POWER AMPLIFIERS WITH ADAPTIVE BIAS FOR ENVELOPE TRACKING APPLICATIONS

BACKGROUND

Field

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

Description of the Related Technology

[0002] Power amplifiers are used in radio frequency (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, for instance, in the range of about 410 MHz to about 7.125 GHz for Fifth Generation (5G) cellular communications in Frequency Range 1 (FR1) 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

[0003a] In an aspect, the present disclosure refers to a mobile device comprising:

a transceiver configured to generate a radio frequency signal;

a power management system including an envelope tracker configured to generate a power amplifier supply voltage that changes in relation to an envelope of the radio frequency signal; and

a front end system including a power amplifier configured to amplify the radio frequency signal and to receive power from the power amplifier supply voltage, the power amplifier including a current mirror having an input configured to receive a reference current and an output electrically connected to the power amplifier supply voltage, and a field-effect transistor configured to amplify the radio frequency signal and having a gate biased based on an internal voltage of the current mirror, wherein the internal voltage of the current mirror increases in response to a decrease of the power amplifier supply voltage, and decreases in response to an increase of the power amplifier supply voltage

[0003b] In an aspect, the present disclosure refers to an envelope tracking system comprising:

an envelope tracker configured to generate a power amplifier supply voltage that changes in relation to an envelope of a radio frequency signal; and

a power amplifier configured to amplify the radio frequency signal and to receive power from the power amplifier supply voltage, the power amplifier including a current mirror having an input configured to receive a reference current and an output electrically connected to the power amplifier supply voltage, and a field-effect transistor configured to amplify the radio frequency signal and having a gate biased based on an internal voltage of the current mirror, wherein the internal voltage of the current mirror increases in response to a decrease of the power amplifier supply voltage, and decreases in response to an increase of the power amplifier supply voltage

[0003c] In an aspect, the present disclosure refers to a method of radio frequency signal amplification in a mobile device, the method comprising:

generating a power amplifier supply voltage that changes in relation to an envelope of a radio frequency signal using an envelope tracker;

powering a power amplifier using the power amplifier supply voltage;

amplifying the radio frequency signal using a field-effect transistor of the power amplifier;

generating a gate bias voltage of the field-effect transistor using an internal voltage of a current mirror of the power amplifier, including providing a reference current to an input of the current mirror and providing the power amplifier supply voltage to an output of the current mirror;

increasing the internal voltage of the current mirror in response to a decrease of the power amplifier supply voltage, and decreasing the internal voltage of the current mirror in response to an increase of the power amplifier supply voltage.

[0004] In one example, the present disclosure relates to a mobile device. The mobile device includes a transceiver configured to generate a radio frequency signal, a power management system including an envelope tracker configured to generate a power amplifier supply voltage that changes in relation to an envelope of the radio frequency signal, and a front end system including a power amplifier configured to amplify the radio frequency signal and to receive power from the power amplifier supply voltage. The power amplifier includes a

[0012] In some examples, the envelope tracker includes a DC-to-DC converter configured to output a plurality of regulated voltages, a modulator configured to generate a modulator output voltage at an output based on the plurality of regulated voltages and the envelope of the radio frequency signal, and a modulator output filter coupled between the output of the modulator and the power amplifier supply voltage.

[0013] In various examples, the envelope tracker includes a DC-to-DC converter and an error amplifier configured to operate in parallel with one another to generate the power amplifier supply voltage.

[0014] In another example, the present disclosure relates to an envelope tracking system. The envelope tracking system includes an envelope tracker configured to generate a power amplifier supply voltage that changes in relation to an envelope of a radio frequency signal, and a power amplifier configured to amplify the radio frequency signal and to receive power from the power amplifier supply voltage. The power amplifier includes a current mirror having an input configured to receive a reference current and an output electrically connected to the power amplifier supply voltage, and a field-effect transistor configured to amplify the radio frequency signal and having a gate biased based on an internal voltage of the current mirror.

[0015] In various examples, the internal voltage of the current mirror increases in response to a decrease of the power amplifier supply voltage, and decreases in response to an increase of the power amplifier supply voltage.

[0016] In several examples, the field-effect transistor is a short channel metal oxide semiconductor transistor.

[0017] In some examples, the power amplifier further includes a choke inductor electrically connected between the power amplifier supply voltage and a drain of the field-effect transistor.

[0018] In various examples, the current mirror is a Wilson current mirror.

[0019] In several examples, the power amplifier further includes a buffer configured to buffer the internal voltage of the current mirror to generate a gate bias voltage of the field-effect transistor. According to a number of examples, the buffer includes a first depletion-mode transistor and a second depletion-mode transistor configured to provide buffering with a zero shift.

[0020] In some examples, the current mirror includes a first mirror transistor having a drain configured to output the internal voltage, a second mirror transistor, a third mirror transistor, and a fourth mirror transistor, the third mirror transistor and the first mirror transistor connected in series between the input of the current mirror and a ground voltage, and the fourth mirror transistor and the second mirror transistor connected in series between the output of the current mirror and the ground voltage. According to a number of examples, a gate of the first mirror transistor is connected to a gate of the second mirror transistor, and a gate of the third mirror transistor is connected to a gate of the fourth mirror transistor. In various examples, a drain of the second mirror transistor is connected to the gate of the second mirror transistor, and a drain of the third mirror transistor is connected to the gate of the third mirror transistor.

[0021] In several examples, the power amplifier further includes a current source configured to generate the reference current.

[0022] In some examples, the envelope tracker includes a DC-to-DC converter configured to output a plurality of regulated voltages, a modulator configured to generate a modulator output voltage at an output based on the plurality of regulated voltages and the envelope of the radio frequency signal, and a modulator output filter coupled between the output of the modulator and the power amplifier supply voltage.

[0023] In several examples, the envelope tracker includes a DC-to-DC converter and an error amplifier configured to operate in parallel with one another to generate the power amplifier supply voltage.

[0024] In another example, the present disclosure relates to a method of radio frequency signal amplification in a mobile device. The method includes generating a power amplifier supply voltage that changes in relation to an envelope of a radio frequency signal using an envelope tracker, powering a power amplifier using the power amplifier supply voltage, amplifying the radio frequency signal using a field-effect transistor of the power amplifier, and generating a gate bias voltage of the field-effect transistor using an internal voltage of a current mirror of the power amplifier, including providing a reference current to an input of the current mirror and providing the power amplifier supply voltage to an output of the current mirror.

WHAT IS CLAIMED IS:

1. A mobile device comprising:

a transceiver configured to generate a radio frequency signal;

a power management system including an envelope tracker configured to generate a power amplifier supply voltage that changes in relation to an envelope of the radio frequency signal; and

a front end system including a power amplifier configured to amplify the radio frequency signal and to receive power from the power amplifier supply voltage, the power amplifier including a current mirror having an input configured to receive a reference current and an output electrically connected to the power amplifier supply voltage, and a field-effect transistor configured to amplify the radio frequency signal and having a gate biased based on an internal voltage of the current mirror, wherein the internal voltage of the current mirror increases in response to a decrease of the power amplifier supply voltage, and decreases in response to an increase of the power amplifier supply voltage.

2. The mobile device of claim 1 wherein the field-effect transistor is a short channel metal oxide semiconductor transistor.

3. The mobile device of claim 1 wherein the power amplifier further includes a choke inductor electrically connected between the power amplifier supply voltage and a drain of the field-effect transistor.

4. The mobile device of claim 1 wherein the current mirror is a Wilson current mirror.

5. The mobile device of claim 1 wherein the power amplifier further includes a buffer configured to buffer the internal voltage of the current mirror to generate a gate bias voltage of the field-effect transistor.

6. The mobile device of claim 5 wherein the buffer includes a first depletion-mode transistor and a second depletion-mode transistor configured to provide buffering with a zero shift.

7. The mobile device of claim 1 wherein the current mirror includes a first mirror transistor having a drain configured to output the internal voltage, a second mirror transistor, a third mirror transistor, and a fourth mirror transistor, the third mirror transistor and the first mirror transistor connected in series between the input of the current mirror and a ground voltage, and the fourth mirror transistor and the second mirror transistor connected in series between the output of the current mirror and the ground voltage.

8. The mobile device of claim 7 wherein a gate of the first mirror transistor is connected to a gate of the second mirror transistor, and a gate of the third mirror transistor is connected to a gate of the fourth mirror transistor.

9. The mobile device of claim 8 wherein a drain of the second mirror transistor is connected to the gate of the second mirror transistor, and a drain of the third mirror transistor is connected to the gate of the third mirror transistor.

10. The mobile device of claim 1 wherein the power amplifier further includes a current source configured to generate the reference current.

11. An envelope tracking system comprising:

an envelope tracker configured to generate a power amplifier supply voltage that changes in relation to an envelope of a radio frequency signal; and

a power amplifier configured to amplify the radio frequency signal and to receive power from the power amplifier supply voltage, the power amplifier including a current mirror having an input configured to receive a reference current and an output electrically connected to the power amplifier supply voltage, and a field-effect transistor configured to amplify the radio frequency signal and having a gate biased based on an internal voltage of the current mirror, wherein the internal voltage of the current mirror increases in response to a decrease of the power amplifier supply voltage, and decreases in response to an increase of the power amplifier supply voltage.

12. The envelope tracking system of claim 11 wherein the field-effect transistor is a short channel metal oxide semiconductor transistor.

13. The envelope tracking system of claim 11 wherein the current mirror is a Wilson current mirror.

14. The envelope tracking system of claim 11 wherein the power amplifier further includes a buffer configured to buffer the internal voltage of the current mirror to generate a gate bias voltage of the field-effect transistor.

15. The envelope tracking system of claim 11 wherein the current mirror includes a first mirror transistor having a drain configured to output the internal voltage, a second mirror transistor, a third mirror transistor, and a fourth mirror transistor, the third mirror transistor and the first mirror transistor connected in series between the input of the current mirror and a ground voltage, and the fourth mirror transistor and the second mirror transistor connected in series between the output of the current mirror and the ground voltage.

16. A method of radio frequency signal amplification in a mobile device, the method comprising:

generating a power amplifier supply voltage that changes in relation to an envelope of a radio frequency signal using an envelope tracker;

powering a power amplifier using the power amplifier supply voltage;

amplifying the radio frequency signal using a field-effect transistor of the power amplifier;

generating a gate bias voltage of the field-effect transistor using an internal voltage of a current mirror of the power amplifier, including providing a reference current to an input of the current mirror and providing the power amplifier supply voltage to an output of the current mirror;

increasing the internal voltage of the current mirror in response to a decrease of the power amplifier supply voltage, and decreasing the internal voltage of the current mirror in response to an increase of the power amplifier supply voltage.

17. The method of claim 16 further comprising buffering the internal voltage of the current mirror to generate the gate bias voltage of the field-effect transistor.