BALUNS WITH INTEGRATED MATCHING NETWORKS

BACKGROUND

Technical Field

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

Description of Related Technology

[0002] A balun can be used to convert a single-ended RF signal to a differential RF signal, or vice versa. Examples of RF communication systems with one or more baluns include, but are not limited to, mobile phones, tablets, base stations, network access points, customer-premises equipment (CPE), laptops, and wearable electronics.

[0003] Baluns can be included in RF communication systems to provide conversion of RF signals of a wide range of frequencies. For example, baluns can handle RF signals in a frequency 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 balun. The balun includes a first pair of coupled lines including a first conductive line and a second conductive line, a second pair of coupled lines including a third conductive line and a fourth conductive line, and a transmission line connecting the first conductive line of the first pair of coupled lines to the third conductive line of the second pair of ~~conductive~~ coupled lines, wherein the first pair of coupled lines and the second pair of coupled lines are separately adjustable to have different odd-mode impedance or different even-mode impendences.

[0005] In several examples, the first pair of conductive lines and the second pair of conductive lines have different lengths.

[0006] In various examples, the first pair of conductive lines and the second pair of conductive lines have different odd-mode impedances.

[0007] In some examples, the first pair of conductive lines and the second pair of conductive lines have different even-mode impedances.

conductive line of the first pair of coupled lines to the third conductive line of the second pair of ~~conductive~~ coupled lines, wherein the first pair of coupled lines and the second pair of coupled lines are separately adjustable to have different odd-mode impedance or different even-mode impendences.

[0021] In various examples, the first pair of conductive lines and the second pair of conductive lines have different lengths.

[0022] In several examples, the first pair of conductive lines and the second pair of conductive lines have different odd-mode impedances.

[0023] In a number of examples, the first pair of conductive lines and the second pair of conductive lines have different even-mode impedances.

[0024] In some examples, the first pair of conductive lines, the second pair of conductive lines, and the transmission line are implemented to provide input matching.

[0025] In various examples, the first pair of conductive lines, the second pair of conductive lines, and the transmission line are implemented to provide output matching.

[0026] In several examples, the transmission line includes a coil.

[0027] In some examples, the balun further includes a first port connected to an end of the first conductive line opposite the transmission line, a second port connected to the second conductive line of the first pair of conductive lines, and a third port connected to the fourth conductive line of the second pair of conductive lines.

[0028] According to a number of examples, the first port is an unbalanced terminal for a single-ended signal, the second port is a positive terminal for a differential signal, and the third port is a negative terminal for the differential signal.

[0029] In accordance with several examples, an end of the third conductive line opposite the transmission line is connected to a reference voltage.

[0030] According to various examples, an end of the second conductive line opposite the second port is connected to a reference voltage.

[0031] In accordance with a number of examples, an end of the fourth conductive line opposite the third port is connected to a reference voltage.

[0032] According to various examples, the front end system further includes an amplifier configured to receive a single-ended signal from the first port.

[0033] In accordance with several examples, the front end system further includes an amplifier configured to provide a single-ended signal to the first port.

[0034] According to a number of examples, the front end system further includes an amplifier configured to receive a differential signal from the second port and the third port.

[0035] In accordance with several examples, the front end system further includes an amplifier configured to provide a differential signal to the second port and the third port.

[0036] In another aspect, the present disclosure relates to a method of signal conversion in a balun. The method includes providing coupling between a first conductive line and a second conductive line of a first pair of coupled lines, providing coupling between a third conductive line and a fourth conductive line of a second pair of coupled lines, and using a transmission line to provide a signal path from the first conductive line of the first pair of coupled lines to the third conductive line of the second pair of conductive lines, wherein the first pair of coupled lines and the second pair of coupled lines are separately adjustable to have different odd-mode impedance or different even-mode impendences.

[0037] In various examples, the first pair of conductive lines and the second pair of conductive lines have different lengths.

[0038] In several examples, the first pair of conductive lines and the second pair of conductive lines have different odd-mode impedances.

[0039] In a number of examples, the first pair of conductive lines and the second pair of conductive lines have different even-mode impedances.

[0040] In some examples, the method further includes providing input matching using the first pair of conductive lines, the second pair of conductive lines, and the transmission line.

[0041] In various examples, the method further includes providing output matching using the first pair of conductive lines, the second pair of conductive lines, and the transmission line.

[0042] In some examples, the method further includes providing a first port on an end of the first conductive line opposite the transmission line, providing a second port on an end of the second conductive line of the first pair of conductive lines, and providing a third port on an end of the fourth conductive line of the second pair of conductive lines.

[0043] According to a number of examples, the method further includes using the first port as an unbalanced terminal for a single-ended signal, using the second port as a

WHAT IS CLAIMED IS:

1. A balun comprising:

a first pair of coupled lines including a first conductive line and a second conductive line;

a second pair of coupled lines including a third conductive line and a fourth conductive line; and

a transmission line connecting the first conductive line of the first pair of coupled lines to the third conductive line of the second pair of coupled ~~conductive~~ lines;

wherein the first pair of coupled lines and the second pair of coupled lines are separately adjustable to have different odd-mode impedance or different even-mode impendences.

2. The balun of claim 1 further comprising a first port connected to an end of the first conductive line opposite the transmission line, a second port connected to the second conductive line of the first pair of ~~conductive~~ coupled lines, and a third port connected to the fourth conductive line of the second pair of ~~conductive~~ coupled lines.

3. The balun of claim 2 wherein the first port is as an unbalanced terminal for a single-ended signal, the second port is as a positive terminal for a differential signal, and the third port is as a negative terminal for the differential signal.

4. The balun of claim 2 wherein an end of the third conductive line opposite the transmission line is connected to a reference voltage.

5. The balun of claim 2 wherein an end of the second conductive line opposite the second port is connected to a reference voltage.

6. The balun of claim 2 wherein an end of the fourth conductive line opposite the third port is connected to a reference voltage.

7. The balun of claim 1 wherein the first pair of ~~conductive~~ coupled lines and the second pair of ~~conductive~~ coupled lines have different lengths.

~~8. The balun of claim 1 wherein the first pair of conductive lines and the second pair of conductive lines have different odd-mode impedances.~~

~~9. The balun of claim 1 wherein the first pair of conductive lines and the second pair of conductive lines have different even-mode impedances.~~

~~10.~~8. The balun of claim 1 wherein the transmission line includes a coil.

~~11.~~9. A wireless device comprising:

a transceiver; and

a front-end system coupled to the transceiver, the front-end system including a balun that includes a first pair of coupled lines including a first conductive line and a second conductive line, a second pair of coupled lines including a third conductive line and a fourth conductive line, and a transmission line connecting the first conductive line of the first pair of coupled lines to the third conductive line of the second pair of coupled ~~conductive~~ lines, wherein the first pair of coupled lines and the second pair of coupled lines are separately adjustable to have different odd-mode impedance or different even-mode impendences.

~~12.~~10. The wireless device of claim ~~11~~ 9 wherein the balun further includes a first port connected to an end of the first conductive line opposite the transmission line, a second port connected to the second conductive line of the first pair of coupled ~~conductive~~ lines, and a third port connected to the fourth conductive line of the second pair of coupled ~~conductive~~ lines.

~~13.~~11. The wireless device of claim ~~12~~ 10 the front end system further includes an amplifier configured to provide a single-ended signal to the first port.

~~14.~~12. The wireless device of claim ~~12~~ 10 wherein the front end system further includes an amplifier configured to provide a differential signal to the second port and the third port.

~~15.~~13. The wireless device of claim ~~11~~ 9 further comprising an amplifier, the first pair of coupled ~~conductive~~ lines, the second pair of coupled ~~conductive~~ lines, and the transmission line operable to provide input matching to the amplifier.

~~16.~~14. The wireless device of claim ~~11~~ 9 further comprising an amplifier, the first pair of coupled ~~conductive~~ lines, the second pair of coupled ~~conductive~~ lines, and the transmission line operable to provide output matching to the amplifier.

~~17.~~15. The wireless device of claim ~~11~~ 9 wherein the transmission line includes a coil.

~~18.~~16. A method of signal conversion in a balun, the method comprising:

providing coupling between a first conductive line and a second conductive line of a first pair of coupled lines;

providing coupling between a third conductive line and a fourth conductive line of a second pair of coupled lines; and

providing a signal path through a transmission line from the first conductive line of the first pair of coupled lines to the third conductive line of the second pair of coupled ~~conductive~~ lines, wherein the first pair of coupled lines and the second pair of coupled lines are separately adjustable to have different odd-mode impedance or different even-mode impendences.

~~19.~~17. The method of claim ~~18~~ 16 further comprising providing input matching using the first pair of coupled ~~conductive~~ lines, the second pair of coupled ~~conductive~~ lines, and the transmission line.

~~20.~~18. The method of claim ~~18~~ 16 further comprising providing output matching using the first pair of coupled ~~conductive~~ lines, the second pair of coupled ~~conductive~~ lines, and the transmission line.