BIDIRECTIONAL VARIABLE GAIN AMPLIFIERS FOR RADIO FREQUENCY COMMUNICATION SYSTEMS

BACKGROUND

Technical Field

[0001] Embodiments of the invention relate to electronic systems, and in particular, to radio frequency (RF) electronics.

Description of the Related Technology

[0002] Variable gain amplifiers (VGAs) are used in RF communication systems to provide a controllable amount of amplification to RF signals that are transmitted or received wirelessly using antennas.

[0003] Examples of RF communication systems that can include one or more VGAs include, but are not limited to, mobile phones, tablets, base stations, network access points, customer-premises equipment (CPE), laptops, and wearable electronics. An RF signal can have a frequency in the range of about 30 kHz to 300 GHz, such as in the range of about 425 MHz to about 7.125 GHz for Frequency Range 1 (FR1) of the Fifth Generation (5G) communication standard or in the range of about 24.250 GHz to about 52.600 GHz for Frequency Range 2 (FR2) of the 5G communication standard.

SUMMARY

[0004] In an aspect, the present disclosure relates to a wireless device. The wireless device includes an antenna array including a plurality of antenna elements, a plurality of radio frequency signal conditioning circuits each operatively associated with a corresponding one of the plurality of antenna elements and including a bidirectional variable gain amplifier, and a transceiver electrically coupled to the plurality of radio frequency signal conditioning circuits. The bidirectional variable gain amplifier includes a first amplifier including an input coupled to a transmit/receive port, a second amplifier including an output coupled to a transmit port, a third amplifier including an input coupled to a receive port, a fourth amplifier including an output coupled to the transmit/receive port and to the input of the first amplifier, and a switch circuit configured to connect an output of the first amplifier to an

input of the second amplifier in a transmit mode, and to connect an output of the third amplifier to an input of the fourth amplifier in a receive mode.

[0005] In various embodiments, the first amplifier is a first common-gate amplifier and the fourth amplifier is a first common-drain amplifier. According to a number of embodiments, the second amplifier is a second common-gate amplifier, and the third amplifier is a second common-drain amplifier.

[0006] In several embodiments, the first amplifier includes a first pair of transistors having a first pair of sources, and the second amplifier includes a second pair of transistors having a second pair of sources directly connected to the first pair of sources.

[0007] In some embodiments, the switch circuit includes a first switch and a second switch connected at a common node, the bidirectional variable gain amplifier further including a controllable resistor connected to the common node.

[0008] In various embodiments, at least one of the first amplifier or the third amplifier includes a first pair of input transistors and a second pair of input transistors that are selectable, the first pair of input transistors configured to provide a signal inversion when selected and the second pair of input transistors configured to provide no signal inversion when selected.

[0009] In several embodiments, each of the plurality of radio frequency signal conditioning circuits further includes a phase shifter connected to the transmit/receive port.

[0010] In some embodiments, each of the plurality of radio frequency signal conditioning circuits further includes a power amplifier having an input connected to the transmit port and a low noise amplifier having an output connected to the receive port.

[0011] In an aspect, the present disclosure relates to a bidirectional variable gain amplifier. The bidirectional variable gain amplifier includes a first amplifier including an input coupled to a transmit/receive port, a second amplifier including an output coupled to a transmit port, a third amplifier including an input coupled to a receive port, a fourth amplifier including an output coupled to the transmit/receive port and to the input of the first amplifier, and a switch circuit configured to connect an output of the first amplifier to an input of the second amplifier in a transmit mode, and to connect an output of the third amplifier to an input of the fourth amplifier in a receive mode.

[0012] In some embodiments, the first amplifier is a first common-gate amplifier and the fourth amplifier is a first common-drain amplifier. According to a number of embodiments, the second amplifier is a second common-gate amplifier, and the third amplifier is a second common-drain amplifier.

[0013] In several embodiments, the first amplifier includes a first pair of transistors having a first pair of sources, and the second amplifier includes a second pair of transistors having a second pair of sources directly connected to the first pair of sources. According to a number of embodiments, the bidirectional variable gain amplifier further includes a pair of inductors connected to the first pair of sources and the second pair of sources, the pair of inductors configured to provide input matching to the first amplifier and output matching to the fourth amplifier.

[0014] In some embodiments, the switch circuit includes a first switch and a second switch connected at a common node. According to various embodiments, the bidirectional variable gain amplifier further includes a controllable resistor connected to the common node.

[0015] In a number of embodiments, at least one of the first amplifier or the third amplifier includes a first pair of input transistors and a second pair of input transistors that are selectable, the first pair of input transistors configured to provide a signal inversion when selected and the second pair of input transistors configured to provide no signal inversion when selected.

[0016] In several embodiments, the bidirectional variable gain amplifier further includes a bias and control circuit configured turn off the third amplifier and the fourth amplifier in the transmit mode, and to turn off the first amplifier and the second amplifier in the receive mode.

[0017] In an aspect, the present disclosure relates to a front end system. The front end system includes a power amplifier, a low noise amplifier, and a bidirectional variable gain amplifier including a first amplifier having an input coupled to a transmit/receive port, a second amplifier having an output coupled to an input of the power amplifier at a transmit port, a third amplifier having an input coupled to an output of the low noise amplifier at a receive port, a fourth amplifier having an output coupled to the transmit/receive port and to the input of the first amplifier, and a switch circuit configured to connect an output of the