LOAD MODULATED DOHERTY POWER AMPLIFIERS

BACKGROUND

Field

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

Description of the Related Technology

[0002] Power amplifiers are used in RF communication systems to amplify RF signals for transmission via antennas.

[0003] Examples of RF communication systems with one or more power amplifiers 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 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 a first aspect~~certain embodiments~~, the present disclosure relates to a power amplifier system. The power amplifier system includes a combiner including a first terminal, a second terminal, a third terminal, and a fourth terminal, the combiner configured to provide a radio frequency output signal from the fourth terminal. The power amplifier system further includes a carrier amplifier including an output coupled to the first terminal of the combiner, a peaking amplifier including an output coupled to the second terminal of the combiner, and a load modulating amplifier including an output coupled to the third terminal of the combiner.

[0005] In some ~~embodiment~~examples, the peaking amplifier is configured to activate at a first power threshold, and the load modulating amplifier is configured to activate at a second

power threshold greater than the first power threshold. According to various ~~embodiment~~examples, when activated the load modulating power amplifier is operable to modulate down a load of the carrier amplifier and of the peaking amplifier. In accordance with several ~~embodiment~~examples, the carrier amplifier includes a saturation detector configured to monitor an amount of saturation of the carrier amplifier, the saturation detector operable to control activation of the peaking amplifier and to control activation of the load modulating amplifier. According to a number of ~~embodiment~~examples, the carrier amplifier includes a class AB bias circuit, the peaking amplifier includes a first class C bias circuit, and the load modulating amplifier includes a second class C bias circuit.

[0006] In various ~~embodiment~~examples, the load modulating amplifier includes a cascode amplifier stage. According to a number of ~~embodiment~~examples, the carrier amplifier includes a first common-emitter amplifier stage, and the peaking amplifier includes a second common-emitter amplifier stage.

[0007] In several ~~embodiment~~examples, the combiner is a hybrid coupler, the first terminal corresponding to a zero degree port, the second terminal corresponding to a ninety degree port, the third terminal corresponding to an isolation port, and the fourth terminal corresponding to a common port.

[0008] In some ~~embodiment~~examples, the power amplifier system further includes an input splitter configured to split a radio frequency input signal into a plurality of input signal components including a first input signal component provided to an input of the carrier amplifier and a second input signal component provided to an input of the peaking amplifier. According to a number of ~~embodiment~~examples, the plurality of input signal components further include a third input signal component provided to an input of the load modulating amplifier.

[0009] In a second aspect ~~certain embodiments~~, the present disclosure relates to a mobile device. The mobile device includes an antenna configured to transmit a radio frequency output signal, and a front end system. The front end system includes a power amplifier system including a combiner, a carrier amplifier having an output coupled to a first terminal of the combiner, a peaking amplifier having an output coupled to a second terminal of the combiner, and a load modulating amplifier having an output coupled to a third terminal of the combiner, the combiner configured to provide the radio frequency output signal at a fourth terminal.

[0010] In various ~~embodiment~~examples, the peaking amplifier is configured to activate at a first power threshold, and the load modulating amplifier is configured to activate at a second power threshold greater than the first power threshold. According to several ~~embodiment~~examples, when activated the load modulating power amplifier is operable to modulate down a load of the carrier amplifier and of the peaking amplifier. In accordance with some ~~embodiment~~examples, the carrier amplifier includes a saturation detector configured to monitor an amount of saturation of the carrier amplifier, the saturation detector operable to control activation of the peaking amplifier and to control activation of the load modulating amplifier. According to a number of ~~embodiment~~examples, the carrier amplifier includes a class AB bias circuit, the peaking amplifier includes a first class C bias circuit, and the load modulating amplifier includes a second class C bias circuit.

[0011] In various ~~embodiment~~examples, the load modulating amplifier includes a cascode amplifier stage. According to several ~~embodiment~~examples, the carrier amplifier includes a first common-emitter amplifier stage, and the peaking amplifier includes a second common-emitter amplifier stage.

[0012] In a number of ~~embodiment~~examples, the combiner is a hybrid coupler, the first terminal corresponding to a zero degree port, the second terminal corresponding to a ninety degree port, the third terminal corresponding to an isolation port, and the fourth terminal corresponding to a common port.

[0013] In several ~~embodiment~~examples, the mobile device includes an input splitter configured to split a radio frequency input signal into a plurality of input signal components including a first input signal component provided to an input of the carrier amplifier and a second input signal component provided to an input of the peaking amplifier. According to a number of ~~embodiment~~examples, the plurality of input signal components further include a third input signal component provided to an input of the load modulating amplifier.

[0014] In certain ~~embodiment~~examples, the present disclosure relates to a method of amplification in a mobile phone. The method includes providing a first radio frequency signal from an output of a carrier amplifier to a first terminal of a combiner, providing a first radio frequency signal from an output of a peaking amplifier to a second terminal of the combiner, providing a first radio frequency signal from an output of a load modulating amplifier to a third terminal of the combiner, and combining the first radio frequency signal, the second radio

frequency signal, and the third radio frequency signal to generate a radio frequency output signal using the combiner, and providing the radio frequency output signal at a fourth terminal of the combiner.

[0015] In various ~~embodiment~~examples, the method further includes activating the peaking amplifier at a first power threshold, and activating the load modulating amplifier at a second power threshold greater than the first power threshold. According to a number of ~~embodiment~~examples, activating the load modulating amplifier includes modulating down a load of the carrier amplifier and of the peaking amplifier.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Embodiments of this disclosure will now be described, by way of non-limiting example, with reference to the accompanying drawings.

[0017] Figure 1 is a schematic diagram of one embodiment of a load modulated Doherty power amplifier.

[0018] Figure 2 is a schematic diagram of another embodiment of a load modulated Doherty power amplifier.

[0019] Figure 3 is a schematic diagram of another embodiment of a load modulated Doherty power amplifier.

[0020] Figure 4 is a schematic diagram of another embodiment of a load modulated Doherty power amplifier.

[0021] Figure 5 is a schematic diagram of another embodiment of a load modulated Doherty power amplifier.

[0022] Figure 6 is a schematic diagram of another embodiment of a load modulated Doherty power amplifier.

[0023] Figure 7 is a graph of one example of gain versus output power for a load modulated Doherty power amplifier.

[0024] Figure 8 is a graph of one example of power added efficiency (PAE) versus output power for a load modulated Doherty power amplifier.

[0025] Figure 9 is a graph of another example of PAE versus output power for a load modulated Doherty power amplifier.

[0026] Figure 10 is a schematic diagram of one embodiment of a mobile device.