MULTI-LEVEL ENVELOPE TRACKING SYSTEMS WITH ADJUSTED VOLTAGE STEPS

BACKGROUND

Field

[0001] Embodiments of the invention relate to electronic systems, and in particular, to power amplifiers for 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. It is important to manage the power of RF signal transmissions to prolong battery life and/or provide a suitable transmit power level.

[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 410 MHz to about 7.125 GHz for fifth generation (5G) communications in frequency range 1 (FR1).

SUMMARY

[0004] In a first aspect~~certain embodiments~~, the present disclosure relates to an envelope tracking system. The envelope tracking system includes a power amplifier configured to amplify a radio frequency signal and to receive power from a power amplifier supply voltage, and an envelope tracker configured to generate the power amplifier supply voltage based on an envelope signal corresponding to an envelope of the radio frequency signal. The envelope tracker includes a DC-to-DC converter configured to output a plurality of regulated voltages, a modulator configured to control the power amplifier supply voltage based on the plurality of regulated voltages and the envelope signal, and a switching point adaptation circuit configured

to control a voltage level of at least one of the plurality of regulated voltages based on a power level of the radio frequency signal.

[0005] In some examples~~embodiments~~, the switching point adaptation circuit is configured to control the voltage level of each of the plurality of regulated voltages based on the power level of the radio frequency signal.

[0006] In various examples~~embodiments~~, the switching point adaptation circuit includes a power estimation circuit configured to estimate the power level of the radio frequency signal based on a signal power value for or at least one of a transmit frame or a transmit symbol. According to a number of ~~embodiments~~examples, the signal power value indicates an average power for the transmit frame or symbol. In accordance with several ~~embodiments~~examples, the signal power value indicates a peak power for the transmit frame or symbol. According to some ~~embodiments~~examples, the switching point adaptation circuit further includes a voltage estimation circuit configured to estimate a plurality of desired voltage levels associated with the signal power value. In accordance with a number of ~~embodiments~~examples, the switching point adaptation circuit further includes a programming circuit configured to control the DC-to-DC converter to output the plurality of regulated voltages each with a corresponding one of the plurality of desired voltage levels.

[0007] In several ~~embodiments~~examples, the envelope tracking system further includes two or more power amplifiers configured to amplify two or more radio frequency signals, the envelope tracker including two or more modulators each configured to receive the plurality of regulated voltages and to provide modulation to generate a supply voltage for a corresponding one of the two or more power amplifiers. According to a number of ~~embodiments~~examples, the switching point adaptation circuit is configured to control the voltage level based on a largest power level of the two or more radio frequency signals.

[0008] In several ~~embodiments~~examples, the DC-to-DC converter is configured to receive a battery voltage, and to generate the plurality of regulated voltages based on providing DC-to-DC conversion of the battery voltage.

[0009] In some ~~embodiments~~examples, each of the plurality of regulated voltages has a different voltage level.

[0010] In various ~~embodiments~~examples, the envelope tracker further includes a plurality of decoupling capacitors each coupled between ground and a corresponding one of the plurality of regulated voltages.

[0011] In a number of examples~~embodiments~~, the modulator includes a plurality of switches each coupled between the modulator output voltage and a corresponding one of the plurality of regulated voltages.

[0012] In several examples~~embodiments~~, the envelope tracker further includes a modulator output filter connected between an output of the modulator and the power amplifier supply voltage, the modulator output filter including at least one series inductor and at least one shunt capacitor.

[0013] In certain examples~~embodiments~~, the present disclosure relates to a mobile device. The mobile device includes a transceiver configured to generate a radio frequency transmit signal, a front end circuit including a power amplifier configured to amplify the radio frequency transmit signal and to receive power from a power amplifier supply voltage, and a power management circuit including an envelope tracker configured to generate the power amplifier supply voltage based on an envelope signal corresponding to an envelope of the radio frequency transmit signal. The envelope tracker includes a DC-to-DC converter configured to output a plurality of regulated voltages, a modulator configured to control the power amplifier supply voltage based on the plurality of regulated voltages and the envelope signal, and a switching point adaptation circuit configured to control a voltage level of at least one of the plurality of regulated voltages based on a power level of the radio frequency transmit signal.

[0014] In various examples~~embodiments~~, the switching point adaptation circuit is configured to control the voltage level of each of the plurality of regulated voltages based on the power level of the radio frequency transmit signal.

[0015] In some examples~~embodiments~~, the switching point adaptation circuit includes a power estimation circuit configured to estimate the power level of the radio frequency transmit signal based on a signal power value for at least one of a transmit frame or a transmit symbol. According to a number of examples~~embodiments~~, the signal power value indicates an average power for the transmit frame or symbol. In accordance with various examples~~embodiments~~, the signal power value indicates a peak power for the transmit frame or symbol. According to several examples~~embodiments~~, the switching point adaptation circuit further includes a voltage estimation

circuit configured to estimate a plurality of desired voltage levels associated with the signal power value. In accordance with a number of examples~~embodiments~~, the switching point adaptation circuit further includes a programming circuit configured to control the DC-to-DC converter to output the plurality of regulated voltages each with a corresponding one of the plurality of desired voltage levels.

[0016] In several examples~~embodiments~~, the mobile device further includes two or more power amplifiers configured to amplify two or more radio frequency transmit signals, the envelope tracker including two or more modulators each configured to receive the plurality of regulated voltages and to provide modulation to generate a supply voltage for a corresponding one of the two or more power amplifiers. According to various examples~~embodiments~~, the switching point adaptation circuit is configured to control the voltage level based on a largest power level of the two or more radio frequency transmit signals.

[0017] In some examples~~embodiments~~, the DC-to-DC converter is configured to receive a battery voltage, and to generate the plurality of regulated voltages based on providing DC-to-DC conversion of the battery voltage.

[0018] In various examples~~embodiments~~, each of the plurality of regulated voltages has a different voltage level.

[0019] In several examples~~embodiments~~, the envelope tracker further includes a plurality of decoupling capacitors each coupled between ground and a corresponding one of the plurality of regulated voltages.

[0020] In some examples~~embodiments~~, the modulator includes a plurality of switches each coupled between the modulator output voltage and a corresponding one of the plurality of regulated voltages.

[0021] In various examples~~embodiments~~, mobile device further includes a modulator output filter connected between an output of the modulator and the power amplifier supply voltage, the modulator output filter including at least one series inductor and at least one shunt capacitor.

[0022] In certain examples~~embodiments~~, the present disclosure relates to a method of envelope tracking. The method includes amplifying a radio frequency signal using a power amplifier, supplying power to the power amplifier using a power amplifier supply voltage, outputting a plurality of regulated voltages from a DC-to-DC converter, and controlling the

power amplifier supply voltage based on the plurality of regulated voltages and an envelope signal using a modulator, the envelope signal corresponding to an envelope of the radio frequency signal. The method further includes controlling a voltage level of at least one of the plurality of regulated voltages based on a power level of the radio frequency signal.

[0023] In various examples~~embodiments~~, the method further includes controlling each of the plurality of regulated voltages based on the power level of the radio frequency signal.

[0024] In some examples~~embodiments~~, the method further includes estimating the power level of the radio frequency signal based on a signal power value for at least one of a transmit frame or a transmit symbol. According to a number of examples~~embodiments~~, the signal power value indicates an average power for the transmit frame or symbol. In accordance with several examples~~embodiments~~, the signal power value indicates a peak power for the transmit frame or symbol. According to various examples~~embodiment~~, the method further includes estimating a plurality of desired voltage levels associated with the signal power value. In accordance with several embodiments, the method further includes controlling the DC-to-DC converter to output the plurality of regulated voltages each with a corresponding one of the plurality of desired voltage levels.

[0025] In several examples~~embodiments~~, the method further includes generating the plurality of regulated voltages based on providing DC-to-DC conversion of a battery voltage.

[0026] In various examples~~embodiments~~, each of the plurality of regulated voltages has a different voltage level.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] Figure 1 is a schematic diagram of a mobile device according to one embodiment.

[0028] Figure 2 is a schematic diagram of one embodiment of an envelope tracking system for a power amplifier.

[0029] Figure 3A is a schematic diagram of another embodiment of an envelope tracking system.

[0030] Figure 3B is a schematic diagram of another embodiment of an envelope tracking system.