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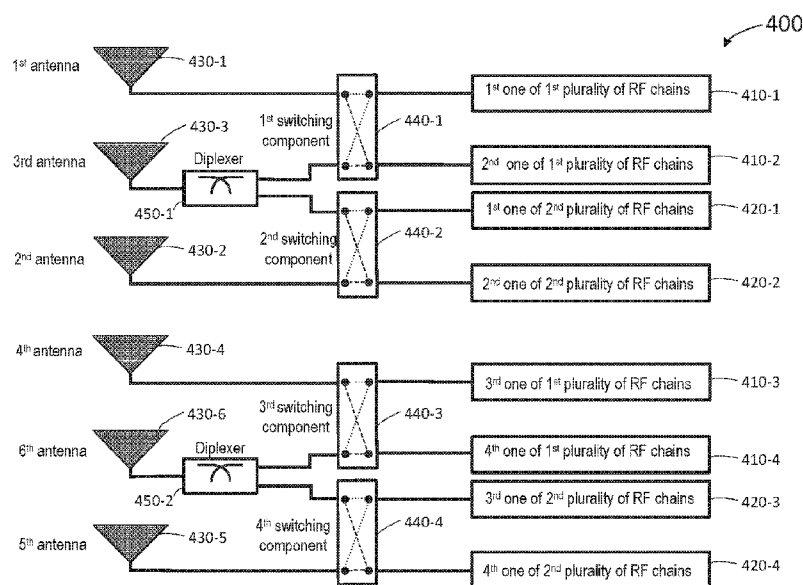


FIG. 4

(57) Abstract: A multiple-input, multiple-output (MIMO) transceiver comprises a plurality of RF chains, a plurality of antennas, a plurality of switching components, and control circuitry operatively coupled to the plurality of switching components. In some examples, a total quantity of RF chains included in the plurality of RF chains is equal to a first value, and a total quantity of antennas included in the plurality of antennas is equal to a second value that is less than the first value.

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ANTENNA SWITCHING ON MIMO DEVICES

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CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/908,313, filed on September 30, 2019, entitled “ANTENNA SWITCHING ON DEVICES,” the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

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BACKGROUND OF THE INVENTION

[0002] Multiple-input multiple-output (MIMO) systems have received significant attention by increasing the capacity and spectral efficiency through spatial multiplexing. MIMO or large scaled antenna systems having a large number of antenna elements at the base station have been deployed in recent years.

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[0003] Despite the progress made in MIMO systems, there is a need in the art for improved methods and systems related to MIMO systems.

SUMMARY OF THE INVENTION

[0004] The present invention relates in general to the field of wireless communication, and more specifically, to devices and methods for a multiple-input multiple-output (MIMO) communication device. Embodiments of the present invention provide circuits and methods for efficient use of antennas in a MIMO system that includes antenna switching and carrier aggregation.

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[0005] In some embodiments, a multiple-input, multiple-output (MIMO) transceiver in a communication device can include a plurality of RF (radio frequency) chains, a plurality of antennas, a plurality of switching components, and control circuitry operatively coupled to the plurality of switching components. A total quantity of RF chains is equal to a first value, and a total quantity of antennas is equal to a second value that is less than the first value. The

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plurality of RF chains includes a first plurality of RF chains to support communication on a first RF band and a second plurality of RF chains to support communication on a second RF band. The plurality of antennas includes a first antenna configured to communicate on the first RF band, a second antenna configured to communicate on the second RF band different from the first RF band, and a third antenna configured to communicate on the first and second RF bands.

[0006] This approach permits use of antennas operating at two different frequency bands, which helps reduce the total number of antennas in the device, while reducing the amount of switching on a path. The arrangement also provides for reduced insertion loss and provides simplified and flexible routing of RF paths. It can also help in locating RF front end components near their respective antennas, hence improving the link budget of the device.

[0007] In some embodiments, a multiple-input, multiple-output (MIMO) transceiver comprises a plurality of RF chains, a plurality of antennas, a plurality of switching components, and control circuitry operatively coupled to the plurality of switching components. In some examples, a total quantity of RF chains included in the plurality of RF chains is equal to a first value, and a total quantity of antennas included in the plurality of antennas is equal to a second value that is less than the first value.

[0008] In some embodiments, the plurality of RF chains comprises a first plurality of RF chains comprising electronics configured to support communication on a first RF band and a second plurality of RF chains comprising electronics configured to support communication on a second RF band.

[0009] In some embodiments, the plurality of antennas includes a first antenna configured to communicate on the first RF band, a second antenna configured to communicate on a second RF band different from the first RF band, and a third antenna configured to communicate on the first and second RF bands. In some examples, the plurality of switching components comprises a first switching component electrically coupled to two of the first plurality of RF chains, the first antenna, and the third antenna. In some examples, the plurality of switching components further comprises a second switching component electrically coupled to two of the second plurality of RF chains, the second antenna, and the third antenna.

[0010] In some embodiments, the control circuitry may be configured to selectively cause the first switching component to toggle between (i) a state in which a first one of the first plurality of RF chains is electrically coupled to the first antenna and a second one of the plurality of the RF chains is electrically coupled to the third antenna, and (ii) a state in which the first one of the first plurality of the RF chains is electrically coupled to the third antenna and the second one of the first plurality of RF chains is electrically coupled to the first antenna. In some examples, the control circuitry may be configured to selectively cause the second switching component to toggle between (i) a state in which a first one of the second plurality of RF chains is electrically coupled to the second antenna and a second one of the second plurality of RF chains is electrically coupled to the third antenna, and (ii) a state in which the first one of the second plurality of RF chains is electrically coupled to the third antenna and the second one of the second plurality of RF chains is electrically coupled to the second antenna.

[0011] In some embodiments, the transceiver is configured to communicate with a base station. In some such embodiments, the transceiver is configured to selectively cause the first and/or second switching component to toggle from states in response to receiving a command to do so from the base station. In at least some of these embodiments, the transceiver is configured to communicate with the base station in accordance with a time division duplexing (TDD) protocol. Furthermore, in some such embodiments, the transceiver is configured to selectively cause the first and/or second switching component to toggle from states in accordance with an SSR protocol.

[0012] In some embodiments, the transceiver further comprises a diplexer. In these embodiments, the first and second switching components are electrically coupled to the third antenna by way of the diplexer.

[0013] In some embodiments, each switching component in the plurality of switching components is a double-pole double-throw switch.

[0014] In some embodiments, the transceiver is configured to communicate with a base station.

[0015] In some embodiments, the plurality of antennas further includes:

- a fourth antenna configured to communicate on the first RF band;
- a fifth antenna configured to communicate on the second RF band; and
- a sixth antenna configured to communicate on the first and second RF bands.

In some embodiments, the plurality of switching components further includes:

a third switching component electrically coupled to two of the first plurality of RF chains, the fourth antenna, and the sixth antenna; and

5 a fourth switching component electrically coupled to two of the second plurality of RF chains, the fifth antenna, and the sixth antenna.

[0016] In some embodiments, the control circuitry is further configured to:

10 selectively cause the third switching component to toggle between (i) a state in which a third one of the first plurality of RF chains is electrically coupled to the fourth antenna and a fourth one of the first plurality of the RF chains is electrically coupled to the sixth antenna, and (ii) a state in which the third one of the first plurality of the RF chains is electrically coupled to the sixth antenna and the fourth one of the first plurality of RF chains is electrically coupled to the fourth antenna; and

15 selectively cause the fourth switching component to toggle between (i) a state in which a third one of the second plurality of RF chains is electrically coupled to the fifth antenna and a fourth one of the second plurality of the RF chains is electrically coupled to the sixth antenna, and (ii) a state in which the third one of the second plurality of the RF chains is electrically coupled to the sixth antenna and the fourth one of the second plurality of RF chains is electrically coupled to the fifth antenna.

[0017] In some embodiments, each switching component in the plurality of switching components is a triple pole triple throw switch.

20 **[0018]** In some embodiments, the first switching component is electrically coupled to the third switching component, and the second switching component is electrically coupled to the fourth switching component.

[0019] Some embodiments further include a diplexer, wherein the third and fourth switching components are electrically coupled to the sixth antenna by way of the diplexer.

25 **[0020]** In some embodiments, the first and second bands correspond to n78 and n79 bands, respectively.

[0021] In some embodiments, at least a portion of the RF chains comprises electronics configured to support communication RF transmission.

[0022] In some embodiments, at least a portion of the RF chains comprises electronics that are not configured to support communication RF transmission.

[0023] In some embodiments, at least a portion of the RF chains comprises electronics configured to support communication RF reception.

[0024] In some embodiments, all of the RF chains comprise electronics configured to support communication RF reception.

5 **[0025]** Some embodiments further include a wearable device comprising the MIMO transceiver described above.

[0026] According to some embodiments of the present invention, a communication device includes two first-band antennas, two second-band antennas, two dual-band antennas configured for communication in both the first frequency band and the second frequency
10 band, four first-band receive chains, four second-band receive chains, two first-band transmit chains, and two second-band transmit chains. Each one of the four first-band receive chains is switchably coupled to a respective one of the two first-band antennas and the two dual-band antennas. Each one of the four second-band receive chains is switchably coupled to a
15 respective one of the two second-band antennas and the two dual-band antennas. Each one of the two first-band transmit chains is switchably coupled to one of the two first-band antennas or a first one of the two dual-band antennas. Each one of the two second-band transmit chains is switchably coupled to one of the two second-band antennas or a second one of the two dual-band antennas.

[0027] In some embodiments, a communication device, comprising six antennas, eight
20 receive chains, and four transmit chains. The six antennas comprise two first-band antennas, two second-band antennas, and two dual-band antennas. The two first-band antennas include a first first-band antenna and a second first-band antenna, configured for communication in a first frequency band. The two second-band antenna includes a first second-band antenna and a second second-band antenna, configured for communication in a second frequency band.
25 The two dual-band antennas include a first dual-band antenna and a second dual-band antenna, configured for communication in both the first frequency band and second frequency band. The eight receive chains comprise four first-band receive chains and four second band receive chains. The four first-band receive chains includes first, second, third, and fourth first-band receive chains, configured for receiving signals in the first frequency

band, each one of the four first-band receive chains being switchably coupled to a respective one of the two first-band antennas and the two dual-band antennas, The four second band receive chains include first, second, third, and fourth second-band receive chains, configured for receiving signals in the second frequency band, each one of the four second-band receive chains being switchably coupled to a respective one of the two second-band antennas and the two dual-band antennas. The four transmit chains comprise two first-band transmit chains and second-band transmit chains. The two first-band transmit chains include a first first-band transmit chain and a second first-band transmit chain, configured for transmitting signals in the first frequency band, each one of the two first-band transmit chains being switchably coupled to one of the two first-band antennas or a first one of the two dual-band antennas; and two second-band transmit chains. The two second-band transmit chains include a first second-band transmit chain and a second second-band transmit chain, configured for transmitting signals in the second frequency band, each one of the two second-band transmit chains being switchably coupled to one of the two second-band antennas or a second one of the two dual-band antennas.

[0028] In some embodiments of the above communication device, each of the first first-band receive chain, the first first-band transmit chain, and the third first-band receive chain is switchably coupled to either the first first-band antenna or the first dual-band antenna through a first switch. Each of the third second-band receive chain, the first second-band transmit chain, and the first second-band receive chain is switchably coupled to either the first dual-band antenna or the first second-band antenna through a second switch. Each of the second first-band receive chain, the second first-band transmit chain, and the fourth first-band receive chain is switchably coupled to either the second first-band antenna or the second dual-band antenna through a third switch. Each of the fourth second-band receive chain, the first second-band transmit chain, and the second second-band receive chain is switchably coupled to either the second dual-band antenna or the second second-band antenna through a fourth switch.

[0029] In some embodiments, the communication device also includes a first diplexer and a second diplexer. The first diplexer couples the first dual-band antenna to the first switch and

the second switch, and the second diplexer couples the second dual-band antenna to the third switch and the fourth switch.

[0030] In some embodiments, each of the first switch, the second switch, the third switch, and the fourth switch is a DPDT (double-pole double-throw, or 2P2T) switch.

5 **[0031]** In some embodiments, the four first-band receive chains and the four second-band receive chains are configured to perform 4x4 MIMO (multiple-input multiple-output) down link (DL) communication, with carrier aggregation (CA) in the first and second frequency bands, with a base station. The two first-band transmit chains and the two second-band transmit chains are configured to perform 2x2 MIMO up link (UL) communication, in the
10 first and second frequency bands, respectively, in TDD (time division duplexing) with a base station with UL antenna switching according to 1T2R SRS (sounding reference signal) protocol.

[0032] In some embodiments, the UL antenna switching comprises a first antenna switching state and a second antenna switching state.

15 **[0033]** In some embodiments, in the first antenna switching state, the first first-band transmit chain is coupled to the first first-band antenna; the first second-band transmit chain is coupled to the first dual-band antenna, the second first-band transmit chain is coupled to the second first-band antenna, and the second second-band transmit chain is coupled to the second second-band antenna. In the second antenna switching state, the first first-band
20 transmit chain is coupled to the first dual-band antenna, the first second-band transmit chain is coupled to the first second-band antenna, the second first-band transmit chain is coupled to the second dual-band antenna, and the second second-band transmit chain is coupled to the second second-band antenna.

[0034] In some embodiments, in the first antenna switching state, the first first-band
25 transmit chain is coupled to the first first-band antenna, the first second-band transmit chain is coupled to the first dual-band antenna, the second first-band transmit chain is coupled to the second dual-band antenna, and the second second-band transmit chain is coupled to the second dual-band antenna. In the second antenna switching state, the first first-band transmit

chain is coupled in the first dual-band antenna, the first second-band transmit chain is coupled to the first second-band antenna, the second first-band transmit chain is coupled to the second first-band antenna, and the second second-band transmit chain is coupled to the second second-band antenna.

5 **[0035]** In some embodiments, in the first antenna switching state, the first first-band transmit chain is coupled to the first dual-band antenna, the first second-band transmit chain is coupled to the first dual-band antenna, the second first-band transmit chain is coupled to the second first-band antenna, and the second second-band transmit chain is coupled to the second second-band antenna. In the second antenna switching state, the first first-band
10 transmit chain is coupled to the first first-band antenna, the first second-band transmit chain is coupled to the first second-band antenna, the second first-band transmit chain is coupled to the second dual-band antenna, and the second second-band transmit chain is coupled to the second dual-band antenna.

15 **[0036]** In some embodiments, in the first antenna switching state, the first first-band transmit chain is coupled to the first dual-band antenna, the first second-band transmit chain is coupled to the first dual-band antenna, the second first-band transmit chain is coupled to the second dual-band antenna, and the second second-band transmit chain is coupled to the second dual-band antenna. In the second antenna switching state, the first first-band transmit chain is coupled to the first first-band antenna, the first second-band transmit chain is coupled
20 to the first second-band antenna, the second first-band transmit chain is coupled to the second first-band antenna, and the second second-band transmit chain is coupled to the second second-band antenna.

25 **[0037]** In some embodiments, each one of the two first-band transmit chains is switchably coupled to any one of the two first-band antennas and the two dual-band antennas, and each one of the two second-band transmit chains is switchably coupled to any one of the two second-band antennas and the two dual-band antennas.

[0038] In some embodiments, each of the first switch, the second switch, the third switch, and the fourth switch is a 3P3T (triple-pole triple-throw) switch.

[0039] In some embodiments, the first switch is coupled to the third switch, and the second switch is coupled to the fourth switch.

[0040] In some embodiments, the two first-band transmit chains and the two second-band transmit chains are configured to perform 2x2 MIMO up link (UL) communication, in the first and second frequency bands, respectively, in TDD (time division duplexing) with a base station with UL antenna switching according to 1T4R SRS (sounding reference signal) protocol.

[0041] According to some embodiments of the present invention, a method for wireless communication includes providing a communication device having four first-band receive chains, four second-band receive chains, two first-band transmit chains, two second-band transmit chains, and six antennas. The method includes performing 4x4 MIMO (multiple-input multiple-output) down link (DL) communication with a base station, in the first and second frequency bands with carrier aggregation (CA). The method also includes performing 2x2 MIMO up link (UL) communication with the base station, in the first and second frequency bands, in TDD (time division duplexing), and performing up link antenna switching to connect a given transmit chain to one of two antennas based on a signal from the base station.

[0042] In some embodiments, the six antennas include two first-band antennas, two second-band antennas, and two dual-band antennas, the two dual-band antennas configured to operate in the first-band and the second-band.

[0043] In some embodiments, the method also includes coupling the transmit chains and the receiver chains to the antennas using four 2P2T switches and two diplexers.

[0044] In some embodiments, the antenna switching is performed according to a 2T4R (two transmitter and four receiver) SRS (sounding reference signal) protocol.

[0045] In some embodiments, the method also includes performing up link antenna switching to connect a given transmit chain to one of four antennas based on a signal from the base station according to a 1T4R (one transmitter and four receiver) SRS (sounding reference signal) protocol.

[0046] In some embodiments, the method also includes coupling the transmit chains and the receiver chains to the antennas using four 3P3T switches and two diplexers.

[0047] A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0048] FIG. 1 is a simplified block diagram illustrating a cellular system for wireless communication according to some embodiments of the present invention;

10 [0049] FIG. 2A is a simplified block diagram illustrating a down link (DL) 4x4 MIMO configuration with four antennas for receiving streams according to some embodiments of the present invention;

[0050] FIG. 2B is a simplified block diagram illustrating an up link (UL) 2x2 MIMO configuration with two antennas for transmitting streams according to some embodiments of the present invention;

15 [0051] FIG. 2C is a simplified block diagram illustrating DL 4x4 MIMO and UL 2x2 MIMO configuration with time division multiplexing (TDD) using four antennas for RX streams and two antennas for 2 TX streams a simplified block diagram illustrating;

20 [0052] FIG. 3A is a simplified block diagram illustrating an example of the transmitting path switching used to support 2T4R (1T2R + 1T2R) (2TX Chains, 4 Antennas) SRS scenario according to some embodiments of the present invention;

[0053] FIG. 3B is a simplified block diagram illustrating an example of the transmitting path switching used to support 1T4R (1 TX chain, 4 Antennas) SRS scenario according to some embodiments of the present invention;

25 [0054] FIG. 4 is a simplified block diagram illustrating an example of a MIMO transceiver according to some embodiments of the present invention;

[0055] FIG. 5 is a simplified block diagram illustrating a communication device according to some embodiments of the present invention;

[0056] FIG. 6 is a simplified block diagram illustrating part of a communication device according to some embodiments of the present invention;

[0057] FIG. 7A is a simplified block diagram illustrating part of a communication device according to some embodiments of the present invention;

5 [0058] FIG. 7B is a simplified block diagram illustrating communication signal paths in a first antenna switching state of the communication device of FIG. 6A according to some embodiments of the present invention;

[0059] FIG. 7C is a simplified block diagram illustrating communication signal paths in a second antenna switching state of the communication device of FIG. 6A according to some
10 embodiments of the present invention;

[0060] FIG. 7D is a table listing the connections between the transmit and receive chains and the antennas in the first antenna switching state and the second antenna switching state according to some embodiments of the present invention;

[0061] FIG. 7E is a table listing the connections between the transmit and receive chains
15 and the antennas in the first antenna switching state and the second antenna switching state according to some embodiments of the present invention;

[0062] FIG. 8 is a simplified block diagram illustrating another example of the communication device of FIG. 7A according to some embodiments of the present invention;

[0063] FIG. 9 is a simplified block diagram illustrating another example of the
20 communication device of FIG. 7A according to some embodiments of the present invention;

[0064] FIG. 10 is a simplified block diagram illustrating another example of the communication device of FIG. 7A according to some embodiments of the present invention;

[0065] FIG. 11A is a simplified block diagram illustrating an example of another communication device according to some embodiments of the present invention.

25 [0066] FIG. 11B is a simplified block diagram illustrating an example of antenna switching communication signal paths for a transmit chain in the communication device of FIG. 11A according to some embodiments of the present invention;

[0067] FIG. 12 is a simplified block diagram illustrating another example of the communication device of FIG. 11 according to some embodiments of the present invention;

[0068] FIG. 13 is a simplified block diagram illustrating another example of the communication device of FIG. 11 according to some embodiments of the present invention;

5 [0069] FIG. 14 is a simplified block diagram illustrating another example of the communication device of FIG. 11 according to some embodiments of the present invention; and

[0070] FIG. 15 is a simplified flowchart illustrating a method for operating a communication device according to some embodiments of the present invention.

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DETAILED DESCRIPTION OF THE INVENTION

[0071] The present disclosure describes systems and methods for antenna switching on devices. Some embodiments provide for sounding reference signal (SRS) uplink (UL) antenna switching on devices that employ six total antennas to support the use of different
15 frequency bands, such as 5G new radio (NR) bands n78+n79 downlink (DL) carrier aggregation (CA) with 4x4 MIMO operation.

[0072] Frequency bands for 5G NR are being separated into two different frequency ranges. One is Frequency Range 1 (FR1) that includes sub-6 GHz frequency bands, some of which are bands traditionally used by previous standards, but has been extended to cover
20 potential new spectrum offerings from 410 MHz to 7125 MHz. The other is Frequency Range 2 (FR2) that includes frequency bands from 24.25 GHz to 52.6 GHz. Bands in this millimeter wave range have shorter range, but higher available bandwidth than bands in the FR1.

[0073] Practical MIMO systems usually require the antenna elements to be placed in
25 limited space, due to the small size of the mobile terminals and the large number of antennas at the base station. In a MIMO system, antenna switching and carrier aggregation can be used to improve the quality of wireless communication. Antenna switching uses two or more antennas to improve the quality and reliability of a wireless link. In a switching receiver, the

signal from only one antenna is fed to the receiver for as long as the quality of that signal remains above some prescribed threshold. If and when the signal degrades, another antenna is switched in. Carrier aggregation is a technique used in wireless communication to increase the data rate per user, whereby multiple frequency blocks (called component carriers) are assigned to the same user. The data rate per user can be increased the more frequency blocks are assigned to a user. The sum data rate of a cell is increased as well because of a better resource utilization.

[0074] FIG. 1 is a simplified block diagram illustrating a cellular system for telecommunication according to some embodiments of the present invention. FIG. 1 illustrates an embodiment of a cellular system 100 that can enable wireless communication according to various protocols. Cellular system 100 can include: base station 110, antenna tower 120, 5G core network 130, and user equipment (UE) 140 (including 140-1, 140-2, 140-3, and 140-4). While cellular system 100 refers to 5G in FIG. 1, the embodiments detailed herein can be applicable to other types of cellular networks, such as a 4G Long Term Evolution (LTE) cellular network. In this example, cellular system 100 operates according to the 5G New Radio (NR) radio access technology (RAT).

[0075] UE 140 can be various forms of communication devices that are capable of communication in cellular system 100. For instance, UE 140 can be smartphones, wireless modems, cellular phones, laptop computers, wireless access points (APs), wearable devices, VR (virtual reality) or AR (augmented reality) headsets, etc. In response to signals received from base station 110, each UE may engage in wireless communication according to various protocols.

[0076] FIG. 2A is a simplified block diagram illustrating a down link (DL) 4x4 MIMO (multiple-input and multiple-output) configuration with four antennas for receiving streams according to some embodiments of the present invention. In 4x4 MIMO, the base station transmits four different signals (or streams) via four transmit antennas to one user equipment (UE). The UE is equipped with four antennas to receive the signals. FIG. 2A shows four receive chains for frequency band Band-x: BAND-x RX Chain-0, BAND-x RX Chain-1, BAND-x RX Chain-2, and BAND-x RX Chain-3. The four receive chains are configured to

receive signals from four antennas, ANT-0 BAND-x, ANT-1 BAND-x, ANT-2 BAND-x, and ANT-3 BAND-x, respectively, for performing 4x4 MIMO down link (DL) operation.

[0077] As used herein, an RF chain refers to RF front-end modules (e.g., amplifiers, filters, switches, mixers, A/D converters, etc.) that support a radio frequency signal handling of a wireless antenna. A receive chain refers to RF front-end modules that support receiving a radio frequency signal from a wireless antenna. A transmit chain refers to RF front-end modules that support transmitting a radio frequency signal through a wireless antenna. An RF chain can include a receive chain, a transmit chain, or a combination thereof.

[0078] FIG. 2B is a simplified block diagram illustrating an up link (UL) 2x2 MIMO configuration with two antennas for transmitting streams according to some embodiments of the present invention. A 2x2 MIMO device has two antennas for two simultaneous data streams. FIG. 2B shows two transmit chains for frequency band Band-x: BAND-x TX Chain-0 and BAND-x TX Chain-1. The two transmit chains are configured to transmit signals to two antennas, ANT-0 BAND-x and ANT-1 BAND-x, respectively for performing 2x2 MIMO up link (UL) operation.

[0079] FIG. 2C is a simplified block diagram illustrating DL 4x4 MIMO and UL 2x2 MIMO configuration with time division multiplexing (TDD) using four antennas for RX streams and two antennas for 2 TX streams. FIG. 2C shows four receive chains for frequency band Band-x: BAND-x RX Chain-0, BAND-x RX Chain-1, BAND-x RX Chain-2, and BAND-x RX Chain-3. The four receive chains are configured to receive signals from four antennas, ANT-0 BAND-x, ANT-1 BAND-x, ANT-2 BAND-x, and ANT-3 BAND-x, respectively, for performing 4x4 MIMO down link (DL) operation. FIG. 2C shows two transmit chains for frequency band Band-x: BAND-x TX Chain-0 and BAND-x TX Chain-1. The two transmit chains are configured to transmit signals to two antennas, ANT-0 BAND-x and ANT-1 BAND-x, respectively, for performing 2x2 MIMO up link (UL) operation. In time division multiplexing (TDD), the receiving streams and the transmitting streams take place at different times. Therefore, the same two antennas, ANT-0 BAND-x and ANT-1 BAND-x, can be used for both the receiving streams and the transmitting streams. As shown in FIG. 2C, receive chain BAND-x RX Chain-0 and transmit chain BAND-x TX Chain-0 are both coupled to the same antenna, ANT-0 BAND-x. Similarly, receive chain BAND-x RX

Chain-1 and transmit chain BAND-x TX Chain-1 share one antenna, ANT-0 BAND-x. For TDD bands, in some embodiments, there can be a TX/RX switch between the TX chain(s) and Rx chains so that in total four BAND-x capable antennas would be used to support DL 4x4 MIMO and UL 2x2 MIMO for that band.

5 [0080] FIG. 3A is a simplified block diagram illustrating an example of the transmitting path switching used to support 2T4R (more specifically 1T2R+1T2R, with 2TX chain, 4 Antennas) sounding reference signal (SRS) scenario according to some embodiments of the present invention. In sounding reference signal (SRS) uplink (UL) transmission, the transmit chain may switch to a different antenna based on an instruction from a base station. In FIG.
10 3A, transmit chain BAND-x TX Chain-0 is coupled to two antennas ANT-0 and ANT-1 through a switch, and can switch antennas in a 1T2R SRS uplink (UL) transmission. Similarly, transmit chain BAND-x TX Chain-1 is coupled to two antennas ANT-2 and ANT-3 through a second switch, and can switch antennas in a 1T2R SRS uplink (UL) transmission. With the two antennas in FIG. 3A, 2T4R (2TX chain, 4 Antennas) sounding reference signal
15 (SRS) can be implemented.

[0081] FIG. 3B is a simplified block diagram illustrating an example of the transmitting path switching used to support a 1T4R (1 TX chain, 4 Antennas) SRS scenario according to some embodiments of the present invention. In FIG. 3B, transmit chain BAND-x TX Chain-0 is coupled to four antennas ANT-0, ANT-1, ANT-2, and ANT-3 through a switch, and can
20 switch among the four antennas in a 1T4R SRS uplink (UL) transmission.

[0082] The embodiments described below relate to implementing antenna switching to support UL transmitter SRS antenna switching on 5G NR FR1 capable devices, also described as user equipment (UE). The UE can employ six antennas to support DL CA with 4x4 MIMO on 5G NR FR1 TDD bands (e.g., n78 and n79) while also supporting 2x2 UL
25 MIMO on either n78 or n79 bands.

[0083] In some embodiments, two transmit chains can be active, operating in either n78 or n79 bands. At the same time, there could be four simultaneous receive chains that are active in each of n78 and n79 bands (e.g., for a total of 8 receive chains). In an exemplary six antenna scheme, two antennas may support both n78 and n79 bands, while two antennas may
30 be dedicated to n78 band, and another two antennas are dedicated to n79 bands.

[0084] Under UL SRS switching, the UE under base station (BS) controls is configured to switch either one or both UL TX chains (e.g., operating either n78 or n79) to any of the four antennas available for that band on the UE, while at the same time keeping all eight independent receiver chains active to support 4x4 DL CA in n78 and n79 bands.

5 **[0085]** As used herein, in time division duplex (TDD), a single frequency band is used for both transmit and receive. Then it shares that band by assigning alternating time slots to transmit and receive operations. For example, in some embodiments of the invention, carrier aggregation is implemented such that the n-78 band and the n-79 band are assigned to the same user.

10 **[0086]** In some embodiments, the switching scheme implemented on UE employs n78-n79 band diplexers and two pairs of double-pole double-throw (DPDT) switches with ports arranged to support two transmit and four receive (2T4R) SRS switching while simultaneously supporting DL CA with 4x4 MIMO on 5G NR FR1 TDD in N78 and n79 bands and also supporting 2x2 UL MIMO on either n78 or n79 bands. This switching
15 scheme provides the advantage of minimizing insertion loss through use of lower loss DPDT switches instead of larger switches. The arrangement of diplexers and DPDT switches enables reduction of a required number of antennas. Use of two pairs of DPDT switches (e.g., instead of 2x 4P4T switches) provides for layout flexibility and ease in configuring devices such that radio frequency (RF) front end components are located near their respective
20 antennas, hence improving link budget of the device and resulting in better overall radiated power and sensitivity performance of the device.

[0087] In some embodiments, another switching scheme is employed, which makes use of two pairs of triple-pole triple-throw (3P3T) switches in conjunction with n78-n79 band diplexers on UE, that supports both 1 transmit and 4 receive (1T4R) and 2 transmit and 4
25 receive (2T4R) SRS switching, while simultaneously supporting DL CA with 4x4 MIMO on 5G NR FR1 TDD in N78 and n79 bands and also supporting 2x2 UL MIMO on either n78 or n79 bands. This switching scheme provides the benefits of minimizing insertion loss and layout flexibility.

[0088] In some embodiments, the n78 band spans a frequency range of approximately
30 3.3GHz to 3.8GHz, and the n79 band spans a frequency range of approximately 4.4GHz to

5GHz. Other suitable frequency ranges may also be supported by embodiments of the invention.

[0089] Some embodiments provide a 5G NR FR1 (FR1 = Sub 6GHz frequency spectrum) device that can operate in TDD in N78 and n79 bands and that supports one or more of the following features: n78-n79 DL CA; n78 and n79 DL 4x4 MIMO; UL 2x2 MIMO supported on the TX band; and/or SRS for TX. In some embodiments, 2T4R is supported, applicable to devices supporting UL 2x2 MIMO. In some embodiments, 2T4R and 1T4R are supported, applicable to devices supporting UL 2x2 MIMO or single UL.

[0090] The 5G-NR device in this scheme could be a non-standalone (NSA) mode device using an LTE anchor, or a standalone (SA) mode device. There is no UL CA requirement between n78 and n79, meaning that either n78 TX or n79 TX may be active at a time but, not both. The system utilizes TDD slot synchronization between both n78 and n79 bands, since most current duplexers available in the market, would not be able to provide enough transmit-receive isolation between the n78 and n79 bands due the proximity of the frequency bands..

[0091] Embodiments support simultaneous operation of n78 and n79 bands (DL CA), while also supporting DL 4x4 MIMO (e.g., FIG. 2) and 2T4R/1T4R (e.g., FIGS. 3A and 3B) for each of these bands.

[0092] FIG. 4 is a simplified block diagram illustrating an example of a MIMO transceiver according to some embodiments of the present invention. FIG. 4 illustrates a multiple-input, multiple-output (MIMO) transceiver 400 that comprises a plurality of RF chains (410-1, 410-2, 410-3, 410-4, 420-1, 420-2, 420-3, and 420-4), a plurality of antennas (430-1, 430-2, 430-3, 430-4, 430-5, and 430-6), a plurality of switching components (440-1, 440-2, 440-3, and 440-4), and control circuitry (not shown) operatively coupled to the plurality of switching components. In some examples, a total quantity of RF chains included in the plurality of RF chains is equal to a first value, and a total quantity of antennas included in the plurality of antennas is equal to a second value that is less than the first value. In the example of FIG. 4, the total quantity of RF chains included in the plurality of RF chains is equal to a first value, 8, and a total quantity of antennas included in the plurality of antennas is equal to a second value, 6, that is less than the first value. However, it is understood that the first value and the second value can be other values.

[0093] In some embodiments, the plurality of RF chains comprises a first plurality of RF chains 410 (including 410-1 and 410-2) comprising electronics configured to support communication on a first RF band, and a second plurality of RF chains 420 (including 420-1 and 420-2) comprising electronics configured to support communication on a second RF band. In some embodiments, the plurality of antennas 430 includes a first antenna 430-1 configured to communicate on the first RF band, a second antenna 430-2 configured to communicate on a second RF band different from the first RF band, and a third antenna 430-3 configured to communicate on the first and second RF bands. In some examples, the plurality of switching components 440 comprises a first switching component 440-1 electrically coupled to two of the first plurality of RF chains 410, the first antenna, 430-1, and the third antenna 430-3. In some examples, the plurality of switching components 440 further comprises a second switching component 440-2 electrically coupled to two of the second plurality of RF chains 420, the second antenna 430-2, and the third antenna 430-3.

[0094] In some embodiments, the control circuitry may be configured to selectively cause the first switching component 440-1 to toggle between (i) a first state in which a first one of the first plurality of RF chains 410-1 is electrically coupled to the first antenna 430-1 and a second one of the plurality of the RF chains 410-2 is electrically coupled to the third antenna 430-3, and (ii) a second state in which the first one of the first plurality of the RF chains 410-1 is electrically coupled to the third antenna 430-3 and the second one of the first plurality of RF chains 410-2 is electrically coupled to the first antenna 430-1. In FIG. 4, the signal paths in the first state and the second state are shown by the dotted lines and the broken lines in the first switching component 440-1. In some examples, the control circuitry may be configured to selectively cause the second switching component 440-2 to toggle between (i) a state in which a first one of the second plurality of RF chains 420-1 is electrically coupled to the second antenna 430-2 and a second one of the second plurality of RF chains 420-2 is electrically coupled to the third antenna 430-3, and (ii) a state in which the first one of the second plurality of RF chains 420-1 is electrically coupled to the third antenna 430-3 and the second one of the second plurality of RF chains 420-2 is electrically coupled to the second antenna 430-2. In FIG. 4, the signal paths in the first state and the second state are shown by the dotted lines and the broken lines in the second switching component 440-2.

[0095] In some embodiments, the transceiver 400 is configured to communicate with a base station (not shown). In some such embodiments, the transceiver 400 is configured to selectively cause the first 440-1 and/or second 440-2 switching component to toggle from states in response to receiving a command to do so from the base station. In at least some of these embodiments, the transceiver 400 is configured to communicate with the base station in accordance with a time division duplexing (TDD) protocol. Furthermore, in some such embodiments, the transceiver 400 is configured to selectively cause the first 440-1 and/or second 440-2 switching component to toggle from states in accordance with an SRS protocol.

[0096] In some embodiments, the transceiver 400 further comprises a diplexer 450-1. In these embodiments, the first 440-1 and second 440-2 switching components are electrically coupled to the third antenna 430-3 by way of the diplexer 450-1.

[0097] In some embodiments, each switching component in the plurality of switching components 440 is a double-pole double-throw (DPDT) switch.

[0098] In some embodiments, the plurality of antennas further includes a fourth antenna 430-4 configured to communicate on the first RF band, a fifth antenna 430-5 configured to communicate on the second RF band, and a sixth antenna 430-6 configured to communicate on the first and second RF bands.

[0099] In some embodiments, the plurality of switching components further includes a third switching component 440-3 electrically coupled to two of the first plurality of RF chains (410-3 and 410-4), the fourth antenna 430-4, and the sixth antenna 430-6. A fourth switching component 440-4 is electrically coupled to two of the second plurality of RF chains (420-3 and 420-4), the fifth antenna 430-5, and the sixth antenna 430-6.

[0100] In some embodiments, the control circuitry is further configured to selectively cause the third switching component to toggle between (i) a state in which a third one of the first plurality of RF chains is electrically coupled to the fourth antenna and a fourth one of the first plurality of the RF chains is electrically coupled to the sixth antenna, and (ii) a state in which the third one of the first plurality of the RF chains is electrically coupled to the sixth antenna and the fourth one of the first plurality of RF chains is electrically coupled to the fourth antenna. The control circuitry is further configured to selectively cause the fourth switching

component to toggle between (i) a state in which a third one of the second plurality of RF chains is electrically coupled to the fifth antenna and a fourth one of the second plurality of the RF chains is electrically coupled to the sixth antenna, and (ii) a state in which the third one of the second plurality of the RF chains is electrically coupled to the sixth antenna and the fourth one of the second plurality of RF chains is electrically coupled to the fifth antenna.

[0101] In some embodiments, each switching component in the plurality of switching components is a triple pole triple throw switch.

[0102] In some embodiments, the first switching component is electrically coupled to the third switching component, and the second switching component is electrically coupled to the fourth switching component.

[0103] Some embodiments further include a diplexer, wherein the third and fourth switching components are electrically coupled to the sixth antenna by way of the diplexer.

[0104] In some embodiments, the first and second bands correspond to n78 and n79 bands, respectively.

[0105] In some embodiments, at least a portion of the RF chains comprises electronics configured to support RF transmission.

[0106] In some embodiments, at least a portion of the RF chains comprises electronics that are not configured to support RF transmission.

[0107] In some embodiments, at least a portion of the RF chains comprises electronics configured to support RF reception.

[0108] In some embodiments, all of the RF chains comprise electronics configured to support RF reception.

[0109] Some embodiments further include a wearable device comprising the MIMO transceiver described above.

[0110] FIG. 5 is a simplified block diagram illustrating part of a communication device according to some embodiments of the present invention. Communication device 500 can represent a smartphone, wireless modem, cellular phone, laptop computer, wireless access

point (AP), wearable devices, VR (virtual reality) or AR (augmented reality) headset, etc. As shown in FIG. 5, communication device 500 includes a transceiver 510, an RF IC 520, D/A and A/D modules 530, and control circuitry 540. Control circuitry 540 can include a baseband processor providing signal processing, network management, and other control functions. Transceiver 510 can be similar to transceiver 400 of FIG. 4, and can include antennas, duplexers, switches, and RF chains. RF IC 520 can include circuitries or modules for up conversion, down conversion, mixing componentry, etc. Control circuitry 540 can include one or more processors, etc.

[0111] FIG. 6 is a simplified block diagram illustrating part of a communication device according to some embodiments of the present invention. As shown in FIG. 6, communication device 600 includes eight receive chains (610-1, 610-2, 610-3, 610-4, 620-1, 620-2, 620-3, and 620-4), four transmit chains (615-1, 615-2, 625-1, and 625-2), and six antennas (631-1, 631-2, 632-1, 632-2, 635-1, and 635-2). The six antennas include two first-band antennas 631, having a first first-band antenna 631-1 and a second first-band antenna 631-2, both configured for communication in a first frequency band. The six antennas also include two second-band antennas 632, including a first second-band antenna 632-1 and a second second-band antenna 632-2 configured for communication in a second frequency band. The six antennas further include two dual-band antennas 635, including a first dual-band antenna 635-1 and a second dual-band antenna 635-2, configured for communication in both the first frequency band and second frequency band.

[0112] In communication device 600, the eight receive chains include four first-band receive chains 610, including first 610-1, second 610-2, third 610-3, and fourth 610-4 first-band receive chains, configured for receiving signals in the first frequency band. Each one of the four first-band receive chains 610 is switchably coupled to a respective one of the two first-band antennas 631 and the two dual-band antennas 635. The eight receive chains also include four second band receive chains 620, including first 620-1, second 620-2, third 620-3, and fourth 620-4 second-band receive chains, configured for receiving signals in the second frequency band. Each one of the four second-band receive chains 620 is switchably coupled to a respective one of the two second-band antennas 632 and the two dual-band antennas 635. The four transmit chains include two first-band transmit chains 615, including a first first-

band transmit chain 615-1, and a second first-band transmit chain 615-2, configured for transmitting signals in the first frequency band. Each one of the two first-band transmit chains 615 is switchably coupled to one of the two first-band antennas 631 or a first one of the two dual-band antennas 635. The four transmit chains also include two second-band transmit chains 625, including a first second-band transmit chain 625-1, and a second second-band transmit chain 625-2, configured for transmitting signals in the second frequency band. Each one of the two second-band transmit chains 625 is switchably coupled to one of the two second-band antennas 632 or a second one of the two dual-band antennas 635.

[0113] In communication device 600 of FIG. 6, the first first-band receive chain 610-1 is switchably coupled to either the first first-band antenna 631-1 or the first dual-band antenna 635-1 through a first switch 640-1. The first first-band transmit chain 615-1 is switchably coupled to either the first first-band antenna 631-1 or the first dual-band antenna 635-1 through a first switch 640-1. The third first-band receive chain 610-3 is switchably coupled to either the first dual-band antenna 635-1 or the first first-band antenna 631-1 through the first switch 640-1. The third second-band receive chain 620-3 is switchably coupled to either the first dual-band antenna 635-1 or the first second-band antenna 632-1 through a second switch 670-2. The first second-band transmit chain 625-1 is switchably coupled to either the first dual-band antenna 635-1 or the first second-band antenna 632-1 through the second switch 670-2. The first second-band receive chain 620-1 is switchably coupled to either the first second-band antenna 632-1 or the first dual-band antenna 635-1 through the second switch 640-2. The second first-band receive chain 610-2 is switchably coupled to either the second first-band antenna 631-2 or the second dual-band antenna 635-2 through a third switch 640-3. The second first-band transmit chain 615-2 is switchably coupled to either the second first-band antenna 631-2 or the second dual-band antenna 635-2 through the third switch. The fourth first-band receive chain 610-4 is switchably coupled to either the second dual-band antenna 635-2 or the second first-band antenna 631-2 through the third switch 640-3. The fourth second-band receive chain 620-4 is switchably coupled to either the second dual-band antenna 635-2 or the second second-band antenna 632-2 through a fourth switch 640-4. The second second-band transmit chain 625-2 is switchably coupled to either the second dual-band antenna 635-2 or the second second-band antenna 632-2 through a fourth switch 640-4. The second second-band receive chain 620-2 is switchably coupled to either

the second second-band antenna 632-2 or the second dual-band antenna 635-2 through the fourth switch 640-4.

[0114] As shown in FIG. 6, communication device 600 also includes a first diplexer 650-1 and a second diplexer 650-2. The first diplexer 650-1 couples the first dual-band antenna 635-1 to the first switch 640-1 and the second switch 640-2. The second diplexer 650-2 couples the second dual-band antenna 635-2 to the third switch 640-3 and the fourth switch 640-4.

[0115] FIG. 7A is a simplified block diagram illustrating part of a communication device 700 according to some embodiments of the present invention. FIG. 7A illustrates an example of 2T4R (1T2R + 1T2R) SRS configuration in n78 + n79 bands DL CA with DL 4x4 MIMO on n78+n79 and UL 2x2 MIMO n78/n79 with SRS antenna switching.

[0116] Similar to communication device 600 in FIG. 6, communication device 700 in FIG. 7A also includes eight receive chains (710-1, 710-2, 710-3, 710-4, 720-1, 720-2, 720-3, and 720-4), four transmit chains (715-1, 715-2, 725-1, and 725-2), six antennas (731-1, 731-2, 732-1, 732-2, 735-1, and 735-2), four switching components (740-1, 740-2, 740-3, and 740-4), and two diplexers (750-1 and 750-2). However, in the example of FIG. 7, the four switching components (740-1, 740-2, 740-3, and 740-4) are implemented with double-pole double-throw (DPDT) switches. Each DPDT switch is configured to couple two receive chains and a transmit chain to two alternative antennas. Therefore, each of the two poles of the DPDT switch is coupled to a respective receive chain, and a transmit chain shares a pole of the DPDT switch with one of the receive chains. Further, the first frequency band is identified as the n78 band, and the second frequency band is identified as the n79 band. Each DPDT switch provides 1T2R switching of n78 or n79 transmit (TX) chain connected to that switch. The two diplexers (750-1 and 750-2) are n78+n79 diplexers, used to combine n78 and n79 paths for shared antennas.

[0117] In communication device 700 of FIG. 7A, the first first-band (n78-band) receive chain 710-1 is switchably coupled to either the first first-band (n78-band) antenna 731-1 or the first dual-band antenna 735-1 through a first switch 740-1. The third first-band (n78-band) receive chain 710-3 is switchably coupled to either the first dual-band (n78/n79-band) antenna 735-1 or the first first-band (n78-band) antenna 731-1 through the first switch 740-1.

The third second-band (n79-band) receive chain 720-3 is switchably coupled to either the first dual-band (n78/n79-band) antenna 735-1 or the first second-band (n79-band) antenna 732-1 through a second switch 740-2. The first second-band (n79-band) receive chain 720-1 is switchably coupled to either the first second-band (n79-band) antenna 732-1 or the first dual-band (n78/n79-band) antenna 735-1 through the second switch 740-2. The second first-band (n78-band) receive chain 710-2 is switchably coupled to either the second first-band (n78-band) antenna 731-2 or the second dual-band (n78/n79-band) antenna 735-2 through a third switch 740-3. The fourth first-band (n78-band) receive chain 710-4 is switchably coupled to either the second dual-band (n78/n79-band) antenna 735-2 or the second first-band (n78-band) antenna 731-2 through the third switch 740-3. The fourth second-band (n79-band) receive chain 720-4 is switchably coupled to either the second dual-band (n78/n79-band) antenna 735-2 or the second second-band (n79-band) antenna 732-2 through a fourth switch 740-4. The second second-band (n79-band) receive chain 720-2 is switchably coupled to either the second second-band (n79-band) antenna 732-2 or the second dual-band (n78/n79-band) antenna 735-2 through the fourth switch 740-4.

[0118] In FIG. 7A, the first first-band (n78-band) transmit chain 715-1 shares a first pole of the first switch 740-1 with the first first-band (n78-band) receive chain 710-1, and is switchably coupled to either the first first-band (n78-band) antenna 731-1 or the first dual-band antenna 735-1 through a first switch 740-1. In some embodiments, the sharing of a single pole of the switch can be implemented through an additional single-pole double-throw (SPDT) switch. Similarly, the first second-band (n79-band) transmit chain 725-1 shares a first pole of the second switch 740-2 with the first second-band (n79-band) receive chain 720-1. The second first-band (n78-band) transmit chain 715-2 shares a first pole of the third switch 740-3 with the second first-band (n78-band) receive chain 710-2. The second second-band (n79-band) transmit chain 725-2 shares a first pole of the fourth switch 740-4 with the second second-band (n79-band) receive chain 720-2.

[0119] As described above, FIG. 7A illustrates an example of 2T4R (1T2R + 1T2R) SRS configuration in n78 + n79 Bands DL CA with DL 4x4 MIMO on n78+ n79 and UL 2x2 MIMO n78/n79 with SRS antenna switching. This embodiment can reduce insertion loss by use of two pairs of DPDT switches (instead of arrangements that might use 2x 4P4T

switches). The arrangement of diplexers and DPDT switches enables reduction of required number of antennas. Further, the use of two pairs of DPDT switches (instead of 2x 4P4T switches) can provide for layout flexibility and ease in locating RF front end components near their respective antennas and hence improving link budget of the device, for better total radiated power (TRP) and total isotropic sensitivity performance (TIS).

[0120] In communication device 700, the four first-band receive chains and the four second-band receive chains are configured to perform 4x4 MIMO (multiple-input multiple-output) down link (DL) communication, in the first and second frequency bands, respectively, with a base station with carrier aggregation (CA). Further, the two first-band transmit chains and the two second-band transmit chains are configured to perform 2x2 MIMO up link (UL) communication, in the first and second frequency bands, respectively, in TDD (time division duplexing) with a base station with UL antenna switching according to 1T2R SRS (sounding reference signal) protocol. The UL antenna switching includes a first switching state and a second antenna switching state, as described below with reference to FIGS. 7B and 7C. In some embodiments, only two TX chains in either the n78 band or the n79 band can be active at a time, whereas eight RX chains, i.e., four RX chains in the n78 band and four RX chains in the n79 band can be simultaneously active to support carrier aggregation (CA).

[0121] FIG. 7B is a simplified block diagram illustrating communication signal paths in a first antenna switching state of the communication device of FIG. 7A according to some embodiments of the present invention. FIG. 7B illustrates the connections between the transmit chains and the antennas in the first antenna switching state under the SRS UL antenna switching protocol. It can be seen that in the first antenna switching state, the first n78-band transmit chain 715-1 is coupled to the first n78-band antenna 731-1, the first n79-band transmit chain 725-1 is coupled to the first n79-band antenna 732-1, the second n78-band transmit chain 715-2 is coupled to the second n78-band antenna 731-2, and the second n79-band transmit chain 725-2 is coupled to the second n-79-band antenna 732-2. Since the receiver chains are not involved in the antenna switching, the connections of the receiver chains are shown in bold broken lines and are not described in detail here.

[0122] FIG. 7C is a simplified block diagram illustrating communication signal paths in a second antenna switching state of the communication device of FIG. 7A according to some embodiments of the present invention. FIG. 7C illustrates the connections between the transmit chains and the antennas in the second antenna switching state under the SRS UL antenna switching protocol. It can be seen that in the first antenna switching state, the first n78-band transmit chain 715-1 is coupled to the first n78/n79-band antenna 735-1, and the first n79-band transmit chain 725-1 is coupled to the first n78/n79-band antenna 735-1, the second n78-band transmit chain 715-2 is coupled to the second n78/n79-band antenna 735-2, and the second n79-band transmit chain 725-2 is coupled to the second n78/n79-band antenna 735-2. Again, since the receiver chains are not involved in the antenna switching, the connections of the receiver chains are shown in bold broken lines and are not described in detail here.

[0123] FIGS. 7D and 7E are tables listing the connections between the transmit and receive chains and the antennas in the first antenna switching state and the second antenna switching state according to some embodiments of the present invention. In FIG. 7D, the active n78 transmit chains and receive chains are shaded. In FIG. 7E, the active n79 transmit chains and receive chains are shaded.

[0124] As shown in FIG. 7D, in the first antenna switching state, the first first-band transmit chain n78 Tx0 is coupled to the first first-band antenna ANT-0, and the second first-band transmit chain n78 Tx1 is coupled to the second first-band antenna ANT-3. In the second antenna switching state, the first first-band transmit chain n78 Tx0 is coupled to the first dual-band antenna ANT-2, and the second first-band transmit chain n78 Tx1 is coupled to the second dual-band antenna ANT-4.

[0125] As shown in FIG. 7E, in the first antenna switching state, the first second-band transmit chain n79 Tx0 is coupled to the first second-band antenna ANT-1, and the second second-band transmit chain n79 Tx1 is coupled to the second second-band antenna ANT-5. In the second antenna switching state, the first second-band transmit chain n79 Tx0 is coupled to the first dual-band antenna ANT-2, and the second second-band transmit chain n79 Tx1 is coupled to the second second-band antenna ANT-4.

[0126] FIG. 8 is a simplified block diagram illustrating another example of the communication device of FIG. 7A according to some embodiments of the present invention. As shown in FIG. 8, communication device 800 is similar to communication device 700 of FIG. 7A, with the exception that the second first-band (n78-band) transmit chain 715-2 shares a second pole of the third switch 740-3 with the fourth first-band (n78-band) receive chain 710-2, and the second second-band (n79-band) transmit chain 725-2 shares a second pole of the fourth switch 740-4 with the fourth second-band (n79-band) receive chain 720-4. The operation of communication device 800 is otherwise similar to the operation of communication device 700 of FIG. 7A as described above.

[0127] FIG. 9 is a simplified block diagram illustrating another example of the communication device of FIG. 7A according to some embodiments of the present invention. As shown in FIG. 9, communication device 900 is similar to communication device 700 of FIG. 7A, with the exception that the first first-band (n78-band) transmit chain 715-1 shares a second pole of the first switch 740-1 with the third first-band (n78-band) receive chain 710-3, and the first second-band (n79-band) transmit chain 725-1 shares a second pole of the second switch 740-2 with the third second-band (n79-band) receive chain 720-3. The operation of communication device 900 is otherwise similar to the operation of communication device 700 of FIG. 7A as described above.

[0128] FIG. 10 is a simplified block diagram illustrating another example of the communication device of FIG. 7A according to some embodiments of the present invention. As shown in FIG. 10, communication device 1000 is similar to communication device 700 of FIG. 7A, with the exception that the first first-band (n78-band) transmit chain 715-1 shares a second pole of the first switch 740-1 with the third first-band (n78-band) receive chain 710-3, the first second-band (n79-band) transmit chain 725-1 shares a second pole of the second switch 740-2 with the third second-band (n79-band) receive chain 720-3, the second first-band (n78-band) transmit chain 715-2 shares a second pole of the third switch 740-3 with the fourth first-band (n78-band) receive chain 710-2, and the second second-band (n79-band) transmit chain 725-2 shares a second pole of the fourth switch 740-4 with the fourth second-band (n79-band) receive chain 720-4. The operation of communication device 1000 is

otherwise similar to the operation of communication device 700 of FIG. 7A as described above.

[0129] FIG. 11A is a simplified block diagram illustrating an example of another communication device according to some embodiments of the present invention. FIG. 11A illustrates an example of 1T4R AND 2T4R (1T2R + 1T2R) SRS Configuration – n78 + n79 Bands DL CA with DL 4x4 MIMO on n78+ n79 and UL 2x2 MIMO on n78/n79.

[0130] Similar to communication device 700 in FIG. 7A, communication device 1100 in FIG. 11A also includes eight receive chains (710-1, 710-2, 710-3, 710-4, 720-1, 720-2, 720-3, and 720-4), four transmit chains (715-1, 715-2, 725-1, and 725-2), six antennas (731-1, 731-2, 732-1, 732-2, 735-1, and 735-2), four switching components (1140-1, 1140-2, 1140-3, and 1140-4), and two diplexers (750-1 and 750-2). Further, the first frequency band is identified as the n78 band, and the second frequency band is identified as the n79 band. However, in the example of FIG. 11A, the four switching components (1140-1, 1140-2, 1140-3, and 1140-4) are implemented with triple-pole triple-throw (3P3T) switches. Each 3P3T switch is configured to couple two receive chains and a transmit chain to four alternative antennas. Further, the first frequency band is identified as the n78 band, and the second frequency band is identified as the n79 band.

[0131] In communication device 1100 of FIG. 11A, the first first-band (n78-band) receive chain 710-1 is switchably coupled to either the first first-band (n78-band) antenna 731-1 or the first dual-band antenna 735-1 through a first switch 1140-1. The third first-band (n78-band) receive chain 710-3 is switchably coupled to either the first dual-band (n78/n79-band) antenna 735-1 or the first first-band (n78-band) antenna 731-1 through the first switch 1140-1. The third second-band (n79-band) receive chain 720-3 is switchably coupled to either the first dual-band (n78/n79-band) antenna 735-1 or the first second-band (n79-band) antenna 732-1 through a second switch 1140-2. The first second-band (n79-band) receive chain 720-1 is switchably coupled to either the first second-band (n79-band) antenna 732-1 or the first dual-band (n78/n79-band) antenna 735-1 through the second switch 1140-2. The second first-band (n78-band) receive chain 710-2 is switchably coupled to either the second first-band (n78-band) antenna 731-2 or the second dual-band (n78/n79-band) antenna 735-2 through a third switch 1140-3. The fourth first-band (n78-band) receive chain 710-4 is

switchably coupled to either the second dual-band (n78/n79-band) antenna 735-2 or the second first-band (n78-band) antenna 731-2 through the third switch 1140-3. The fourth second-band (n79-band) receive chain 720-4 is switchably coupled to either the second dual-band (n78/n79-band) antenna 735-2 or the second second-band (n79-band) antenna 732-2 through a fourth switch 1140-4. The second second-band (n79-band) receive chain 720-2 is switchably coupled to either the second second-band (n79-band) antenna 732-2 or the second dual-band (n78/n79-band) antenna 735-2 through the fourth switch 1140-4.

[0132] In FIG. 11A, the first first-band (n78-band) transmit chain 715-1 shares a first pole of the first switch 1140-1 with the first first-band (n78-band) receive chain 710-1, and is switchably coupled to either the first first-band (n78-band) antenna 731-1 or the first dual-band antenna 735-1 through a first switch 1140-1. In some embodiments, the sharing of a single pole of the switch can be implemented through an additional single-pole double-throw (SPDT) switch. Similarly, the first second-band (n79-band) transmit chain 725-1 shares a first pole of the second switch 1140-2 with the first second-band (n79-band) receive chain 720-1. The second first-band (n78-band) transmit chain 715-2 shares a first pole of the third switch 1140-3 with the second first-band (n78-band) receive chain 710-2. The second second-band (n79-band) transmit chain 725-2 shares a first pole of the fourth switch 1140-4 with the second second-band (n79-band) receive chain 720-2.

[0133] In FIG. 11A, each of the 3P3T switches 1140 provides 1T2R switching of the n78 or n79 TX chain attached to that switch. Additionally, a path is provided between the n78 3P3T switches and the n79 3P3T switches allowing the switches to support 1T4R switching of n78 or n79 TX chains. In Fig. 11A, the 3P3T switches allow each transmit chain to switch among four antennas for SRS UL 1T4R antenna switching. As shown in FIG. 11A, the first switch 1140-1 is coupled to the third switch 1140-3, and the second switch 1140-2 is coupled to the fourth switch 1140-4. FIG. 11B illustrates an example of the four possible signal paths for a transmit chain.

[0134] FIG. 11B is a simplified block diagram illustrating an example of antenna switching communication signal paths for a transmit chain in the communication device of FIG. 11A according to some embodiments of the present invention. As shown by the bold broken lines in FIG. 11B, the first n78-band transmit chain 715-1 (n78 TX Chan-0) can be connected to

one of four antennas based on the instruction from the base station. In the first signal path 1151-1, n78 transmit chain 715-1 is coupled to the first n78-band antenna 731-1 through the first switch 1140-1. In the second signal path 1151-2, n78 transmit chain 715-1 is coupled to the first n78/n79-band antenna 735-1 through the first switch 1140-1 and the first diplexer 750-1. In the third signal path 1151-3, n78 transmit chain 715-1 is coupled to the second n78-band antenna 731-2 through the first switch 1140-1 and the third switch 1150-3. In the fourth signal path 1151-4, n78 transmit chain 715-1 is coupled to the second n78/n79-band antenna 735-2 through the first switch 1140-1, the third switch 1150-3, and the second diplexer 750-2. Similarly, it can be shown from FIG. 11A that each of the second n78-band transmit chain 715-2, the first n79-band transmit chain 725-1, and the second n79-band transmit chain 725-2 can be connected to one of four antennas based on the instruction from the base station.

[0135] As described above, FIG. 11A illustrates an example of 2T4R (1T2R + 1T2R) and 1T4R configuration in n78 + n79 Bands DL CA with DL 4x4 MIMO on n78+ n79 and UL 2x2 MIMO n78/n79 with SRS antenna switching. This embodiment can reduce insertion loss by use of two pair of 3P3Ts (e.g., instead of arrangements that might use 2x 4P4T switches in cascade with other switches). The arrangement of diplexers and 3P3T enables reduction of required number of antennas. The use of two pairs of 3P3Ts provides for layout flexibility and ease in locating RF front end components near their respective antennas and hence improving link budget of the device, for better total radiated power (TRP) and total isotropic sensitivity performance (TIS).

[0136] FIG. 12 is a simplified block diagram illustrating another example of the communication device of FIG. 11A according to some embodiments of the present invention. As shown in FIG. 12, communication device 1200 is similar to communication device 1100 of FIG. 11A, with the exception that the second first-band (n78-band) transmit chain 715-2 shares a second pole of the third switch 1140-3 with the fourth first-band (n78-band) receive chain 710-2, and the second second-band (n79-band) transmit chain 725-2 shares a second pole of the fourth switch 1140-4 with the fourth second-band (n79-band) receive chain 720-4. The operation of communication device 1200 is otherwise similar to the operation of communication device 1100 of FIG. 11A as described above.

[0137] FIG. 13 is a simplified block diagram illustrating another example of the communication device of FIG. 11A according to some embodiments of the present invention. As shown in FIG. 13, communication device 1300 is similar to communication device 1100 of FIG. 11A, with the exception that the first first-band (n78-band) transmit chain 715-1 shares a second pole of the first switch 1140-1 with the third first-band (n78-band) receive chain 710-3, and the first second-band (n79-band) transmit chain 725-1 shares a second pole of the second switch 1140-2 with the third second-band (n79-band) receive chain 720-3. The operation of communication device 1300 is otherwise similar to the operation of communication device 1100 of FIG. 11A as described above.

[0138] FIG. 14 is a simplified block diagram illustrating another example of the communication device of FIG. 11A according to some embodiments of the present invention. As shown in FIG. 14, communication device 1400 is similar to communication device 1100 of FIG. 11A, with the exception that the first first-band (n78-band) transmit chain 715-1 shares a second pole of the first switch 1140-1 with the third first-band (n78-band) receive chain 710-3, the first second-band (n79-band) transmit chain 725-1 shares a second pole of the second switch 1140-2 with the third second-band (n79-band) receive chain 720-3, the second first-band (n78-band) transmit chain 715-2 shares a second pole of the third switch 1140-3 with the fourth first-band (n78-band) receive chain 710-2, and the second second-band (n79-band) transmit chain 725-2 shares a second pole of the fourth switch 1140-4 with the fourth second-band (n79-band) receive chain 720-4. The operation of communication device 1400 is otherwise similar to the operation of communication device 1100 of FIG. 11A as described above.

[0139] FIG. 15 is a simplified flowchart illustrating a method for operating a communication device according to some embodiments of the present invention. The method enables a communication device, such as a user equipment, to perform MIMO communication with a base station in multiple frequency bands using a limited number of antennas. The embodiments described herein relate to a switching scheme for a six antenna approach. However, this scheme can also be adapted to any suitable situation involving the use of shared antennas for n78 and n79 or other suitable frequency bands.

[0140] Embodiments support simultaneous operation of n78 and n79 bands (DL CA), while also supporting DL 4x4 MIMO (e.g., FIG. 2 Figure 3) and 2T4R/1T4R (e.g., FIGS. 3A and 3B Figure 5, Figure 4) for each of these bands. Embodiments provide for a novel antenna architecture, with novel form factor and mechanical/thermal design constraints, which in some examples, includes six antennas that can support n78 and n79 (2 dedicated n78 band antennas, two dedicated n79 band antennas and two shared n78+n79 band antennas). Some of these antennas can also be shared with other antennas (other cellular bands, GNSS, WLAN, BT, etc.).

[0141] This antenna architecture may lead to a switching scheme which enables support of DL 4x4 MIMO + 2x2 UL MIMO + 2T4R/1T4R SRS capabilities while allowing for DL CA of n78 and n79 bands. The scheme, presented in this disclosure, minimizes insertion loss (and hence TX and RX lineup path loss), provides flexibility of routing to different antennas, and allows the use of shared antennas for n78 and n79.

[0142] From an RF and antenna architecture perspective, to support DL 4x4 MIMO + 2x2 UL MIMO + 2T4R/1T4R SRS, while also allowing for DL CA of n78 and n79 bands, connections are provided for simultaneously connecting four antennas to n78 TX/RX chains and four antennas to n79 TX/RX chains.

[0143] There can be many permutations in which the above functions can be implemented. For example, the following can be implemented: eight antennas (four dedicated n78, four dedicated n79); seven antennas (three dedicated n78, three dedicated n79, one shared n78+n79); six antennas (two dedicated n78, two dedicated n79, two shared n78+n79); five antennas (one dedicated n78, one dedicated n79, three shared n78+n79); or four antennas (four shared n78+n79).

[0144] These configurations are independent of the total number of antennas in the system which likely would include many other cellular and WLAN bands, and the above examples merely identify how many antennas in the system would have to be capable of operating in n78 and n79 bands. Some of these antennas could be shared with cellular bands, some could be shared with WLAN bands and yet some might be dedicated to either n78 band or n79 band or both.

[0145] As shown in the flowchart in FIG. 15, method 1500 for wireless communication can be summarized as follows.

1510: providing a communication device having four first-band receive chains, four second-band receive chains, two first-band transmit chains, two second-band transmit chains, and six antennas;

1520: performing 4x4 MIMO (multiple-input multiple-output) down link (DL) communication with a base station, in the first and second frequency bands with carrier aggregation (CA);

1530: performing 2x2 MIMO up link (UL) communication with the base station, in the first and second frequency bands, in TDD (time division duplexing);

1540: performing up link antenna switching to connect a given transmit chain to one of two antennas based on a signal from the base station; and

1550: performing up link antenna switching to connect a given transmit chain to one of four antennas based on a signal from the base station according to a 1T4R (one transmitter and four receiver) SRS (sounding reference signal) protocol.

[0146] Each of the above processes is further described below with reference to FIGS. 1-14. At 1510, the method includes providing a communication device having four first-band receive chains, four second-band receive chains, two first-band transmit chains, two second-band transmit chains, and six antennas. Examples of the communication device are described above in connection with FIGS. 4-14. In the examples of FIGS. 4-14, the communication device has six antennas including two first-band antennas, two second-band antennas, and two dual-band antennas, the two dual-band antennas configured to operate in the first-band and the second-band.

[0147] At 1520, the method includes performing 4x4 MIMO (multiple-input multiple-output) down link (DL) communication with a base station, in the first and second frequency bands with carrier aggregation (CA). For example, in communication devices 700 of FIG. 7A and communication device 1100 in FIG. 11A, there are four first-band receiver chains, four second-band receiver chains that can provide 4x4 MIMO (multiple-input multiple-

output) down link (DL) communication with a base station, in the n78 and n79 bands with carrier aggregation (CA).

[0148] At 1530, the method includes performing 2x2 MIMO up link (UL) communication with the base station, in either the first frequency band or the second frequency band, in TDD (time division duplexing). For example, in communication devices 700 of FIG. 7A and communication device 1100 in FIG. 11A, there are two first-band transmit chains and two second-band transmit chains that can provide 2x2 MIMO up link (UL) communication with the base station, in the n78 and n79 bands.

[0149] At 1540, the method includes performing up link antenna switching to connect a given transmit chain to one of two antennas based on a signal from the base station. For example, in communication devices 700 of FIG. 7A, the transmit chains and the receiver chains are coupled to the antennas using four 2P2T switches and two diplexers. The antenna switching is performed according to a 2T4R (two transmitter and four receiver) SRS (sounding reference signal) protocol.

[0150] At 1550, the method includes performing up link antenna switching to connect a given transmit chain to one of four antennas based on a signal from the base station according to a 1T4R (one transmitter and four receiver) SRS (sounding reference signal) protocol. For example, in communication devices 1100 of FIG. 11A, the transmit chains and the receiver chains are coupled to the antennas using four 3P3T switches and two diplexers. The antenna switching is performed according to a 1T4R (one transmitter and four receiver) SRS (sounding reference signal) protocol.

[0151] As described above, in some embodiments, two pairs of DPDT switches are used along with n78-n79 diplexers and arrange the ports to support 2T4R SRS. This approach permits use of antenna sharing between n78 and n79 which helps reduce the total number of antennas in the device, while minimizing the amount of switching on a path. The arrangement also provides for reduced insertion loss and provides simplified and flexible routing of RF paths, when compared to use of 2x 4P4T switches. Use of two pairs of DPDT switches helps in locating RF front end components near their respective antennas, hence improving link budget of the device.

[0152] In some embodiments, the concept is extended to provide 1T4R support in addition to 2T4R support. In this scheme, the idea is to use two pairs of 3P3T switches along with n78-n79 diplexers and arrange the ports to support both 2T4R and 1T4R SRS. This approach also permits use of antenna sharing between n78 and n79, which helps reduce the total number of antennas in the device, while minimizing the amount of switching on a path and reduced insertion loss compared to cascaded switches and/or using 4P4T switches. Use of two pairs of 3P3T switches helps in locating RF front end components near their respective antennas and hence improving link budget of the device.

[0153] It should be appreciated that the specific steps illustrated in FIG. 15 provide a particular method of operating a communication device according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 15 may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0154] While various embodiments of the invention have been described above, it should be understood that they have been presented by way of example only, and not by way of limitation. Likewise, the various diagrams may depict an example architectural or other configuration for the disclosure, which is done to aid in understanding the features and functionality that can be included in the disclosure. The disclosure is not restricted to the illustrated example architectures or configurations, but can be implemented using a variety of alternative architectures and configurations. Additionally, although the disclosure is described above in terms of various exemplary embodiments and implementations, it should be understood that the various features and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described. They instead can be applied alone or in some combination, to one or more of the other embodiments of the disclosure, whether or not such embodiments are described, and whether or not such features are presented as being a part of a described

embodiment. Thus the breadth and scope of the present disclosure should not be limited by any of the above-described exemplary embodiments.

[0155] It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to different functional units and processors.

5 However, it will be apparent that any suitable distribution of functionality between different functional units, processors or domains may be used without detracting from the invention. For example, functionality illustrated to be performed by separate processors or controllers may be performed by the same processor or controller. Hence, references to specific functional units are only to be seen as references to suitable means for providing the
10 described functionality, rather than indicative of a strict logical or physical structure or organization.

[0156] Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing: the term “including” should be read as meaning “including, without limitation”
15 or the like; the term “example” is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof; and adjectives such as “conventional,” “traditional,” “normal,” “standard,” “known”, and terms of similar meaning, should not be construed as limiting the item described to a given time period, or to an item available as of a given time. But instead these terms should be read to encompass conventional, traditional,
20 normal, or standard technologies that may be available, known now, or at any time in the future. Likewise, a group of items linked with the conjunction “and” should not be read as requiring that each and every one of those items be present in the grouping, but rather should be read as “and/or” unless expressly stated otherwise. Similarly, a group of items linked with the conjunction “or” should not be read as requiring mutual exclusivity among that group, but
25 rather should also be read as “and/or” unless expressly stated otherwise. Furthermore, although items, elements or components of the disclosure may be described or claimed in the singular, the plural is contemplated to be within the scope thereof unless limitation to the singular is explicitly stated. The presence of broadening words and phrases such as “one or more,” “at least,” “but not limited to”, or other like phrases in some instances shall not be

read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent.

[0157] It is also understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims.

WHAT IS CLAIMED IS:

1 1. A multiple-input, multiple-output (MIMO) transceiver, comprising:
2 a plurality of RF chains;
3 a plurality of antennas;
4 a plurality of switching components; and
5 a control circuitry operatively coupled to the plurality of switching
6 components.

1 2. The MIMO transceiver of claim 1, wherein a total quantity of RF
2 chains included in the plurality of RF chains is equal to a first value, and a total quantity of
3 antennas included in the plurality of antennas is equal to a second value that is less than the
4 first value.

1 3. The MIMO transceiver of claim 2, wherein the plurality of RF chains
2 comprises:
3 a first plurality of RF chains comprising electronics configured to support
4 communication on a first RF band; and
5 a second plurality of RF chains comprising electronics configured to support
6 communication on a second RF band.

1 4. The MIMO transceiver of claim 3, wherein the plurality of antennas
2 comprises:
3 a first antenna configured to communicate on the first RF band;
4 a second antenna configured to communicate on a second RF band different
5 from the first RF band; and
6 a third antenna configured to communicate on the first and second RF bands.

1 5. The MIMO transceiver of claim 4, wherein the plurality of switching
2 components comprises a first switching component electrically coupled to two of the first
3 plurality of RF chains, the first antenna, and the third antenna.

1 6. The MIMO transceiver of claim 5, wherein the plurality of switching
2 components further comprises a second switching component electrically coupled to two of
3 the second plurality of RF chains, the second antenna, and the third antenna.

1 7. The MIMO transceiver of claim 6, wherein the control circuitry is
2 configured to selectively cause the first switching component to toggle between

3 (i) a state in which a first one of the first plurality of RF chains is electrically
4 coupled to the first antenna and a second one of the plurality of the RF chains is electrically
5 coupled to the third antenna; and

6 (ii) a state in which the first one of the first plurality of the RF chains is
7 electrically coupled to the third antenna and the second one of the first plurality of RF chains
8 is electrically coupled to the first antenna.

1 8. The MIMO transceiver of claim 7, wherein the control circuitry is
2 configured to selectively cause the second switching component to toggle between:

3 (i) a state in which a first one of the second plurality of RF chains is
4 electrically coupled to the second antenna and a second one of the second plurality of RF
5 chains is electrically coupled to the third antenna; and

6 (ii) a state in which the first one of the second plurality of RF chains is
7 electrically coupled to the third antenna and the second one of the second plurality of RF
8 chains is electrically coupled to the second antenna.

1 9. The MIMO transceiver of claim 8, wherein the transceiver is
2 configured to communicate with a base station; and

3 wherein the transceiver is configured to selectively cause one or both of the
4 first and second switching components to toggle from states in response to receiving a
5 command to do so from the base station.

1 10. The MIMO transceiver of claim 9, wherein the transceiver is
2 configured to communicate with the base station in accordance with a time division
3 duplexing (TDD) protocol.

1 11. The MIMO transceiver of claim 10, wherein the transceiver is
2 configured to selectively cause one or both of the first and second switching components to
3 toggle from states in accordance with an SSR protocol.

1 12. The MIMO transceiver of claim 11, wherein the transceiver further
2 comprises a diplexer, and the first and second switching components are electrically coupled
3 to the third antenna by way of the diplexer.

1 13. The MIMO transceiver of claim 12, wherein each switching
2 component in the plurality of switching components is a double-pole double-throw switch.

1 14. The MIMO transceiver of claim 1, wherein the transceiver is
2 configured to communicate with a base station.

1 15. The MIMO transceiver of claim 6, wherein the plurality of antennas
2 further includes:

- 3 a fourth antenna configured to communicate on the first RF band;
4 a fifth antenna configured to communicate on the second RF band; and
5 a sixth antenna configured to communicate on the first and second RF bands.

1 16. The MIMO transceiver of claim 15, wherein the plurality of switching
2 components further includes:

- 3 a third switching component electrically coupled to two of the first plurality of RF
4 chains, the fourth antenna, and the sixth antenna; and
5 a fourth switching component electrically coupled to two of the second plurality of
6 RF chains, the fifth antenna, and the sixth antenna.

1 17. The MIMO transceiver of claim 16, wherein the control circuitry is
2 further configured to:

3 selectively cause the third switching component to toggle between:

4 (i) a state in which a third one of the first plurality of RF chains is electrically
5 coupled to the fourth antenna and a fourth one of the first plurality of RF chains is electrically
6 coupled to the sixth antenna; and

7 (ii) a state in which the third one of the first plurality of RF chains is
8 electrically coupled to the sixth antenna and the fourth one of the first plurality of RF chains
9 is electrically coupled to the fourth antenna; and

10 selectively cause the fourth switching component to toggle between:

11 (i) a state in which a third one of the second plurality of RF chains is
12 electrically coupled to the fifth antenna and a fourth one of the second plurality of RF chains
13 is electrically coupled to the sixth antenna; and

14 (ii) a state in which the third one of the second plurality of RF chains is
15 electrically coupled to the sixth antenna and the fourth one of the second plurality of RF
16 chains is electrically coupled to the fifth antenna.

1 18. The MIMO transceiver of claim 17, wherein each switching
2 component in the plurality of switching components is a triple-pole triple-throw (3P3T)
3 switch.

1 19. The MIMO transceiver of claim 18, wherein the first switching
2 component is electrically coupled to the third switching component, and the second switching
3 component is electrically coupled to the fourth switching component.

1 20. The MIMO transceiver of claim 19, further comprising a diplexer,
2 wherein the third and fourth switching components are electrically coupled to the sixth
3 antenna by way of the diplexer.

1 21. The MIMO transceiver of claim 3, wherein the first and second RF
2 bands correspond to n78 and n79 bands, respectively.

1 22. The MIMO transceiver of claim 1, wherein at least a portion of the RF
2 chains comprises electronics configured to support RF transmission.

1 23. The MIMO transceiver of claim 1, wherein at least a portion of the RF
2 chains comprises electronics that are not configured to support RF transmission.

1 24. The MIMO transceiver of claim 1, wherein at least a portion of the RF
2 chains comprises electronics configured to support RF reception.

1 25. The MIMO transceiver of claim 1, wherein each of the RF chains
2 comprises electronics configured to support RF reception.

1 26. A wearable device comprising the MIMO transceiver of any of claims
2 1-25.

1 27. A communication device, comprising six antennas, eight receive
2 chains, and four transmit chains;

3 wherein the six antennas comprise:

4 two first-band antennas, including a first first-band antenna and a
5 second first-band antenna, configured for communication in a first frequency band;

6 two second-band antennas, including a first second-band antenna and a
7 second second-band antenna, configured for communication in a second frequency band; and

8 two dual-band antennas, including a first dual-band antenna and a
9 second dual-band antenna, configured for communication in both the first frequency band
10 and second frequency band;

11 wherein the eight receive chains comprise:

12 four first-band receive chains, including first, second, third, and fourth
13 first-band receive chains, configured for receiving signals in the first frequency band, each
14 one of the four first-band receive chains being switchably coupled to a respective one of the
15 two first-band antennas and the two dual-band antennas; and

16 four second band receive chains, including first, second, third, and
17 fourth second-band receive chains, configured for receiving signals in the second frequency

band, each one of the four second-band receive chains being switchably coupled to a respective one of the two second-band antennas and the two dual-band antennas;

wherein the four transmit chains comprise:

two first-band transmit chains, including a first first-band transmit chain and a second first-band transmit chain, configured for transmitting signals in the first frequency band, each one of the two first-band transmit chains being switchably coupled to one of the two first-band antennas or a first one of the two dual-band antennas; and

two second-band transmit chains, including a first second-band transmit chain and a second second-band transmit chain, configured for transmitting signals in the second frequency band, each one of the two second-band transmit chains being switchably coupled to one of the two second-band antennas or a second one of the two dual-band antennas.

28. The communication device of claim 27, wherein:

each of the first first-band receive chain, the first first-band transmit chain, and the third first-band receive chain is switchably coupled to either the first first-band antenna or the first dual-band antenna through a first switch;

each of the third second-band receive chain, the first second-band transmit chain, and the first second-band receive chain is switchably coupled to either the first dual-band antenna or the first second-band antenna through a second switch;

each of the second first-band receive chain, the second first-band transmit chain, and the fourth first-band receive chain is switchably coupled to either the second first-band antenna or the second dual-band antenna through a third switch; and

each of the fourth second-band receive chain, the first second-band transmit chain, and the second second-band receive chain is switchably coupled to either the second dual-band antenna or the second second-band antenna through a fourth switch.

29. The communication device of claim 28, further comprising a first diplexer and a second diplexer, wherein:

the first diplexer couples the first dual-band antenna to the first switch and the second switch; and

the second diplexer couples the second dual-band antenna to the third switch and the fourth switch.

1 30. The communication device of claim 29, wherein each of the first
2 switch, the second switch, the third switch, and the fourth switch is a DPDT (double-pole
3 double-throw, or 2P2T)) switch.

1 31. The communication device of claim 30, wherein the four first-band
2 receive chains and the four second-band receive chains are configured to perform 4x4 MIMO
3 (multiple-input multiple-output) down link (DL) communication, with carrier aggregation
4 (CA) in the first and second frequency bands, with a base station,
5 wherein the two first-band transmit chains and the two second-band transmit
6 chains are configured to perform 2x2 MIMO up link (UL) communication, in the first and
7 second frequency bands, respectively, in TDD (time division duplexing) with a base station
8 with UL antenna switching according to 1T2R SRS (sounding reference signal) protocol.

1 32. The communication device of claim 31, wherein the UL antenna
2 switching comprises a first antenna switching state and a second antenna switching state.

1 33. The communication device of claim 32, wherein:
2 in the first antenna switching state:
3 the first first-band transmit chain is coupled to the first first-band
4 antenna;
5 the first second-band transmit chain is coupled to the first dual-band
6 antenna;
7 the second first-band transmit chain is coupled to the second first-band
8 antenna; and
9 the second second-band transmit chain is coupled to the second
10 second-band antenna; and
11 in the second antenna switching state:
12 the first first-band transmit chain is coupled to the first dual-band
13 antenna;
14 the first second-band transmit chain is coupled to the first second-band
15 antenna;
16 the second first-band transmit chain is coupled to the second dual-band
17 antenna; and

the second second-band transmit chain is coupled to the second second-band antenna.

34. The communication device of claim 32, wherein:

in the first antenna switching state:

the first first-band transmit chain is coupled to the first first-band antenna;

the first second-band transmit chain is coupled to the first dual-band antenna;

the second first-band transmit chain is coupled to the second dual-band antenna; and

the second second-band transmit chain is coupled to the second dual-band antenna; and

in the second antenna switching state:

the first first-band transmit chain is coupled in the first dual-band antenna;

the first second-band transmit chain is coupled to the first second-band antenna;

the second first-band transmit chain is coupled to the second first-band antenna; and

the second second-band transmit chain is coupled to the second second-band antenna.

35. The communication device of claim 32, wherein:

in the first antenna switching state:

the first first-band transmit chain is coupled to the first dual-band antenna;

the first second-band transmit chain is coupled to the first dual-band antenna;

the second first-band transmit chain is coupled to the second first-band antenna; and

the second second-band transmit chain is coupled to the second second-band antenna; and

11 in the second antenna switching state:
12 the first first-band transmit chain is coupled to the first first-band
13 antenna;
14 the first second-band transmit chain is coupled to the first second-band
15 antenna;
16 the second first-band transmit chain is coupled to the second dual-band
17 antenna; and
18 the second second-band transmit chain is coupled to the second dual-
19 band antenna.

1 36. The communication device of claim 32, wherein:
2 in the first antenna switching state:
3 the first first-band transmit chain is coupled to the first dual-band
4 antenna;
5 the first second-band transmit chain is coupled to the first dual-band
6 antenna;
7 the second first-band transmit chain is coupled to the second dual-band
8 antenna; and
9 the second second-band transmit chain is coupled to the second dual-
10 band antenna; and

11 in the second antenna switching state:
12 the first first-band transmit chain is coupled to the first first-band
13 antenna;
14 the first second-band transmit chain is coupled to the first second-band
15 antenna;
16 the second first-band transmit chain is coupled to the second first-band
17 antenna; and
18 the second second-band transmit chain is coupled to the second
19 second-band antenna.

1 37. The communication device of claim 29, wherein:
2 each one of the two first-band transmit chains is switchably coupled to any
3 one of the two first-band antennas and the two dual-band antennas; and

each one of the two second-band transmit chains is switchably coupled to any one of the two second-band antennas and the two dual-band antennas.

38. The communication device of claim 37, wherein each of the first switch, the second switch, the third switch, and the fourth switch is a 3P3T (triple-pole triple-throw) switch.

39. The communication device of claim 38, wherein:
the first switch is coupled to the third switch; and
the second switch is coupled to the fourth switch.

40. The communication device of claim 37, wherein the two first-band transmit chains and the two second-band transmit chains are configured to perform 2x2 MIMO up link (UL) communication, in the first and second frequency bands, respectively, in TDD (time division duplexing) with a base station with UL antenna switching according to 1T4R SRS (sounding reference signal) protocol.

41. A method for wireless communication, comprising:
providing a communication device having four first-band receive chains, four second-band receive chains, two first-band transmit chains, two second-band transmit chains, and six antennas;
performing 4x4 MIMO (multiple-input multiple-output) down link (DL) communication with a base station, in the first and second frequency bands with carrier aggregation (CA);
performing 2x2 MIMO up link (UL) communication with the base station, in the first and second frequency bands, in TDD (time division duplexing); and
performing up link antenna switching to connect a given transmit chain to one of two antennas based on a signal from the base station.

42. The method of claim 41, wherein the six antennas comprise two first-band antennas, two second-band antennas, and two dual-band antennas, the two dual-band antennas configured to operate in the first-band and the second-band.

1 43. The method of claim 42, further comprising coupling the transmit
2 chains and the receiver chains to the antennas using four 2P2T switches and two diplexers.

1 44. The method of claim 43, wherein the antenna switching is performed
2 according to a 2T4R (two transmitter and four receiver) SRS (sounding reference signal)
3 protocol.

1 45. The method of claim 42, further comprising performing up link
2 antenna switching to connect a given transmit chain to one of four antennas based on a signal
3 from the base station according to a 1T4R (one transmitter and four receiver) SRS (sounding
4 reference signal) protocol.

1 46. The method of claim 45, further comprising coupling the transmit
2 chains and the receiver chains to the antennas using four 3P3T switches and two diplexers.

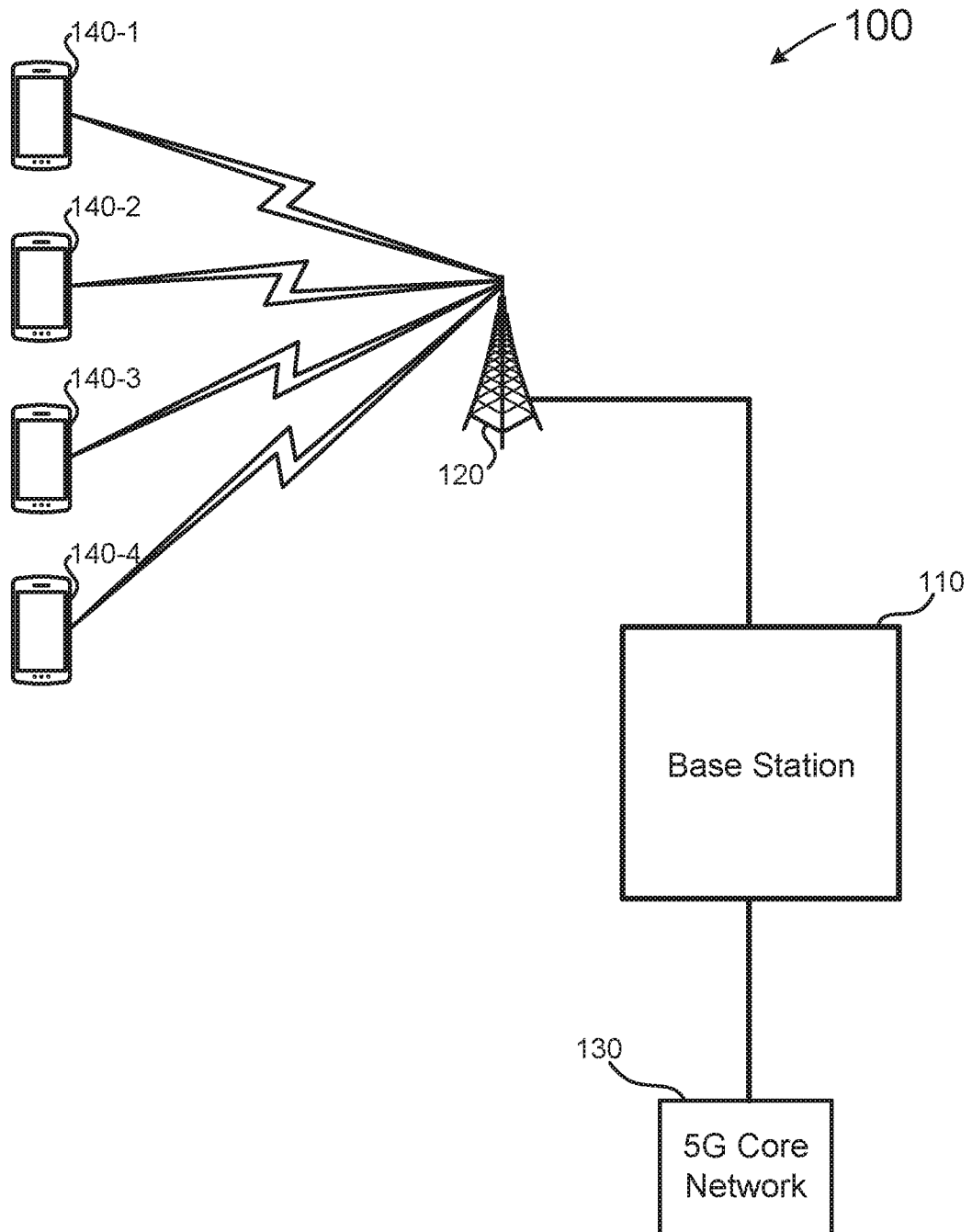


FIG. 1

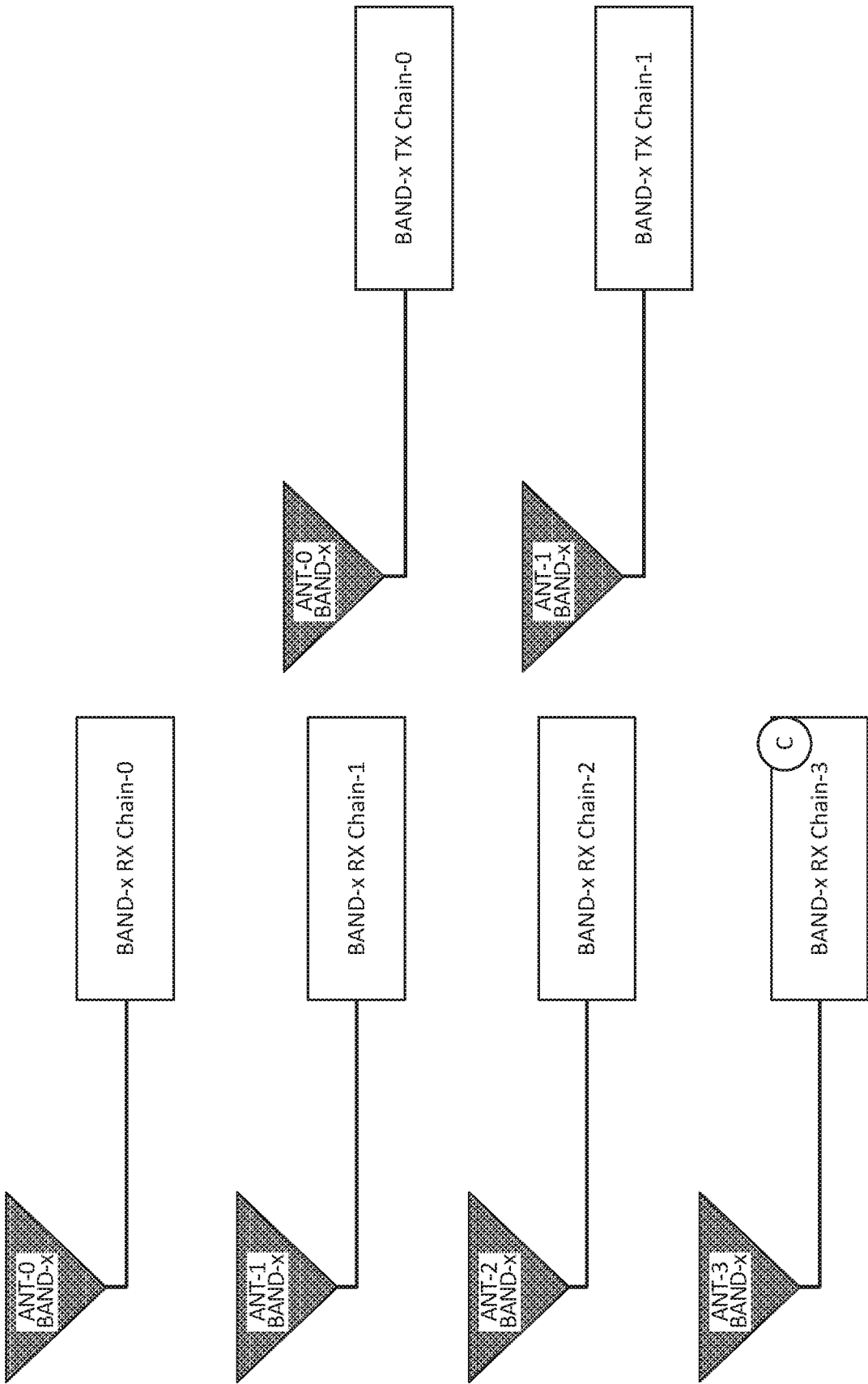


FIG. 2B

FIG. 2A

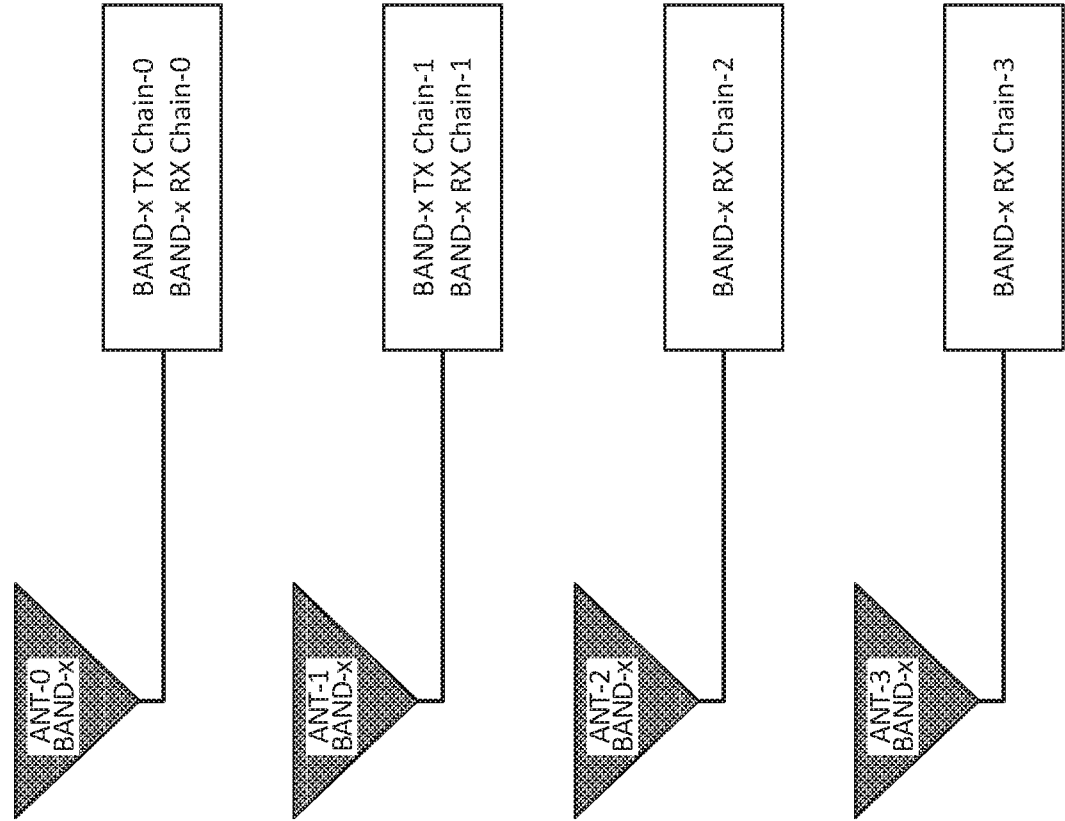


FIG. 2C

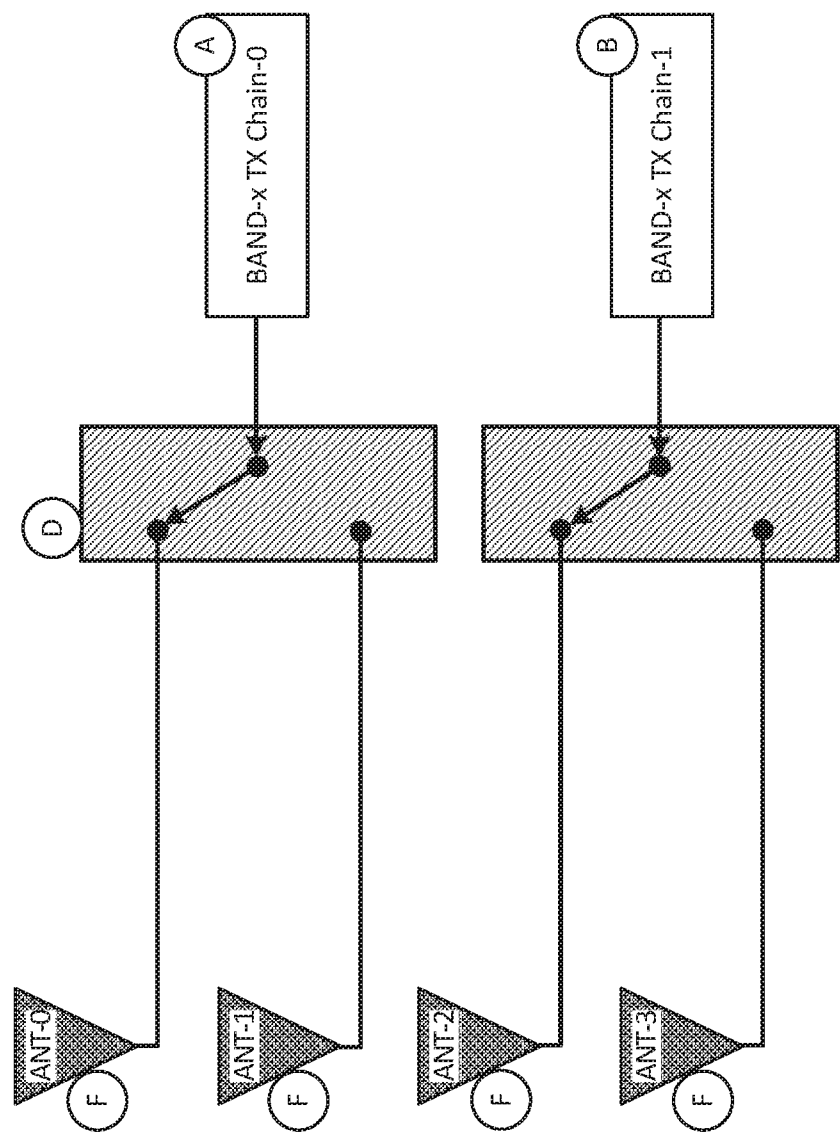


FIG. 3A

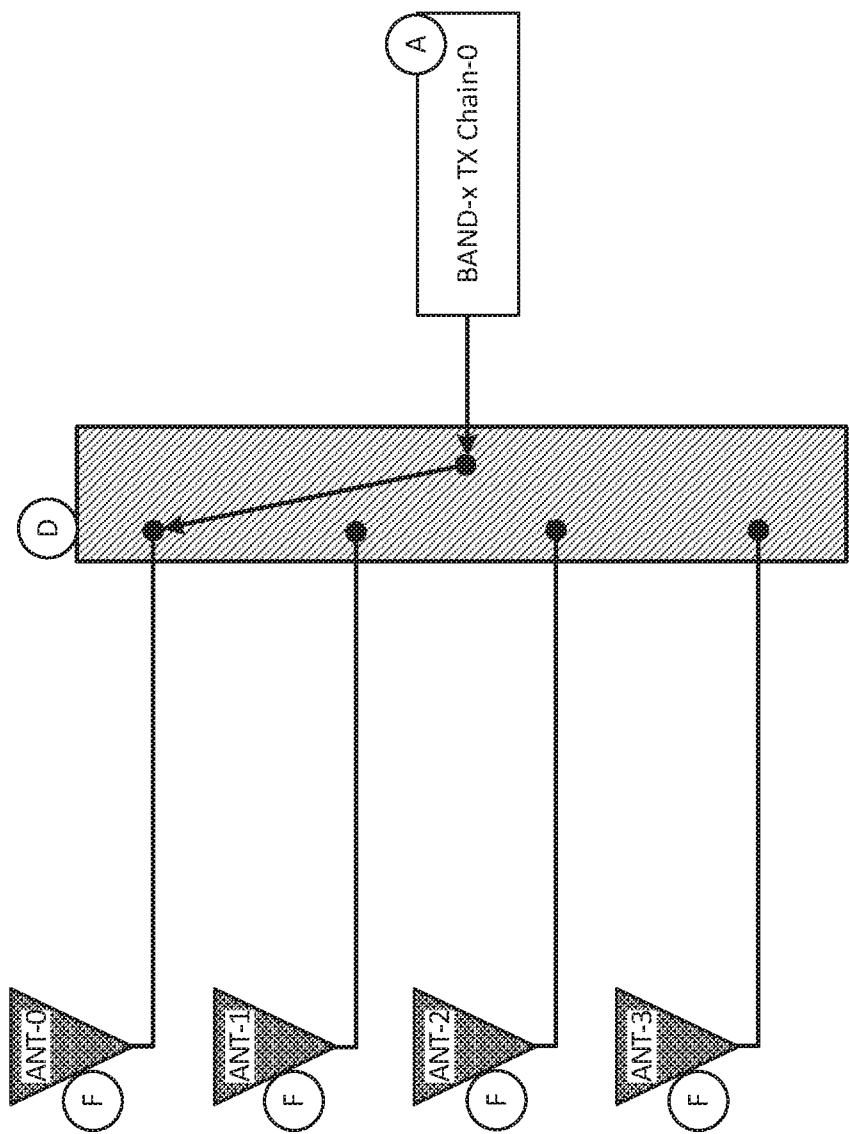


FIG. 3B

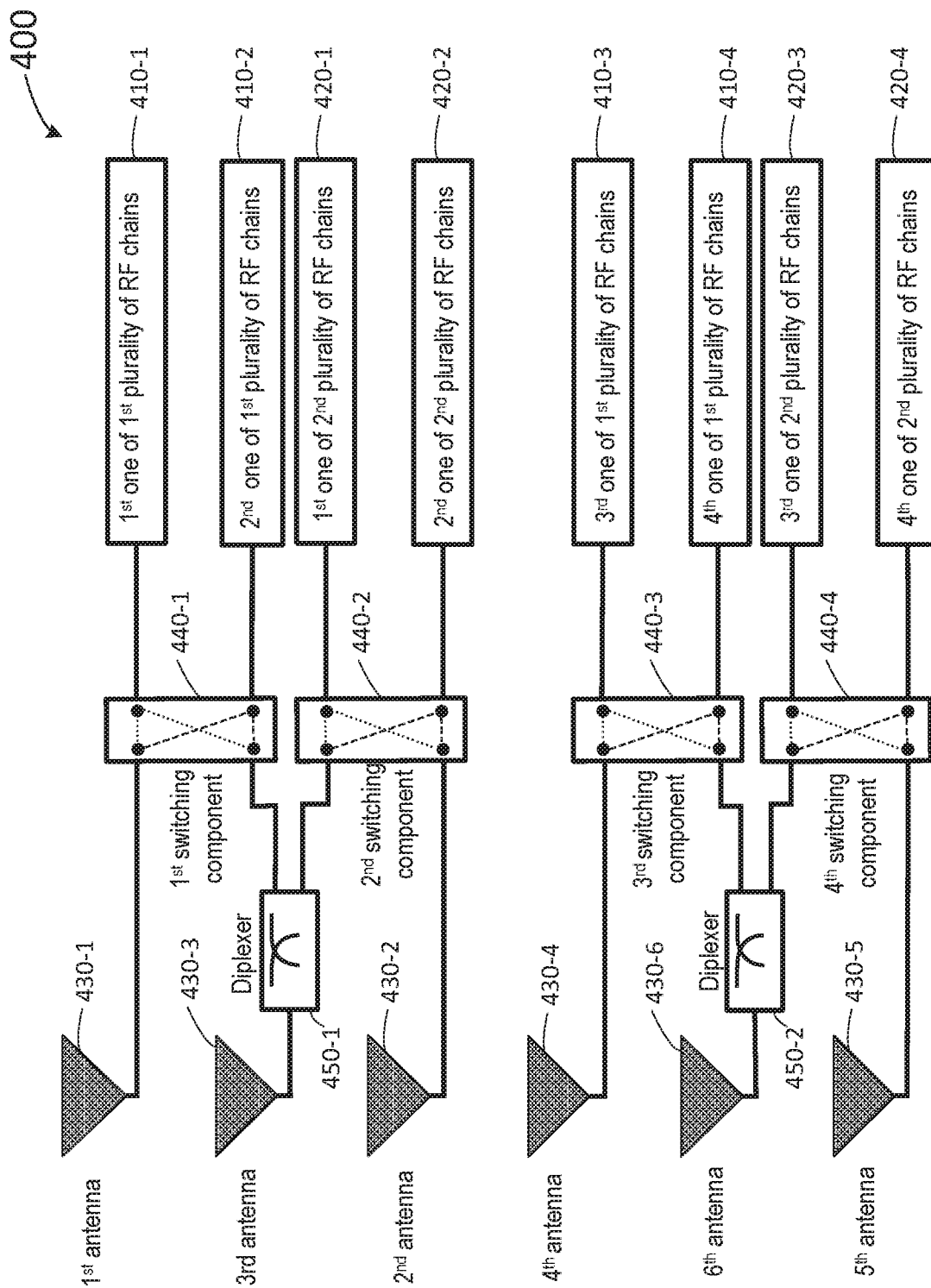


FIG. 4

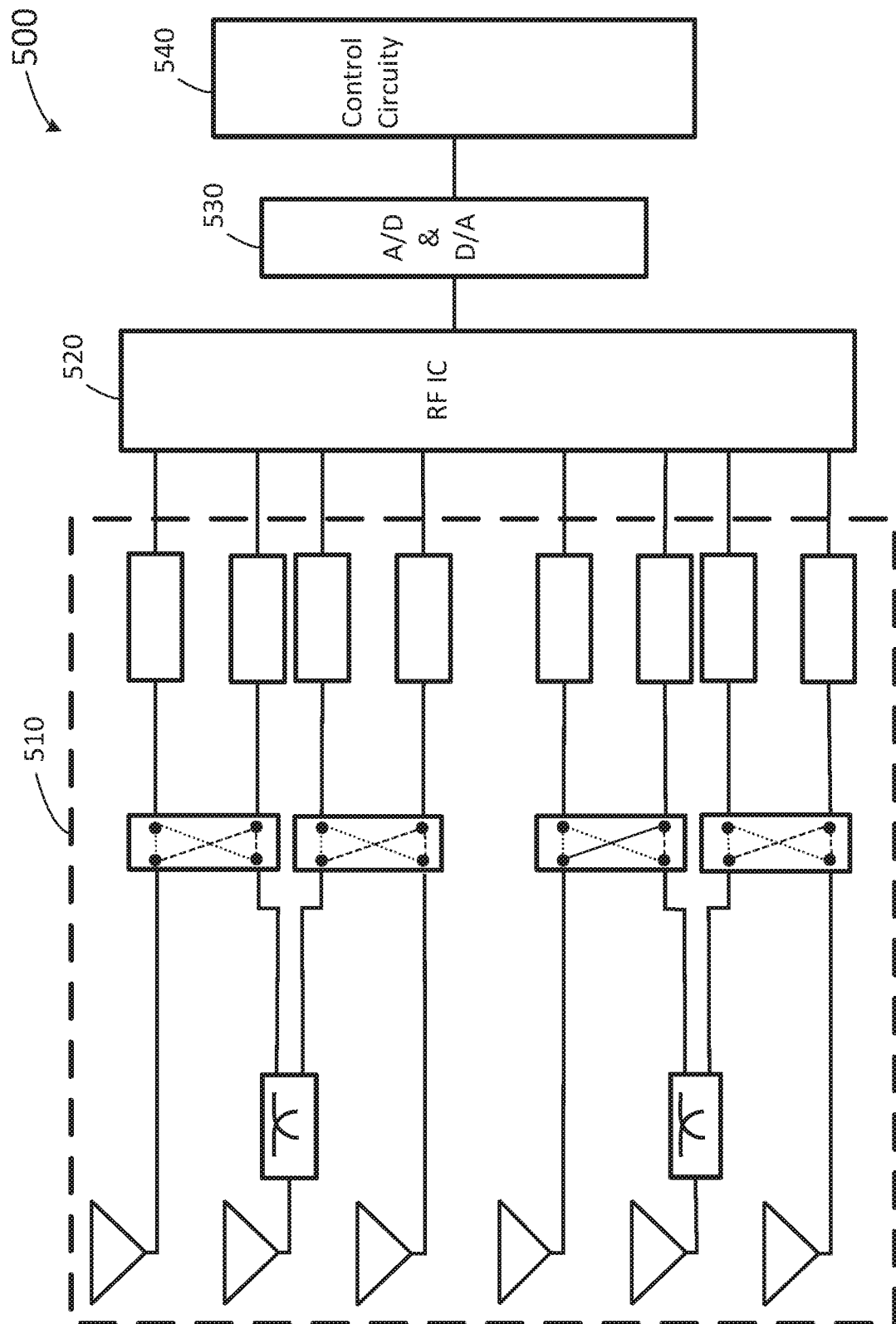


FIG. 5

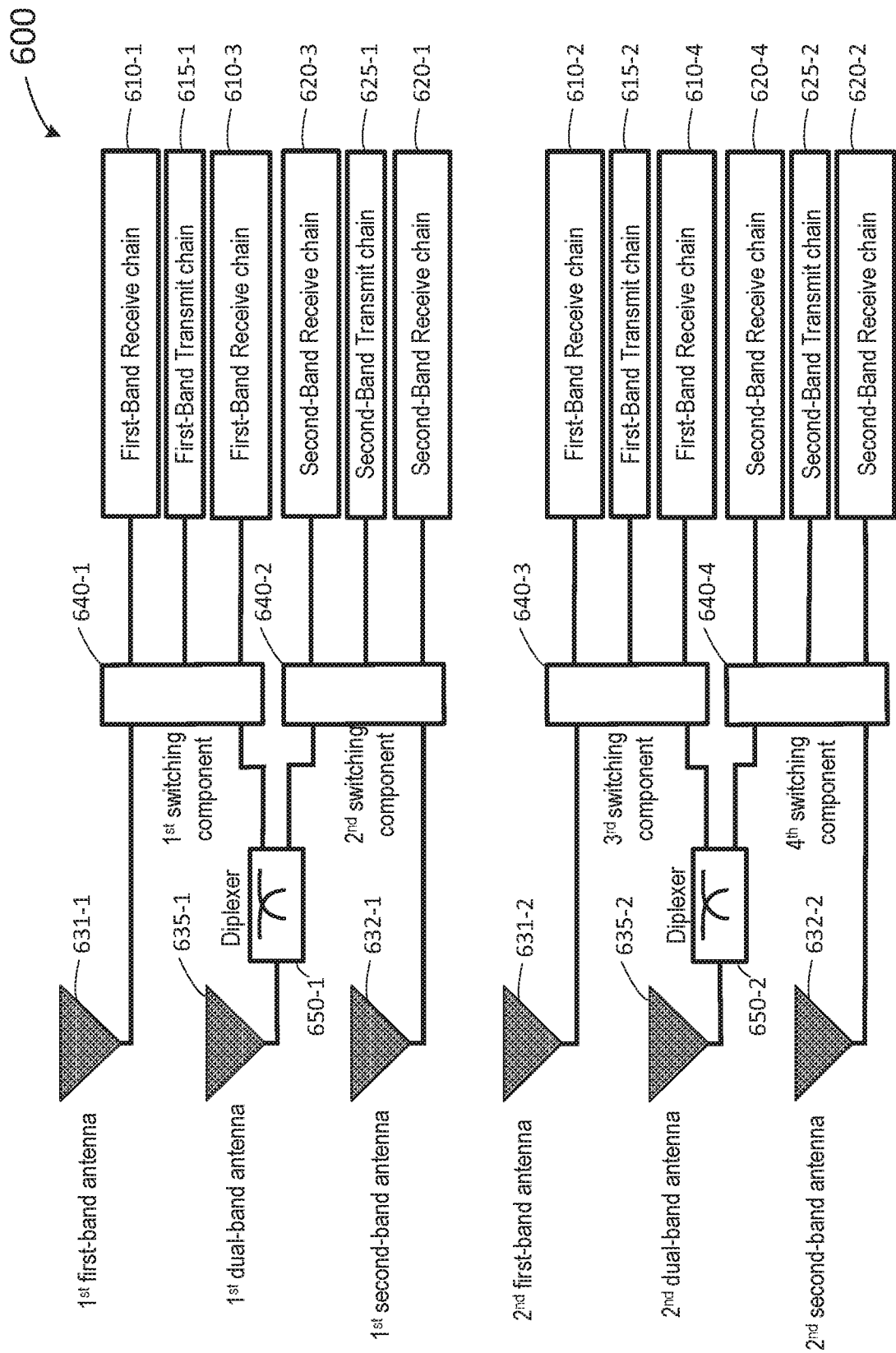


FIG. 6

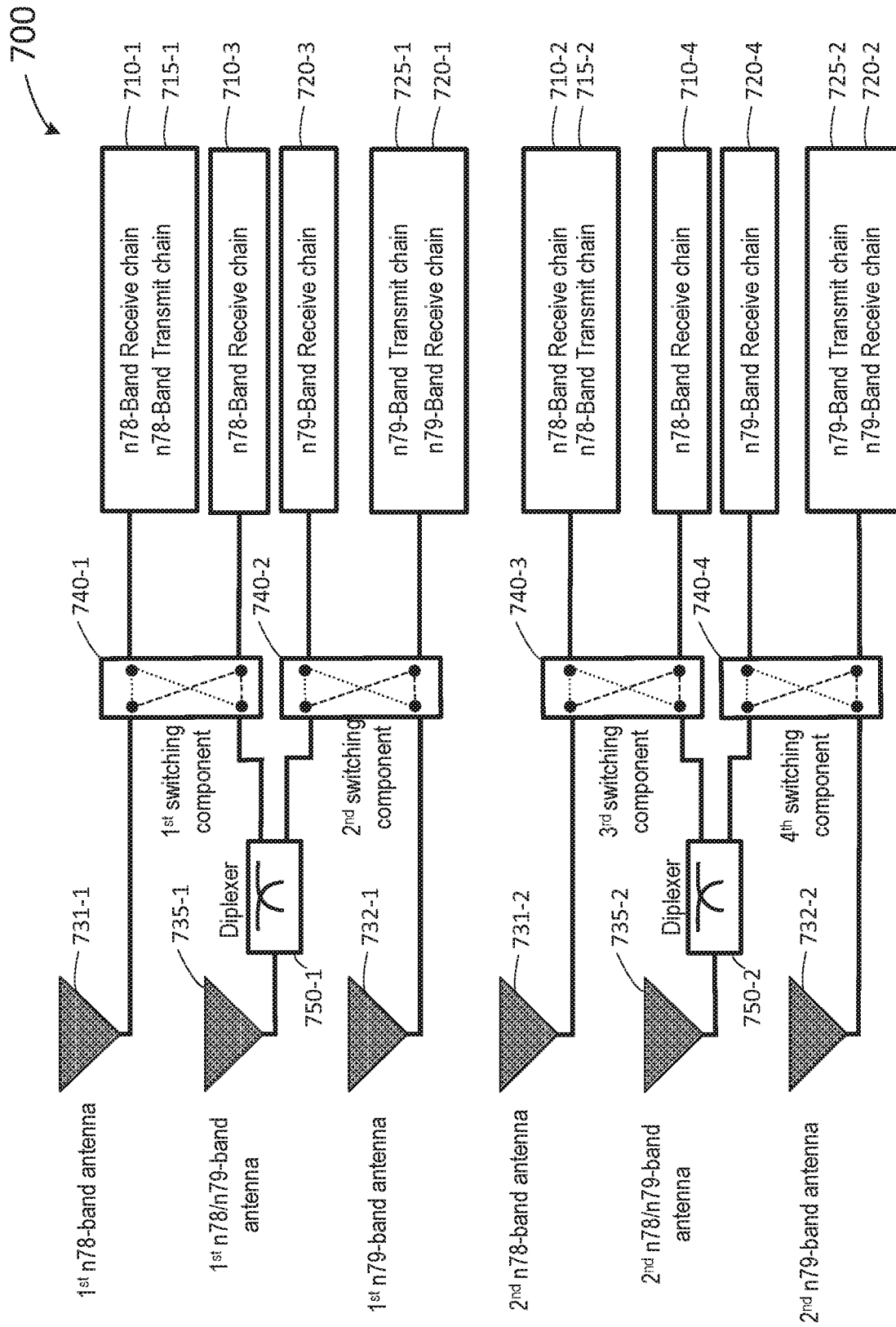


FIG. 7A

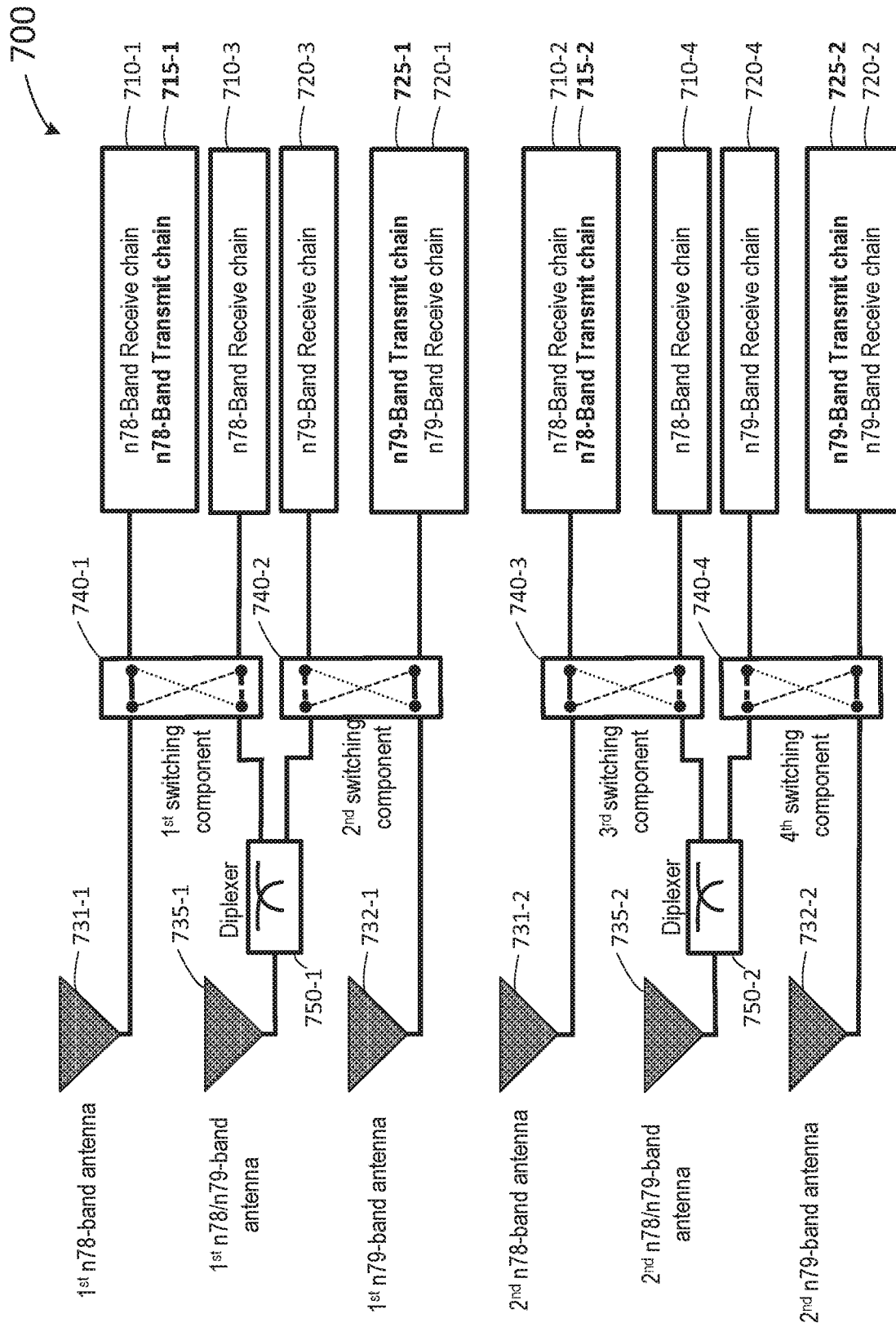


FIG. 7B

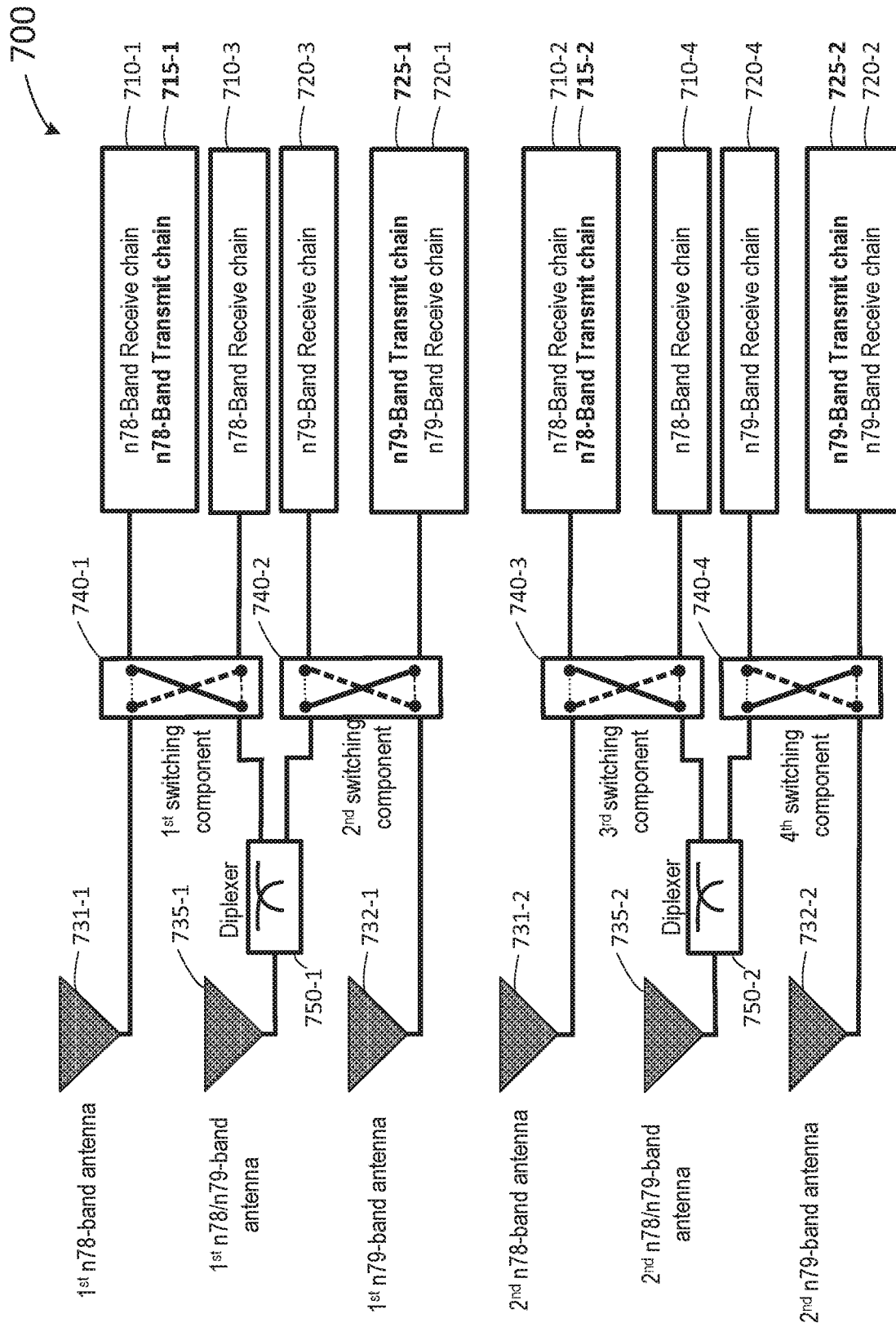


FIG. 7C

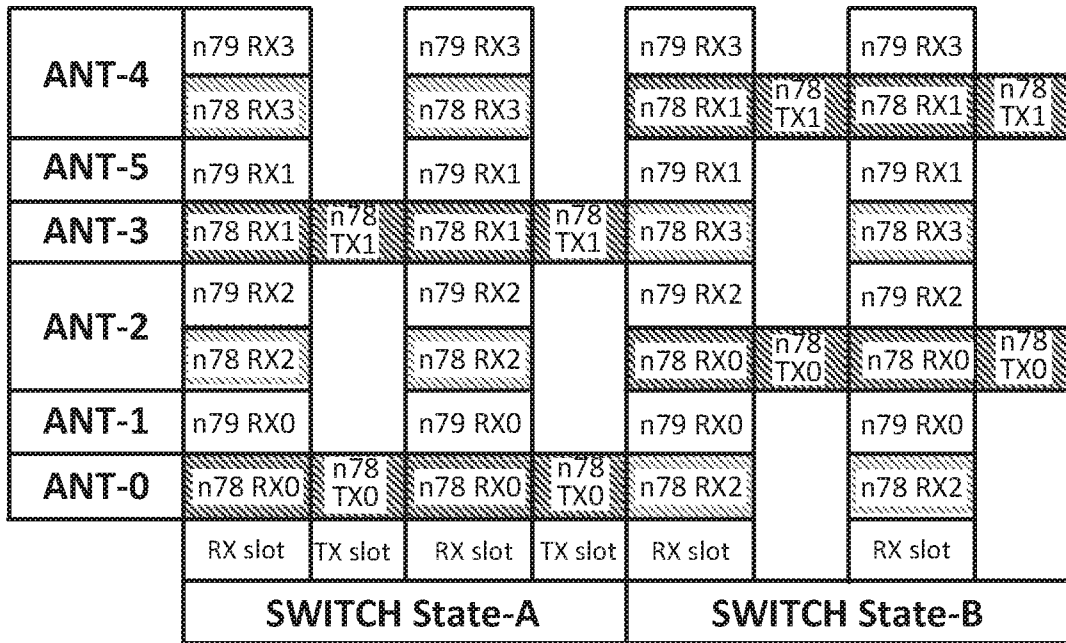


FIG. 7D

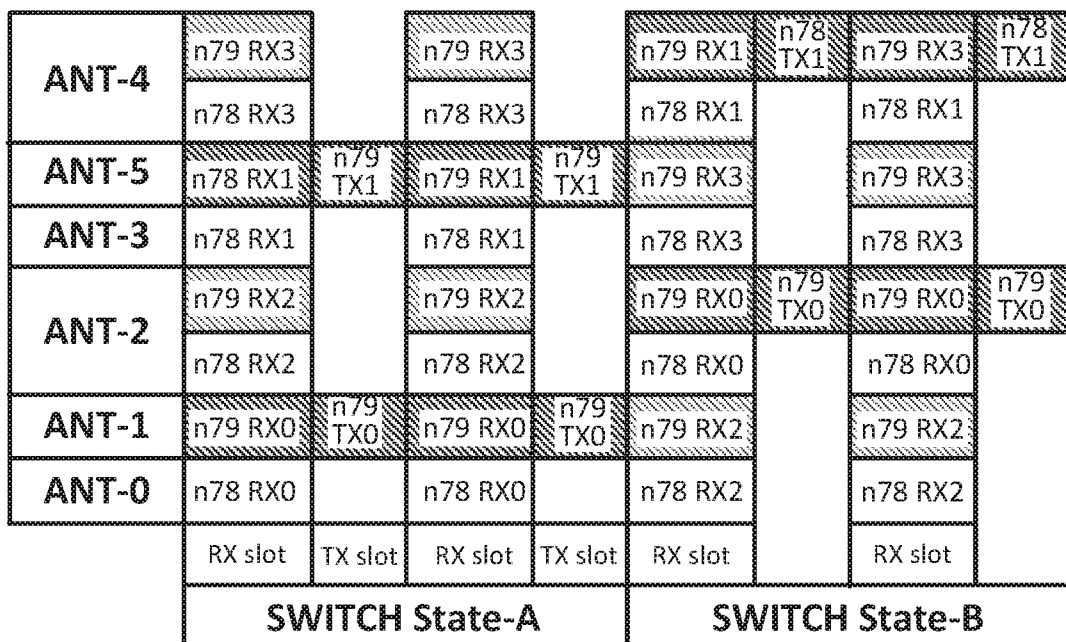


FIG. 7E

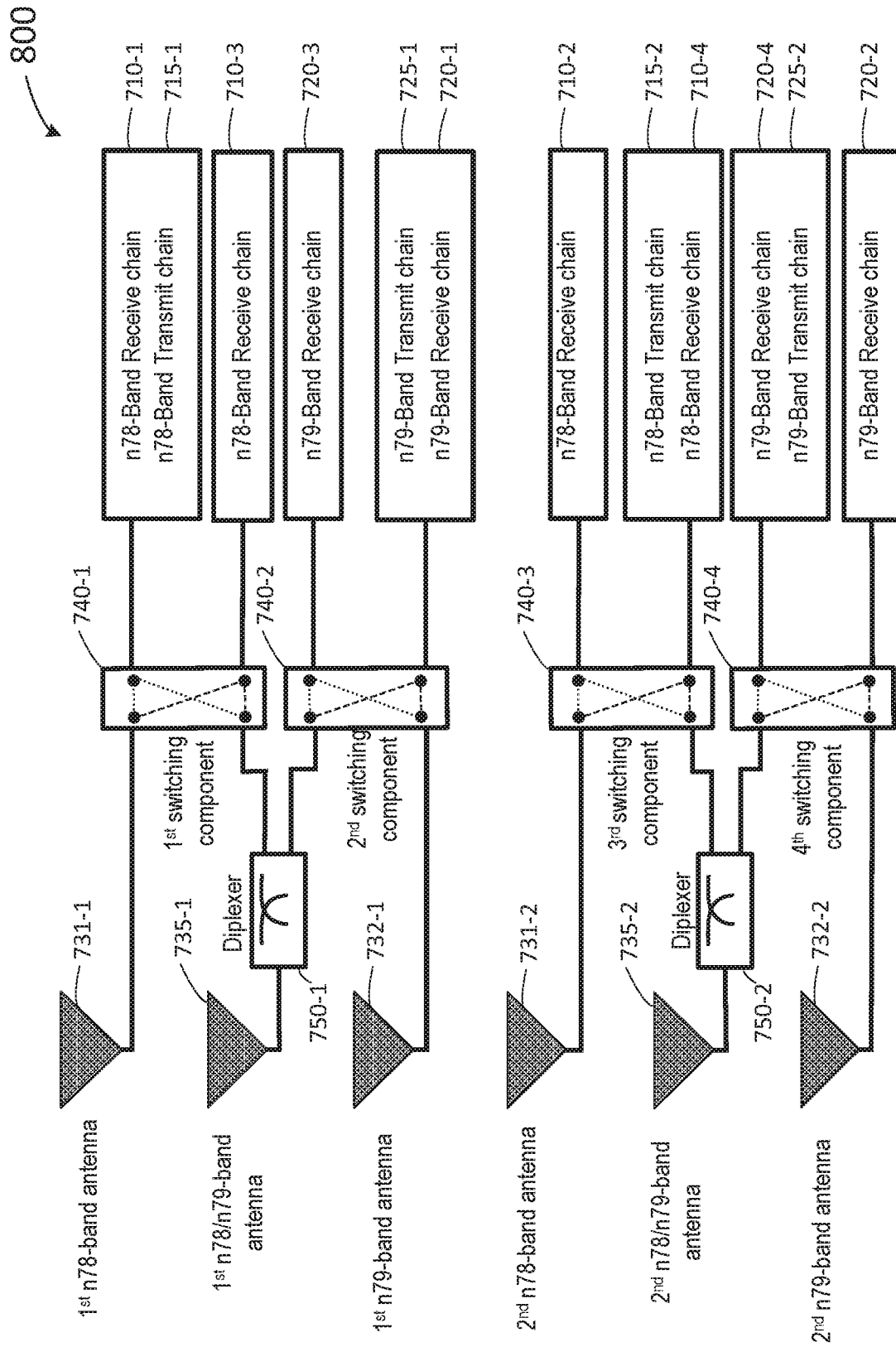


FIG. 8

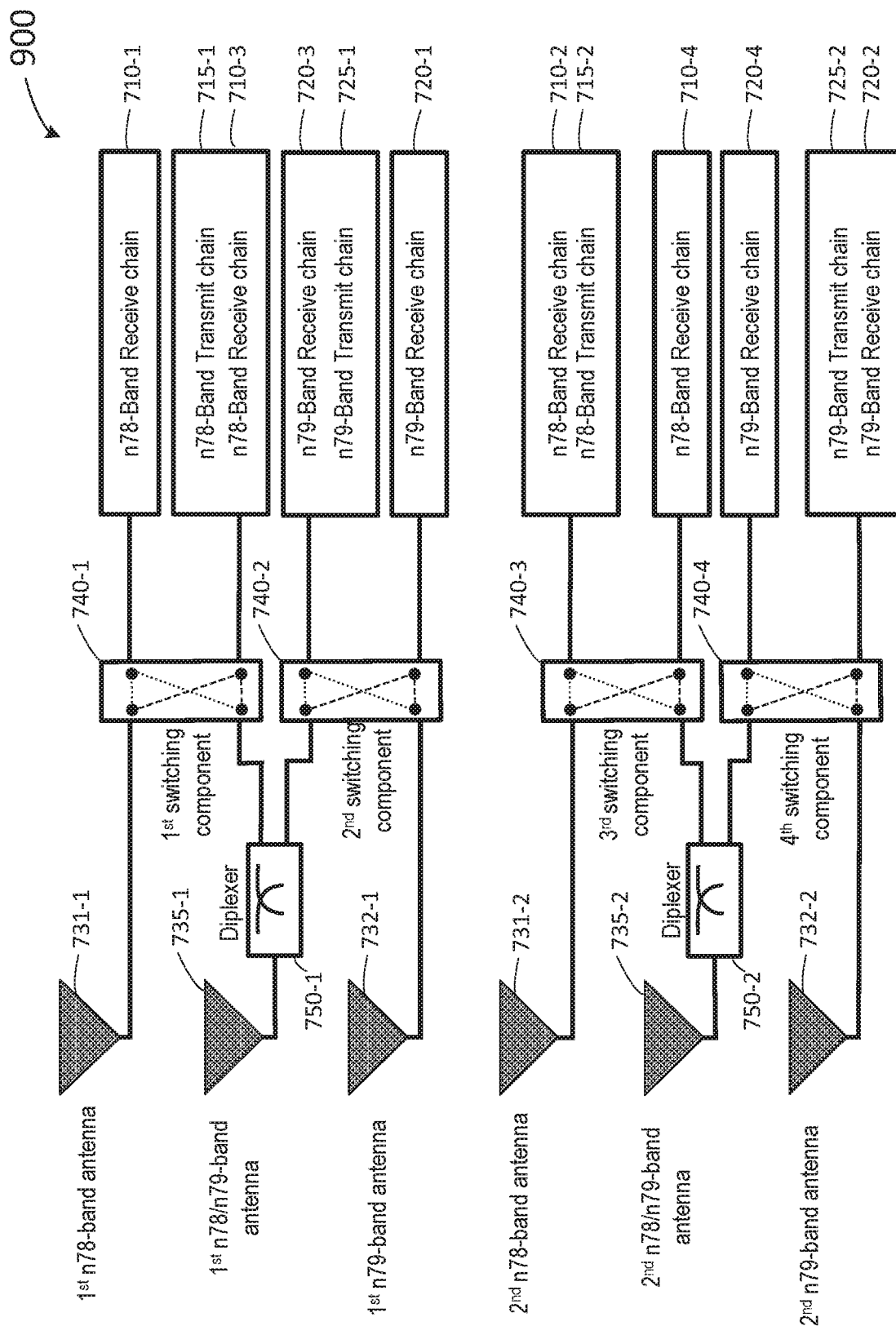


FIG. 9

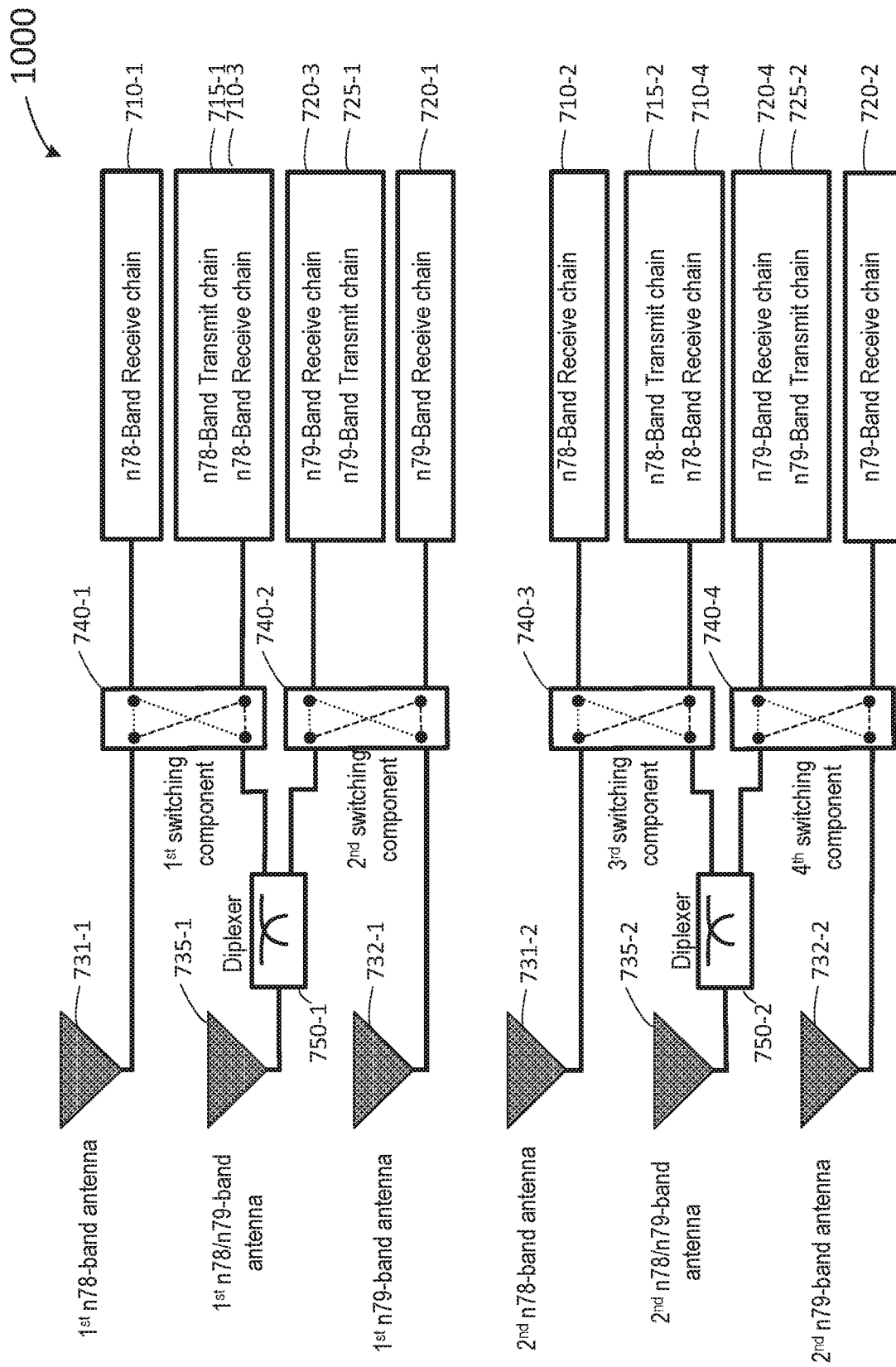


FIG. 10

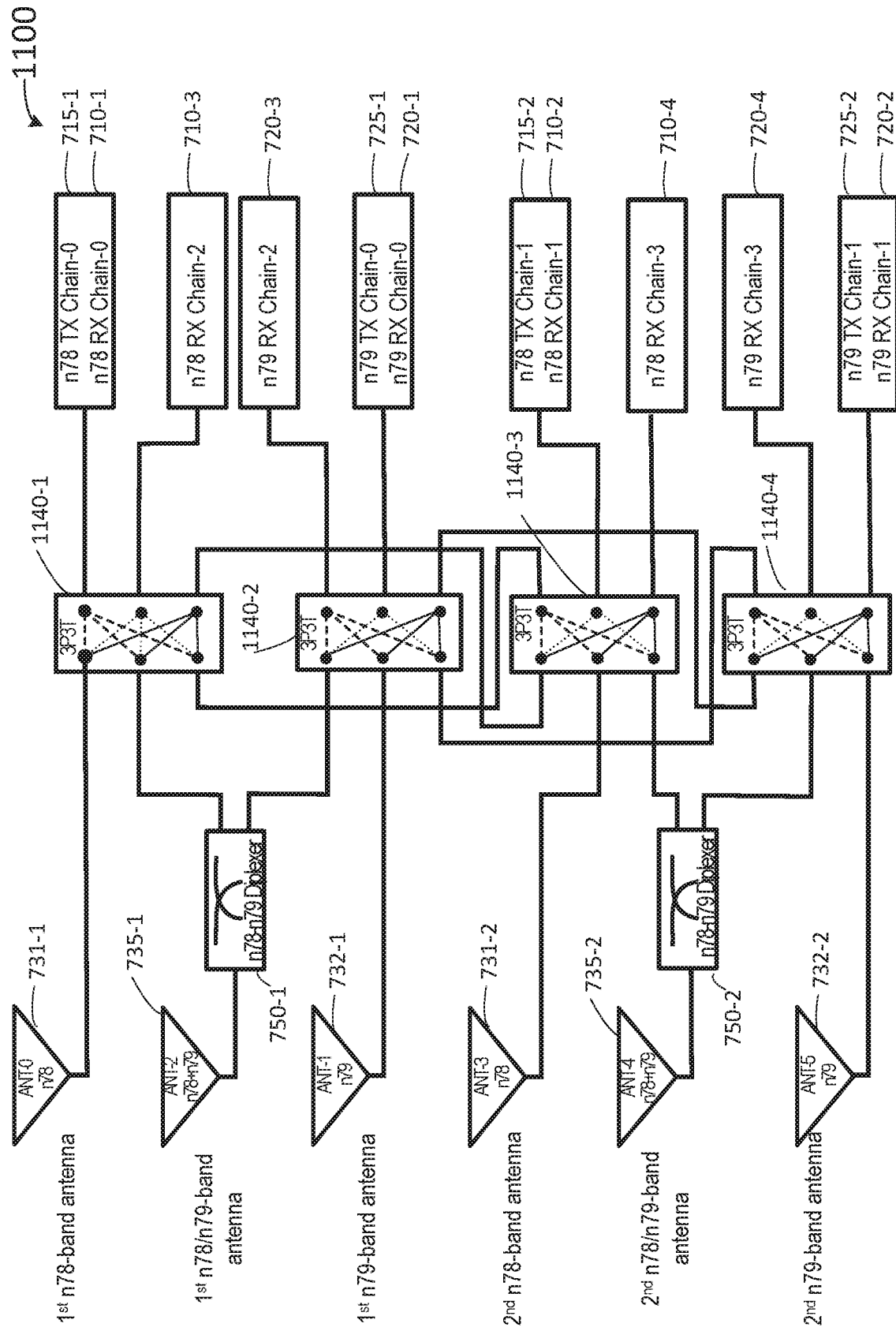


FIG. 11A

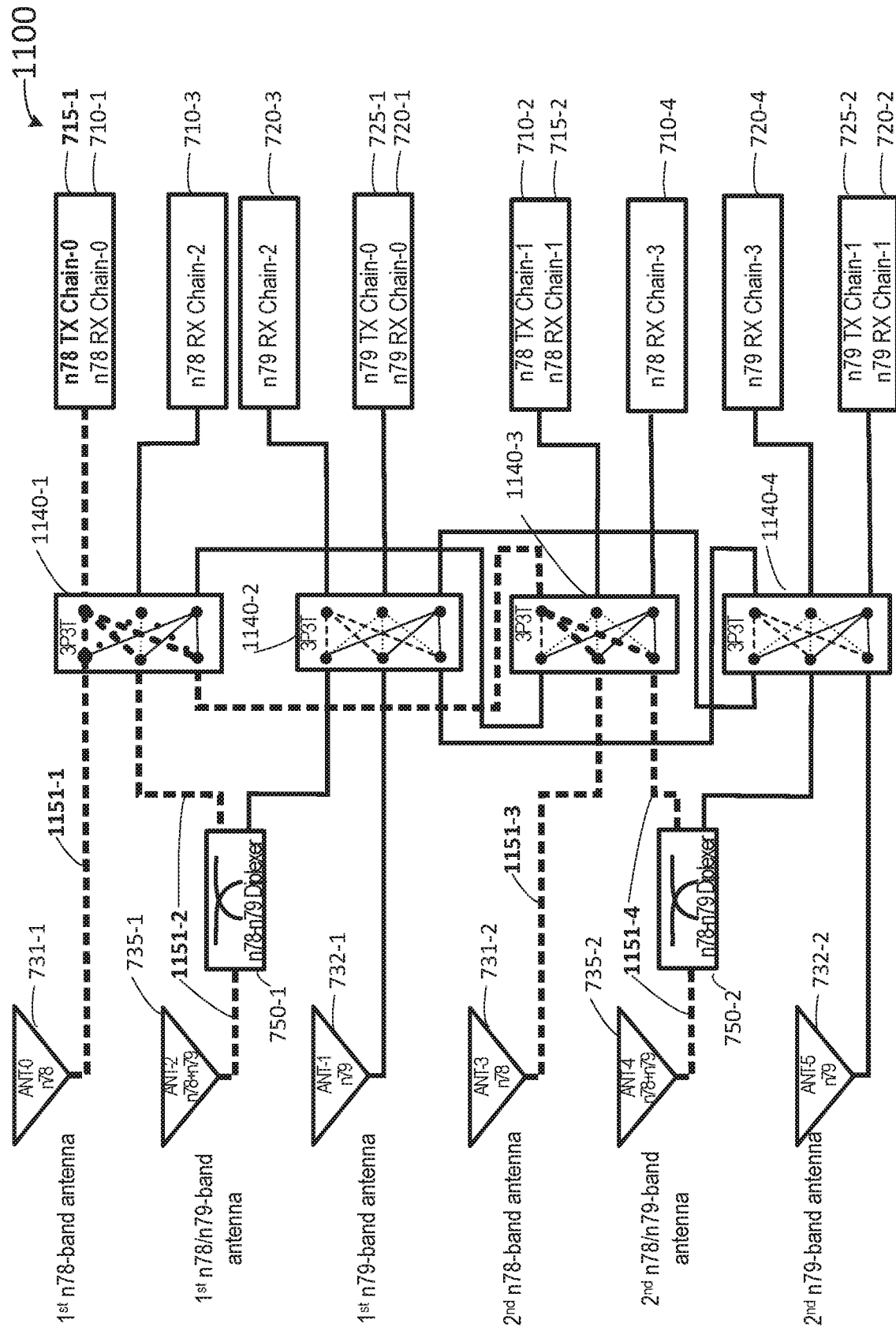


FIG. 11B

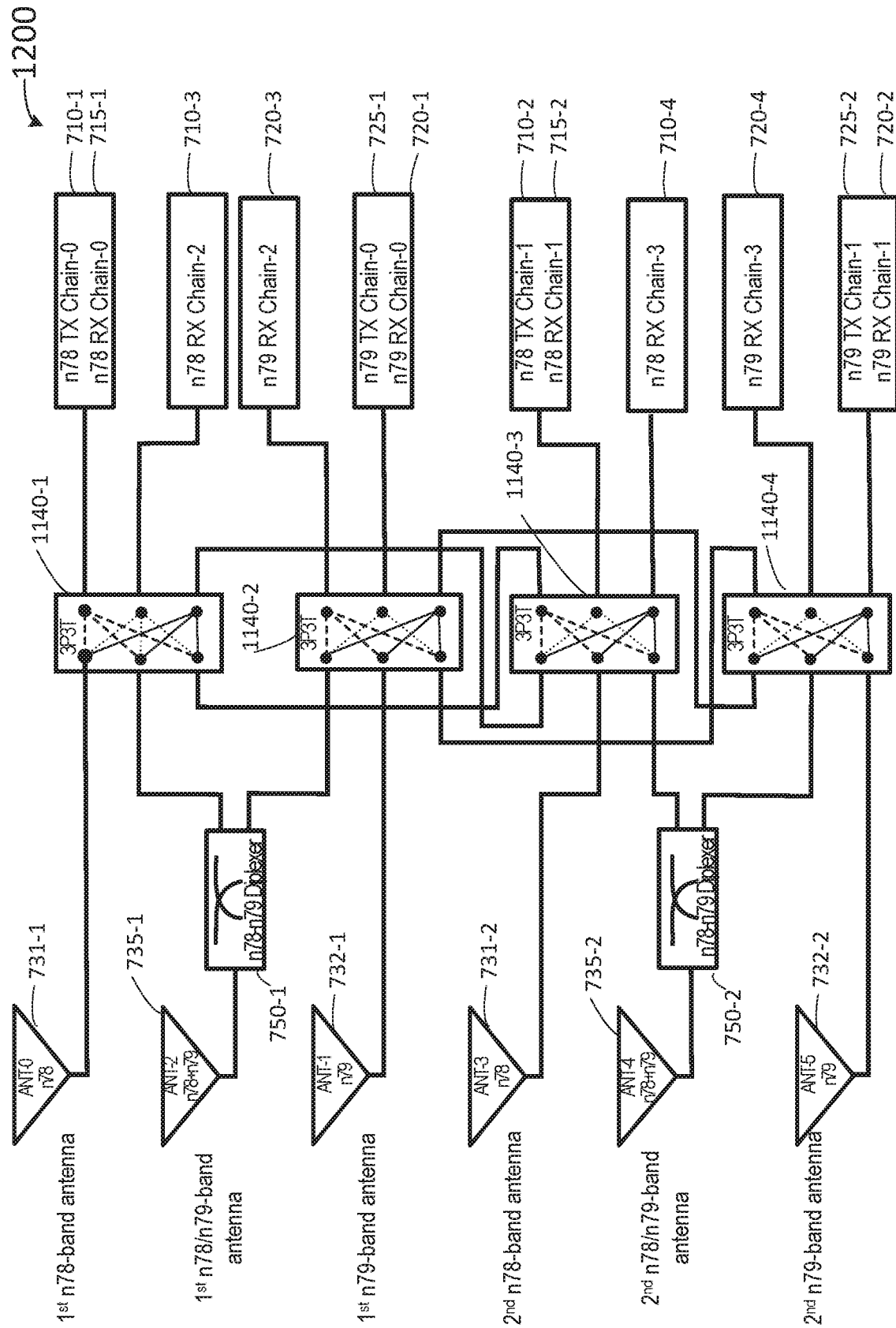


FIG. 12

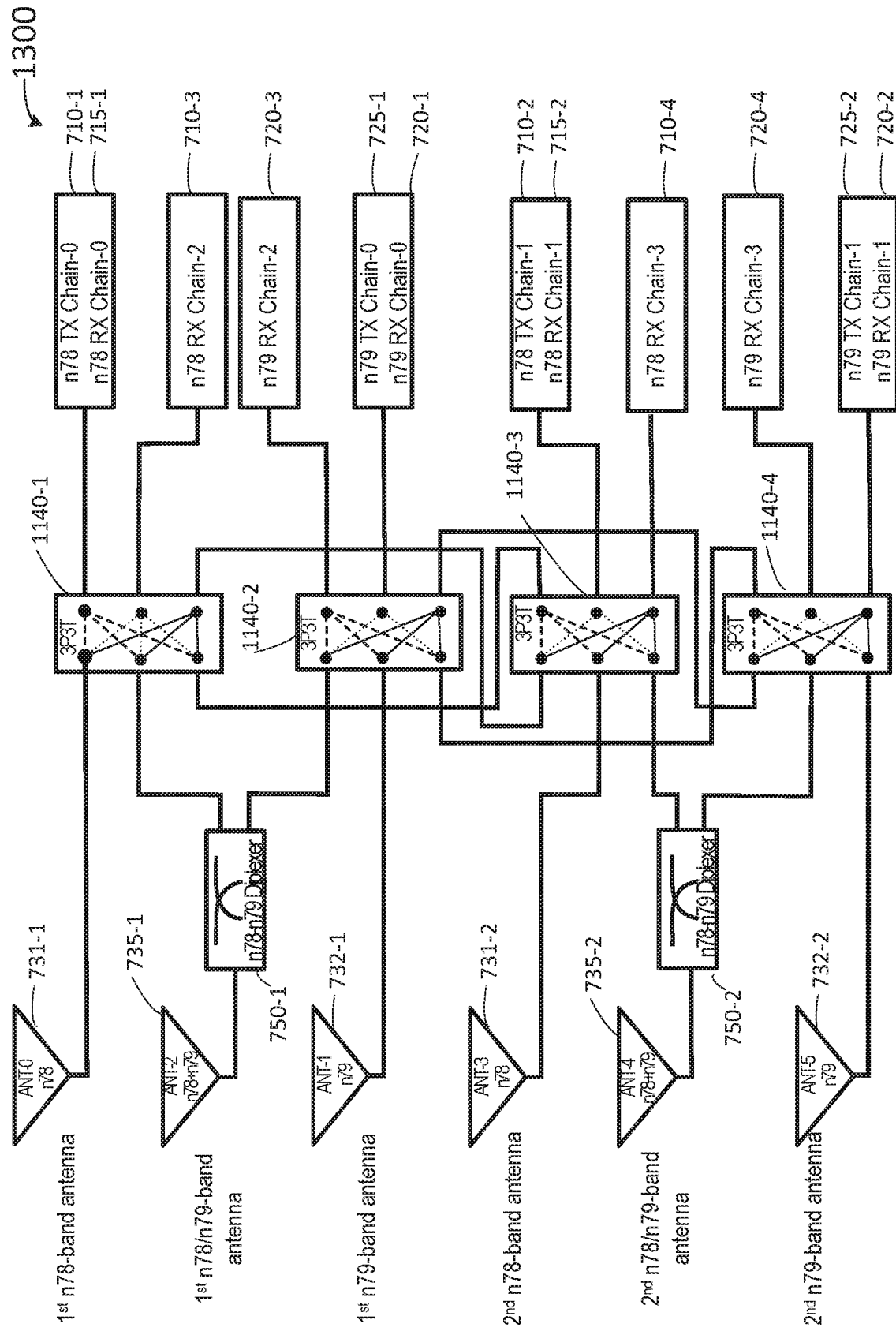


FIG. 13

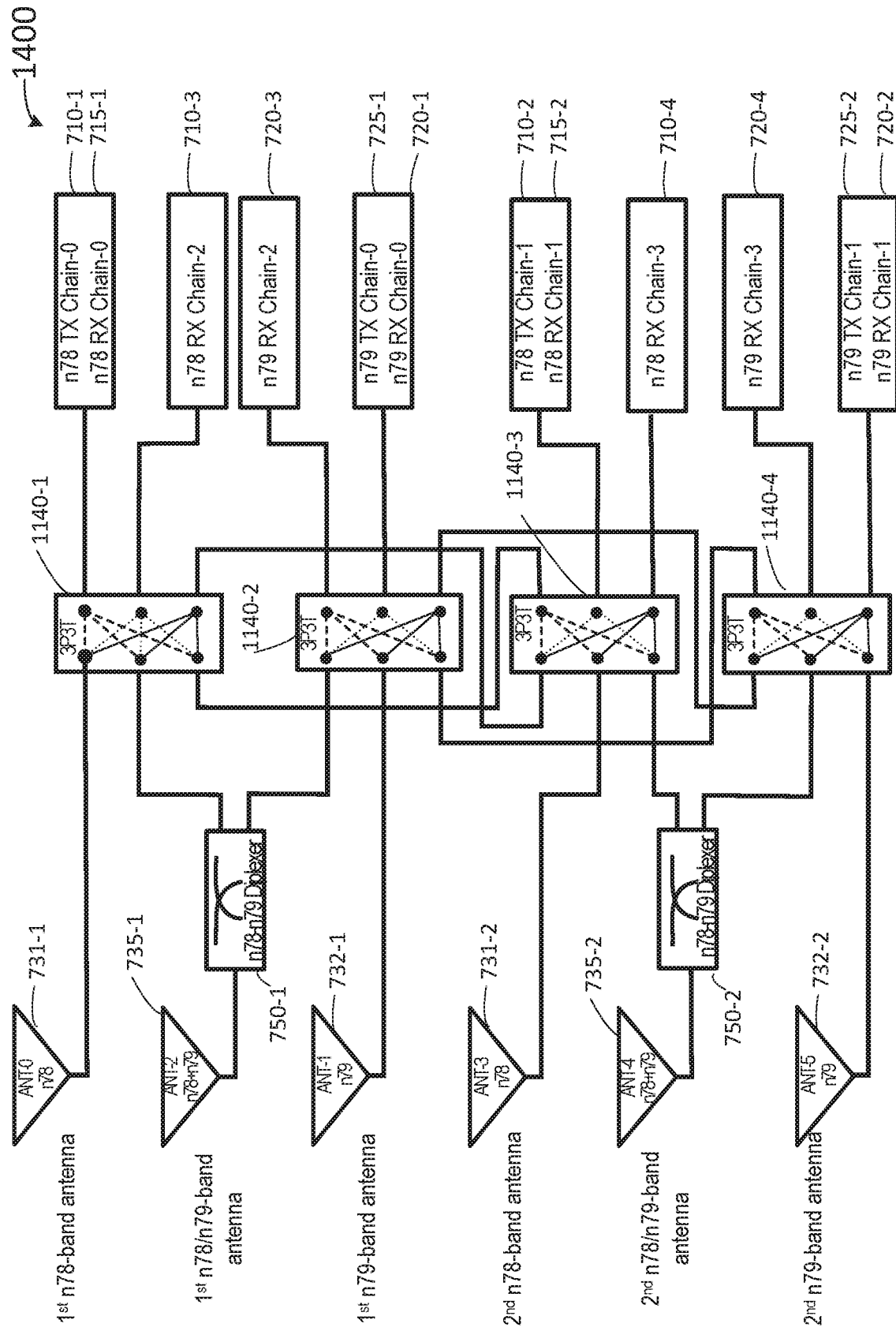
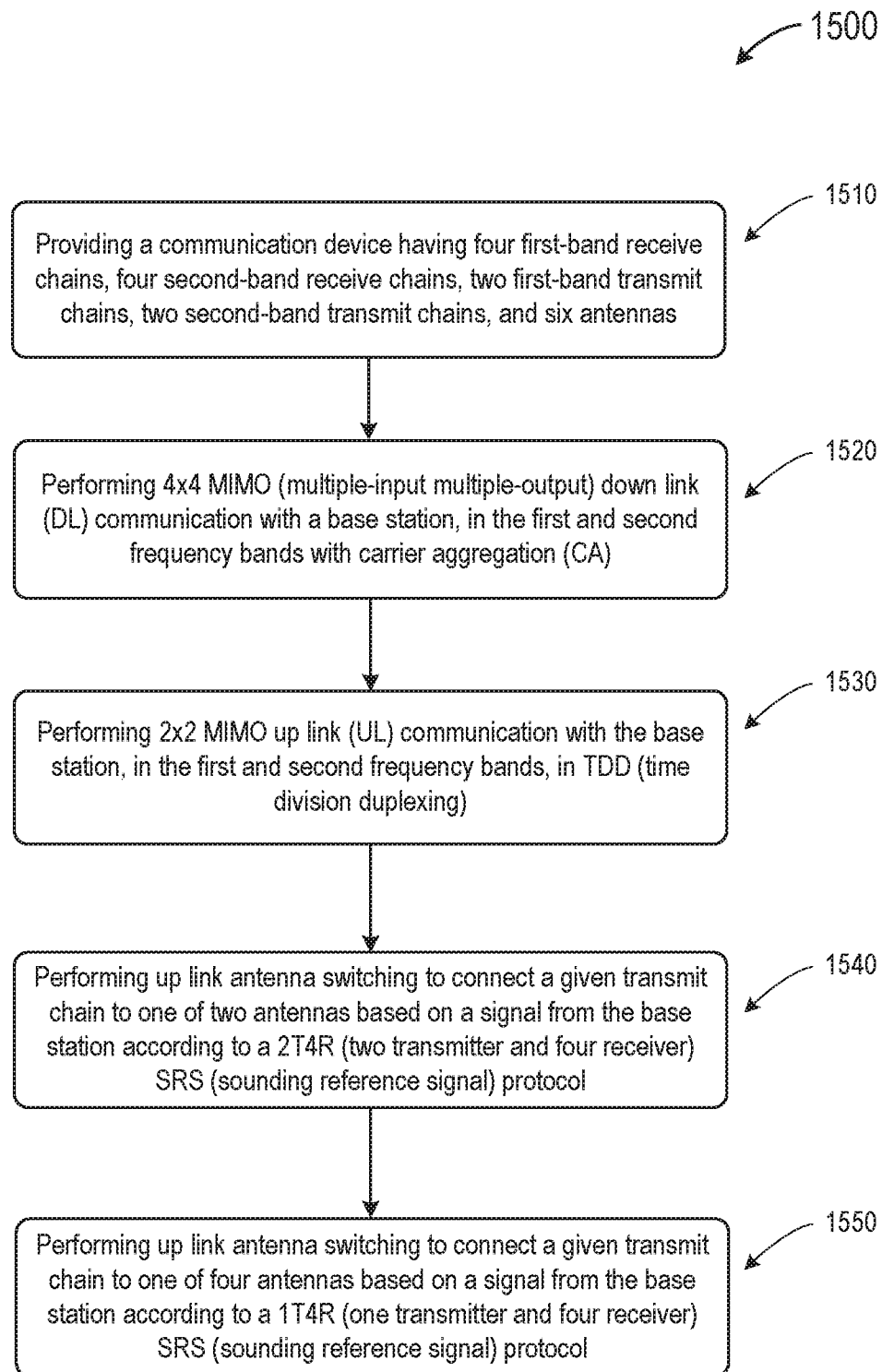


FIG. 14

**FIG. 15**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2020/053334

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H04B 7/04; H04B 5/00; H04B 7/02; H04J 3/06 (2020.01)

CPC - H04B 7/0413; H03J 7/04; H04B 1/40; H04B 5/0031; H04B 7/0689 (2020.08)

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)

see Search History document

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

see Search History document

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

see Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y --- A	US 2009/0180466 A1 (SOUL et al) 16 July 2009 (16.07.2009) entire document	1, 14, 22-25 --- 26 --- 27-46
Y --- A	US 2018/0317070 A1 (INTEL IP CORPORATION) 01 November 2018 (01.11.2018) entire document	26 --- 41-46
A	US 2010/0283707 A1 (FOO) 11 November 2010 (11.11.2010) entire document	27-40
A	US 2014/0233526 A1 (MARVELL WORLD TRADE LTD.) 21 August 2014 (21.08.2014) entire document	27-40
A	US 2013/0315170 A1 (DAWID et al) 28 November 2013 (28.11.2013) entire document	41-46
A	CETINER et al. "Multifunctional reconfigurable MEMS integrated antennas for adaptive MIMO systems." In: IEEE Communications Magazine. 20 December 2004 (20.12.2004) Retrieved on 23 November 2020 (23.11.2020) from < http://newport.eecs.uci.edu/rfmems/projects/publications/papers/mems/J023.pdf > entire document	1-46
A	US 2011/0201368 A1 (FACCIN et al) 18 August 2011 (18.08.2011) entire document	1-46



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

24 November 2020

Date of mailing of the international search report

05 JAN 2021

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Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2020/053334

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/0336415 A1 (HON HAI PRECISION INDUSTRY CO., LTD.) 19 December 2013 (19.12.2013) entire document	1-46
A	US 2015/0036760 A1 (PANG et al) 05 February 2015 (05.02.2015) entire document	1-46