LOW NOISE CHARGE PUMPS

BACKGROUND

Field

[0001] Embodiments of the invention relate to electronic systems, and in particular, to charge pumps for radio frequency electronics.

Description of Related Technology

[0002] Radio frequency (RF) communication systems can utilize DC-to-DC power conversion to enhance operating performance. Often, voltages that exceed a battery voltage are needed or desired, while in other situations, voltages that are significantly less than the battery voltage are utilized. A charge pump it a type of DC-to-DC power converter that receives an input voltage and generates a higher or lower voltage based on the input voltage. For example, a charge pump can use capacitors as energy storage elements to convert the input voltage into a higher voltage or a lower voltage.

[0003] Examples of RF communication systems with one or more charge pumps 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, 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).

SUMMARY

[0004] In ~~certain embodiments~~a first aspect, the present disclosure relates to a front end system. The front end system includes a radio frequency switch, a switch controller configured to bias the radio frequency switch with a charge pump voltage in a first state of a switch enable signal, and a charge pump configured to generate the charge pump voltage at a charge pump output terminal. The charge pump includes a switched capacitor and a plurality of switches configured to charge the switched capacitor during a charging operation of the charge pump and to connect the switched capacitor to the charge pump output terminal during a discharging

operation of the charge pump. The plurality of switches are configured to operate with non-overlap between the charging operation and the discharging operation.

[0005] In various ~~embodiments~~examples, the charge pump is powered by a power high supply voltage and a ground voltage, the charge pump voltage less than the ground voltage.

[0006] In several ~~embodiments~~examples, the charge pump includes an inverter having an output electrically connected to a first end of the switched capacitor. According to some ~~embodiments~~examples, the plurality of switches includes a pair of charging switches connected between a second end of the switched capacitor and a reference voltage, and a pair of discharging switches connected between the second end of the switched capacitor and the charge pump output terminal. In accordance with a number of ~~embodiments~~examples, the pair of charging switches is closed during the charging operation and open during the discharging operation, and the pair of discharging switches is closed during the discharging operation and open during the charging operation. According to various ~~embodiments~~examples, during a transition from the charging operation to the discharging operation, one charging switch of the pair of charging switches is open and the other charging switch of the pair of charging switches is closed. In accordance with some ~~embodiments~~examples, during the transition from the charging operation to the discharging operation, one discharging switch of the pair of discharging switches is open and the other discharging switch of the pair of discharging switches is closed. According to a number ~~embodiments~~examples, a first charging switch of the pair of charging switches is controlled by a first clock phase signal, an input of the inverter receives a second clock phase signal delayed relative to the first clock phase signal, and a second charging switch of the pair of charging switches is controlled by a third clock signal phase delayed relative to the second clock phase signal. In accordance with various ~~embodiments~~examples, a first discharging switch of the pair of discharging switches is controlled by an inverted version of the first clock phase signal and a second discharging switch of the pair of discharging switches is controlled by an inverted version of the third clock phase signal. According to some ~~embodiments~~examples, the inverter is powered by a power high supply voltage and a ground voltage.

[0007] In several ~~embodiments~~examples, the charge pump further includes an oscillator configured to generate a first plurality of clock signal phases, and combinatorial logic configured to process the first plurality of clock signal phases to generate a second plurality of

clock signal phases, at least a portion of the switches controlled by the second plurality of clock signal phases.

[0008] In ~~various embodiments~~a second aspect, the charge pump includes a plurality of stages including a first stage and a second stage, the first stage including the plurality of switches and the switched capacitor. According to a number of ~~embodiments~~examples, the plurality of switches are controlled in part by a clock signal from the second stage.

[0009] In certain ~~embodiments~~examples, the present disclosure relates to a method of generating a charge pump voltage. The method includes charging a switched capacitor using a plurality of switches during a charging operation of a charge pump, transitioning the charge pump from the charging operation to a discharging operation with non-overlap, and connecting the switched capacitor to a charge pump output terminal during the discharging operation.

[0010] In various ~~embodiments~~examples, the method further includes powering the charge pump using a power high supply voltage and a ground voltage, and providing a providing a charge pump output voltage less than the ground voltage at the charge pump output terminal.

[0011] In ~~several embodiments~~a third aspect, the method further includes controlling a first end of the switched capacitor using an output of an inverter. According to a number of ~~embodiments~~examples, the method further includes controlling a second end of the switched capacitor using the plurality of switches. In accordance with some ~~embodiments~~examples, the plurality of switches includes a pair of charging switches connected between a second end of the switched capacitor and a reference voltage, and a pair of discharging switches connected between the second end of the switched capacitor and the charge pump output terminal. According to several ~~embodiments~~examples, the method further includes closing the pair of charging switches during the charging operation, opening the pair of discharging switches during the charging operation, opening the pair of charging switches during the discharging operation, and closing the pair of discharging switches during the discharging operation. In accordance with a number of ~~embodiments~~examples, the method further includes opening one charging switch of the pair of charging switches and closing the other charging switch of the pair of charging switches during a transition from the charging

operation to the discharging operation. According to some ~~embodiments~~examples, the method further includes opening one discharging switch of the pair of discharging switches and closing the other discharging switch of the pair of discharging switches during a transition from the charging operation to the discharging operation. In

accordance with several ~~embodiments~~examples, the method further includes controlling a first charging switch of the pair of charging switches with a first clock phase signal, providing an input of the inverter with a second clock phase signal delayed relative to the first clock phase signal, and controlling a second charging switch of the pair of charging switches with a third clock signal phase delayed relative to the second clock phase signal. According to a number of ~~embodiments~~examples, the method further includes controlling a first discharging switch of the pair of discharging switches with an inverted version of the first clock phase signal, and controlling a second discharging switch of the pair of discharging switches with an inverted version of the third clock phase signal.

[0012] In some ~~embodiments~~examples, the method further includes generating a first plurality of clock signal phases using an oscillator, processing the first plurality of clock signal phases to generate a second plurality of clock signal phases using combinatorial logic, and controlling at least a portion of the switches using the second plurality of clock signal phases.

[0013] In several ~~embodiments~~examples, the charge pump includes a plurality of stages including a first stage and a second stage, the first stage including the plurality of switches and the switched capacitor, the method further comprising controlling the plurality of switches in part by a clock signal from the second stage.

[0014] In certain ~~embodiments~~examples, the present disclosure relates to a charge pump. The charge pump includes a charge pump output terminal configured to provide a charge pump voltage, a switched capacitor, and a plurality of switches configured to charge the switched capacitor during a charging operation of the charge pump and to connect the switched capacitor to the charge pump output terminal during a discharging operation of the charge pump. The plurality of switches is configured to operate with non-overlap between the charging operation and the discharging operation.

[0015] In various ~~embodiments~~examples, the charge pump voltage is less than a ground voltage.

[0016] In some ~~embodiments~~examples, the charge pump further includes an inverter having an output electrically connected to a first end of the switched capacitor. According to a number of ~~embodiments~~examples, the plurality of switches includes a pair of charging switches connected between a second end of the switched capacitor and a reference

voltage, and a pair of discharging switches connected between the second end of the switched capacitor and the

charge pump output terminal. In accordance with various ~~embodiments~~examples, the pair of charging switches is closed during the charging operation and open during the discharging operation, and the pair of discharging switches is closed during the discharging operation and open during the charging operation. According to several ~~embodiments~~examples, during a transition from the charging operation to the discharging operation, one charging switch of the pair of charging switches is open and the other charging switch of the pair of charging switches is closed. In accordance with a number of ~~embodiments~~examples, during the transition from the charging operation to the discharging operation, one discharging switch of the pair of discharging switches is open and the other discharging switch of the pair of discharging switches is closed. In accordance with various ~~embodiments~~examples, a first charging switch of the pair of charging switches is controlled by a first clock phase signal, an input of the inverter receives a second clock phase signal delayed relative to the first clock phase signal, and a second charging switch of the pair of charging switches is controlled by a third clock signal phase delayed relative to the second clock phase signal. According to several ~~embodiments~~examples, a first discharging switch of the pair of discharging switches is controlled by an inverted version of the first clock phase signal and a second discharging switch of the pair of discharging switches is controlled by an inverted version of the third clock phase signal. In accordance with a number of ~~embodiments~~examples, the inverter is powered by a power high supply voltage and a ground voltage.

[0017] In several ~~embodiments~~examples, the charge pump further includes an oscillator configured to generate a first plurality of clock signal phases, and combinatorial logic configured to process the first plurality of clock signal phases to generate a second plurality of clock signal phases, at least a portion of the switches controlled by the second plurality of clock signal phases.

[0018] In various ~~embodiments~~examples, the charge pump includes a plurality of stages including a first stage and a second stage, the first stage including the plurality of switches and the switched capacitor. According to a number of ~~embodiments~~examples, the plurality of switches are controlled in part by a clock signal from the second stage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Figure 1 is a schematic diagram of one example of a communication network.