SUMMARY

According to at least one aspect is provided a front-end module comprising a power amplifier configured to amplify a radio frequency signal, the power amplifier having an input configured to receive the radio frequency signal and an output configured to provide an amplified radio frequency signal, a first coupler having an input port, an output port, a coupled port and an isolated port, the input port being coupled to the output of the power amplifier, an antenna switch module having an input coupled to the output port of the first coupler and an output, a second coupler having an input port, an output port, a coupled port and an isolated port, the input port of the second coupler being coupled to the output of the antenna switch module, an antenna port configured to be coupled to an antenna, the antenna port being coupled to the output port of the second coupler, and a first switch sub assembly to switchably connect one of the coupled port and the isolated port of the second coupler to an output of the first switch sub assembly and the other one of the coupled port and the isolated port of the second coupler to a first termination impedance.

In one example, the isolated port of the first coupler is connected to a second termination impedance.

In another example, the front-end module further comprises a second switch sub assembly to switchably connect one of the coupled port and the isolated port of the first coupler to an output of the second switch sub assembly and the other one of the coupled port and the isolated port of the first coupler to a second termination impedance.

In one example, the front-end module further comprises a filter connected between the output port of the first coupler and the input of the antenna switch module.

In another example, the front-end module, further comprises a controller coupled to the first switch sub assembly and the second switch sub assembly and configured to connect the coupled port of the first coupler to the output of the second switch sub assembly and to connect the isolated port of the first coupler to the second termination impedance to obtain a first measurement from the output of the second switch sub assembly, the first measurement providing an indication of forward power provided by the power amplifier.

In one example, the controller is further configured to connect the coupled port of the second coupler to the output of the first switch sub assembly and to connect the isolated port of the

second coupler to the first termination impedance to obtain a second measurement from the output of the first switch sub assembly, the second measurement providing an indication of forward power present on the antenna.

In another example, the controller is further configured to connect the isolated port of the second coupler to the output of the first switch sub assembly and to connect the coupled port of the second coupler to the first termination impedance to obtain a second measurement from the output of the first switch sub assembly, the second measurement providing an indication of power reflected from the antenna.

In one example, the controller is further configured to adjust an impedance of the antenna based on the indication of power reflected from the antenna.

In another example, the controller is further configured to obtain the first measurement from the output of the second switch sub assembly and a second measurement from the output of the first switch sub assembly.

In one example, the controller is further configured to linearize the amplified radio frequency signal by modifying, based on the first measurement and the second measurement, the radio frequency signal received by the power amplifier.

In another example, the controller is further configured to determine, based on the first measurement and the second measurement, an amplitude and a phase of a transfer function that describes a change in power of the amplified radio frequency signal between the power amplifier and the antenna.

In one example, the controller is further configured to operate the first switch sub assembly and the second switch sub assembly to obtain a measurement of forward power provided to the antenna, operate the first switch sub assembly and the second switch sub assembly to obtain a measurement of reflected power from the antenna, calculate a ratio between the measurement of forward power and the measurement of reflected power, and adjust an amount of power provided by the power amplifier based on the calculated ratio.

In another example, the front-end module further comprises a second power amplifier configured to amplify a second radio frequency signal, the second power amplifier having an input configured to receive the second radio frequency signal and an output configured to provide a second amplified radio frequency signal, a third coupler having an input port, an output port, a coupled port and an isolated port, the input port of the third coupler being coupled to the

output of the second power amplifier and the output port of the third coupler being coupled to a second input of the antenna switch module, a fourth coupler having an input port, an output port, a coupled port and an isolated port, the input port of the fourth coupler being coupled to a second output of the antenna switch module and a second antenna port configured to be coupled to a second antenna, the second antenna port being coupled to the second output of the second coupler.

In one example, the power amplifier, the first coupler, the second coupler, and the antenna port form a first chain, the second power amplifier, the third coupler, the fourth coupler, and the second antenna port form a second chain, and the amplified radio frequency signal of the first chain is in a different frequency band than the second amplified radio frequency signal of the second chain.

In another example, the amplified radio frequency signal and the second amplified radio frequency signal are transmitted at the same time.

In one example, the radio frequency signal received by the input of the power amplifier has a frequency in one of a range of about 600 MHz to about 2.5 GHz , a range of about 450 MHz to about 6 GHz, and a range of about 24 GHz to 52 GHz.

In another example, the first coupler is a unidirectional coupler and the second coupler is a bidirectional coupler.

According to at least one aspect there is provided a front-end module comprising a power amplifier configured to amplify a radio frequency signal, the power amplifier having an input configured to receive the radio frequency signal and an output configured to provide an amplified radio frequency signal, a first coupler having an input port, an output port, a coupled port and an isolated port, the input port being coupled to the output of the power amplifier, an antenna switch module having an input coupled to the output port of the first coupler and an output, a second coupler having an input port, an output port, a coupled port and an isolated port, the input port of the second coupler being coupled to the output of the antenna switch module, an antenna port configured to be coupled to an antenna, the antenna port being coupled to the output port of the second coupler, and a first switch sub assembly to switchably connect one of the coupled port and the isolated port of the second coupler to an output of the first switch sub assembly and the other one of the coupled port and the isolated port of the second coupler to a

second termination impedance, or to connect each of the coupled port and the isolated port of the second coupler to the second termination impedance.

In one example, the isolated port of the first coupler is connected to a second termination impedance.

In another example, the front-end module further comprises a second switch sub assembly to switchably connect one of the coupled port and the isolated port of the first coupler to an output of the second switch sub assembly and the other one of the coupled port and the isolated port of the first coupler to a second termination impedance.

In one example, the front-end module further comprises a filter connected between the output port of the first coupler and the input of the antenna switch module.

In another example, the front-end module further comprises a controller coupled to the first switch sub assembly and the second switch sub assembly and configured to connect the coupled port of the first coupler to the output of the second switch sub assembly and to connect the isolated port of the first coupler to the second termination impedance to obtain a first measurement from the output of the second switch sub assembly, the first measurement providing an indication of forward power provided by the power amplifier.

Still other aspects, embodiments, and advantages of these exemplary aspects and embodiments are discussed in detail below. Embodiments disclosed herein may be combined with other embodiments in any manner consistent with at least one of the principles disclosed herein, and references to "an embodiment," "some embodiments," "an alternate embodiment," "various embodiments," "one embodiment" or the like are not necessarily mutually exclusive and are intended to indicate that a particular feature, structure, or characteristic described may be included in at least one embodiment. The appearances of such terms herein are not necessarily all referring to the same embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

Various aspects of at least one embodiment are discussed below with reference to the accompanying figures, which are not intended to be drawn to scale. The figures are included to provide illustration and a further understanding of the various aspects and embodiments, and are incorporated in and constitute a part of this specification, but are not intended as a definition of the

CLAIMS

1. A front-end module comprising:

a power amplifier configured to amplify a radio frequency signal, the power amplifier having an input configured to receive the radio frequency signal and an output configured to provide an amplified radio frequency signal;

a first coupler having an input port, an output port, a coupled port and an isolated port, the input port being coupled to the output of the power amplifier;

an antenna switch module having an input coupled to the output port of the first coupler and an output;

a second coupler having an input port, an output port, a coupled port and an isolated port, the input port of the second coupler being coupled to the output of the antenna switch module;

an antenna port configured to be coupled to an antenna, the antenna port being coupled to the output port of the second coupler; and

a first switch sub assembly to switchably connect one of the coupled port and the isolated port of the second coupler to an output of the first switch sub assembly and the other one of the coupled port and the isolated port of the second coupler to a first termination impedance.

2. The front-end module of claim 1 wherein the isolated port of the first coupler is connected to a second termination impedance.

3. The front-end module of claim 1 further comprising a second switch sub assembly to switchably connect one of the coupled port and the isolated port of the first coupler to an output of the second switch sub assembly and the other one of the coupled port and the isolated port of the first coupler to a second termination impedance.

4. The front-end module of claim 3, further comprising a filter connected between the output port of the first coupler and the input of the antenna switch module.

5. The front-end module of claim 4, further comprising a controller coupled to the first switch sub assembly and the second switch sub assembly and configured to connect the coupled

port of the first coupler to the output of the second switch sub assembly and to connect the isolated port of the first coupler to the second termination impedance to obtain a first measurement from the output of the second switch sub assembly, the first measurement providing an indication of forward power provided by the power amplifier.

6. The front-end module of claim 5 wherein the controller is further configured to connect the coupled port of the second coupler to the output of the first switch sub assembly and to connect the isolated port of the second coupler to the first termination impedance to obtain a second measurement from the output of the first switch sub assembly, the second measurement providing an indication of forward power present on the antenna.

7. The front-end module of claim 5 wherein the controller is further configured to connect the isolated port of the second coupler to the output of the first switch sub assembly and to connect the coupled port of the second coupler to the first termination impedance to obtain a second measurement from the output of the first switch sub assembly, the second measurement providing an indication of power reflected from the antenna.

8. The front-end module of claim 7 wherein the controller is further configured to adjust an impedance of the antenna based on the indication of power reflected from the antenna.

9. The front-end module of claim 5 wherein the controller is further configured to obtain the first measurement from the output of the second switch sub assembly and a second measurement from the output of the first switch sub assembly.

10. The front-end module of claim 9 wherein the controller is further configured to linearize the amplified radio frequency signal by modifying, based on the first measurement and the second measurement, the radio frequency signal received by the power amplifier.

11. The front-end module of claim 9 wherein the controller is further configured to determine, based on the first measurement and the second measurement, an amplitude and a

phase of a transfer function that describes a change in power of the amplified radio frequency signal between the power amplifier and the antenna.

12. The front-end module of claim 5 wherein the controller is further configured to:

operate the first switch sub assembly and the second switch sub assembly to obtain a measurement of forward power provided to the antenna;

operate the first switch sub assembly and the second switch sub assembly to obtain a measurement of reflected power from the antenna;

calculate a ratio between the measurement of forward power and the measurement of reflected power; and

adjust an amount of power provided by the power amplifier based on the calculated ratio.

13. The front-end module of claim 1 further comprising:

a second power amplifier configured to amplify a second radio frequency signal, the second power amplifier having an input configured to receive the second radio frequency signal and an output configured to provide a second amplified radio frequency signal;

a third coupler having an input port, an output port, a coupled port and an isolated port, the input port of the third coupler being coupled to the output of the second power amplifier and the output port of the third coupler being coupled to a second input of the antenna switch module;

a fourth coupler having an input port, an output port, a coupled port and an isolated port, the input port of the fourth coupler being coupled to a second output of the antenna switch module; and

a second antenna port configured to be coupled to a second antenna, the second antenna port being coupled to the second output of the second coupler.

14. The front-end module of claim 13 wherein:

the power amplifier, the first coupler, the second coupler, and the antenna port form a first chain;

the second power amplifier, the third coupler, the fourth coupler, and the second antenna port form a second chain; and

the amplified radio frequency signal of the first chain is in a different frequency band than the second amplified radio frequency signal of the second chain.

15. The front-end module of claim 14, wherein the amplified radio frequency signal and the second amplified radio frequency signal are transmitted at the same time.

16. The front-end module of claim 1 wherein the radio frequency signal received by the input of the power amplifier has a frequency in one of a range of about 600 MHz to about 2.5 GHz , a range of about 450 MHz to about 6 GHz, and a range of about 24 GHz to 52 GHz.

17. The front-end module of claim 1 wherein the first coupler is a unidirectional coupler and the second coupler is a bidirectional coupler.

18. A front-end module comprising:

a power amplifier configured to amplify a radio frequency signal, the power amplifier having an input configured to receive the radio frequency signal and an output configured to provide an amplified radio frequency signal;

a first coupler having an input port, an output port, a coupled port and an isolated port, the input port being coupled to the output of the power amplifier;

an antenna switch module having an input coupled to the output port of the first coupler and an output;

a second coupler having an input port, an output port, a coupled port and an isolated port, the input port of the second coupler being coupled to the output of the antenna switch module;

an antenna port configured to be coupled to an antenna, the antenna port being coupled to the output port of the second coupler; and

a first switch sub assembly to switchably connect one of the coupled port and the isolated port of the second coupler to an output of the first switch sub assembly and the other one of the coupled port and the isolated port of the second coupler to a second termination impedance, or to

connect each of the coupled port and the isolated port of the second coupler to the second termination impedance.

19. The front-end module of claim 18 wherein the isolated port of the first coupler is connected to the second termination impedance.

20. The front-end module of claim 18 further comprising a second switch sub assembly to switchably connect one of the coupled port and the isolated port of the first coupler to an output of the second switch sub assembly and the other one of the coupled port and the isolated port of the first coupler to the second termination impedance.

21. The front-end module of claim 20, further comprising a filter connected between the output port of the first coupler and the input of the antenna switch module.

22. The front-end module of claim 21, further comprising a controller coupled to the first switch sub assembly and the second switch sub assembly and configured to connect the coupled port of the first coupler to the output of the second switch sub assembly and to connect the isolated port of the first coupler to the second termination impedance to obtain a first measurement from the output of the second switch sub assembly, the first measurement providing an indication of forward power provided by the power amplifier.