PHASE SHIFTERS WITH SWITCHED TRANSMISSION LINE LOADS

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] Phase shifters are used in RF communication systems to control the phase of RF signals transmitted or received wirelessly via antennas.

[0003] Examples of RF communication systems with one or more phase shifters include, but are not limited to, mobile phones, tablets, base stations, network access points, customer-premises equipment (CPE), laptops, and wearable electronics. For example, in wireless devices that communicate using a cellular standard, a wireless local area network (WLAN) standard, and/or any other suitable communication standard, a power amplifier can be used for RF signal amplification. An RF signal can have a frequency in the range of about 30 kHz to 300 GHz, such as in the range of about 410 MHz to about 7.125 GHz for fifth generation (5G) communications using Frequency Range 1 (FR1) or in the range of about 24.25 GHz to 52.6 GHz for 5G communications using Frequency Range 2 (FR2).

SUMMARY

[0004] In an aspect, the present disclosure relates to a phase shifter. The phase shifter includes a first port, a second port, a first controllable reflective load including a first transmission line and a first plurality of shunt switches connected along the first transmission line, a second controllable reflective load, and a pair of coupled lines that are electromagnetically coupled to one another. The pair of coupled lines including a first conductive line connected between the first port and the first controllable reflective load and a second conductive line connected between the second controllable reflective load and the second port.

[0005] In some examples, the first controllable reflective load further includes a first ground conductor on a first side of the first transmission line and a second ground

conductor on a second side of the first transmission line. According to a number of examples, each of the first plurality of shunt switches is implemented as a pair of field-effect transistors including a first field-effect transistor connected between the first transmission line and the first ground conductor and a second field-effect transistor connected between the first transmission line and the second ground conductor.

[0006] In several examples, one or more of the first plurality of shunt switches are closed based on a phase shifting setting of the phase shifter.

[0007] In various examples, the first port receives a radio frequency input signal and the second port provides a phase-shifted radio frequency output signal.

[0008] In some examples, the second port receives a radio frequency input signal and the first port provides a phase-shifted radio frequency output signal.

[0009] In several examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having uninform distance from one another.

[0010] In various examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having non-uniform distance from one another. According to a number of examples, the distance between adjacent pairs of the plurality of points gradually decreases along a length of the first transmission line.

[0011] In some examples, the first plurality of shunt switches each have a common size.

[0012] In several examples, the first plurality of shunt switches each have a different size. According to a number of examples, the size of the first plurality of shunt transistors gradually increases along a length of the first transmission line.

[0013] In various examples, the first transmission line includes a plurality of meandering sections. In accordance with some examples, at least one of the plurality of meandering sections includes a loop.

[0014] In several examples, the second controllable reflective load includes a second transmission line and a second plurality of shunt switches connected along the second transmission line.

[0015] In some examples, the phase shifter further includes a hybrid coupler including the pair of coupled lines.

[0016] In another aspect, the present disclosure relates to a wireless device. The wireless device includes a transceiver, and a front-end system coupled to the transceiver. The front-end system includes a phase shifter including a first port, a second port, a first controllable reflective load including a first transmission line and a first plurality of shunt switches connected along the first transmission line, a second controllable reflective load, and a pair of coupled lines that are electromagnetically coupled to one another. The pair of coupled lines includes a first conductive line connected between the first port and the first controllable reflective load and a second conductive line connected between the second controllable reflective load and the second port.

[0017] In various examples, the first controllable reflective load further includes a first ground conductor on a first side of the first transmission line and a second ground conductor on a second side of the first transmission line. According to a number of examples, each of the first plurality of shunt switches is implemented as a pair of field-effect transistors including a first field-effect transistor connected between the first transmission line and the first ground conductor and a second field-effect transistor connected between the first transmission line and the second ground conductor.

[0018] In several examples, one or more of the first plurality of shunt switches are closed based on a phase shifting setting of the phase shifter.

[0019] In some examples, the first port receives a radio frequency input signal and the second port provides a phase-shifted radio frequency output signal.

[0020] In various examples, the second port receives a radio frequency input signal and the first port provides a phase-shifted radio frequency output signal.

[0021] In several examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having uninform distance from one another.

[0022] In some examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having non-uniform distance from one another. According to a number of examples, the distance between adjacent pairs of the plurality of points gradually decreases along a length of the first transmission line.

[0023] In various examples, the first plurality of shunt switches each have a common size.

[0024] In several examples, the first plurality of shunt switches each have a different size. According to a number of examples, the size of the first plurality of shunt transistors gradually increases along a length of the first transmission line.

[0025] In some examples, the first transmission line includes a plurality of meandering sections. According to various examples, at least one of the plurality of meandering sections includes a loop.

[0026] In several examples, the second controllable reflective load includes a second transmission line and a second plurality of shunt switches connected along the second transmission line.

[0027] In various examples, the phase shifter further includes a hybrid coupler including the pair of coupled lines.

[0028] In another aspect, the present disclosure relates to a method of phase shifting. The method includes receiving a radio frequency input signal at a first port. The method further includes controlling a first controllable reflective load and a second controllable reflective load to control a phase shift of a radio frequency output signal at a second port, the first controllable reflective load including a first transmission line and a first plurality of shunt switches connected along the first transmission line. The method further includes providing coupling between a first conductive line and a second conductive line of a pair of coupled lines, the first conductive line connected between the first port and the first controllable reflective load, and the second conductive line connected between the second controllable reflective load and the second port.

[0029] In various examples, the first controllable reflective load further includes a first ground conductor on a first side of the first transmission line and a second ground conductor on a second side of the first transmission line. According to several examples, each of the first plurality of shunt switches is implemented as a pair of field-effect transistors including a first field-effect transistor connected between the first transmission line and the first ground conductor and a second field-effect transistor connected between the first transmission line and the second ground conductor.

[0030] In a number of examples, the method further includes closing one or more of the first plurality of shunt switches based on a phase shifting setting of the phase shifter.

[0031] In several examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having uninform distance from one another.

[0032] In various examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having non-uniform distance from one another. According to a number of examples, the distance between adjacent pairs of the plurality of points gradually decreases along a length of the first transmission line.

[0033] In several examples, the first plurality of shunt switches each have a common size.

[0034] In some examples, the first plurality of shunt switches each have a different size. In accordance with various examples, the size of the first plurality of shunt transistors gradually increases along a length of the first transmission line.

[0035] In a number of examples, the first transmission line includes a plurality of meandering sections. According to several examples, at least one of the plurality of meandering sections includes a loop.

[0036] In various examples, the second controllable reflective load includes a second transmission line and a second plurality of shunt switches connected along the second transmission line.

[0037] In some examples, the phase shifter further includes a hybrid coupler including the pair of coupled lines.

[0038] In another aspect, the present disclosure relates to a phase shifter. The phase shifter includes a coupler including an input terminal, a thru terminal, a first coupled line connected between the input terminal and the thru terminal, an isolation terminal, a coupling terminal, and a second coupled line connected between the isolation terminal and the coupling terminal. The phase shifter further includes an input port connected to the input terminal of the coupler and configured to receive a radio frequency input signal, an output port connected to the coupling terminal of the coupler and configured to output a radio frequency output signal having a phase shift with respect to the radio frequency input signal, and a first controllable reflective load connected to the thru terminal of the coupler. The first controllable reflective load includes a transmission line and a plurality of shunt switches each connected between a ground voltage and a different point along the transmission line, the plurality of shunt switches selectable to control the phase shift.

[0039] In various examples, the first controllable reflective load further includes a first ground conductor on a first side of the transmission line and a second ground conductor on a second side of the transmission line. According to a number of examples, each of the plurality of shunt switches is implemented as a pair of field-effect transistors including a first field-effect transistor connected between the transmission line and the first ground conductor and a second field-effect transistor connected between the transmission line and the second ground conductor.

[0040] In several examples, the plurality of shunt switches are connected to the transmission line at a plurality of points that are non-uniformly spaced. According to a number of embodiments, a distance between adjacent pairs of the plurality of points gradually decreases along a length of the transmission line.

[0041] In various examples, the plurality of shunt switches each have a different size. According to a number of examples, the size of the plurality of shunt transistors gradually increases along a length of the first transmission line.

[0042] In several examples, the transmission line includes a plurality of meandering sections. According to some examples, at least one of the plurality of meandering sections includes a loop.

[0043] In a number of examples, the phase shifter further includes a second controllable reflective load connected to the isolation terminal of the coupler.

[0044] In another aspect, the present disclosure relates to a wireless device. The wireless device includes a transceiver, and a front-end system coupled to the transceiver. The front-end system includes a phase shifter including a coupler having an input terminal configured to receive a radio frequency input signal, a thru terminal, a first coupled line connected between the input terminal and the thru terminal, an isolation terminal, a coupling terminal configured to output a radio frequency output signal having a phase shift with respect to the radio frequency input signal, and a second coupled line connected between the isolation terminal and the coupling terminal. The phase shifter further includes a first controllable reflective load connected to the thru terminal of the coupler and including a transmission line and a plurality of shunt switches each connected between a ground voltage and a different point along the transmission line, the plurality of shunt switches selectable to control the phase shift.

[0045] In some examples, the first controllable reflective load further includes a first ground conductor on a first side of the transmission line and a second ground conductor on a second side of the transmission line. According to a number of examples, each of the plurality of shunt switches is implemented as a pair of field-effect transistors including a first field-effect transistor connected between the transmission line and the first ground conductor and a second field-effect transistor connected between the transmission line and the second ground conductor.

[0046] In various examples, the plurality of shunt switches are connected to the transmission line at a plurality of points that are non-uniformly spaced. According to some examples, a distance between adjacent pairs of the plurality of points gradually decreases along a length of the transmission line.

[0047] In several examples, the plurality of shunt switches each have a different size. According to a number of examples, the size of the plurality of shunt transistors gradually increases along a length of the first transmission line.

[0048] In some examples, the mobile device further includes a second controllable reflective load connected to the isolation terminal of the coupler.

[0049] In another aspect, the present disclosure relates to a method of phase shifting. The method includes receiving a radio frequency input signal at an input terminal of a coupler. The method further includes providing coupling from a first coupled line of the coupler to a second coupled line of the coupler, the first coupled line connected between the input terminal of the coupler and a thru terminal of the coupler, and the second coupled line connected between an isolation terminal of the coupler and a coupling terminal of the coupler. The method further includes providing a radio frequency output signal from the coupling terminal of the coupler, the radio frequency output signal having a phase shift with respect to the radio frequency input signal. The method further includes controlling the phase shift using a first controllable reflective load connected to the thru terminal of the coupler, including selecting one or more of a plurality of shunt switches of the first controllable reflective load, each of the plurality of shunt switches connected between a ground voltage and a different point along a transmission line of the first controllable reflective load.

[0050] In some examples, the method further includes controlling a second controllable reflective load connected to the isolation terminal of the coupler.

[0051] In certain examples, the present disclosure relates to a phase shifter. The phase shifter includes a first port, a second port, a first controllable reflective load, and a second controllable reflective load including a first transmission line and a first plurality of shunt switches connected along the first transmission line. The phase shifter further includes a pair of coupled lines that are electromagnetically coupled to one another. The pair of coupled lines includes a first conductive line connected between the first port and the first controllable reflective load and a second conductive line connected between the second controllable reflective load and the second port.

[0052] In various examples, the second controllable reflective load further includes a first ground conductor on a first side of the first transmission line and a second ground conductor on a second side of the first transmission line. According to several examples, each of the first plurality of shunt switches is implemented as a pair of field-effect transistors including a first field-effect transistor connected between the first transmission line and the first ground conductor and a second field-effect transistor connected between the first transmission line and the second ground conductor.

[0053] In a number of examples, one or more of the first plurality of shunt switches are closed based on a phase shifting setting of the phase shifter.

[0054] In some examples, the first port receives a radio frequency input signal and the second port provides a phase-shifted radio frequency output signal.

[0055] In several examples, the second port receives a radio frequency input signal and the first port provides a phase-shifted radio frequency output signal.

[0056] In various examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having uninform distance from one another.

[0057] In some examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having non-uniform distance from one another. According to a number of examples, the distance between adjacent pairs of the plurality of points gradually decreases along a length of the first transmission line.

[0058] In several examples, the first plurality of shunt switches each have a common size.

[0059] In a number of examples, the first plurality of shunt switches each have a different size. According to some examples, the size of the first plurality of shunt transistors gradually increases along a length of the first transmission line.

[0060] In various examples, the first transmission line includes a plurality of meandering sections. According to a number of examples, at least one of the plurality of meandering sections includes a loop.

[0061] In several examples, the first controllable reflective load includes a second transmission line and a second plurality of shunt switches connected along the second transmission line.

[0062] In some examples, the phase shifter further includes a hybrid coupler including the pair of coupled lines.

[0063] In certain examples, the present disclosure relates to a wireless device. The wireless device includes a transceiver and a front-end system coupled to the transceiver. The front-end system includes a phase shifter including a first port, a second port, a first controllable reflective load, a second controllable reflective load including a first transmission line and a first plurality of shunt switches connected along the first transmission line. The phase shifter further includes a pair of coupled lines that are electromagnetically coupled to one another. The pair of coupled lines includes a first conductive line connected between the first port and the first controllable reflective load and a second conductive line connected between the second controllable reflective load and the second port.

[0064] In various examples, the second controllable reflective load further includes a first ground conductor on a first side of the first transmission line and a second ground conductor on a second side of the first transmission line. According to a number of examples, each of the first plurality of shunt switches is implemented as a pair of field-effect transistors including a first field-effect transistor connected between the first transmission line and the first ground conductor and a second field-effect transistor connected between the first transmission line and the second ground conductor.

[0065] In several examples, one or more of the first plurality of shunt switches are closed based on a phase shifting setting of the phase shifter.

[0066] In various examples, the first port receives a radio frequency input signal and the second port provides a phase-shifted radio frequency output signal.

[0067] In some examples, the second port receives a radio frequency input signal and the first port provides a phase-shifted radio frequency output signal.

[0068] In a number of examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having uninform distance from one another.

[0069] In several examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having non-uniform distance from one another. According to a number of examples, the distance between adjacent pairs of the plurality of points gradually decreases along a length of the first transmission line.

[0070] In various examples, the first plurality of shunt switches each have a common size.

[0071] In several examples, the first plurality of shunt switches each have a different size. According to some examples, the size of the first plurality of shunt transistors gradually increases along a length of the first transmission line.

[0072] In a number of examples, the first transmission line includes a plurality of meandering sections. According to various examples, at least one of the plurality of meandering sections includes a loop.

[0073] In some examples, the first controllable reflective load includes a second transmission line and a second plurality of shunt switches connected along the second transmission line.

[0074] In several examples, the phase shifter further includes a hybrid coupler including the pair of coupled lines.

[0075] In certain examples, a method of phase shifting is provided. The method includes receiving a radio frequency input signal at a first port. The method further includes controlling a first controllable reflective load and a second controllable reflective load to control a phase shift of a radio frequency output signal at a second port, the first controllable reflective load including a first transmission line and a first plurality of shunt switches connected along the first transmission line. The method further includes providing coupling between a first conductive line and a second conductive line of a pair of coupled lines, the first conductive line connected between the first port and the first controllable reflective load, and

the second conductive line connected between the second controllable reflective load and the second port.

[0076] In several examples, the second controllable reflective load further includes a first ground conductor on a first side of the first transmission line and a second ground conductor on a second side of the first transmission line. According to some examples, each of the first plurality of shunt switches is implemented as a pair of field-effect transistors including a first field-effect transistor connected between the first transmission line and the first ground conductor and a second field-effect transistor connected between the first transmission line and the second ground conductor.

[0077] In a number of examples, the method further includes closing one or more of the first plurality of shunt switches based on a phase shifting setting of the phase shifter.

[0078] In various examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having uninform distance from one another.

[0079] In several examples, the first plurality of shunt switches are connected to the first transmission line at a plurality of points having non-uniform distance from one another. According to a number of examples, the distance between adjacent pairs of the plurality of points gradually decreases along a length of the first transmission line.

[0080] In various examples, the first plurality of shunt switches each have a common size.

[0081] In some examples, the first plurality of shunt switches each have a different size. According to a number of examples, the size of the first plurality of shunt transistors gradually increases along a length of the first transmission line.

[0082] In several examples, the first transmission line includes a plurality of meandering sections. According to a number of examples, at least one of the plurality of meandering sections includes a loop.

[0083] In various examples, the first controllable reflective load includes a second transmission line and a second plurality of shunt switches connected along the second transmission line.

[0084] In some examples, the phase shifter further includes a hybrid coupler including the pair of coupled lines.