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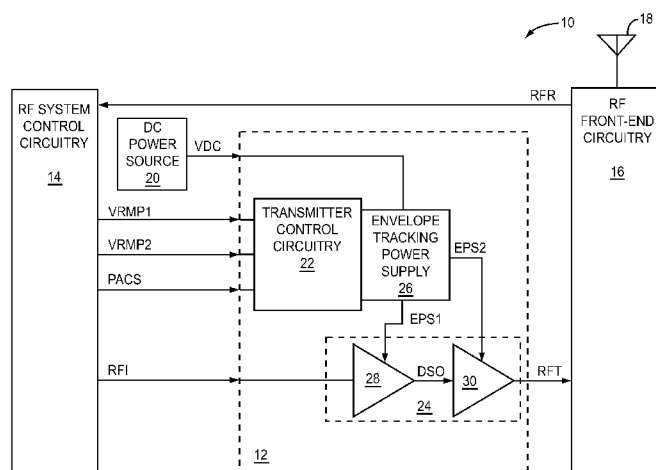


FIG. 1

(57) Abstract: An envelope tracking power supply and transmitter control circuitry are disclosed. The transmitter control circuitry receives a first envelope power supply control signal and a second envelope power supply control signal. The envelope tracking power supply operates in one of a group of operating modes, which includes a first operating mode and a second operating mode. During both the first operating mode and the second operating mode, a first envelope power supply signal is provided to a driver stage based on the first envelope power supply control signal. During the first operating mode, a second envelope power supply signal is provided to a final stage based on the first envelope power supply control signal. However, during the second operating mode, the second envelope power supply signal is provided to the final stage based on the second envelope power supply control signal.



***SPLIT VCC AND COMMON VCC POWER MANAGEMENT ARCHITECTURE
FOR ENVELOPE TRACKING***

Related Applications

- 5 **[0001]** This application claims the benefit of U.S. provisional patent application No. 61/530,625, filed September 2, 2011, the disclosure of which is incorporated herein by reference in its entirety.

Field of the Disclosure

- 10 **[0002]** Embodiments of the present disclosure relate to switching power supplies and radio frequency (RF) power amplifiers, both of which may be used in RF communication systems.

Background

- 15 **[0003]** As wireless communications technologies evolve, wireless communications systems become increasingly sophisticated. As such, wireless communications protocols continue to expand and change to take advantage of the technological evolution. As a result, to maximize flexibility, many wireless communications devices must be capable of supporting any number of wireless
- 20 communications protocols, each of which may have certain performance requirements, such as specific out-of-band emissions requirements, linearity requirements, or the like. Further, portable wireless communications devices are typically battery powered and need to be relatively small, and have low cost. As such, to minimize size, cost, and power consumption, RF circuitry in such a
- 25 device needs to be as simple, small, and efficient as is practical. Thus, there is a need for RF circuitry in a communications device that is low cost, small, simple, efficient, and meets performance requirements.

Summary

- 30 **[0004]** Embodiments of the present disclosure relate to an envelope tracking power supply and transmitter control circuitry. The transmitter control circuitry

receives a first envelope power supply control signal and a second envelope power supply control signal. The envelope tracking power supply operates in one of a group of operating modes, which includes a first operating mode and a second operating mode. During both the first operating mode and the second operating mode, a first envelope power supply signal is provided to a driver stage based on the first envelope power supply control signal. Further, during the first operating mode, a second envelope power supply signal is provided to a final stage, which is coupled to the driver stage, based on the first envelope power supply control signal. However, during the second operating mode, the second envelope power supply signal is provided to the final stage based on the second envelope power supply control signal.

[0005] In one embodiment of the present disclosure, a radio frequency (RF) power amplifier (PA) includes the driver stage and the final stage. To maximize efficiency, during the first operating mode, the first envelope power supply signal and the second envelope power supply signal are both amplitude modulated. However, under certain operating conditions, simultaneously modulating collectors of the driver stage and the final stage may degrade performance, thereby violating linearity or other performance requirements. For example, interstage matching between the driver stage and the final stage may be degraded at higher frequencies, thereby producing a frequency response from the RF PA that is unsymmetrical. As a result, when operating under such conditions, the second operating mode is selected, thereby providing separate control of the first envelope power supply signal and the second envelope power supply signal. In this regard, the second operating mode may be selected when a modulation bandwidth of an RF transmit signal from the RF PA is greater than or equal to a bandwidth threshold, when an output power from the RF PA is greater than a power threshold, or both.

[0006] Those skilled in the art will appreciate the scope of the disclosure and realize additional aspects thereof after reading the following detailed description in association with the accompanying drawings.

Brief Description of the Drawings

[0007] The accompanying drawings incorporated in and forming a part of this specification illustrate several aspects of the disclosure, and together with the description serve to explain the principles of the disclosure.

5 **[0008]** Figure 1 shows an RF communications system according to one embodiment of the RF communications system.

[0009] Figure 2 shows the RF communications system according to an alternate embodiment of the RF communications system.

10 **[0010]** Figure 3 shows the RF communications system according to an additional embodiment of the RF communications system.

[0011] Figure 4 shows details of transmitter control circuitry and an envelope tracking power supply illustrated in Figure 1 according to one embodiment of the transmitter control circuitry and the envelope tracking power supply.

15 **[0012]** Figure 5 shows details of the transmitter control circuitry and the envelope tracking power supply illustrated in Figure 1 according to an alternate embodiment of the transmitter control circuitry and the envelope tracking power supply.

20 **[0013]** Figure 6 shows details of the transmitter control circuitry and the envelope tracking power supply illustrated in Figure 1 according to an additional embodiment of the transmitter control circuitry and the envelope tracking power supply.

25 **[0014]** Figure 7 shows details of the transmitter control circuitry and the envelope tracking power supply illustrated in Figure 1 according to another embodiment of the transmitter control circuitry and the envelope tracking power supply.

[0015] Figure 8 shows details of the transmitter control circuitry and the envelope tracking power supply illustrated in Figure 1 according to a further embodiment of the transmitter control circuitry and the envelope tracking power supply.

30 **[0016]** Figure 9 shows details of the transmitter control circuitry and the envelope tracking power supply illustrated in Figure 1 according to a

supplemental embodiment of the transmitter control circuitry and the envelope tracking power supply.

[0017] Figure 10 shows details of the transmitter control circuitry and the envelope tracking power supply illustrated in Figure 1 according to one

5 embodiment of the transmitter control circuitry and the envelope tracking power supply.

[0018] Figure 11 shows details of the transmitter control circuitry and the envelope tracking power supply illustrated in Figure 1 according to an alternate embodiment of the transmitter control circuitry and the envelope tracking power
10 supply.

[0019] Figure 12 shows details of the transmitter control circuitry and the envelope tracking power supply illustrated in Figure 1 according to an additional embodiment of the transmitter control circuitry and the envelope tracking power supply.

15 **[0020]** Figure 13 shows details of the transmitter control circuitry and the envelope tracking power supply illustrated in Figure 1 according to another embodiment of the transmitter control circuitry and the envelope tracking power supply.

[0021] Figure 14 shows details of the transmitter control circuitry and the
20 envelope tracking power supply illustrated in Figure 1 according to a further embodiment of the transmitter control circuitry and the envelope tracking power supply.

[0022] Figure 15 shows details of the transmitter control circuitry and the
25 envelope tracking power supply illustrated in Figure 1 according to a supplemental embodiment of the transmitter control circuitry and the envelope tracking power supply.

Detailed Description

[0023] The embodiments set forth below represent the necessary information
30 to enable those skilled in the art to practice the disclosure and illustrate the best mode of practicing the disclosure. Upon reading the following description in light

of the accompanying drawings, those skilled in the art will understand the concepts of the disclosure and will recognize applications of these concepts not particularly addressed herein. It should be understood that these concepts and applications fall within the scope of the disclosure and the accompanying claims.

5 **[0024]** Embodiments of the present disclosure relate to an envelope tracking power supply and transmitter control circuitry. The transmitter control circuitry receives a first envelope power supply control signal and a second envelope power supply control signal. The envelope tracking power supply operates in one of a group of operating modes, which includes a first operating mode and a
10 second operating mode. During both the first operating mode and the second operating mode, a first envelope power supply signal is provided to a driver stage based on the first envelope power supply control signal. Further, during the first operating mode, a second envelope power supply signal is provided to a final stage, which is coupled to the driver stage, based on the first envelope power supply control signal. However, during the second operating mode, the second
15 envelope power supply signal is provided to the final stage based on the second envelope power supply control signal.

[0025] In one embodiment of the present disclosure, a radio frequency (RF) power amplifier (PA) includes the driver stage and the final stage. To maximize
20 efficiency, during the first operating mode, the first envelope power supply signal and the second envelope power supply signal are both amplitude modulated. However, under certain operating conditions, simultaneously modulating collectors of the driver stage and the final stage may degrade performance, thereby violating linearity or other performance requirements. For example,
25 interstage matching between the driver stage and the final stage may be degraded at higher frequencies, thereby producing a frequency response from the RF PA that is unsymmetrical. As a result, when operating under such conditions, the second operating mode is selected, thereby providing separate control of the first envelope power supply signal and the second envelope power supply signal. In this regard, the second operating mode may be selected when
30 a modulation bandwidth of an RF transmit signal from the RF PA is greater than

or equal to a bandwidth threshold, when an output power from the RF PA is greater than a power threshold, or both.

[0026] Figure 1 shows an RF communications system 10 according to one embodiment of the RF communications system 10. The RF communications system 10 includes RF transmitter circuitry 12, RF system control circuitry 14, RF front-end circuitry 16, an RF antenna 18, and a DC power source 20. The RF transmitter circuitry 12 includes transmitter control circuitry 22, an RF PA 24, and an envelope tracking power supply 26. The RF PA 24 includes a driver stage 28 and a final stage 30, which is coupled to the driver stage 28.

[0027] In one embodiment of the RF communications system 10, the RF front-end circuitry 16 receives via the RF antenna 18, processes, and forwards an RF receive signal RFR to the RF system control circuitry 14. The transmitter control circuitry 22 receives a first envelope power supply control signal VRMP1, a second envelope power supply control signal VRMP2, and a transmitter configuration signal PACS from the RF system control circuitry 14. The RF system control circuitry 14 selects either a first operating mode or a second operating mode, and the transmitter configuration signal PACS is indicative of the selection of the first operating mode or the second operating mode made by the RF system control circuitry 14. In general, the RF system control circuitry 14 selects one of a group of operating modes, which includes the first operating mode and the second operating mode. The RF system control circuitry 14 provides an RF input signal RFI to the RF PA 24. The DC power source 20 provides a DC source signal VDC to the envelope tracking power supply 26. In one embodiment of the DC power source 20, the DC power source 20 is a battery.

[0028] The envelope tracking power supply 26 is coupled to the transmitter control circuitry 22. The envelope tracking power supply 26 provides a first envelope power supply signal EPS1 to the driver stage 28 based on the first envelope power supply control signal VRMP1. During the first operating mode, the envelope tracking power supply 26 provides a second envelope power supply signal EPS2 to the final stage 30 based on the first envelope power supply

control signal VRMP1 . However, during the second operating mode, the envelope tracking power supply 26 provides the second envelope power supply signal EPS2 to the final stage 30 based on the second envelope power supply control signal VRMP2. It may be noted that the first envelope power supply signal EPS1 is based on the first envelope power supply control signal VRMP1 during both the first operating mode and the second operating mode.

[0029] The DC source signal VDC provides power to the envelope tracking power supply 26. As such, both the first envelope power supply signal EPS1 and the second envelope power supply signal EPS2 are further based on the DC source signal VDC. During both the first operating mode and the second operating mode, the first envelope power supply control signal VRMP1 is representative of a setpoint of the first envelope power supply signal EPS1 . During the first operating mode, the first envelope power supply control signal VRMP1 is further representative of a setpoint of the second envelope power supply signal EPS2. However, during the second operating mode, the second envelope power supply control signal VRMP2 is representative of the setpoint of the second envelope power supply signal EPS2.

[0030] During both the first operating mode and the second operating mode, the driver stage 28 receives and amplifies the RF input signal RFI to provide a driver stage output signal DSO using the first envelope power supply signal EPS1 , which provides power for amplification. Similarly, during both the first operating mode and the second operating mode, the final stage 30 receives and amplifies the driver stage output signal DSO to provide an RF transmit signal RFT using the second envelope power supply signal EPS2, which provides power for amplification. In general, during the selected one of the group of operating modes, the RF PA 24 receives and amplifies the RF input signal RFI to provide the RF transmit signal RFT using the driver stage 28 and the final stage 30. The driver stage 28 and the final stage 30 are coupled in series. In an alternate embodiment of the RF PA 24, the RF PA 24 includes at least one additional driver stage (not shown) coupled in series with the driver stage 28 and the final stage 30.

[0031] The RF front-end circuitry 16 receives, processes, and transmits the RF transmit signal RFT via the RF antenna 18. In one embodiment of the RF transmitter circuitry 12, the transmitter control circuitry 22 configures the RF transmitter circuitry 12 based on the transmitter configuration signal PACS. In one embodiment of the RF front-end circuitry 16, the RF front-end circuitry 16 includes at least one RF switch, at least one RF amplifier, at least one RF filter, at least one RF duplexer, at least one RF diplexer, at least one RF amplifier, the like, or any combination thereof. In one embodiment of the RF system control circuitry 14, the RF system control circuitry 14 is RF transceiver circuitry, which may include an RF transceiver IC, baseband controller circuitry, the like, or any combination thereof.

[0032] In one embodiment of the RF communications system 10, the RF system control circuitry 14 selects the second operating mode when a modulation bandwidth of the RF transmit signal RFT is greater than or equal to a bandwidth threshold. Otherwise, the RF system control circuitry 14 selects the first operating mode. In an alternate embodiment of the RF communications system 10, the RF system control circuitry 14 selects the second operating mode when an output power from the RF PA 24 is greater than a power threshold. Otherwise, the RF system control circuitry 14 selects the first operating mode. In an additional embodiment of the RF communications system 10, the RF system control circuitry 14 selects the second operating mode when the modulation bandwidth of the RF transmit signal RFT is greater than or equal to the bandwidth threshold and the output power from the RF PA 24 is greater than the power threshold. Otherwise, the RF system control circuitry 14 selects the first operating mode.

[0033] In a first exemplary embodiment of the bandwidth threshold, the bandwidth threshold is equal to about ten megahertz. In a second exemplary embodiment of the bandwidth threshold, the bandwidth threshold is equal to about eleven megahertz. In a third exemplary embodiment of the bandwidth threshold, the bandwidth threshold is equal to about twelve megahertz. In a fourth exemplary embodiment of the bandwidth threshold, the bandwidth

threshold is equal to about thirteen megahertz. In a fifth exemplary embodiment of the bandwidth threshold, the bandwidth threshold is equal to about fourteen megahertz. In a sixth exemplary embodiment of the bandwidth threshold, the bandwidth threshold is equal to about fifteen megahertz. In a seventh exemplary embodiment of the bandwidth threshold, the bandwidth threshold is equal to about nine megahertz. In an eighth exemplary embodiment of the bandwidth threshold, the bandwidth threshold is equal to about eight megahertz. In a ninth exemplary embodiment of the bandwidth threshold, the bandwidth threshold is equal to about seven megahertz. In a tenth exemplary embodiment of the bandwidth threshold, the bandwidth threshold is equal to about six megahertz. In an eleventh exemplary embodiment of the bandwidth threshold, the bandwidth threshold is equal to about five megahertz. In a twelfth exemplary embodiment of the bandwidth threshold, the bandwidth threshold is between about nine megahertz and about eleven megahertz. In a thirteenth exemplary embodiment of the bandwidth threshold, the bandwidth threshold is between about eight megahertz and about twelve megahertz. In a fourteenth exemplary embodiment of the bandwidth threshold, the bandwidth threshold is between about seven megahertz and about thirteen megahertz.

[0034] In a first exemplary embodiment of the power threshold, the power threshold is equal to about nine decibels below a maximum target output power from the RF PA 24. In a second exemplary embodiment of the power threshold, the power threshold is equal to about eight decibels below the maximum target output power from the RF PA 24. In a third exemplary embodiment of the power threshold, the power threshold is equal to about seven decibels below the maximum target output power from the RF PA 24. In a fourth exemplary embodiment of the power threshold, the power threshold is equal to about six decibels below the maximum target output power from the RF PA 24. In a fifth exemplary embodiment of the power threshold, the power threshold is equal to about ten decibels below the maximum target output power from the RF PA 24. In a sixth exemplary embodiment of the power threshold, the power threshold is equal to about eleven decibels below the maximum target output power from the

RF PA 24. In a seventh exemplary embodiment of the power threshold, the power threshold is between about eight decibels below the maximum target output power from the RF PA 24 and about ten decibels below the maximum target output power from the RF PA 24. In an eighth exemplary embodiment of the power threshold, the power threshold is between about seven decibels below the maximum target output power from the RF PA 24 and about eleven decibels below the maximum target output power from the RF PA 24.

[0035] In a first exemplary embodiment of the maximum target output power, the maximum target output power is equal to about 28 decibel milliwatts. In a second exemplary embodiment of the maximum target output power, the maximum target output power is equal to about 29 decibel milliwatts. In a third exemplary embodiment of the maximum target output power, the maximum target output power is equal to about 30 decibel milliwatts. In a fourth exemplary embodiment of the maximum target output power, the maximum target output power is equal to about 31 decibel milliwatts. In a fifth exemplary embodiment of the maximum target output power, the maximum target output power is equal to about 27 decibel milliwatts. In a sixth exemplary embodiment of the maximum target output power, the maximum target output power is equal to about 26 decibel milliwatts. In a seventh exemplary embodiment of the maximum target output power, the maximum target output power is equal to about 25 decibel milliwatts.

[0036] In one embodiment of the driver stage 28, the driver stage 28 may operate most efficiently, particularly at high output power levels, when envelope power tracking is used. During envelope power tracking of the driver stage 28, the first envelope power supply signal EPS1 is amplitude modulated, such that the first envelope power supply signal EPS1 at least partially tracks an envelope of the driver stage output signal DSO. However, the driver stage 28 may operate at adequate efficiency levels, particularly at low output power levels, when average power tracking is used. During average power tracking of the driver stage 28, a magnitude of the first envelope power supply signal EPS1 is about constant, such that the magnitude of the first envelope power supply signal EPS1

is large enough to allow the driver stage 28 to function properly. However, the first envelope power supply signal EPS1 at least partially tracks an average output power from the driver stage 28.

[0037] In one embodiment of the final stage 30, the final stage 30 may

5 operate most efficiently, particularly at high output power levels, when envelope power tracking is used. During envelope power tracking of the final stage 30, the second envelope power supply signal EPS2 is amplitude modulated, such that the second envelope power supply signal EPS2 at least partially tracks an envelope of the RF transmit signal RFT. However, the final stage 30 may
10 operate at adequate efficiency levels, particularly at low output power levels, when average power tracking is used. During average power tracking of the final stage 30, a magnitude of the second envelope power supply signal EPS2 is about constant, such that the magnitude of the second envelope power supply signal EPS2 is large enough to allow the final stage 30 to function properly.
15 However, the second envelope power supply signal EPS2 at least partially tracks an average output power from the final stage 30.

[0038] In one embodiment of the RF communications system 10, during the first operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the magnitude of the second envelope power supply
20 signal EPS2 is about constant, such that the magnitude of the first envelope power supply signal EPS1 is about equal to the magnitude of the second envelope power supply signal EPS2. In an alternate embodiment of the RF communications system 10, during the first operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the magnitude of
25 the second envelope power supply signal EPS2 is about constant, such that the magnitude of the first envelope power supply signal EPS1 is less than the magnitude of the second envelope power supply signal EPS2. In an additional embodiment of the RF communications system 10, during the first operating mode, the magnitude of the first envelope power supply signal EPS1 is about
30 constant and the magnitude of the second envelope power supply signal EPS2 is about constant, such that a voltage of the first envelope power supply signal

EPS1 is less than a voltage of the DC source signal VDC and a voltage of the second envelope power supply signal EPS2 is less than the voltage of the DC source signal VDC. In a supplemental embodiment of the RF communications system 10, during the first operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the magnitude of the second envelope power supply signal EPS2 is about constant, such that the first envelope power supply signal EPS1 at least partially tracks the average output power from the driver stage 28 and the second envelope power supply signal EPS2 at least partially tracks the average output power from the final stage 30.

[0039] In another embodiment of the RF communications system 10, during the first operating mode, the first envelope power supply signal EPS1 is amplitude modulated and the second envelope power supply signal EPS2 is amplitude modulated, such that an instantaneous magnitude of the first envelope power supply signal EPS1 is about equal to an instantaneous magnitude of the second envelope power supply signal EPS2. In a further embodiment of the RF communications system 10, during the first operating mode, the first envelope power supply signal EPS1 is amplitude modulated and the second envelope power supply signal EPS2 is amplitude modulated, such that the instantaneous magnitude of the first envelope power supply signal EPS1 is less than the instantaneous magnitude of the second envelope power supply signal EPS2.

[0040] In one embodiment of the RF communications system 10, during the second operating mode, the first envelope power supply signal EPS1 is amplitude modulated and the second envelope power supply signal EPS2 is amplitude modulated, such that the instantaneous magnitude of the first envelope power supply signal EPS1 is less than the instantaneous magnitude of the second envelope power supply signal EPS2. In an alternate embodiment of the RF communications system 10, during the second operating mode, the first envelope power supply signal EPS1 is amplitude modulated and the second envelope power supply signal EPS2 is amplitude modulated, such that second envelope power supply signal EPS2 at least partially tracks the envelope of the RF transmit signal RFT.

[0041] In one embodiment of the RF communications system 10, during the second operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the second envelope power supply signal EPS2 is amplitude modulated, such that the second envelope power supply signal EPS2 at least partially tracks the envelope of the RF transmit signal RFT. In an alternate embodiment of the RF communications system 10, during the second operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the second envelope power supply signal EPS2 is amplitude modulated, such that the second envelope power supply signal EPS2 at least partially tracks the envelope of the RF transmit signal RFT and the voltage of the first envelope power supply signal EPS1 is less than the voltage of the DC source signal VDC. In an additional embodiment of the RF communications system 10, during the second operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the second envelope power supply signal EPS2 is amplitude modulated, such that the second envelope power supply signal EPS2 at least partially tracks the envelope of the RF transmit signal RFT and the voltage of the first envelope power supply signal EPS1 is greater than the voltage of the DC source signal VDC.

[0042] In another embodiment of the RF communications system 10, during the second operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the second envelope power supply signal EPS2 is amplitude modulated, such that the second envelope power supply signal EPS2 at least partially tracks the envelope of the RF transmit signal RFT and the voltage of the first envelope power supply signal EPS1 is about equal to the voltage of the DC source signal VDC. In a further embodiment of the RF communications system 10, during the second operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the second envelope power supply signal EPS2 is amplitude modulated, such that the second envelope power supply signal EPS2 at least partially tracks the envelope of the RF transmit signal RFT and the first envelope power supply signal EPS1 at least partially tracks the average output power from the driver stage 28.

[0043] In one embodiment of the RF communications system 10, during the second operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the magnitude of the second envelope power supply signal EPS2 is about constant. In an alternate embodiment of the RF

5 communications system 10, during the second operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the magnitude of the second envelope power supply signal EPS2 is about constant, such that the first envelope power supply signal EPS1 at least partially tracks the average output power from the driver stage 28 and the second envelope power supply
10 signal EPS2 at least partially tracks the average output power from the final stage 30.

[0044] In an additional embodiment of the RF communications system 10, during the second operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the magnitude of the second envelope
15 power supply signal EPS2 is about constant, such that the voltage of the first envelope power supply signal EPS1 is less than the voltage of the DC source signal VDC and the voltage of the second envelope power supply signal EPS2 is less than the voltage of the DC source signal VDC. In another embodiment of the RF communications system 10, during the second operating mode, the
20 magnitude of the first envelope power supply signal EPS1 is about constant and the magnitude of the second envelope power supply signal EPS2 is about constant, such that the voltage of the first envelope power supply signal EPS1 is greater than the voltage of the DC source signal VDC and the voltage of the second envelope power supply signal EPS2 is greater than the voltage of the DC
25 source signal VDC. In a further embodiment of the RF communications system 10, during the second operating mode, the magnitude of the first envelope power supply signal EPS1 is about constant and the magnitude of the second envelope power supply signal EPS2 is about constant, such that the voltage of the first envelope power supply signal EPS1 is less than the voltage of the DC source
30 signal VDC and the voltage of the second envelope power supply signal EPS2 is greater than the voltage of the DC source signal VDC.

[0045] Figure 2 shows the RF communications system 10 according to an alternate embodiment of the RF communications system 10. The RF communications system 10 illustrated in Figure 2 is similar to the RF communications system 10 illustrated in Figure 1, except in the RF communications system 10 illustrated in Figure 2, the RF transmitter circuitry 12 further includes a digital communications interface 32, which is coupled between the transmitter control circuitry 22 and a digital communications bus 34. The digital communications bus 34 is also coupled to the RF system control circuitry 14. As such, the RF system control circuitry 14 provides the first envelope power supply control signal VRMP1 (Figure 1), the second envelope power supply control signal VRMP2 (Figure 1), and the transmitter configuration signal PACS (Figure 1) to the transmitter control circuitry 22 via the digital communications bus 34 and the digital communications interface 32.

[0046] Figure 3 shows the RF communications system 10 according to an additional embodiment of the RF communications system 10. The RF communications system 10 illustrated in Figure 3 is similar to the RF communications system 10 illustrated in Figure 1, except the RF transmitter circuitry 12 illustrated in Figure 3 further includes an alternate RF PA 36, which includes an alternate driver stage 38 and an alternate final stage 40.

[0047] The RF system control circuitry 14 further selects either a primary operating mode or an alternate operating mode, and the transmitter configuration signal PACS is indicative of the selection of the primary operating mode or the alternate operating mode made by the RF system control circuitry 14. During the primary operating mode, the RF PA 24 is enabled and the alternate RF PA 36 is disabled. Conversely, during the alternate operating mode, the RF PA 24 is disabled and the alternate RF PA 36 is enabled. During the primary operating mode, the RF system control circuitry 14, the RF front-end circuitry 16, the transmitter control circuitry 22, the RF PA 24, and the envelope tracking power supply 26 may function as previously described.

[0048] During the alternate operating mode, the RF system control circuitry 14 selects either the first operating mode or the second operating mode. During the

alternate operating mode, the RF system control circuitry 14 provides an alternate RF input signal RFIA to the alternate RF PA 36. During the alternate operating mode, the envelope tracking power supply 26 provides a third envelope power supply signal EPS3 to the alternate driver stage 38 and a fourth
5 envelope power supply signal EPS4 to the alternate final stage 40. During the alternate operating mode, and during both the first operating mode and the second operating mode, the alternate driver stage 38 receives and amplifies the alternate RF input signal RFIA to provide an alternate driver stage output signal DSA using the third envelope power supply signal EPS3, which provides power
10 for amplification. Similarly, during the alternate operating mode, and during both the first operating mode and the second operating mode, the alternate final stage 40 receives and amplifies the alternate driver stage output signal DSA to provide an alternate RF transmit signal RFTA using the fourth envelope power supply signal EPS4, which provides power for amplification.

15 **[0049]** In general, during the alternate operating mode, and during the selected one of the group of operating modes, the alternate RF PA 36 receives and amplifies the alternate RF input signal RFIA to provide the alternate RF transmit signal RFTA using the alternate driver stage 38 and the alternate final stage 40. The alternate driver stage 38 and the alternate final stage 40 are
20 coupled in series. In an alternate embodiment of the alternate RF PA 36, the alternate RF PA 36 includes at least one additional driver stage (not shown) coupled in series with the alternate driver stage 38 and the alternate final stage 40. During the alternate operating mode, the RF front-end circuitry 16 receives, processes, and transmits the alternate RF transmit signal RFTA via the RF
25 antenna 18.

[0050] In one embodiment of the envelope tracking power supply 26, during the alternate operating mode, the third envelope power supply signal EPS3 behaves similarly to how the first envelope power supply signal EPS1 behaves during the primary operating mode. Further, during the alternate operating
30 mode, the fourth envelope power supply signal EPS4 behaves similarly to how

the second envelope power supply signal EPS2 behaves during the primary operating mode.

[0051] In an alternate embodiment of the envelope tracking power supply 26, during the alternate operating mode, the third envelope power supply signal

5 EPS3 behaves similarly to how the first envelope power supply signal EPS1 behaves during the primary operating mode. Further, during the alternate operating mode, the fourth envelope power supply signal EPS4 behaves similarly to how the first envelope power supply signal EPS1 behaves during the primary operating mode.

10 **[0052]** In an additional embodiment of the envelope tracking power supply 26, during the alternate operating mode, the third envelope power supply signal EPS3 behaves similarly to how the second envelope power supply signal EPS2 behaves during the primary operating mode. Further, during the alternate operating mode, the fourth envelope power supply signal EPS4 behaves similarly
15 to how the second envelope power supply signal EPS2 behaves during the primary operating mode.

[0053] Figure 4 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to one embodiment of the transmitter control circuitry 22 and the envelope tracking
20 power supply 26. The envelope tracking power supply 26 includes a final stage supply 42 and a driver stage supply 44. The envelope tracking power supply 26 is coupled to both the final stage supply 42 and the driver stage supply 44. The DC power source 20 provides the DC source signal VDC to the final stage supply 42 and to the driver stage supply 44.

25 **[0054]** The driver stage supply 44 provides the first envelope power supply signal EPS1 to the driver stage 28 (Figure 1) based on the first envelope power supply control signal VRMP1. During the first operating mode, the final stage supply 42 provides the second envelope power supply signal EPS2 to the final stage 30 (Figure 1) based on the first envelope power supply control signal
30 VRMP1. However, during the second operating mode, the final stage supply 42

provides the second envelope power supply signal EPS2 to the final stage 30 (Figure 1) based on the second envelope power supply control signal VRMP2.

[0055] The DC power source 20 (Figure 1) provides power to the driver stage supply 44 for the first envelope power supply signal EPS1 via the DC source signal VDC. Similarly, the DC power source 20 (Figure 1) provides power to the final stage supply 42 for the second envelope power supply signal EPS2 via the DC source signal VDC. In one embodiment of the driver stage supply 44, the driver stage supply 44 includes a switching power supply. In one embodiment of the final stage supply 42, the final stage supply 42 includes a switching power supply.

[0056] Figure 5 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to an alternate embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. Specifically, Figure 5 shows details of the driver stage supply 44 illustrated in Figure 4, except the driver stage supply 44 illustrated in Figure 5 does not receive the second envelope power supply signal EPS2. The driver stage supply 44 includes a first linear voltage regulator 46. The transmitter control circuitry 22 provides a driver setpoint signal DSPS to a control input to the first linear voltage regulator 46 based on the first envelope power supply control signal VRMP1. The DC power source 20 (Figure 1) provides the DC source signal VDC to the first linear voltage regulator 46. The first linear voltage regulator 46 provides the first envelope power supply signal EPS1 based on the driver setpoint signal DSPS and the DC source signal VDC.

[0057] The DC power source 20 (Figure 1) provides power to the first linear voltage regulator 46 for the first envelope power supply signal EPS1 via the DC source signal VDC. As such, the first linear voltage regulator 46 regulates a voltage magnitude of the first envelope power supply signal EPS1 based on the driver setpoint signal DSPS as long as a voltage magnitude of the DC source signal VDC is high enough for the first linear voltage regulator 46 to maintain voltage regulation. In this regard, the voltage magnitude of the first envelope power supply signal EPS1 is less than the voltage magnitude of the DC source

signal VDC. In an alternate embodiment of the driver setpoint signal DSPS, the driver setpoint signal DSPS is further based on the transmitter configuration signal PACS, which may be based on configuration information as provided by the RF system control circuitry 14 (Figure 1).

5 **[0058]** Figure 6 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to an additional embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. Specifically, Figure 6 shows details of the driver stage supply 44 illustrated in Figure 4. The driver stage supply 44 includes the first
10 linear voltage regulator 46 and a first multiplexer 48. The transmitter control circuitry 22 provides the driver setpoint signal DSPS to the control input to the first linear voltage regulator 46 based on the first envelope power supply control signal VRMP1. The DC power source 20 (Figure 1) provides the DC source signal VDC to the first linear voltage regulator 46. The first linear voltage
15 regulator 46 feeds one input to the first multiplexer 48. Another input to the first multiplexer 48 receives the second envelope power supply signal EPS2. The transmitter control circuitry 22 provides a first multiplexer control signal MCS1 to a control input to the first multiplexer 48 based on the transmitter configuration signal PACS. The first multiplexer 48 provides the first envelope power supply
20 signal EPS1 based on a selected one of the inputs to the first multiplexer 48, as selected by the first multiplexer control signal MCS1.

[0059] When the first multiplexer control signal MCS1 selects the second envelope power supply signal EPS2, the first multiplexer 48 receives and forwards the second envelope power supply signal EPS2 to provide the first
25 envelope power supply signal EPS1. Conversely, when the first multiplexer control signal MCS1 selects the output from the first linear voltage regulator 46, the first multiplexer 48 receives and forwards the signal provided from the output from the first linear voltage regulator 46 to provide the first envelope power supply signal EPS1.

30 **[0060]** In one embodiment of the driver stage supply 44, during the first operating mode, the first envelope power supply signal EPS1 is based on the

second envelope power supply signal EPS2, and during the second operating mode, the first envelope power supply signal EPS1 is based on the driver setpoint signal DSPS. In an alternate embodiment of the driver stage supply 44, during the first operating mode, the first envelope power supply signal EPS1 is
5 based on the driver setpoint signal DSPS, and during the second operating mode, the first envelope power supply signal EPS1 is based on the driver setpoint signal DSPS.

[0061] Figure 7 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to another
10 embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. The envelope tracking power supply 26 includes the final stage supply 42, the driver stage supply 44, and a capacitor-based charge pump 50. The envelope tracking power supply 26 is coupled to the final stage supply 42, to the driver stage supply 44, and to the capacitor-based charge pump 50. The DC
15 power source 20 provides the DC source signal VDC to the final stage supply 42, to the driver stage supply 44, and to the capacitor-based charge pump 50.

[0062] The driver stage supply 44 provides the first envelope power supply signal EPS1 to the driver stage 28 (Figure 1) based on the first envelope power supply control signal VRMP1. During the first operating mode, the final stage
20 supply 42 provides the second envelope power supply signal EPS2 to the final stage 30 (Figure 1) based on the first envelope power supply control signal VRMP1. However, during the second operating mode, the final stage supply 42 provides the second envelope power supply signal EPS2 to the final stage 30 (Figure 1) based on the second envelope power supply control signal VRMP2.

[0063] The DC power source 20 (Figure 1) provides power to the final stage supply 42 for the second envelope power supply signal EPS2 via the DC source signal VDC. However, the capacitor-based charge pump 50 provides power to the driver stage supply 44 for the first envelope power supply signal EPS1 via a first charge pump output signal CP01. As such, the DC power source 20 (Figure
25 1) provides power to the capacitor-based charge pump 50 for the first charge pump output signal CP01 via the DC source signal VDC. In this regard, a
30

voltage magnitude of the first charge pump output signal CP01 may be greater than, less than, or equal to the voltage magnitude of the DC source signal VDC. In an alternate embodiment of the envelope tracking power supply 26, the driver stage supply 44 does not receive the DC source signal VDC.

5 **[0064]** Figure 8 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to a further embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. Specifically, the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 8 are similar to the
10 transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 7, except details of the driver stage supply 44 illustrated in Figure 7 are shown in Figure 8.

[0065] The driver stage supply 44 shown in Figure 8 is similar to the driver stage supply 44 illustrated in Figure 6, except in the driver stage supply 44
15 illustrated in Figure 8, the capacitor-based charge pump 50 provides power to the first linear voltage regulator 46 via the first charge pump output signal CP01 instead of the DC power source 20 (Figure 1) providing power to the first linear voltage regulator 46 via the DC source signal VDC. Further, the first multiplexer 48 illustrated in Figure 6 has two inputs, whereas the first multiplexer 48
20 illustrated in Figure 8 has four inputs.

[0066] The driver stage supply 44 includes the first linear voltage regulator 46 and the first multiplexer 48. The transmitter control circuitry 22 provides the driver setpoint signal DSPS to the control input to the first linear voltage regulator 46 based on the first envelope power supply control signal VRMP1. The
25 capacitor-based charge pump 50 provides power to the first linear voltage regulator 46 via the first charge pump output signal CP01. Further, the capacitor-based charge pump 50 feeds the first charge pump output signal CP01 to a first input to the first multiplexer 48. The first linear voltage regulator 46 feeds a second input to the first multiplexer 48. The DC power source 20 (Figure
30 1) feeds the DC source signal VDC to a third input to the first multiplexer 48. The

final stage supply 42 feeds the second envelope power supply signal EPS2 to a fourth input to the first multiplexer 48.

[0067] The transmitter control circuitry 22 provides the first multiplexer control signal MCS1 to the control input to the first multiplexer 48 based on the

5 transmitter configuration signal PACS. The first multiplexer 48 provides the first envelope power supply signal EPS1 based on a selected one of the four inputs to the first multiplexer 48, as selected by the first multiplexer control signal MCS1 .

[0068] When the first multiplexer control signal MCS1 selects the first input to the first multiplexer 48, the first multiplexer 48 receives and forwards the first

10 charge pump output signal CP01 to provide the first envelope power supply signal EPS1 . When the first multiplexer control signal MCS1 selects the second input to the first multiplexer 48, the first multiplexer 48 receives and forwards the signal provided from the output from the first linear voltage regulator 46 to

15 provide the first envelope power supply signal EPS1 . When the first multiplexer control signal MCS1 selects the third input to the first multiplexer 48, the first multiplexer 48 receives and forwards the DC source signal VDC to provide the first envelope power supply signal EPS1 . When the first multiplexer control signal MCS1 selects the fourth input to the first multiplexer 48, the first

20 multiplexer 48 receives and forwards the second envelope power supply signal EPS2 to provide the first envelope power supply signal EPS1 .

[0069] In one embodiment of the driver stage supply 44, during the first operating mode, the first envelope power supply signal EPS1 is based on the second envelope power supply signal EPS2, and during the second operating mode, the first envelope power supply signal EPS1 is based on the driver

25 setpoint signal DSPS. In an alternate embodiment of the driver stage supply 44, during the first operating mode, the first envelope power supply signal EPS1 is based on the second envelope power supply signal EPS2, and during the second operating mode, the first envelope power supply signal EPS1 is based on the DC source signal VDC. In an additional embodiment of the driver stage supply 44,
30 during the first operating mode, the first envelope power supply signal EPS1 is based on the second envelope power supply signal EPS2, and during the second

operating mode, the first envelope power supply signal EPS1 is based on the first charge pump output signal CP01 . In another embodiment of the driver stage supply 44, during the first operating mode, the first envelope power supply signal EPS1 is based on the driver setpoint signal DSPS, and during the second
5 operating mode, the first envelope power supply signal EPS1 is based on the driver setpoint signal DSPS.

[0070] In an alternate embodiment of the driver stage supply 44, the first multiplexer 48 does not receive the DC source signal VDC. In another embodiment of the driver stage supply 44, the first multiplexer 48 does not
10 receive the first charge pump output signal CP01 . In a further embodiment of the driver stage supply 44, the first multiplexer 48 does not receive the second envelope power supply signal EPS2. In an additional embodiment of the driver stage supply 44, the first linear voltage regulator 46 is omitted. In a supplemental embodiment of the driver stage supply 44, the first multiplexer 48 may not
15 receive any or all of the DC source signal VDC, the first charge pump output signal CP01 , and the second envelope power supply signal EPS2; and the first linear voltage regulator 46 may be omitted.

[0071] Figure 9 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to a
20 supplemental embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. Specifically, Figure 9 shows details of the final stage supply 42 illustrated in Figure 7. The final stage supply 42 includes a primary switching supply 52 and a parallel amplifier 54, both of which are coupled to the transmitter control circuitry 22.

[0072] The transmitter control circuitry 22 controls the parallel amplifier 54 and the primary switching supply 52. The parallel amplifier 54 and the primary
25 switching supply 52 provide the second envelope power supply signal EPS2, such that the parallel amplifier 54 partially provides the second envelope power supply signal EPS2 and the primary switching supply 52 partially provides the
30 second envelope power supply signal EPS2. The DC power source 20 (Figure 1) provides power to the primary switching supply 52 for the second envelope

power supply signal EPS2 via the DC source signal VDC. Similarly, the DC power source 20 (Figure 1) provides power to the parallel amplifier 54 for the second envelope power supply signal EPS2 via the DC source signal VDC.

[0073] The primary switching supply 52 may provide power more efficiently than the parallel amplifier 54. However, the parallel amplifier 54 may provide the second envelope power supply signal EPS2 more accurately than the primary switching supply 52. As such, the parallel amplifier 54 regulates a voltage of the second envelope power supply signal EPS2 based on the setpoint of the second envelope power supply signal EPS2, and the primary switching supply 52 operates to drive an output current from the parallel amplifier 54 toward zero to maximize efficiency. In this regard, the parallel amplifier 54 behaves like a voltage source and the primary switching supply 52 behaves like a current source.

[0074] The parallel amplifier 54 provides a current sense signal CSS to the primary switching supply 52. The current sense signal CSS is indicative of the output current from the parallel amplifier 54. As such, the primary switching supply 52 regulates a duty-cycle of the primary switching supply 52 to drive the output current from the parallel amplifier 54 toward zero, as indicated by the current sense signal CSS. In one embodiment of the current sense signal CSS, a magnitude of the current sense signal CSS is equal to about zero when the output current from the parallel amplifier 54 is equal to about zero.

[0075] Figure 10 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to one embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. Specifically, Figure 10 shows details of the parallel amplifier 54 illustrated in Figure 9. The parallel amplifier 54 includes a second linear voltage regulator 56 and a first capacitive element C 1. The transmitter control circuitry 22 provides a final setpoint signal FSPS to a control input to the second linear voltage regulator 56. The first capacitive element C 1 is coupled in series between an output from the second linear voltage regulator 56 and an output from the primary switching supply 52 to provide the second envelope power

supply signal EPS2. The second linear voltage regulator 56 provides the current sense signal CSS to the primary switching supply 52 based on a current from the output from the second linear voltage regulator 56.

[0076] During the first operating mode, the final setpoint signal FSPS is based on the first envelope power supply control signal VRMP1 and during the second operating mode, the final setpoint signal FSPS is based on the second envelope power supply control signal VRMP2. The DC power source 20 (Figure 1) provides the DC source signal VDC to the second linear voltage regulator 56. The second linear voltage regulator 56 at least partially provides the second envelope power supply signal EPS2 based on the final setpoint signal FSPS and the DC source signal VDC. The DC power source 20 (Figure 1) provides at least partial power to the second linear voltage regulator 56 for the second envelope power supply signal EPS2 via the DC source signal VDC.

[0077] Since the second linear voltage regulator 56 is powered from the DC power source 20 (Figure 1), the output from the second linear voltage regulator 56 cannot be driven higher than the voltage magnitude of the DC source signal VDC. However, in one embodiment of the primary switching supply 52, the output of the primary switching supply 52 is capable of being driven to a voltage magnitude higher than the voltage magnitude of the DC source signal VDC. As such, an offset voltage can be applied across the first capacitive element C1, which allows the second linear voltage regulator 56 to function within its operating range, while a voltage magnitude of the second envelope power supply signal EPS2 is higher than the voltage magnitude of the DC source signal VDC. In an alternate embodiment of the final setpoint signal FSPS, the final setpoint signal FSPS is further based on the transmitter configuration signal PACS, which may be based on configuration information as provided by the RF system control circuitry 14 (Figure 1).

[0078] Figure 11 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to an alternate embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. Specifically, the parallel amplifier 54 illustrated in

Figure 11 is similar to the parallel amplifier 54 illustrated in Figure 10, except the parallel amplifier 54 illustrated in Figure 11 further includes a third linear voltage regulator 58. During low power operations, the third linear voltage regulator 58 may be used instead of the second linear voltage regulator 56 and the primary switching supply 52. In this regard, the RF system control circuitry 14 (Figure 1) further selects either a first final stage operating mode or a second final stage operating mode, and the transmitter configuration signal PACS is indicative of the selection of the first final stage operating mode or the second final stage operating mode made by the RF system control circuitry 14 (Figure 1). During the first final stage operating mode, the primary switching supply 52 and the second linear voltage regulator 56 are enabled and the third linear voltage regulator 58 is disabled. Conversely, during the second final stage operating mode, the third linear voltage regulator 58 is enabled, and either both the primary switching supply 52 and the second linear voltage regulator 56 are disabled, or the primary switching supply 52 is enabled and the second linear voltage regulator 56 is disabled.

[0079] The transmitter control circuitry 22 provides the final setpoint signal FSPS to a control input to the third linear voltage regulator 58. The output from the second linear voltage regulator 56 is coupled to the output from the primary switching supply 52 to at least partially provide the second envelope power supply signal EPS2 during the second final stage operating mode. The DC power source 20 (Figure 1) provides the DC source signal VDC to the third linear voltage regulator 58. During the second final stage operating mode, the third linear voltage regulator 58 at least partially provides the second envelope power supply signal EPS2 based on the final setpoint signal FSPS and the DC source signal VDC.

[0080] In this regard, during the second final stage operating mode, the DC power source 20 (Figure 1) provides at least partial power to the third linear voltage regulator 58 for the second envelope power supply signal EPS2 via the DC source signal VDC. As such, during the second final stage operating mode, the third linear voltage regulator 58 regulates a voltage magnitude of the second

envelope power supply signal EPS2 based on the final setpoint signal FSPS as long as a voltage magnitude of the DC source signal VDC is high enough for the third linear voltage regulator 58 to maintain voltage regulation. In this regard, during the second final stage operating mode, the voltage magnitude of the second envelope power supply signal EPS2 is less than the voltage magnitude of the DC source signal VDC.

[0081] Figure 12 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to an additional embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. Specifically, the envelope tracking power supply 26 illustrated in Figure 12 is similar to the envelope tracking power supply 26 illustrated in Figure 9, except in the envelope tracking power supply 26 illustrated in Figure 12, the capacitor-based charge pump 50 provides power to the parallel amplifier 54 for the second envelope power supply signal EPS2 via a second charge pump output signal CP02 instead of the DC power source 20 (Figure 1) providing power to the parallel amplifier 54 via the DC source signal VDC. In this regard, the second charge pump output signal CP02 may provide more flexibility, since a voltage magnitude of the second charge pump output signal CP02 may be greater than, less than, or equal to the voltage magnitude of the DC source signal VDC.

[0082] Further, the capacitor-based charge pump 50 provides the first charge pump output signal CP01 based on the DC source signal VDC, such that the first envelope power supply signal EPS1 is further based on the first charge pump output signal CP01, and the capacitor-based charge pump 50 provides the second charge pump output signal CP02 based on the DC source signal VDC, such that the second envelope power supply signal EPS2 is further based on the second charge pump output signal CP02. Additionally, the envelope tracking power supply 26 further includes a first flying capacitive element C1F and a second flying capacitive element C2F, both of which are coupled to the capacitor-based charge pump 50. In general, the first flying capacitive element C1F and the second flying capacitive element C2F provide a pair of flying capacitive

elements, which are coupled to the capacitor-based charge pump 50. The capacitor-based charge pump 50 transfers charge from the DC power source 20 (Figure 1) to the driver stage 28 (Figure 1) and to the final stage 30 using the pair of flying capacitive elements.

5 **[0083]** In one embodiment of the envelope tracking power supply 26, the driver stage supply 44 provides the first envelope power supply signal EPS1 to the driver stage 28 (Figure 1) further based on the first charge pump output signal CP01. Further, the parallel amplifier 54 at least partially provides the second envelope power supply signal EPS2 to the final stage 30 (Figure 1)
10 further based on the second charge pump output signal CP02.

[0084] In a first exemplary embodiment of the capacitor-based charge pump 50, a ratio of a voltage magnitude of the second charge pump output signal CP02 divided by a voltage magnitude of the DC source signal VDC is equal to about five-fourths, and a ratio of a voltage magnitude of the first charge pump
15 output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about one.

[0085] In a second exemplary embodiment of the capacitor-based charge pump 50, the ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is
20 equal to about five-fourths, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about three-fourths.

[0086] In a third exemplary embodiment of the capacitor-based charge pump 50, the ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to
25 about five-fourths, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about one-fourth.

[0087] In a fourth exemplary embodiment of the capacitor-based charge pump
30 50, a ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to

about one, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about one.

[0088] In a fifth exemplary embodiment of the capacitor-based charge pump 50, the ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to about one, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about three-fourths.

[0089] In a sixth exemplary embodiment of the capacitor-based charge pump 50, the ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to about one, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about two-thirds.

[0090] In a seventh exemplary embodiment of the capacitor-based charge pump 50, the ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to about one, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about one-half.

[0091] In an eighth exemplary embodiment of the capacitor-based charge pump 50, the ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to about one, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about one-third.

[0092] In a ninth exemplary embodiment of the capacitor-based charge pump 50, the ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to about one, and a ratio of the voltage magnitude of the first charge pump output

signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about one-fourth.

[0093] In a tenth exemplary embodiment of the capacitor-based charge pump 50, a ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to about four-thirds, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about one.

[0094] In an eleventh exemplary embodiment of the capacitor-based charge pump 50, the ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to about four-thirds, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about two-thirds.

[0095] In a twelfth exemplary embodiment of the capacitor-based charge pump 50, the ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to about four-thirds, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about one-third.

[0096] In a thirteenth exemplary embodiment of the capacitor-based charge pump 50, a ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to about three-halves, and a ratio of the voltage magnitude of the first charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about one.

[0097] In a fourteenth exemplary embodiment of the capacitor-based charge pump 50, the ratio of the voltage magnitude of the second charge pump output signal CP02 divided by the voltage magnitude of the DC source signal VDC is equal to about three-halves, and a ratio of the voltage magnitude of the first

charge pump output signal CP01 divided by the voltage magnitude of the DC source signal VDC is equal to about one-half.

[0098] Figure 13 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to another embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. Specifically, the parallel amplifier 54 illustrated in Figure 13 is similar to the parallel amplifier 54 illustrated in Figure 10, except in the parallel amplifier 54 illustrated in Figure 13, the second linear voltage regulator 56 is powered using the second charge pump output signal CP02 instead of the DC source signal VDC. Using the second charge pump output signal CP02 provides greater flexibility since the voltage magnitude of the second charge pump output signal CP02 may be greater than, less than, or equal to the voltage magnitude of the DC source signal VDC.

[0099] Figure 14 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to a further embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. Specifically, the parallel amplifier 54 illustrated in Figure 14 is similar to the parallel amplifier 54 illustrated in Figure 11, except in the parallel amplifier 54 illustrated in Figure 14, the second linear voltage regulator 56 and the third linear voltage regulator 58 are powered using the second charge pump output signal CP02 instead of the DC source signal VDC. Using the second charge pump output signal CP02 provides greater flexibility since the voltage magnitude of the second charge pump output signal CP02 may be greater than, less than, or equal to the voltage magnitude of the DC source signal VDC.

[00100] Figure 15 shows details of the transmitter control circuitry 22 and the envelope tracking power supply 26 illustrated in Figure 1 according to a supplemental embodiment of the transmitter control circuitry 22 and the envelope tracking power supply 26. Specifically, the envelope tracking power supply 26 illustrated in Figure 15 is similar to the envelope tracking power supply 26 illustrated in Figure 12, except the envelope tracking power supply 26 illustrated in Figure 15 further includes a second multiplexer 60. The capacitor-based

charge pump 50 provides the first charge pump output signal CP01 to one input to the second multiplexer 60 instead of providing the first charge pump output signal CP01 to the driver stage supply 44. The DC power source 20 (Figure 1) provides the DC source signal VDC to another input to the second multiplexer 60. The second multiplexer 60 provides a driver stage source signal DSSS to the driver stage supply 44 based on a selected one of the first charge pump output signal CP01 and the DC source signal VDC. As such, the second multiplexer 60 provides power to the driver stage supply 44 via the driver stage source signal DSSS.

[00101] The transmitter control circuitry 22 provides a second multiplexer control signal MCS2 to a control input to the second multiplexer 60 based on the transmitter configuration signal PACS, which may be based on configuration information as provided by the RF system control circuitry 14 (Figure 1). The second multiplexer 60 provides the driver stage source signal DSSS based on a selected one of the inputs to the second multiplexer 60, as selected by the first multiplexer control signal MCS1. When the second multiplexer control signal MCS2 selects the first charge pump output signal CP01, the second multiplexer 60 receives and forwards the first charge pump output signal CP01 to provide the driver stage source signal DSSS. Conversely, when the second multiplexer control signal MCS2 selects the DC source signal VDC, the second multiplexer 60 receives and forwards the DC source signal VDC to provide the driver stage source signal DSSS.

[00102] In one embodiment of the envelope tracking power supply 26, the second multiplexer 60 receives and forwards the selected one of the first charge pump output signal CP01 and the DC source signal VDC. Further, the driver stage 28 (Figure 1) provides the first envelope power supply signal EPS1 (Figure 1) further based on the selected one of the first charge pump output signal CP01 and the DC source signal VDC.

[00103] In one embodiment of the envelope tracking power supply 26, the voltage magnitude of the first charge pump output signal CP01 is less than the voltage magnitude of the DC source signal VDC. As such, the transmitter control

circuitry 22 may select the first charge pump output signal CP01 to be forwarded when the voltage magnitude of the DC source signal VDC is too high, which may improve efficiency.

[00104] Those skilled in the art will recognize improvements and modifications to the embodiments of the present disclosure. All such improvements and modifications are considered within the scope of the concepts disclosed herein and the claims that follow.

Claims

What is claimed is:

1. Circuitry comprising:

- transmitter control circuitry adapted to receive a first envelope power supply control signal and a second envelope power supply control signal; and:
- an envelope tracking power supply coupled to the transmitter control circuitry and adapted to:
 - operate in one of a plurality of operating modes;
 - during a first operating mode of the plurality of operating modes:
 - provide a first envelope power supply signal to a driver stage based on the first envelope power supply control signal; and
 - provide a second envelope power supply signal to a final stage, which is coupled to the driver stage, based on the first envelope power supply control signal; and
 - during a second operating mode of the plurality of operating modes:
 - provide the first envelope power supply signal to the driver stage based on the first envelope power supply control signal; and
 - provide the second envelope power supply signal to the final stage based on the second envelope power supply control signal.

2. The circuitry of claim 1 further comprising a radio frequency power amplifier having the driver stage and the final stage, wherein during the one of the plurality of operating modes, the radio frequency power amplifier is adapted to receive and amplify a radio frequency input signal to provide a radio frequency transmit signal using the driver stage and the final stage.

3. The circuitry of claim 2 wherein control circuitry is adapted to:

- select the one of the first operating mode and the second operating mode;
- provide the first envelope power supply control signal; and
- provide the second envelope power supply control signal.

4. The circuitry of claim 3 wherein radio frequency transceiver circuitry comprises the control circuitry.

5. The circuitry of claim 3 further comprising the control circuitry.

6. The circuitry of claim 3 wherein the control circuitry is further adapted to provide a transmitter configuration signal to the transmitter control circuitry, such that the transmitter configuration signal is indicative of the one of the first operating mode and the second operating mode.

7. The circuitry of claim 3 wherein the control circuitry is further adapted to select the second operating mode when a modulation bandwidth of the radio frequency transmit signal is greater than or equal to a bandwidth threshold.

8. The circuitry of claim 3 wherein the control circuitry is further adapted to select the second operating mode when an output power from the radio frequency power amplifier is greater than a power threshold.

9. The circuitry of claim 3 wherein the control circuitry is further adapted to select the second operating mode when:

- a modulation bandwidth of the radio frequency transmit signal is greater than or equal to a bandwidth threshold; and
- an output power from the radio frequency power amplifier is greater than a power threshold.

10. The circuitry of claim 9 wherein the bandwidth threshold is equal to about ten megahertz.

11. The circuitry of claim 9 wherein the power threshold is equal to about nine decibels below a maximum target output power from the radio frequency power amplifier.

12. The circuitry of claim 11 wherein the maximum target output power is equal to about 28 decibel milliwatts.

13. The circuitry of claim 2 wherein:

- during the first operating mode, a magnitude of the first envelope power supply signal is about constant; and
- during the first operating mode, a magnitude of the second envelope power supply signal is about constant.

14. The circuitry of claim 13 wherein:

- the envelope tracking power supply is further adapted to receive a direct current source signal, such that the first envelope power supply signal and the second envelope power supply signal are based on the direct current source signal;
- during the first operating mode, a voltage of the first envelope power supply signal is less than a voltage of the direct current source signal; and
- during the first operating mode, a voltage of the second envelope power supply signal is less than the voltage of the direct current source signal.

15. The circuitry of claim 2 wherein:

- during the second operating mode, a magnitude of the first envelope power supply signal is about constant; and

- during the second operating mode, the second envelope power supply signal at least partially envelope tracks an envelope of the radio frequency transmit signal.

16. The circuitry of claim 15 wherein:

- 5
- during the first operating mode, the magnitude of the first envelope power supply signal is about constant; and
 - during the first operating mode, a magnitude of the second envelope power supply signal is about constant.

17. The circuitry of claim 15 wherein:

- 10
- the envelope tracking power supply is further adapted to receive a direct current source signal, such that the first envelope power supply signal and the second envelope power supply signal are based on the direct current source signal; and
 - during the second operating mode, a voltage of the first envelope
- 15
- power supply signal is about equal to a voltage of the direct current source signal.

18. The circuitry of claim 15 wherein during the second operating mode, the first envelope power supply signal at least partially tracks an average output power from the driver stage.

19. The circuitry of claim 2 wherein:

- 20
- during the second operating mode, the first envelope power supply signal is amplitude modulated; and
 - during the second operating mode, the second envelope power supply signal at least partially envelope tracks an envelope of the
- 25
- radio frequency transmit signal.

20. The circuitry of claim 2 wherein:

- during the second operating mode, a magnitude of the first envelope power supply signal is about constant; and
- during the second operating mode, a magnitude of the second envelope power supply signal is about constant.

5 21. The circuitry of claim 20 wherein:

- the envelope tracking power supply is further adapted to receive a direct current source signal, such that the first envelope power supply signal and the second envelope power supply signal are based on the direct current source signal;
- 10 • during the second operating mode, a voltage of the first envelope power supply signal is less than a voltage of the direct current source signal; and
- during the second operating mode, a voltage of the second envelope power supply signal is less than the voltage of the direct current
- 15 source signal.

22. The circuitry of claim 20 wherein:

- during the second operating mode, the first envelope power supply signal at least partially tracks an average output power from the driver stage; and
- 20 • during the second operating mode, the second envelope power supply signal at least partially tracks an average output power from the final stage.

23. The circuitry of claim 20 wherein:

- the envelope tracking power supply is further adapted to receive a direct current source signal, such that the first envelope power supply signal and the second envelope power supply signal are based on the direct current source signal;
- 25

- during the second operating mode, a voltage of the first envelope power supply signal is less than a voltage of the direct current source signal; and
- during the second operating mode, a voltage of the second envelope power supply signal is greater than the voltage of the direct current source signal.

24. The circuitry of claim 20 wherein the envelope tracking power supply comprises a capacitor-based charge pump adapted to:

- provide a first charge pump output signal based on a direct current source signal, such that the first envelope power supply signal is further based on the first charge pump output signal; and
- provide a second charge pump output signal based on the direct current source signal, such that the second envelope power supply signal is further based on the second charge pump output signal.

25. The circuitry of claim 24 wherein:

- a direct current power source is adapted to provide the direct current source signal;
- the envelope tracking power supply further comprises a pair of flying capacitive elements, which are coupled to the capacitor-based charge pump; and
- the capacitor-based charge pump is further adapted to transfer charge from the direct current power source to the driver stage and the final stage using the pair of flying capacitive elements.

26. The circuitry of claim 2 wherein the envelope tracking power supply comprises:

- a capacitor-based charge pump adapted to provide a first charge pump output signal and a second charge pump output signal;

- a driver stage supply adapted to provide the first envelope power supply signal to the driver stage further based on the first charge pump output signal; and
- a parallel amplifier adapted to at least partially provide the second envelope power supply signal to the final stage further based on the second charge pump output signal.

27. The circuitry of claim 2 wherein the envelope tracking power supply comprises:

- a multiplexer adapted to receive and forward a selected one of a first charge pump output signal and a direct current source signal;
- a capacitor-based charge pump adapted to provide the first charge pump output signal; and
- a driver stage supply adapted to provide the first envelope power supply signal to the driver stage further based on the selected one of the first charge pump output signal and the direct current source signal.

28. A method comprising:

- receiving a first envelope power supply control signal;
- receiving a second envelope power supply control signal;
- operating in one of a plurality of operating modes;
- during a first operating mode of the plurality of operating modes:
 - providing a first envelope power supply signal to a driver stage based on the first envelope power supply control signal; and
 - providing a second envelope power supply signal to a final stage, which is coupled to the driver stage, based on the first envelope power supply control signal; and
- during a second operating mode of the plurality of operating modes:

- providing the first envelope power supply signal to the driver stage based on the first envelope power supply control signal; and
- providing the second envelope power supply signal based on the second envelope power supply control signal.

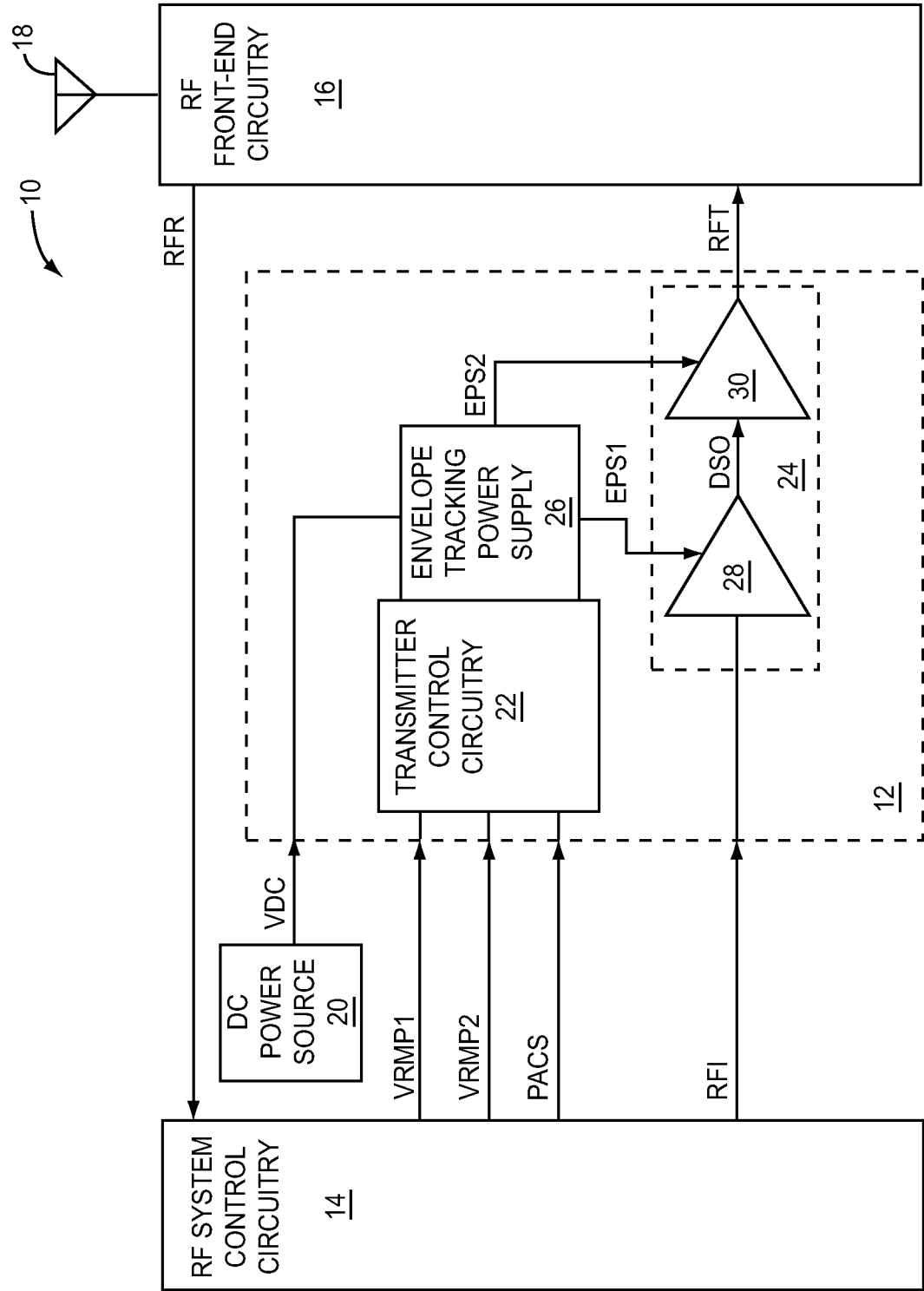


FIG. 1

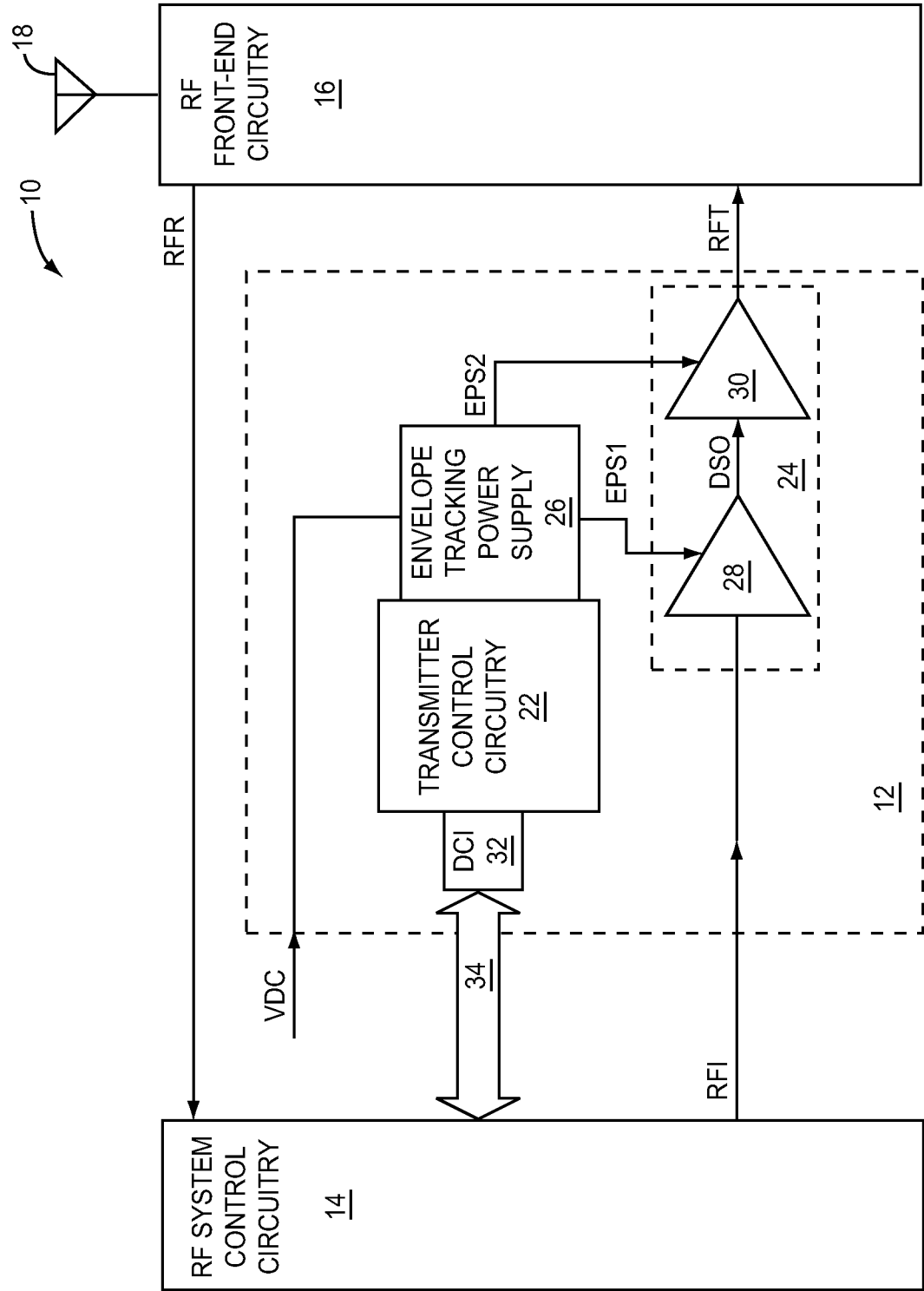


FIG. 2

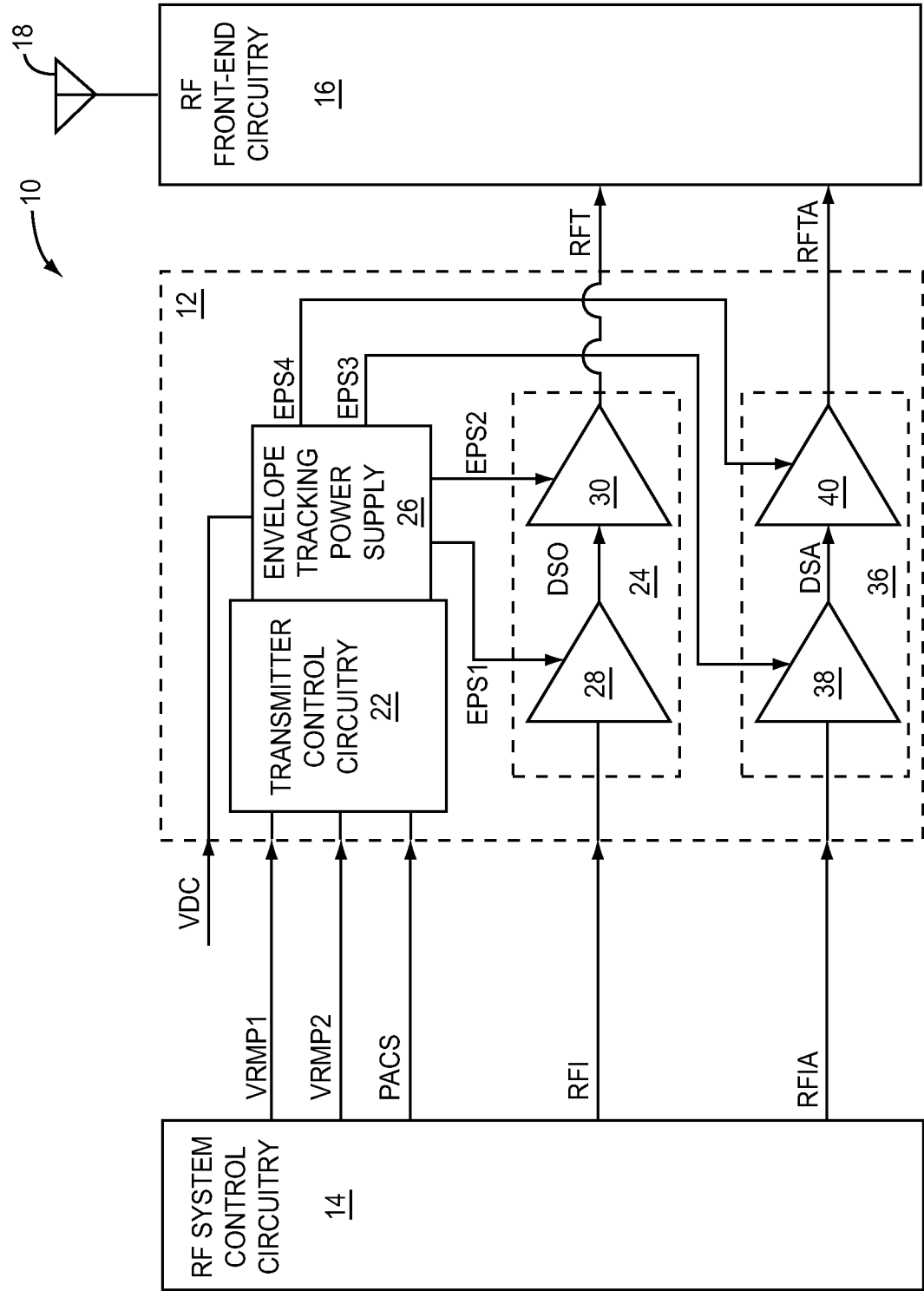


FIG. 3

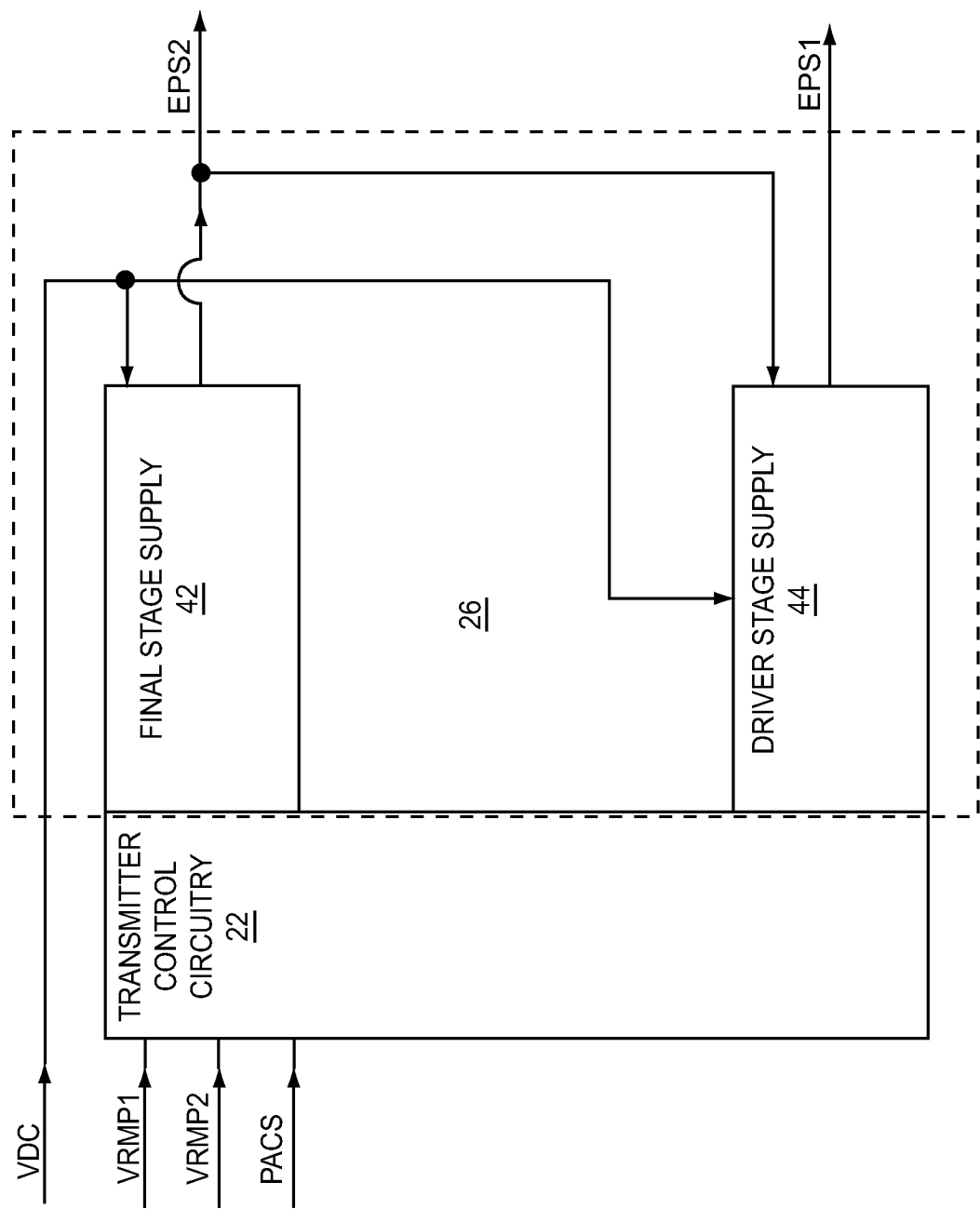


FIG. 4

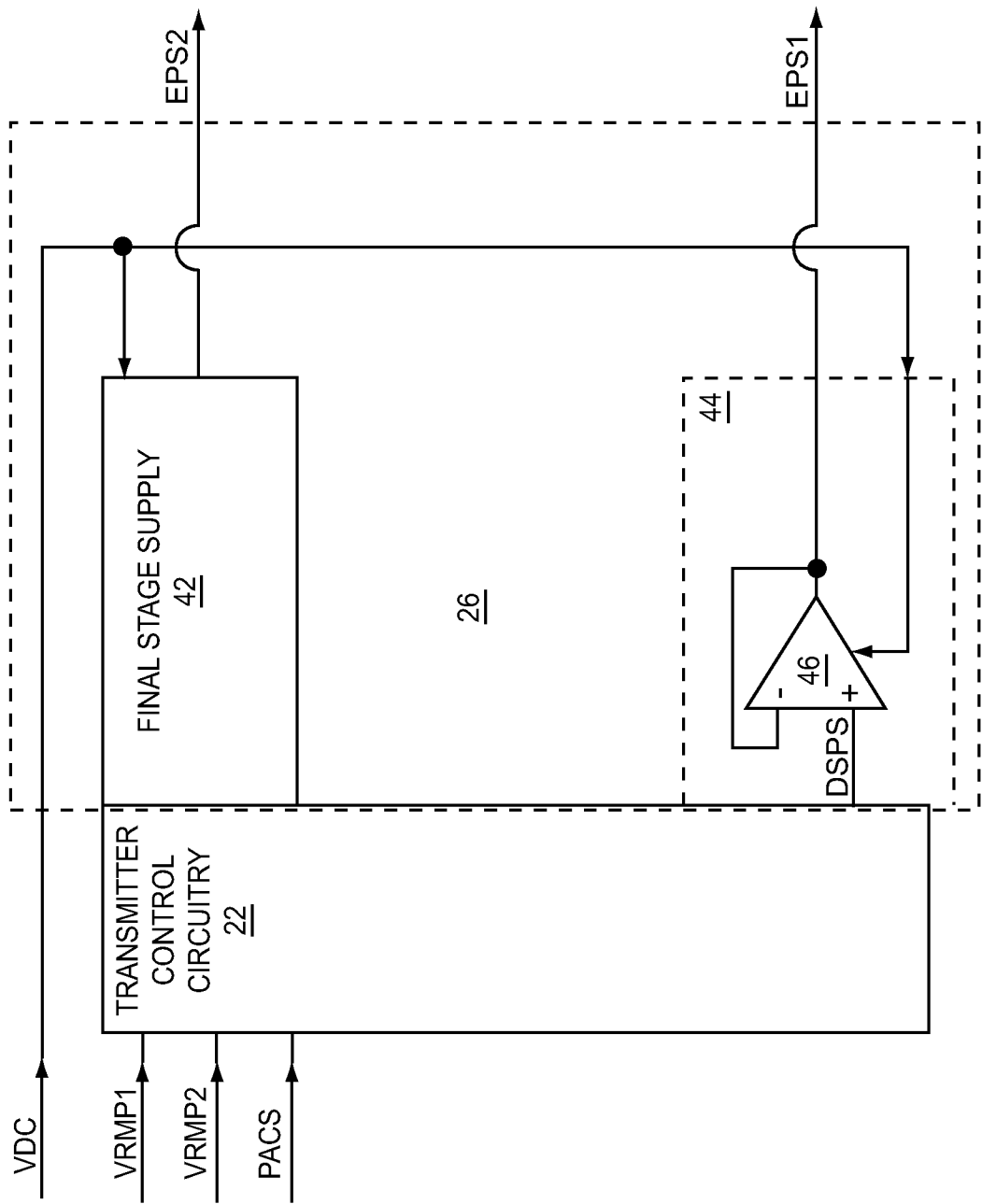


FIG. 5

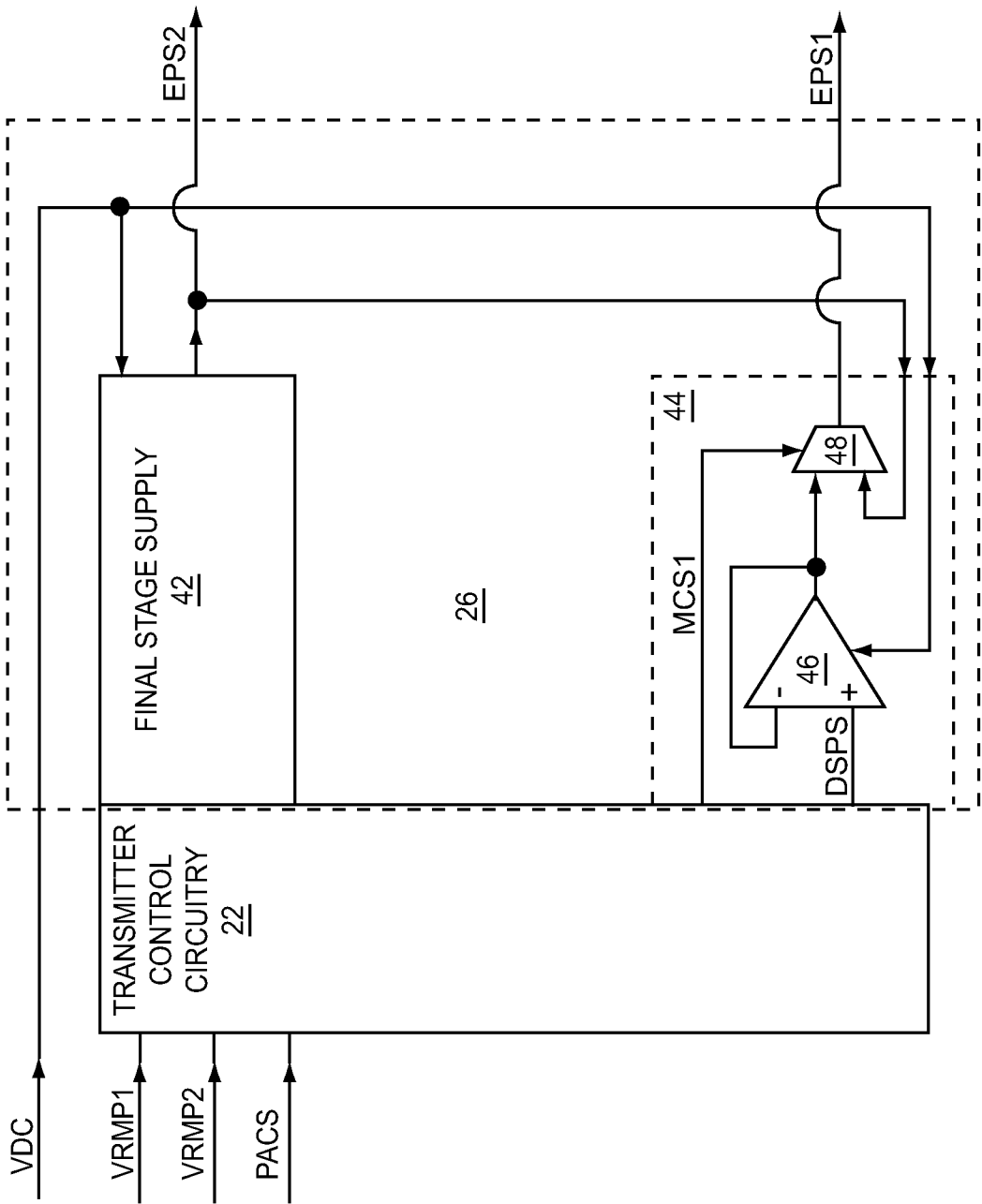


FIG. 6

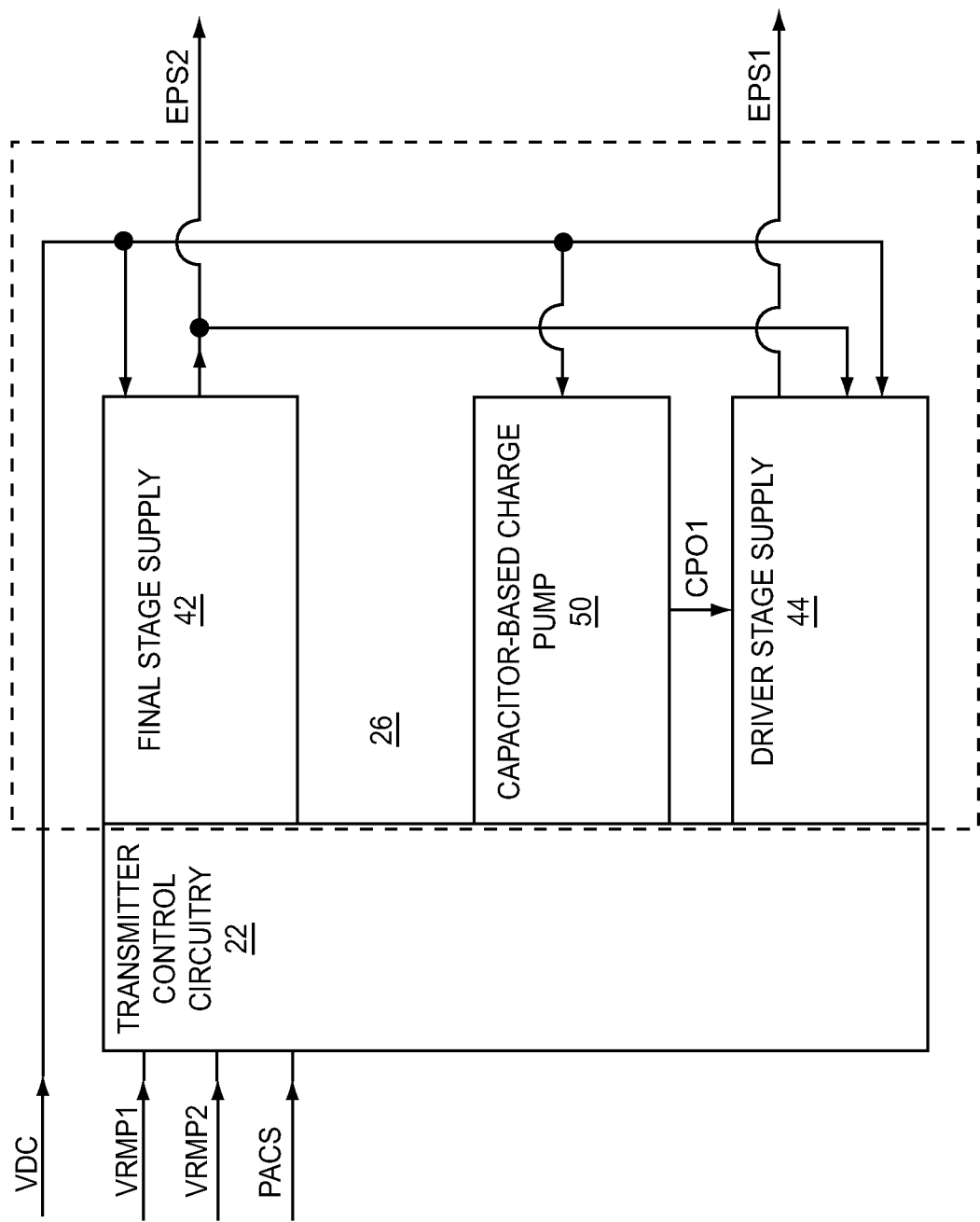


FIG. 7

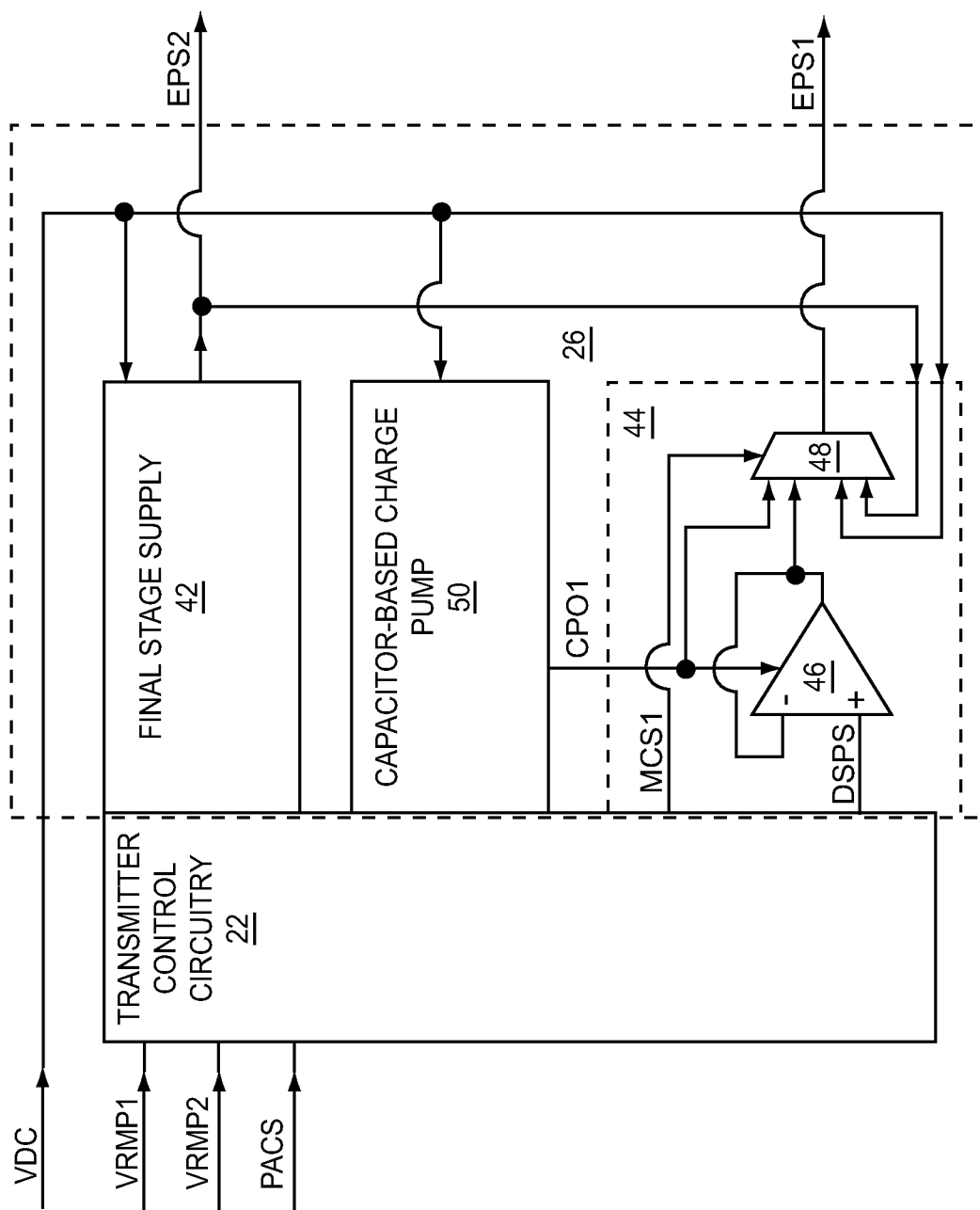


FIG. 8

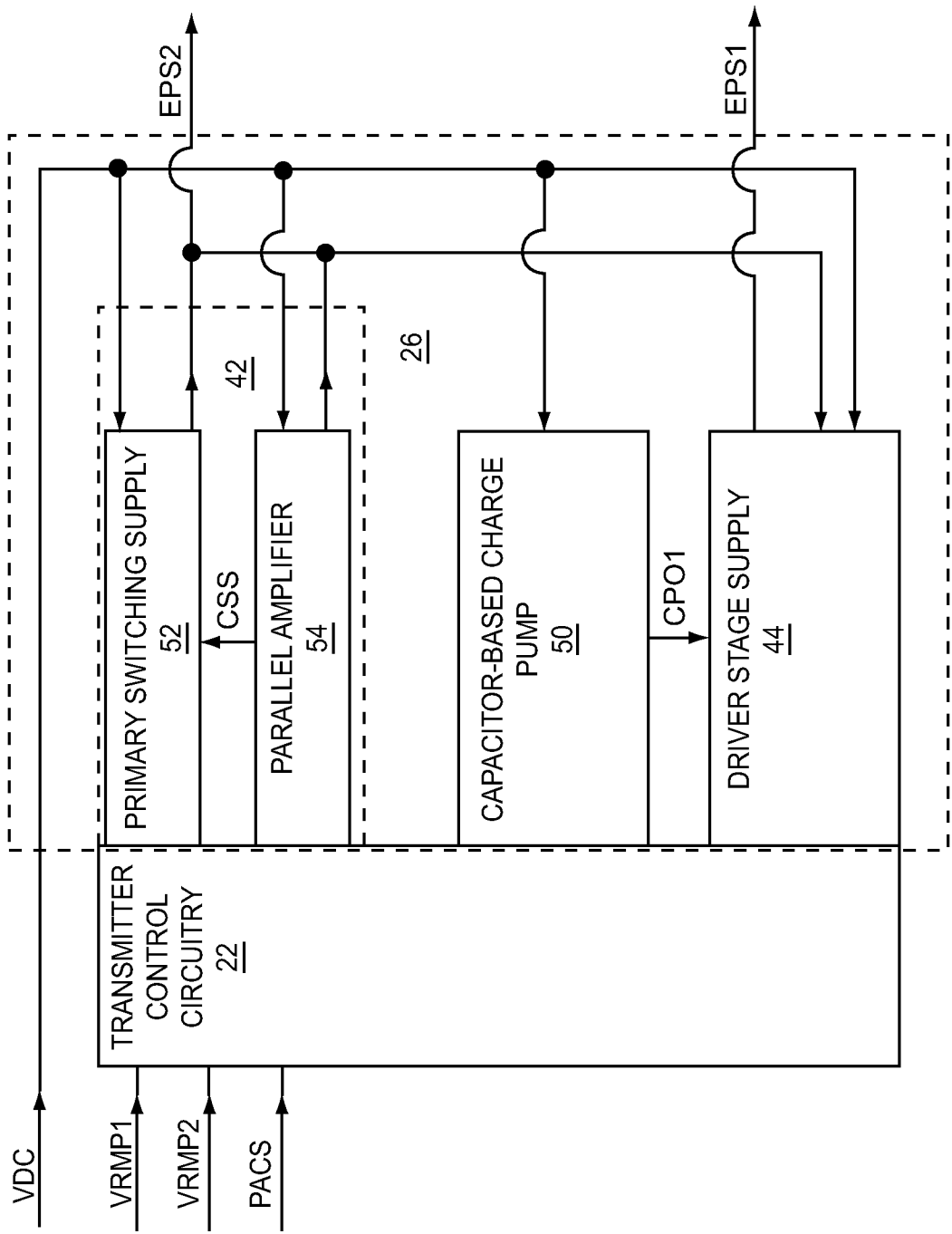


FIG. 9

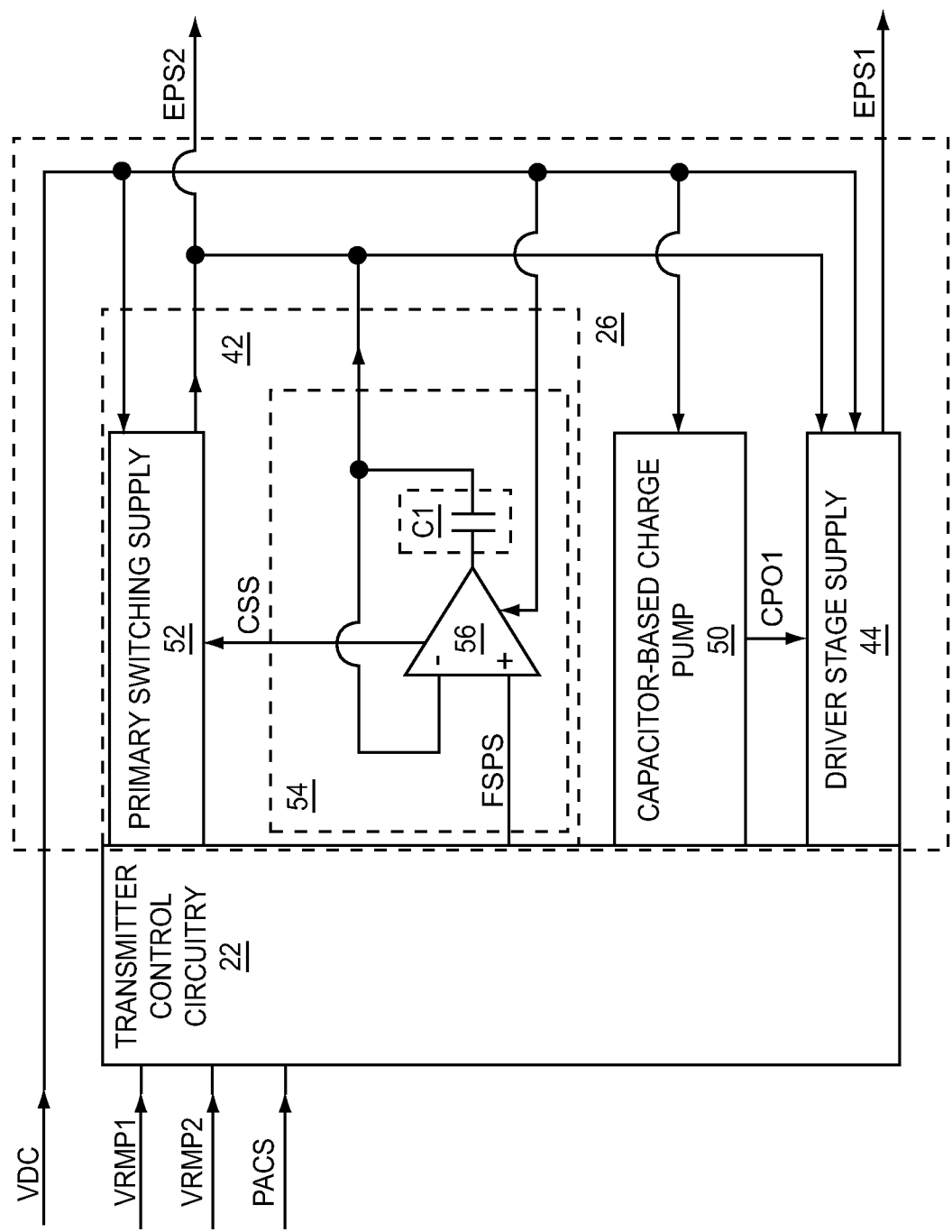


FIG. 10

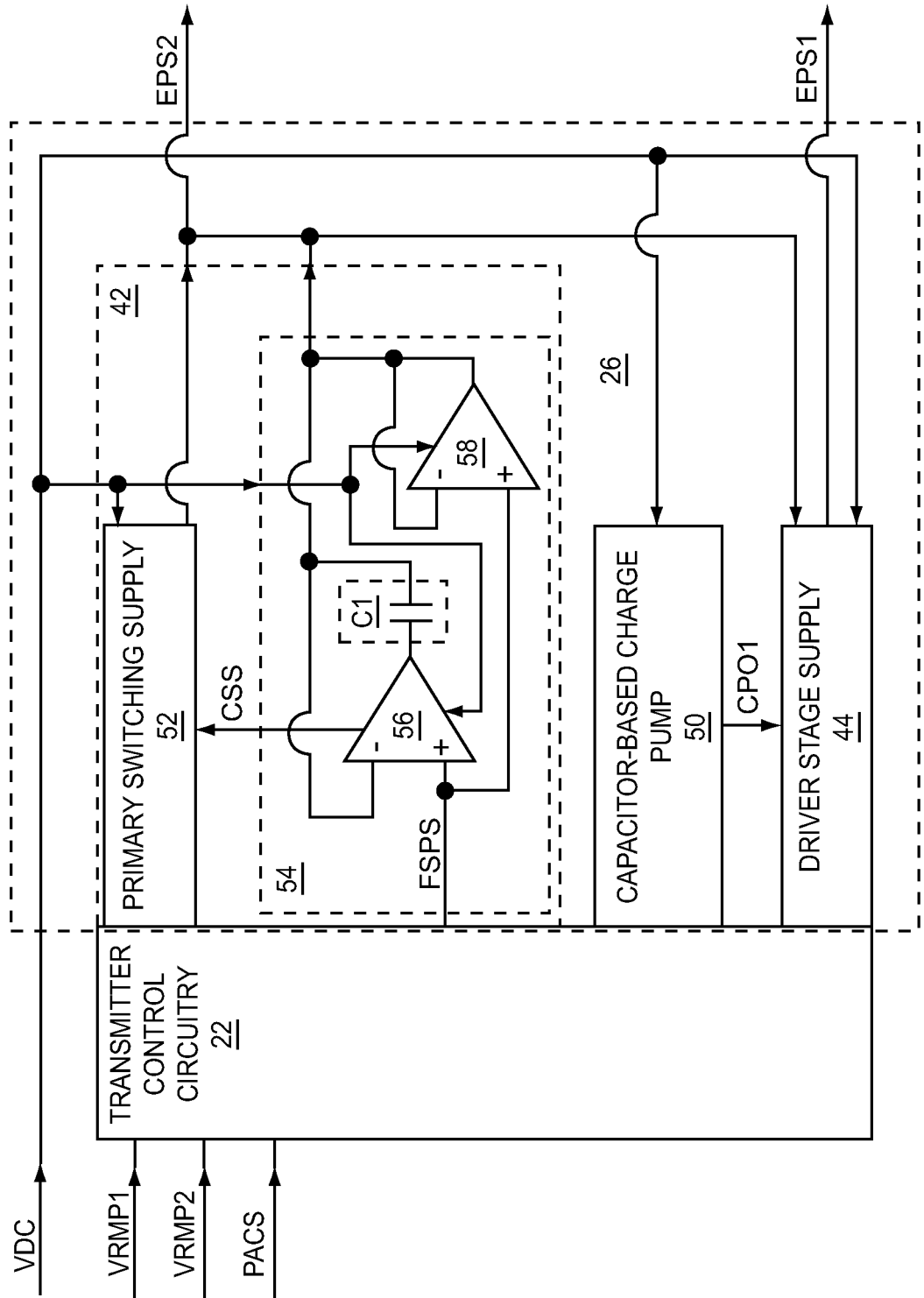


FIG. 11

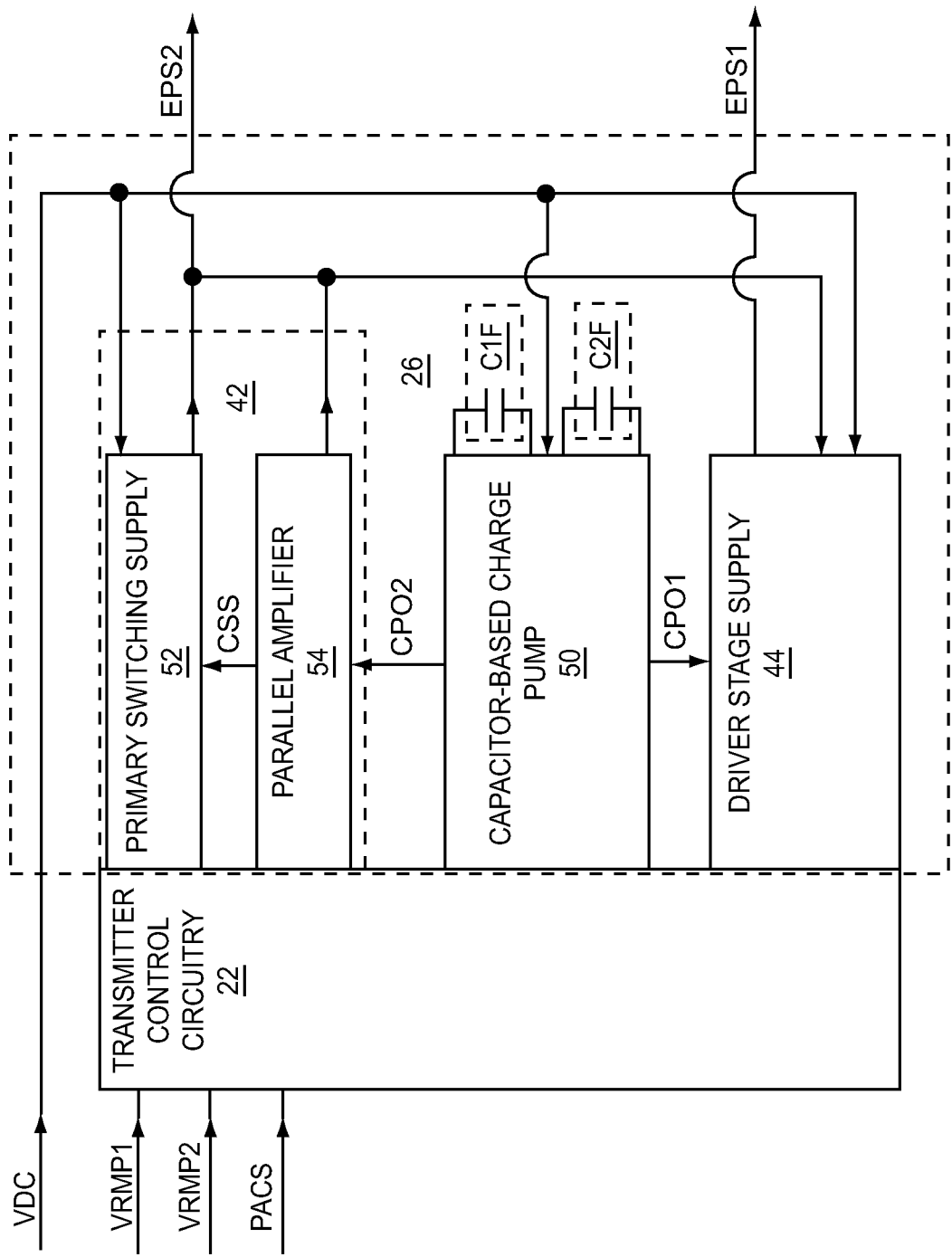


FIG. 12

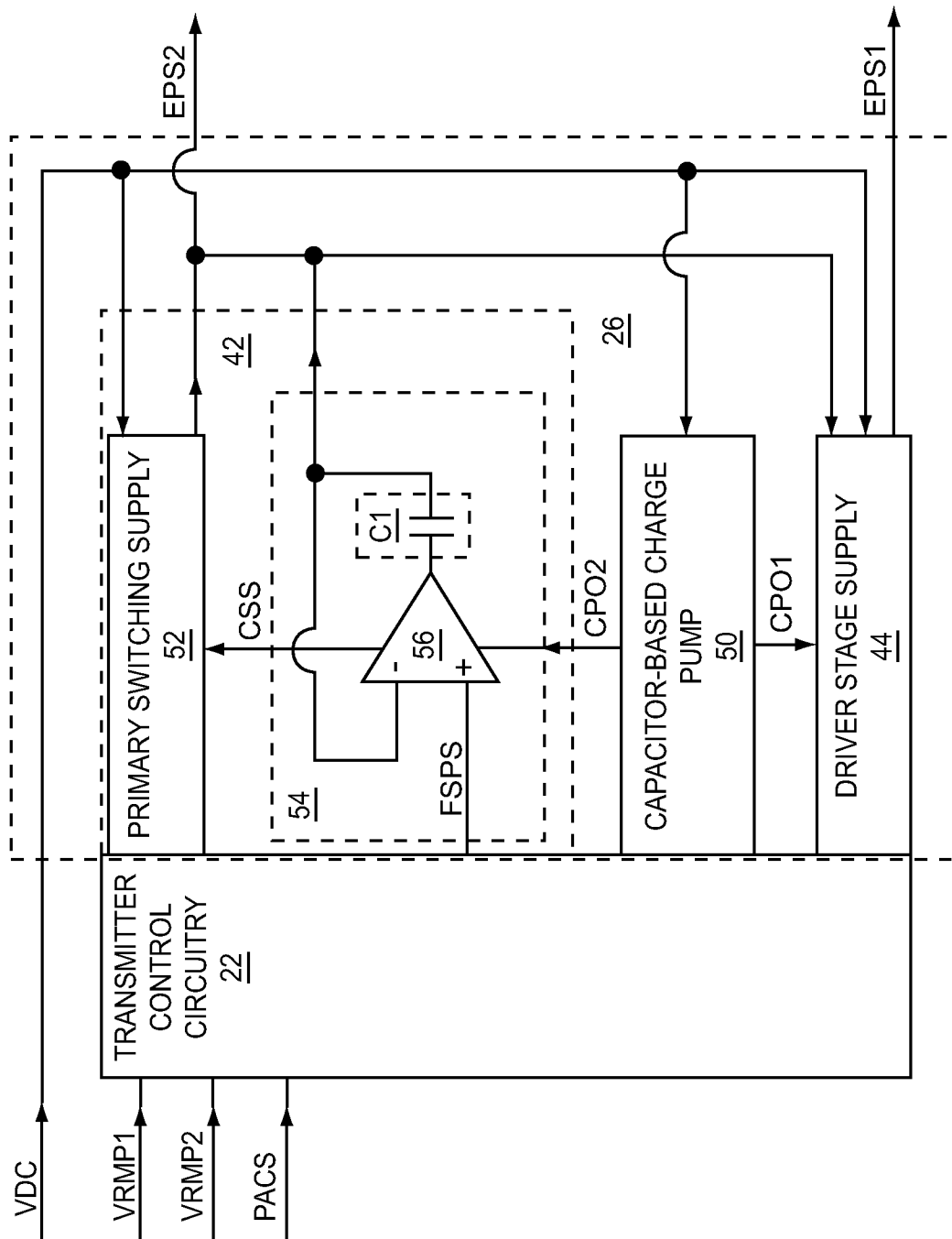


FIG. 13

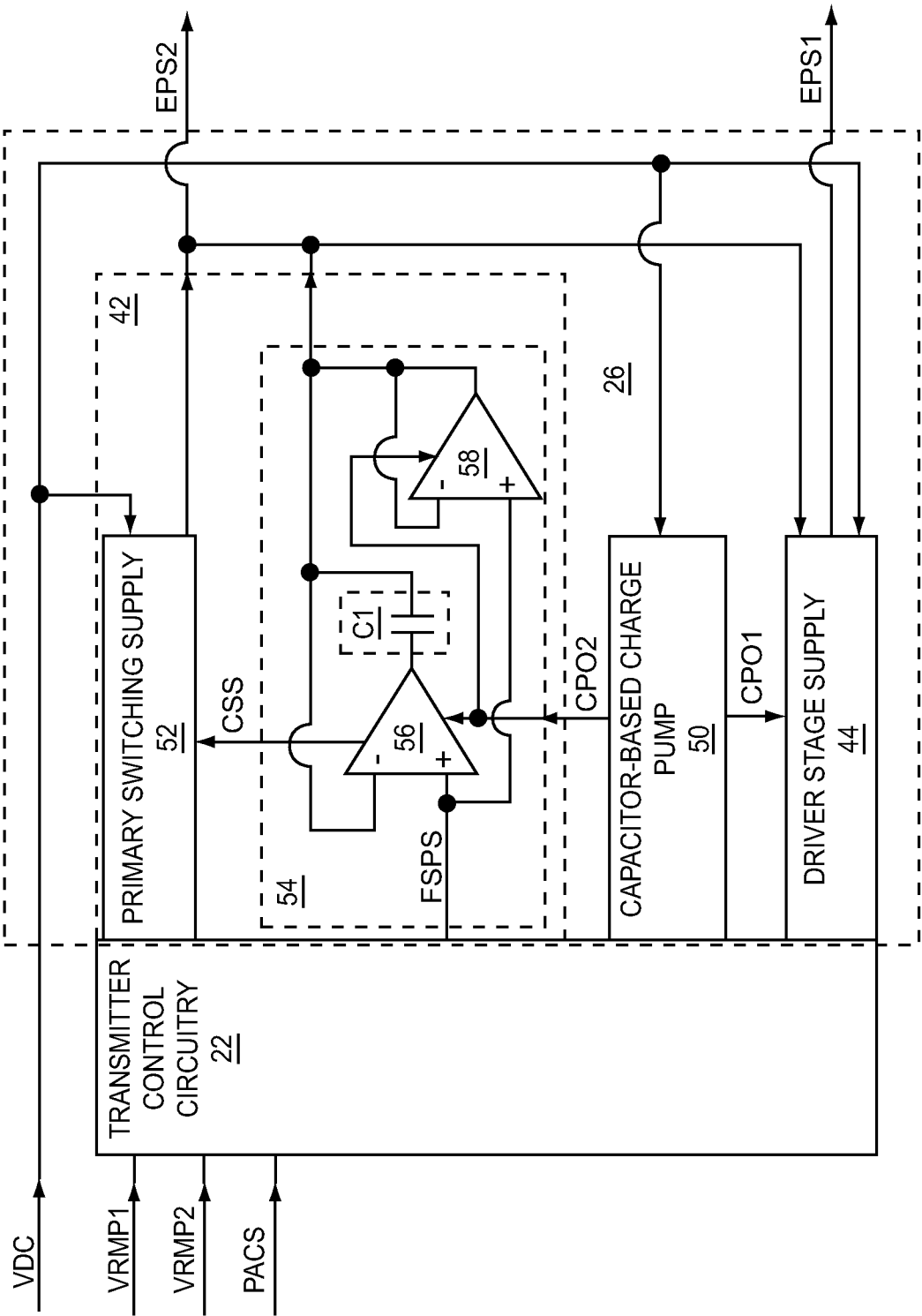


FIG. 14

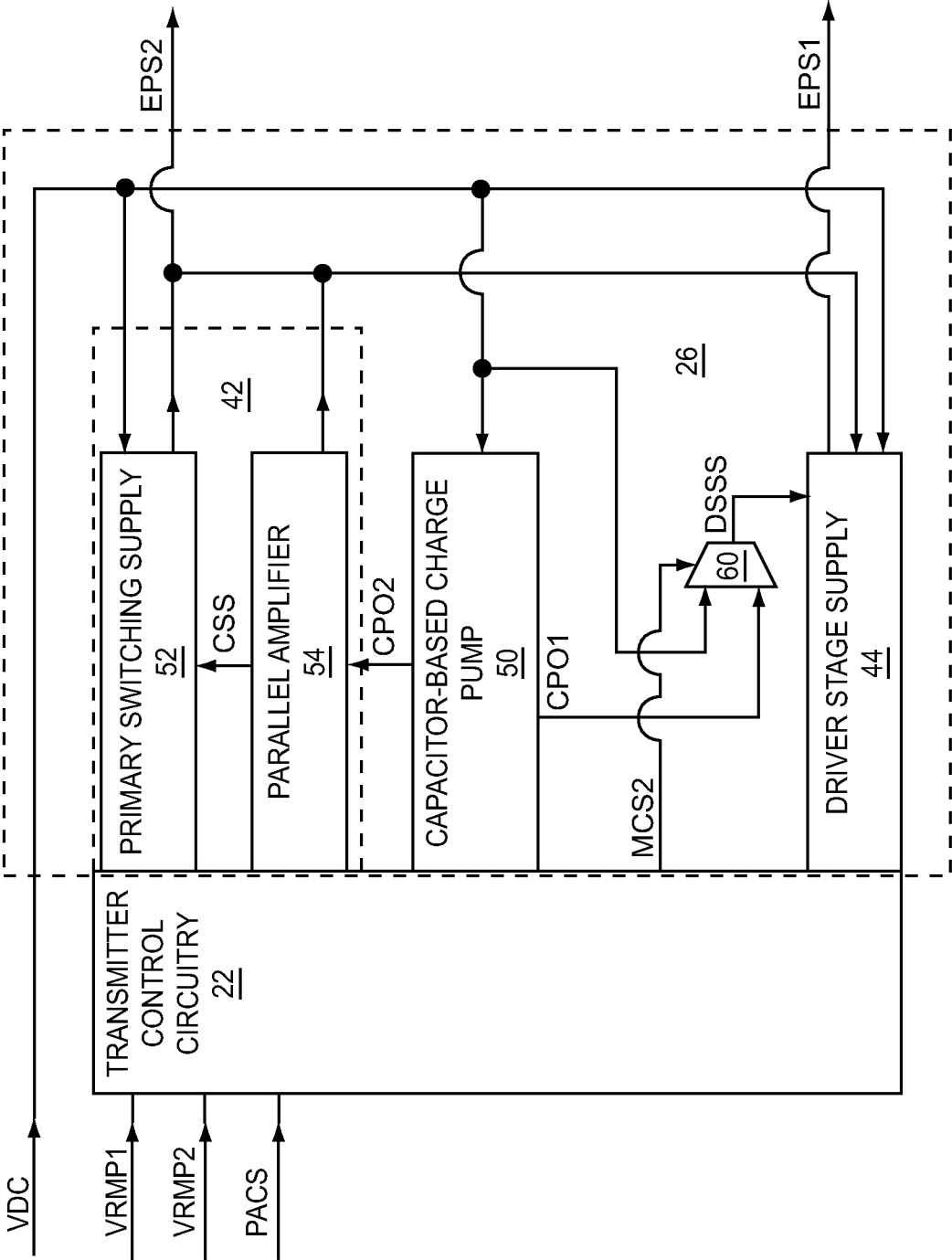


FIG. 15

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/053654

A. CLASSIFICATION OF SUBJECT MATTER INV. H03F1/32 H03F1/02 H03F3/195 H03F3/24 H04B17/00 H03G3/00 H03G3/30			
ADD. According to International Patent Classification (IPC) or to both national classification and IPC			
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H03F H04B H03G			
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched			
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal , WPI Data			
C. DOCUMENTS CONSIDERED TO BE RELEVANT			
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	
A	GB 2 465 552 A (NUJIRA LTD [GB]) 26 May 2010 (2010-05-26) page 31, line 18 - page 34, line 2; figure 8 -----	1-4,8, 11, 12, 28	
A	Wo 2004/002006 Al (MOTOROLA INC [US]) 31 December 2003 (2003-12-31) the whole document page 4, line 13 - page 6, line 16 page 9, line 1 - page 17, line 4; figures 1-3 -----	1-28	
A	EP 1 569 330 Al (RESEARCH IN MOTION LTD [CA]) 31 August 2005 (2005-08-31) paragraphs [0001], [0004], [0010], [0011], [0024] - [0030], [0064]; figures 1,7a, 7b ----- -/- .	1-28	
<div style="display: flex; justify-content: space-between;"> <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex. </div>			
* Special categories of cited documents : <div style="display: flex; justify-content: space-between;"> <div style="width: 48%;"> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 48%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p> </div> </div>			
Date of the actual completion of the international search <div style="text-align: center; font-weight: bold;">8 February 2013</div>		Date of mailing of the international search report <div style="text-align: center; font-weight: bold;">15/02/2013</div>	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer <div style="text-align: center; font-weight: bold;">Kurzbaauer, Werner</div>	

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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