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 examples, the first amplifier is a first common-gate amplifier and the fourth amplifier is a first common-drain amplifier. According to a number of examples, the second amplifier is a second common-gate amplifier, and the third amplifier is a second common-drain amplifier.

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

**[0007]** In some examples, 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 examples, 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 examples, each of the plurality of radio frequency signal conditioning circuits further includes a phase shifter connected to the transmit/receive port.

**[0010]** In some examples, 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 examples, the first amplifier is a first common-gate amplifier and the fourth amplifier is a first common-drain amplifier. According to a number of examples, the second amplifier is a second common-gate amplifier, and the third amplifier is a second common-drain amplifier.

**[0013]** In several examples, the first amplifier includes a first pair of transistors having a first pair of sources, and the fourth 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 examples, 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 examples, the switch circuit includes a first switch and a second switch connected at a common node. According to various examples, the bidirectional variable gain amplifier further includes a controllable resistor connected to the common node.

**[0015]** In a number of examples, 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 examples, 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

WHAT IS CLAIMED IS:

1. A wireless device comprising:

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, the bidirectional variable gain amplifier including 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; and

a transceiver electrically coupled to the plurality of radio frequency signal conditioning circuits.

2. The wireless device of claim 1 wherein the first amplifier is a first common-gate amplifier and the fourth amplifier is a first common-drain amplifier.

3. The wireless device of claim 2 wherein the second amplifier is a second common-drain amplifier, and the third amplifier is a second common-gate amplifier.

4. The wireless device of claim 1 wherein the first amplifier includes a first pair of transistors having a first pair of sources, and the fourth amplifier includes a second pair of transistors having a second pair of sources directly connected to the first pair of sources.

5. The wireless device of claim 1 wherein 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.

6. The wireless device of claim 1 wherein 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.

7. The wireless device of claim 1 wherein each of the plurality of radio frequency signal conditioning circuits further includes a phase shifter connected to the transmit/receive port.

8. The wireless device of claim 1 wherein 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.

9. A bidirectional variable gain amplifier comprising:

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.

10. The bidirectional variable gain amplifier of claim 9 wherein the first amplifier is a first common-gate amplifier and the fourth amplifier is a first common-drain amplifier.

11. The bidirectional variable gain amplifier of claim 10 wherein the second amplifier is a second common-drain amplifier, and the third amplifier is a second common-gate amplifier.

12. The bidirectional variable gain amplifier of claim 9 wherein the first amplifier includes a first pair of transistors having a first pair of sources, and the fourth amplifier includes a second pair of transistors having a second pair of sources directly connected to the first pair of sources.

13. The bidirectional variable gain amplifier of claim 12 further comprising 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.

14. The bidirectional variable gain amplifier of claim 9 wherein the switch circuit includes a first switch and a second switch connected at a common node.

15. The bidirectional variable gain amplifier of claim 14 further comprising a controllable resistor connected to the common node.

16. The bidirectional variable gain amplifier of claim 9 wherein 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.

17. The bidirectional variable gain amplifier of claim 9 further comprising a bias and control circuit configured to 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.

18. A front end system comprising:

a power amplifier;

a low noise amplifier; and

a bidirectional variable gain amplifier including a first amplifier including an input coupled to a transmit/receive port, a second amplifier including an output coupled to an input of the power amplifier at a transmit port, a third amplifier including an input coupled to an output of the low noise amplifier at 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.

19. The front end system of claim 18 wherein the first amplifier is a first common-gate amplifier and the fourth amplifier is a first common-drain amplifier.

20. The front end system of claim 19 wherein the second amplifier is a second common-drain amplifier, and the third amplifier is a second common-gate amplifier.