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~~certain embodiments~~, 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 ~~embodiment~~examples, the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode. According to a number of ~~embodiment~~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 ~~embodiment~~examples, the n-type field-effect transistor discharge switch includes two or more n-type field-effect transistors in series. In accordance with several ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~examples, the n-type field-effect transistor ground switch and the n-type field-effect transistor discharge switch are implemented on a semiconductor die fabricated using a bulk silicon process.

[0008] In certain ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~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 ~~certain embodiments~~, 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 ~~embodiment~~examples, the plurality of supply control modes includes an average power tracking mode and an envelope tracking mode. According to a number of ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~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 ~~embodiment~~examples, the n-type field-effect transistor ground switch and the n-type field-effect transistor discharge switch are implemented on a semiconductor die fabricated using a bulk silicon process.

[0016] In another aspect~~certain embodiments~~, 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 ground switch connected between the second end of the supply capacitor and the supply voltage.

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