least three diversity band signals; and

means for amplifying configured to amplify the diversity band signals to generate at least three amplified diversity band signals that are output to a transceiver.

16. The apparatus of Claim 15, the transmit signal path configured to transmit an uplink time division duplex (TDD) signal from the at least one diversity antenna and the means for band selection configured to filter the downlink diversity signals to generate at least three downlink frequency division duplex (FDD) diversity band signals that are input to the means for amplifying.

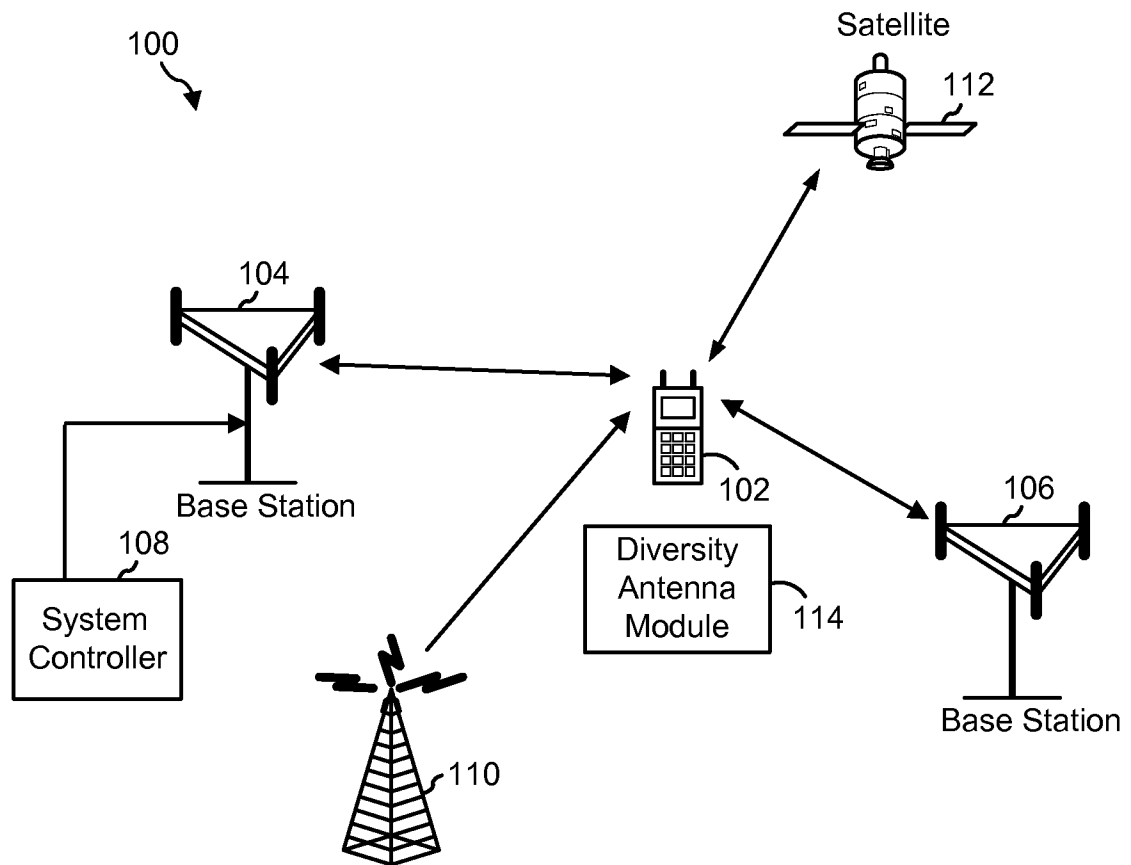
17. The apparatus of Claim 16, the uplink TDD signal resides in a high band group and the at least three downlink FDD diversity band signals reside in at least one of low and mid band groups.

18. The apparatus of Claim 17, the means for amplifying amplifies the at least three downlink FDD diversity band signals to generate amplified versions of the at least three downlink FDD diversity band signals, the amplified diversity band signals in the mid band group are output to the transceiver.

19. The apparatus of Claim 15, the transmit signal path configured to transmit a mid band uplink FDD signal to the at least one diversity antenna and the means for band selection configured to filter the downlink diversity signals to generate first and second downlink diversity band signals comprising TDD signals that reside in a high band, and third and fourth downlink diversity band signals comprising FDD signals that reside in at least one of low and mid bands.

20. The apparatus of Claim 19, the means for amplifying amplifies the four downlink diversity band signals to generate amplified versions of the four downlink diversity band signals, the amplified versions of the four downlink diversity band signals that are in the high band and the mid band are output to the transceiver.

1/8

**FIG. 1**

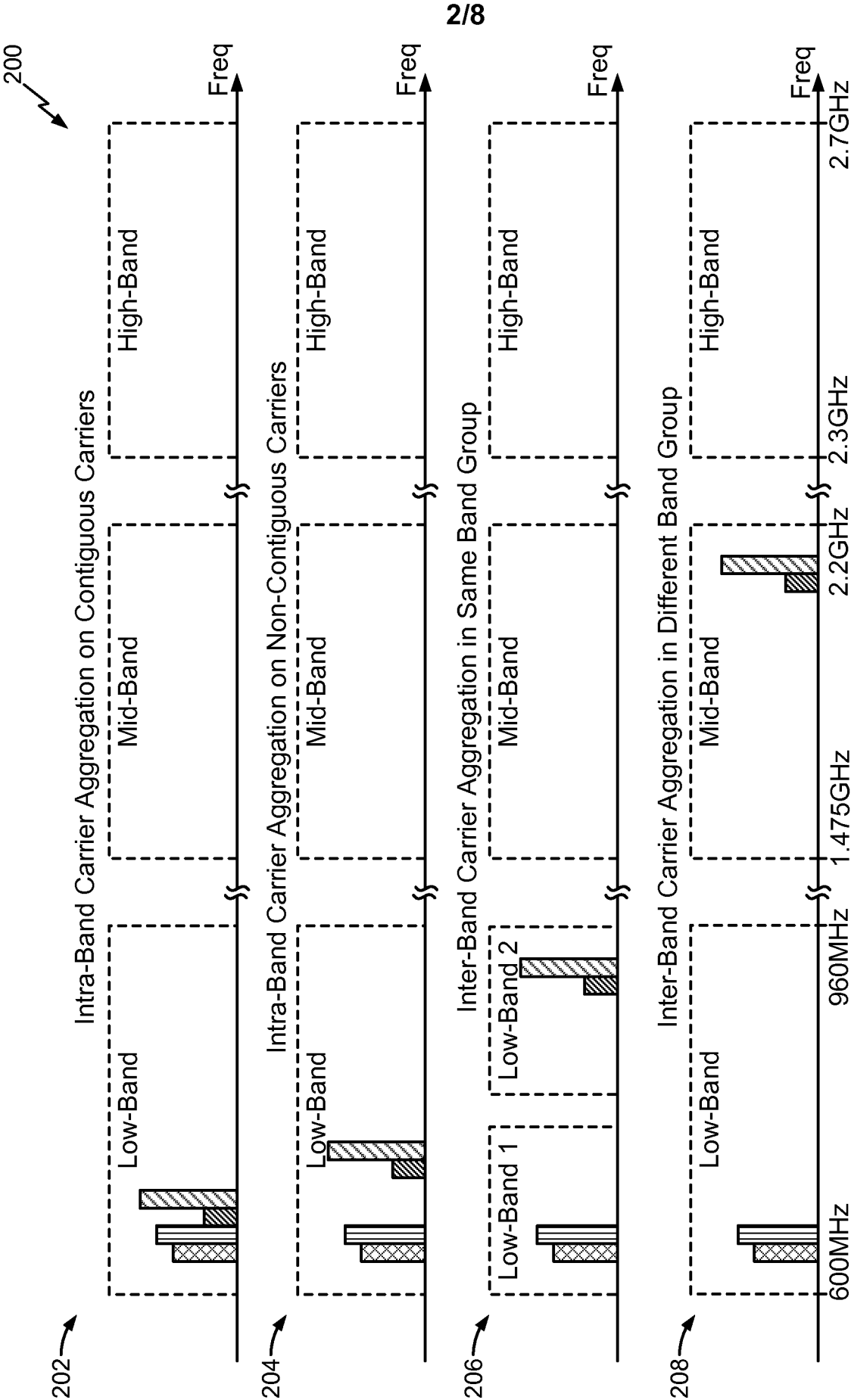


FIG. 2

3/8

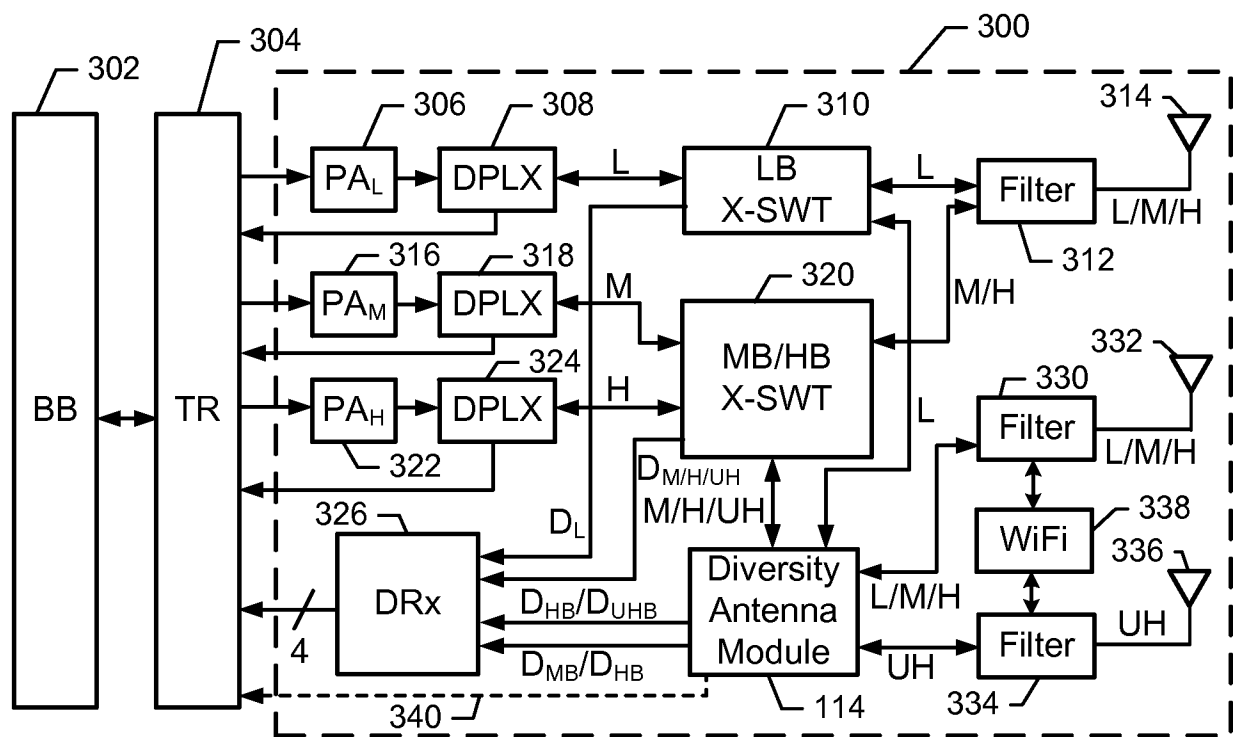


FIG. 3



4/8

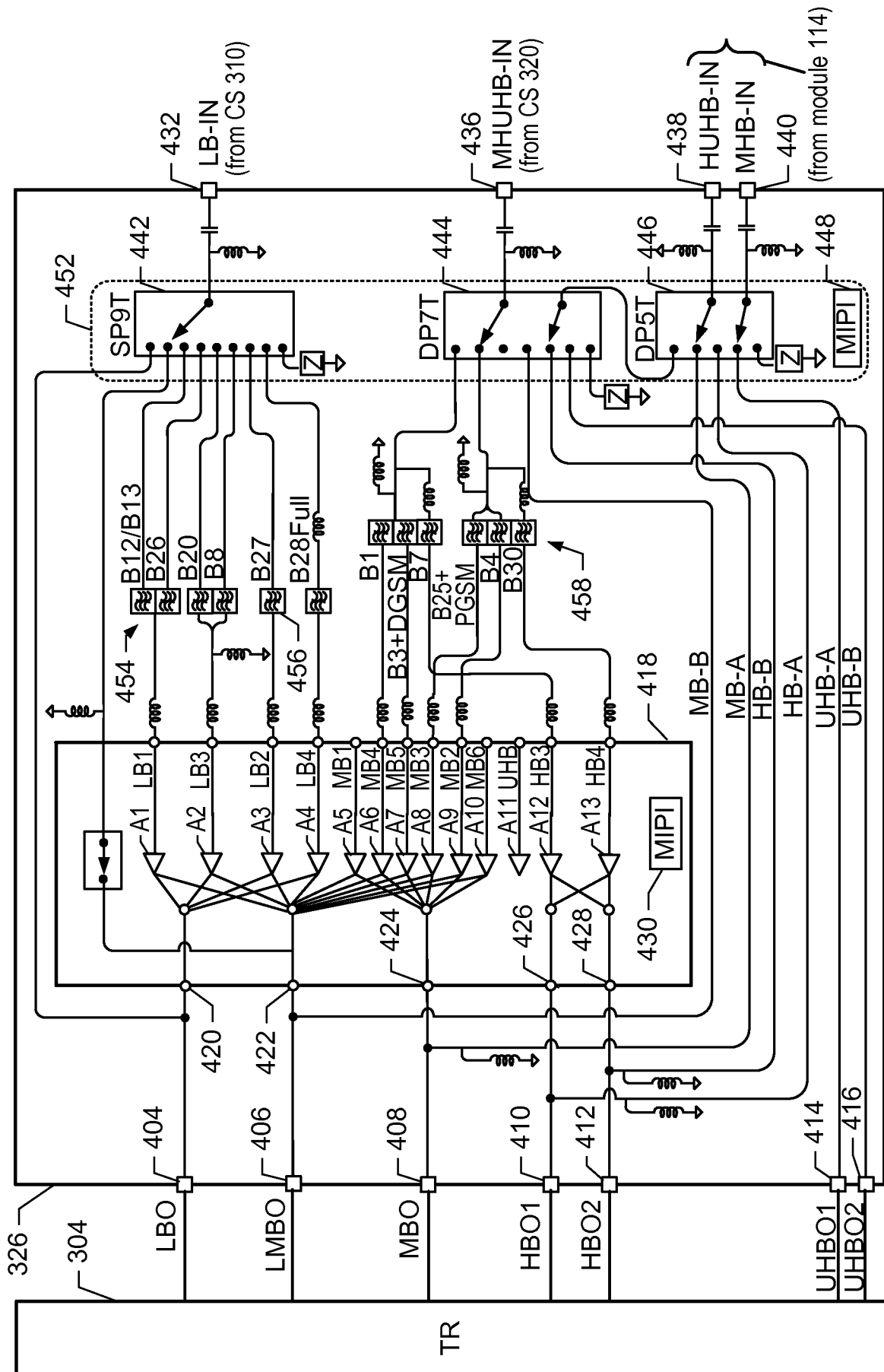
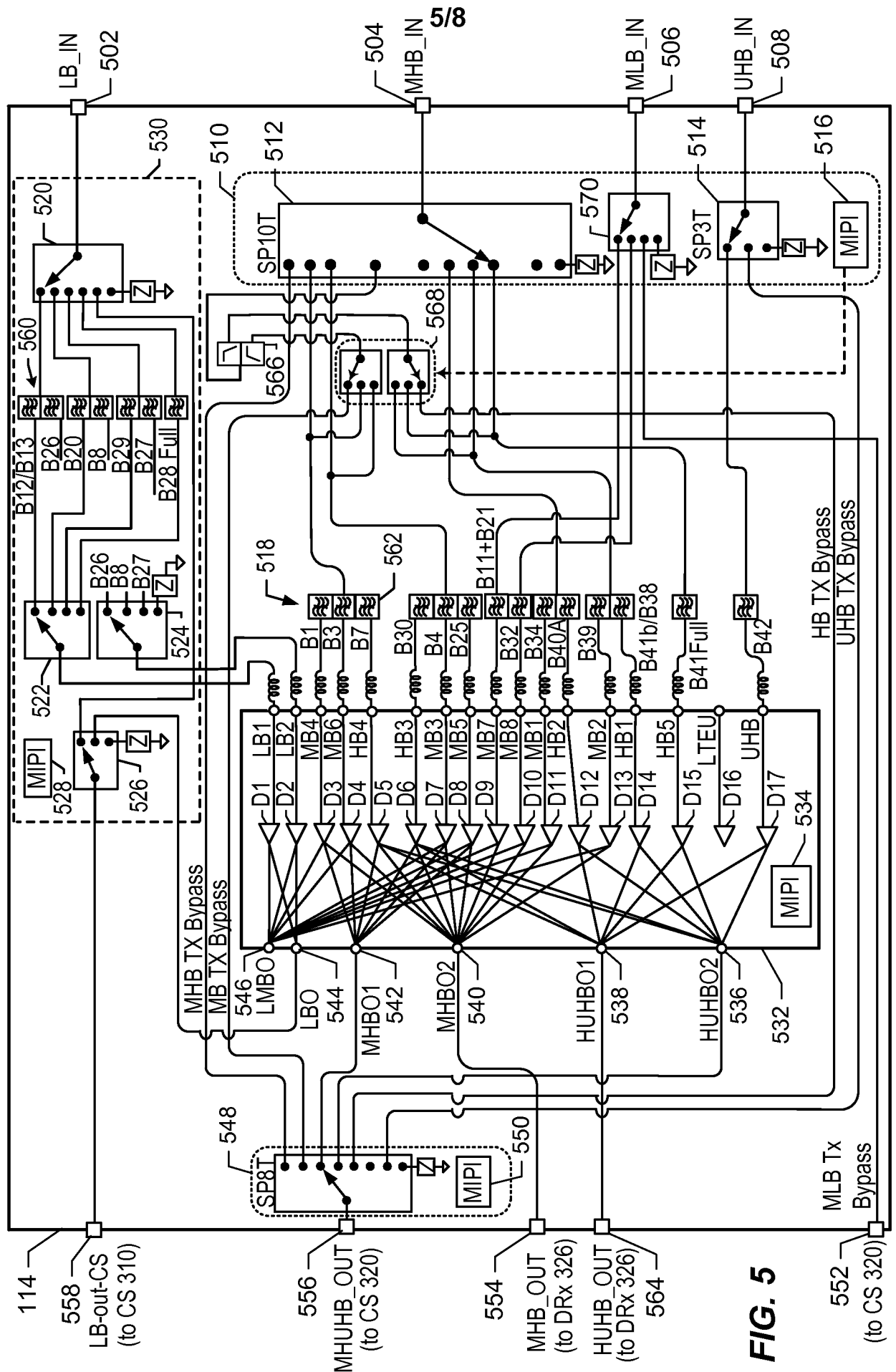
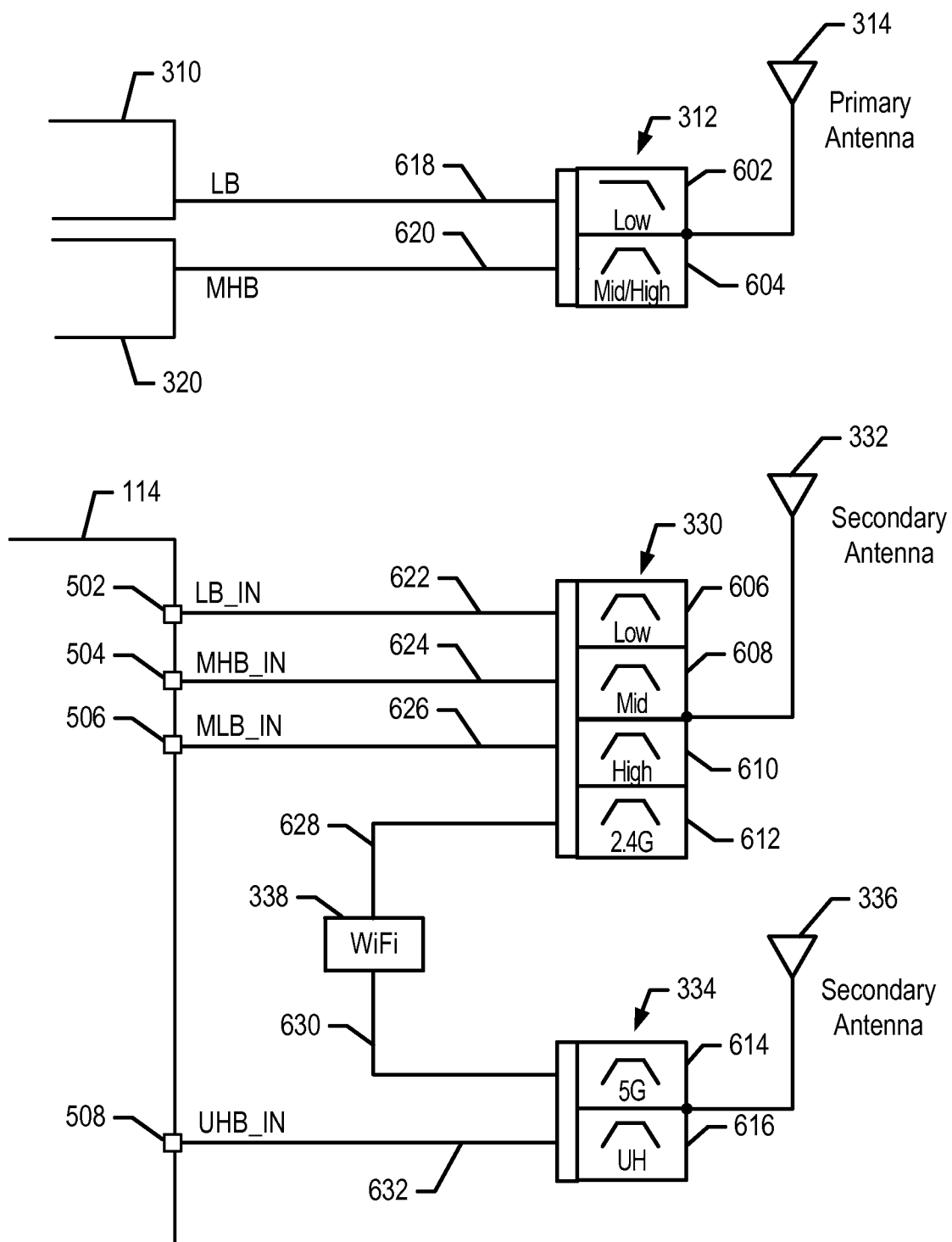


FIG. 4



6/8

**FIG. 6**

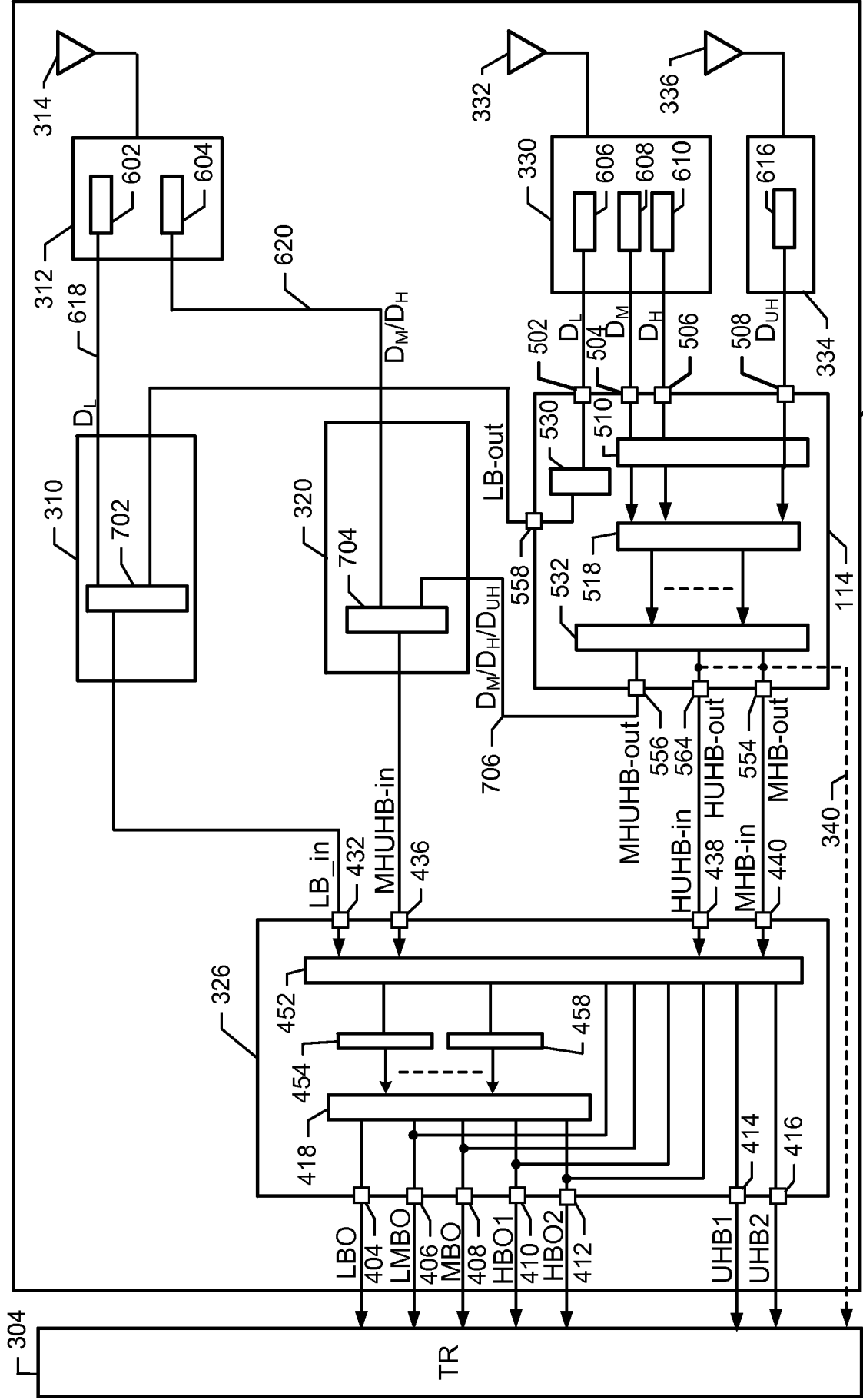
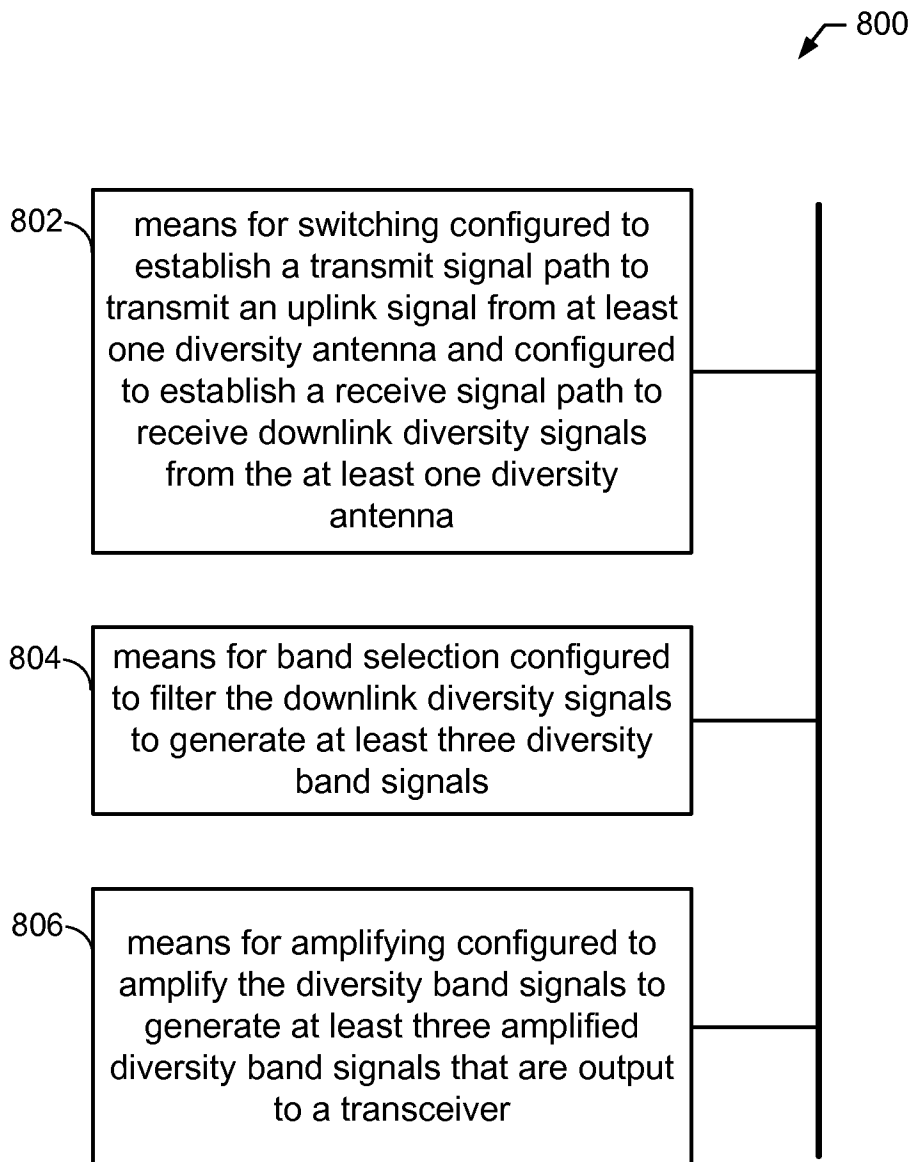


FIG. 7

8/8

**FIG. 8**

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2015/035252

A. CLASSIFICATION OF SUBJECT MATTER  
INV. H04B1/00 H04L27/26 H04B1/44  
ADD.

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 H04L

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         | US 2012/195237 A1 (CHAN CHUNCHUNG [CN] ET AL) 2 August 2012 (2012-08-02) paragraph [0013] - paragraph [0016]; figures 4-5   | 1-20                  |
| A         | -----<br>CN 103 780 280 A (HUAWEI TECH CO LTD) 7 May 2014 (2014-05-07) figure 9<br>-& US 2015/244404 A1 (LIU ZHIGANG [CN] ET AL) 27 August 2015 (2015-08-27)<br>----- | 1-20                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

## \* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

8 September 2015

Date of mailing of the international search report

16/09/2015

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040,  
Fax: (+31-70) 340-3016

Authorized officer

Marques, Gabriela

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2015/035252

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
|---|---------------------|----------------------------|---------------------|
| US 2012195237 A1                          | 02-08-2012          | US 2012195237 A1           | 02-08-2012          |
|   |                     | WO 2012106553 A1           | 09-08-2012          |
| -----                                     |                     |                            |                     |
| CN 103780280 A                            | 07-05-2014          | CN 103780280 A             | 07-05-2014          |
|   |                     | EP 2919391 A2              | 16-09-2015          |
|   |                     | US 2015244404 A1           | 27-08-2015          |
| -----                                     |                     |                            |                     |
| US 2015244404 A1                          | 27-08-2015          | CN 103780280 A             | 07-05-2014          |
|   |                     | EP 2919391 A2              | 16-09-2015          |
|   |                     | US 2015244404 A1           | 27-08-2015          |
| -----                                     |                     |                            |                     |