DRIVE RF POWER AMPLIFIERS WITH A HIGH-FREQUENCY SWITCHING REGULATOR

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USE A DC/DC SWITCHER BETWEEN A SINGLE-CELL LITHIUM-ION BATTERY AND A POWER AMPLIFIER TO GENERATE LESS HEAT AND INCREASE EFFICIENCY AND TALK TIME FOR A GIVEN BATTERY SIZE.

Single-cell lithium-ion batteries traditionally have powered RF (radio-frequency) linear power amplifiers in cell phones. Although the use of these linear power amplifiers can help to meet the specification limits for linearity and ACPR (adjacent-channel power ratio) and ACPL (adjacent-channel power-leakage) ratio, their low power-added efficiency can drain the main battery, cause thermal issues, and reduce talk time. This article aims to demonstrate the benefits of using a dc/dc switcher between the battery and the power amplifier by using dynamic voltage scaling. The resulting increase in efficiency corresponds to less generated heat and increases the talk time for a given battery size.

TABLE 1 USER-EQUIPMENT POWER CLASSES

Power class	Maximum user-equipment output power (dBm/mW)
1	33/2000
2	27/550
3	24/250
4	21/130

RF power amplifiers, whether in 2G TDMA GSM communication, EDGE, or 3G UMTS WCDMA, use linear Class A or Class AB power amplifiers with relatively low efficiency at maximum output power and even lower efficiency at lower output power. When the main battery directly powers these amplifiers during transmitting mode, they draw the most power from the battery in a cell phone. This power consumption effectively depletes the battery and causes a reduction in available talk time. As cellular handsets get more features, such as GPS, cameras, televisions, MP3 players, and e-mail capability, reducing the power draw from the power amplifier can help in the design of handsets with more features and functions.

One of the main challenges designers face with today's mobile handsets is how to design a phone with more features and increase the talk time with same-capacity batteries. Meanwhile, designers must maintain a balance be-

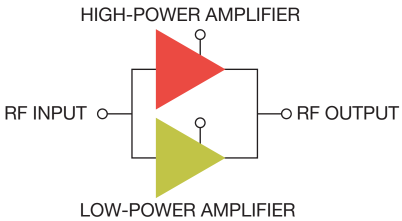

Figure 1 Dual-stage or multistage power amplifiers can have levels for low-, medium-, and high-power transmitting modes and are usually more expensive than a single-stage power amplifier.

AT A GLANCE

- Low power-added efficiency in single-cell lithium-ion batteries can drain cell phones' main battery, cause thermal issues, and reduce talk time.
- One approach to reducing the power loss within an RF power amplifier is to use a dual-stage design, in which each stage achieves the highest efficiency at either low or high power.
- Integrating two parallel power amplifiers can improve the efficiency under both low- and high-power transmitting conditions and can maintain linearity.
- Meeting a specification of approximately –39 dBc helps to improve voice quality and minimize the power amplifier's distortion, which causes interference with neighboring radio channels.

tween linearity at high-power mode and efficiency requirements in their new phone designs. Cell phones are usually in Power Class 2. Devices in this class have maximum allowable RF power output of approximately 27 dBm, or 550 mW (**Table 1**).

With 27 dBm, or 550 mW, of output RF power for Class 2 units, the power loss in an amplifier with a power efficiency of 44% is approximately 700 mW; input power is approximately 1.25W. Managing 700 mW of power dissipation within an RF-power-amplifier section is both challenging and costly.

Most WCDMA or EDGE handset phones use multiple modulation schemes to handle higher data rates and spend little time transmitting at full power. However, power-added efficiency at low to medium output power, rather than high-power power-added efficiency, dictates talk time. The quiescent current at low output power and the current consumption at power of 0 to 16 dBm are also important for talk time.

One approach to reducing the power loss within an RF power amplifier is to use a dual-stage design. In this design, each stage obtains the highest efficiency at either low or high power. You can increase the output power of these dual power amplifiers to a desired transmitting power at the beginning of the transmission burst and adjust it back to the low level when the transmission burst ends. Dual-stage or multistage power amplifiers can have different levels for low-, medium-, and high-power transmitting modes and are usually more expensive than a single-stage power amplifier (**Figure 1**).

Integrating two parallel power amplifiers—one for output power greater than 16 dBm and the other for output power less than 16 dBm—can improve the efficiency under both low- and high-power-transmitting conditions and can maintain linearity, with only one switched-on power amplifier. Appropriate load impedance terminates both low- and high-power amplifiers to achieve optimal efficiency in both low- and high-power modes (**Figure 2**).

Traditionally, in multistage RF-power-amplifier designs, the power amplifier directly connects to the battery. A power detector or a coupler samples the signal at the selected interior section of the amplifier and outputs a feedback signal that reflects the power of the signal at that interior section. The baseband-chip processor then adjusts the amplified signal output at a proper power level to maintain the output power within system specifications. Notice that the power-supply level in this approach remains at the same battery-voltage level during all levels of power transmission. Each cellular phone adjusts its RF output power to keep the effective SNR (signal-to-noise ratio) at the base station the same for each phone.

The addition of the coupler is a direct indication of the output signal, but it requires the insertion of a component in series with the output signal, resulting in reduced power-added efficiency. When the impedance of the amplifier load is improperly matched, the coupler or power detector measures a voltage that could have some errors and does not accurately predict the output power.

An alternative to using battery voltage to supply the amplifier's common-cathode voltage to improve the power amplifier's efficiency is to use a dc/dc switching converter with dynamic voltage scaling to supply the optimal voltage to the amplifier (**Figure 3**). Power-added efficiency is a ratio of the RF output power to the sum of the dc power and RF input power, which you can see when the power amplifier connects directly to the battery, versus a scenario in which the output of a dc/dc switcher replaces the dc power. Lowering the output voltage of the dc/dc switcher yields an increase in the amplifier's overall efficiency. This step reduces output current, which the power amplifier draws, and results in a lower input current draw from the battery due to the dc/dc converter's inherent

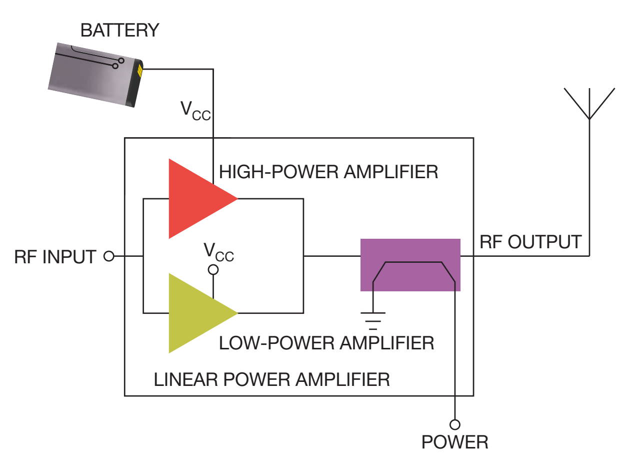

Figure 2 An appropriate low impedance terminates both low- and high-power amplifiers to achieve efficiency at both low- and high-power modes.

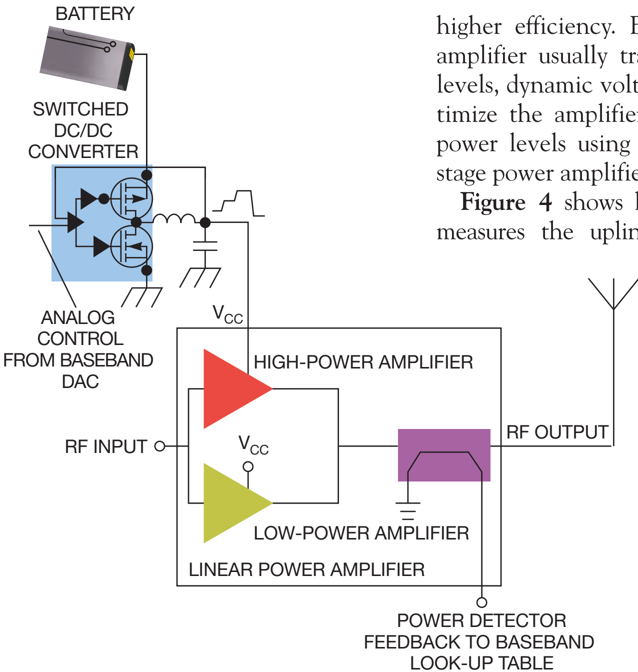

Figure 3 Instead of using battery voltage to supply the amplifier's common-cathode voltage, you can use a dc/dc switching converter with dynamic voltage scaling to supply the optimal voltage to the amplifier.

higher efficiency. Because any power amplifier usually transmits low power levels, dynamic voltage scaling can optimize the amplifier's efficiency at all power levels using a low-cost, single-stage power amplifier.

Figure 4 shows how a base station measures the uplink- and downlink-signal strength from the handset and forces the handset to find an appropriate DAC output from the look-up table to drive the control voltage, which enters the dc/dc switching regulator and therefore adjusts the power amplifier's common-collector voltage for optimal efficiency. With dynamic voltage scaling, the output voltage must vary as the transmitted power levels change to meet the ACPR/ACPL specification. ACPR/ACPL is the ratio of the power spectral density of the main channel to the power spectral density at several offset frequencies.

LOWERING THE OUTPUT VOLTAGE OF THE DC/DC SWITCHER YIELDS AN INCREASE IN THE AMPLIFIER'S OVERALL EFFICIENCY.

Meeting a specification of approximately –39 dBc helps to improve voice quality and minimize the power amplifier's distortion, which causes interference with neighboring radio channels. In this approach, when the base station commands the handset to change the transmitted output radio frequency based on the measured signal from the phone, the handset processor adjusts the RF power into the amplifier by changing the analog control signal from the baseband DAC to obtain the best RF-power-amplifier efficiency.

Buck regulators require several key features to power an RF-power-amplifier section. First, the power amplifier most often operates in the 5- to 10-dBm, or 3.2- to 10-mW power level—not 27 dBm, or 550 mW. Therefore, a useful target for improving amplifier efficiency is to use a dc/dc switching regulator with high efficiency over a wide load range. Buck regulators must also have switching frequencies greater than 6 MHz, depending on the frequency band. This frequency can minimize the effects of harmonics on the RF bands (**Table 2** and **Figure 5**).

Third, the bypass FET (field-effect transistor) must have an on-resistance of less than 35 mΩ. When the battery is low and the dc/dc switcher goes into a bypass mode, a low-on-resistance bypass FET allows full usage of the lithium-ion battery. The buck regulators also must exhibit duty-cycle operation of 10% for output voltages of 0.4V and low spurious signals.

The operating frequency of 6 MHz corresponds to lower spurious noise than that of lower-operating-frequency regulators. Dynamic-output-voltage adjustment allows better efficiency by adjusting the output voltage of the regulator based on the RF output power (**Figure 6**).

Fast turn-on is also important. When using a dc/dc switching converter to power the RF power amplifier, the key transient parameter is the control-voltage transient, which changes the output voltage from a low value to a higher value, or vice versa, without undershoots or overshoots and within the target time (**Figure 7**).

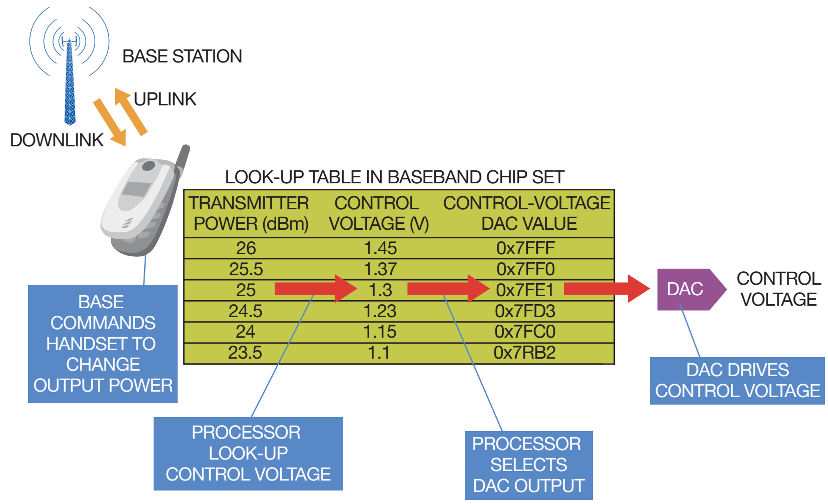

Figure 4 A base station measures the uplink- and downlink-signal strength from the handset and forces the handset to find an appropriate DAC output from the look-up table to drive the control voltage, which enters the dc/dc switching regulator and therefore adjusts the power amplifier's common-cathode voltage for optimal efficiency.

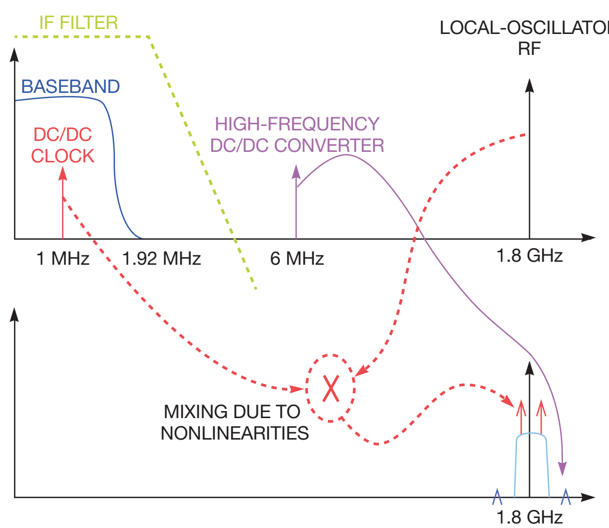

Figure 5 A frequency greater than 6 MHz can minimize the effects of harmonics on the RF bands.

TABLE 2 FREQUENCY-BAND RATES

Frequency band	**Uplink** (MHz)	**Downlink** (MHz)
1	1920 to 1980	2110 to 2170
2	1850 to 1910	1930 to 1990
3	1710 to 1785	1805 to 1850
4	1710 to 1755	2110 to 2155
5	824 to 849	869 to 894
6	830 to 840	875 to 885
7	880 to 915	925 to 960

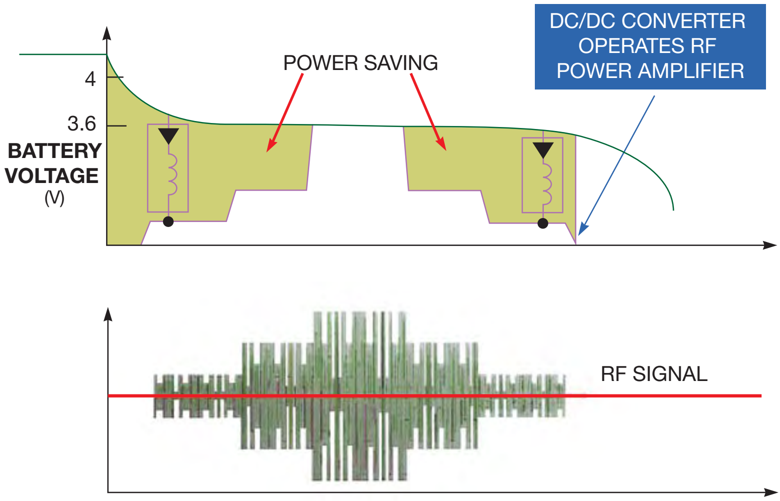

Figure 6 Dynamic output-voltage adjustment allows better efficiency by adjusting the output voltage of the regulator based on the RF output power.

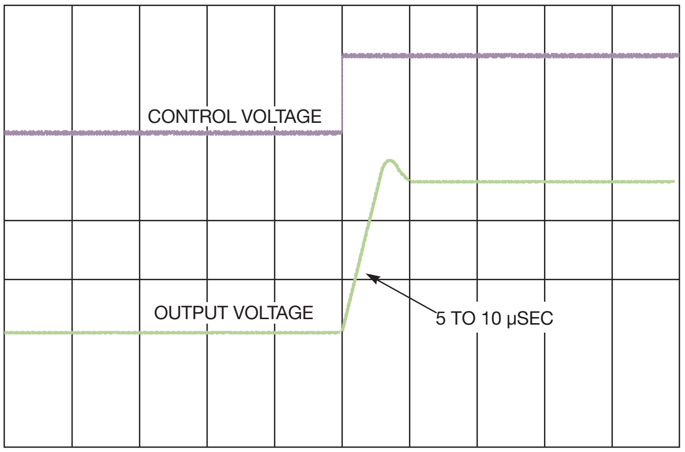

Figure 7 When using a dc/dc switching converter to power the RF power amplifier, the key transient parameter is the control-voltage transient, which changes the output voltage from a low value to a higher value, or vice versa, without undershoots or overshoots and within the target time.

Many cell-phone designs use single-stage RF power amplifiers with the battery as the supply rail. Adding dynamic voltage scaling to the RF power amplifier's supply rail is another effective way to increase the power-added efficiency, reducing the generated power loss within an RF section and increasing the talk time for a lithium-ion battery using a single-stage, low-cost power amplifier. Integrating the dynamic-voltage-scaling switching regulator with a multistage RF power amplifier is another approach. EDN

AUTHOR'S BIOGRAPHY

Majid Dadafshar is a field-application engineer at Fairchild Semiconductor. He has more than 25 years' worth of design-engineering experience in power electronics, both in commercial and military applications, and has worked at ITT Power Systems, ITT Courier, ITT Aerospace/Defense, Sony Electronics, Eastman Kodak, and Pulse Engineering. Dadafshar received a bachelor's degree in engineering in 1984 from Northern Arizona University (Flagstaff, AZ). He holds four patents and has published a number of technical papers on power-supply designs, electromagnetic interference, loop stability, and other topics. He has also conducted numerous domestic and international electronic technical meetings.