POWER AMPLIFIERS WITH SUPPLY CAPACITOR SWITCHING

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 radio frequency (RF) communication systems to amplify RF signals for transmission via antennas. It can be 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, laptops, and wearable electronics. Power amplifiers provide amplification to RF signals, which can have a frequency in the range from 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 one aspect, the present disclosure relates to a mobile device. The mobile device includes a power amplifier configured to amplify a radio frequency signal, a power management circuit configured to control a voltage level of a supply voltage of the power amplifier and operable in a selected supply control mode chosen from a plurality of supply control modes, and a front end system including a supply capacitor having a first end connected to the supply voltage, an n-type field-effect transistor ground switch connected between a second end of the supply capacitor and a ground voltage, and an n-type field-effect transistor discharge switch connected between the second end of the supply capacitor and the supply voltage. The n-type field-effect transistor ground switch and the n-type field-effect transistor discharge switch controlled based on the selected supply control mode.

[0005] In some examples, the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode. According to a number of examples, the n-type field-effect transistor ground switch is configured to turn on in the average power tracking mode and turn off in the envelope tracking mode, and the n-type field-effect transistor discharge switch is configured to turn off in the average power tracking mode and turn on in the envelope tracking mode.

[0006] In various examples, the n-type field-effect transistor discharge switch includes two or more n-type field-effect transistors in series. In accordance with several examples, the front-end system further includes a voltage divider configured to bias the two or more n-type field-effect transistors. According to a number of examples, the voltage divider includes a first terminal connected to the supply voltage and a second terminal connected to the ground voltage through a mode transistor. In accordance with some examples, the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode, the mode transistor configured to turn on in the envelope tracking mode and turn off in the average power tracking mode.

[0007] In several examples, the n-type field-effect transistor ground switch and the n-type field-effect transistor discharge switch are implemented on a bulk silicon semiconductor die.

[0008] In certain examples, the present disclosure relates to a packaged module. The packaged module includes a package substrate, and a first die attached to the package substrate and including a power amplifier configured to amplify a radio frequency signal and to receive power from a supply voltage controlled by a power management circuit. The packaged module further includes a supply capacitor attached to the package substrate and having a first end connected to the supply voltage, and a second die attached to the package substrate and fabricated using a bulk silicon process. The second die includes an n-type field-effect transistor ground switch connected between a second end of the supply capacitor and a ground voltage, and an n-type field-effect transistor discharge switch connected between the second end of the supply capacitor and the supply voltage.

[0009] In various examples, the power management circuit is operable in a selected supply control mode indicating one of an average power tracking mode or an envelope tracking mode, the n-type field-effect transistor ground switch and the n-type field-

effect transistor discharge switch controlled based on the selected supply control mode. According to several examples, the n-type field-effect transistor ground switch is configured to turn on in the average power tracking mode and turn off in the envelope tracking mode, and the n-type field-effect transistor discharge switch is configured to turn off in the average power tracking mode and turn on in the envelope tracking mode.

[0010] In some examples, the n-type field-effect transistor discharge switch includes two or more n-type field-effect transistors in series. According to a number of examples, the second die further includes a voltage divider configured to bias the two or more n-type field-effect transistors. In accordance with several examples, the voltage divider includes a first terminal connected to the supply voltage and a second terminal connected to the ground voltage through a mode transistor.

[0011] In various examples, the packaged module further includes a supply pin configured to receive the supply voltage, the power management circuit external to the package module.

[0012] In another aspect, the present disclosure relates to a power amplifier system. The power amplifier system includes a power amplifier configured to amplify a radio frequency signal, a power management circuit configured to control a voltage level of a supply voltage of the power amplifier and operable in a selected supply control mode chosen from a plurality of supply control modes, a supply capacitor having a first end connected to the supply voltage, an n-type field-effect transistor ground switch connected between a second end of the supply capacitor and a ground voltage, and an n-type field-effect transistor discharge switch connected between the second end of the supply capacitor and the supply voltage. The n-type field-effect transistor ground switch and the n-type field-effect transistor discharge switch controlled based on the selected supply control mode.

[0013] In various examples, the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode. According to a number of examples, the n-type field-effect transistor ground switch is configured to turn on in the average power tracking mode and turn off in the envelope tracking mode, and the n-type field-effect transistor discharge switch is configured to turn off in the average power tracking mode and turn on in the envelope tracking mode.

[0014] In several examples, the n-type field-effect transistor discharge switch includes two or more n-type field-effect transistors in series. According to a number of examples, the power amplifier system further includes a voltage divider configured to bias the two or more n-type field-effect transistors. In accordance with various examples, the voltage divider includes a first terminal connected to the supply voltage and a second terminal connected to the ground voltage through a mode transistor. According to some examples, the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode, the mode transistor configured to turn on in the envelope tracking mode and turn off in the average power tracking mode.

[0015] In various examples, the n-type field-effect transistor ground switch and the n-type field-effect transistor discharge switch are implemented on a bulk silicon semiconductor die.

[0016] In another aspect, the present disclosure relates to a method of power amplification. The method includes amplifying a radio frequency signal using a power amplifier, and controlling a voltage level of a supply voltage of the power amplifier using a power management circuit, the supply voltage coupled to a first end of a supply capacitor. The method further includes operating the power management circuit in a selected supply control mode chosen from a plurality of supply control modes, and controlling an n-type field-effect transistor ground switch based on the selected supply control mode, the n-type field-effect transistor ground switch connected between a second end of the supply capacitor and a ground voltage. The method further includes controlling an n-type field-effect transistor discharge switch based on the selected supply control mode, the n-type field-effect transistor discharge switch connected between the second end of the supply capacitor and the supply voltage.

[0017] In various examples, the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode. According to several examples, the method further includes turning on the n-type field-effect transistor ground switch in the average power tracking mode and turning off the n-type field-effect transistor ground switch in the envelope tracking mode. In accordance with some examples, the method further includes turning off the n-type field-effect transistor discharge switch in the

WHAT IS CLAIMED IS:

1. A mobile device comprising:

a power amplifier configured to amplify a radio frequency signal;

a power management circuit configured to control a voltage level of a supply voltage of the power amplifier, the power management circuit operable in a selected supply control mode chosen from a plurality of supply control modes; and

a front end system including a supply capacitor having a first end connected to the supply voltage, an n-type field-effect transistor ground switch connected between a second end of the supply capacitor and a ground voltage, and an n-type field-effect transistor discharge switch connected between the second end of the supply capacitor and the supply voltage, the n-type field-effect transistor ground switch and the n-type field-effect transistor discharge switch controlled based on the selected supply control mode.

2. The mobile device of claim 1 wherein the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode.

3. The mobile device of claim 2 wherein the n-type field-effect transistor ground switch is configured to turn on in the average power tracking mode and turn off in the envelope tracking mode, and the n-type field-effect transistor discharge switch is configured to turn off in the average power tracking mode and turn on in the envelope tracking mode.

4. The mobile device of claim 1 wherein the n-type field-effect transistor discharge switch includes two or more n-type field-effect transistors in series.

5. The mobile device of claim 4 wherein the front-end system further includes a voltage divider configured to bias the two or more n-type field-effect transistors.

6. The mobile device of claim 5 wherein the voltage divider includes a first terminal connected to the supply voltage and a second terminal connected to the ground voltage through a mode transistor.

7. The mobile device of claim 6 wherein the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode, the mode transistor configured to turn on in the envelope tracking mode and turn off in the average power tracking mode.

8. The mobile device of claim 1 wherein the n-type field-effect transistor ground switch and the n-type field-effect transistor discharge switch are implemented on a bulk silicon semiconductor die.

9. A power amplifier system comprising:

a power amplifier configured to amplify a radio frequency signal;

a power management circuit configured to control a voltage level of a supply voltage of the power amplifier, the power management circuit operable in a selected supply control mode chosen from a plurality of supply control modes;

a supply capacitor having a first end connected to the supply voltage;

an n-type field-effect transistor ground switch connected between a second end of the supply capacitor and a ground voltage; and

an n-type field-effect transistor discharge switch connected between the second end of the supply capacitor and the supply voltage, the n-type field-effect transistor ground switch and the n-type field-effect transistor discharge switch controlled based on the selected supply control mode.

10. The power amplifier system of claim 9 wherein the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode.

11. The power amplifier system of claim 10 wherein the n-type field-effect transistor ground switch is configured to turn on in the average power tracking mode and turn off in the envelope tracking mode, and the n-type field-effect transistor discharge switch is configured to turn off in the average power tracking mode and turn on in the envelope tracking mode.

12. The power amplifier system of claim 9 wherein the n-type field-effect transistor discharge switch includes two or more n-type field-effect transistors in series.

13. The power amplifier system of claim 12 further comprising a voltage divider configured to bias the two or more n-type field-effect transistors.

14. The power amplifier system of claim 13 wherein the voltage divider includes a first terminal connected to the supply voltage and a second terminal connected to the ground voltage through a mode transistor.

15. The power amplifier system of claim 14 wherein the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode, the mode transistor configured to turn on in the envelope tracking mode and turn off in the average power tracking mode.

16. The power amplifier system of claim 9 wherein the n-type field-effect transistor ground switch and the n-type field-effect transistor discharge switch are implemented on a bulk silicon semiconductor die.

17. A method of power amplification, the method comprising:

amplifying a radio frequency signal using a power amplifier;

controlling a voltage level of a supply voltage of the power amplifier using a power management circuit, the supply voltage coupled to a first end of a supply capacitor;

operating the power management circuit in a selected supply control mode chosen from a plurality of supply control modes;

controlling an n-type field-effect transistor ground switch based on the selected supply control mode, the n-type field-effect transistor ground switch connected between a second end of the supply capacitor and a ground voltage; and

controlling an n-type field-effect transistor discharge switch based on the selected supply control mode, the n-type field-effect transistor discharge switch connected between the second end of the supply capacitor and the supply voltage.

18. The method of claim 17 wherein the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode.

19. The method of claim 18 further comprising turning on the n-type field-effect transistor ground switch in the average power tracking mode and turning off the n-type field-effect transistor ground switch in the envelope tracking mode.

20. The method of claim 18 further comprising turning off the n-type field-effect transistor discharge switch in the average power tracking mode and turning on the n-type field-effect transistor discharge switch in the envelope tracking mode.