AN-1438 A Simple Method to Reduce DC Power Consumption in CDMA RF Power Amplifiers Through the LMV225 and an Efficient Switcher

ABSTRACT

This application report presents a simple power tracking technique for efficiency enhancement in CDMA RF power amplifiers. This technique involves the use of a linear-in-dB RF power detector and a DC-DC converter switch. This enhancement scheme switches the DC supply voltage, V_{CC}, of an RF power amplifier into two different levels through a DC-DC converter. Texas Instruments RF power detector LMV225 determines the supply voltage of the RF power amplifier. An off-the-shelf CDMA2000 RF power amplifier can be used in this technique to improve the energy efficiency of the mobile phone.

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1 Introduction

The need for higher wireless data rates is driving the migration of 2G to 3G mobile communication systems. The higher data rates in these systems impose additional performance constraints on the radio design of mobile phones.

In order to achieve the highest bandwidth efficiency of the allocated spectrum, these 3rd generation mobile communication systems use spectrum efficient linear modulation schemes, such as Quadrature Phase Shift Keying, 8-Phase Shift Keying and Quadrature Amplitude Modulation.

In IS-95 and CDMA2000 systems, the RF power amplifier typically operates at 6 dB to 40 dB back-off from the peak power or 1 dB compression point. (This means that it operates from 6 dB to 40 dBbelow the 1 dB compression point.) Consequently, the RF power amplifier operates with very low efficiency most of the time and is one of the most power consuming components in a handset. Studies show that the RF power amplifier consumes as much as 20% to 40% of the battery energy in regular phone operation.

Now, we can see that it is supremely important to reduce the power consumption of RF power amplifiers in order to achieve a long battery life or ‘talk time’ in a mobile phone.

2 RF Power Amplifier

An RF power amplifier is the centerpiece of this application. An off-the-shelf CDMA2000 RF power amplifier, such as the SKY77152, is used in the evaluation. It can have more than 40% power added efficiency near the 1 dB compression point as specified in the datasheet.

In a CDMA RF power amplifier there are usually two supply voltage pins, V_{CC} and V_{BIAS}, as shown in Figure 1. There is also one reference voltage pin, which is usually called V_{REF}. The V_{REF} has to be at 2.85V in all conditions. The power amplifier can be turned off by setting V_{REF} equal to ground level. Since most of the CDMA RF power amplifiers have two operation modes, High Power Mode and Low Power Mode, a V_{CONT} pin is used to set the operation mode of the power amplifier. When the RF output power is in the high level, the CDMA RF power amplifier needs to operate in High Power Mode to keep the right distortion performance. The CDMA RF power amplifier can be switched to Low Power Mode if the output signal level is relatively low. However, an undesired side effect is that the signal path phase shifts have too much difference between the two paths. This may cause problems in base-band processing and correction.

Figure 2 shows the typical P_{OUT} vs. P_{IN} performance of a CDMA RF power amplifier when the DC supply voltages, V_{CC} and V_{BIAS}, are lowered. It shows that output RF power can still be obtainable by reducing the DC supply voltage of the RF power amplifier.

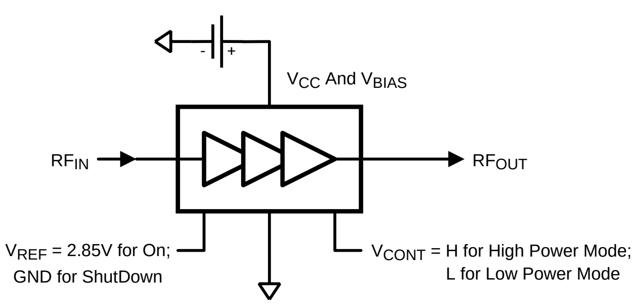

Figure 1. CDMA RF Power Amplifier

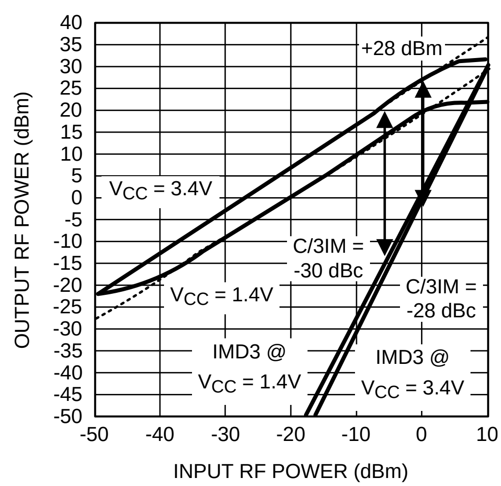

Figure 2. Linearity of CDMA RF Power Amplifier

3 Power Added Efficiency

The DC-to-RF efficiency or Power Added Efficiency, PAE, is defined by

$$PAE = \frac{P_{OUT} - P_{IN}}{P_{DC}} \cdot 100\% \tag{1}$$

The DC power consumption is defined by

$$P_{DC} = V_{CC} \cdot I_{CC} \tag{2}$$

Although the peak DC-to-RF efficiency of the PA occurs at the peak output power level as specified by all RF power amplifier manufacturers, the RF power amplifier itself rarely operates at this peak power level. Nevertheless, the peak power added efficiency contributes significantly to minimizing power dissipation for heat constraints in the handset. On the other hand, the PAE of the RF power amplifier goes downhill when the output RF power is lower.

In battery powered cellular phones, the output RF power probability distribution, shown in Figure 3, should be considered to estimate the average efficiency of the mobile system.

As Figure 3 shows, most of the time the RF power amplifier in a handset is operating at P_{OUT} = +15 dBm and below for an IS-95 handset. Therefore, it makes sense to improve the PAE of RF power amplifiers at small signal levels.

Equation 1 and Equation 2 reveal the idea that the DC power consumption P_{DC} can be reduced by lowering the supply voltage of the RF power amplifier.

It may sound very simple to improve the PAE of an RF power amplifier; however, there are a few major specifications that need to be considered while reducing the supply voltage of the RF power amplifier. These include the ACPR, the EVM and the switching time from one supply voltage level to another.

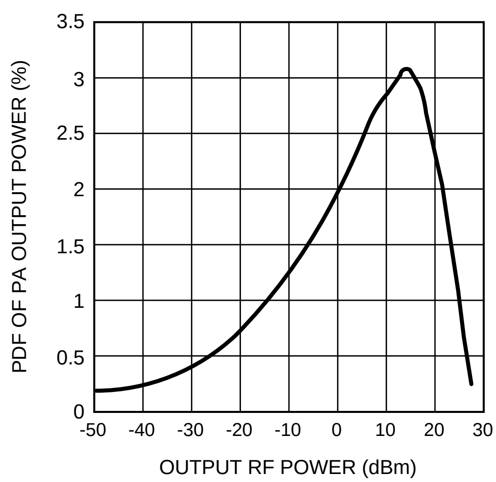

Figure 3. RF Output Power Distribution

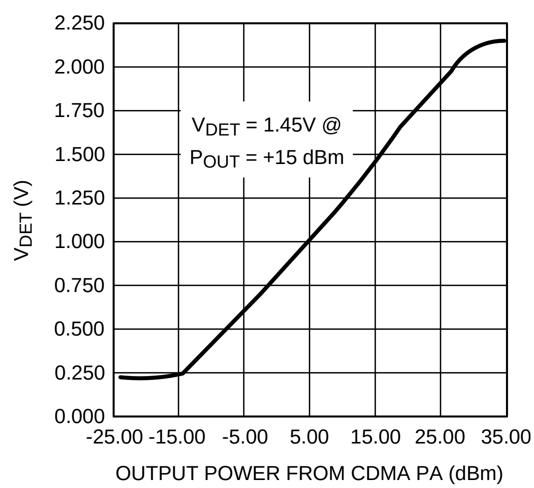

Figure 4. LMV225 Detected Voltage vs. P_{OUT}

4 Adjacent Channel Power Rejection

The Adjacent Channel Power Rejection, known as ACPR, is defined as the ratio of the average power in a specific offset frequency to the average power in the transmitted frequency. Table 1 shows the performance requirements from the CDMA2000. Although ACPR is not officially required by the IS-95 or the IS-98 air interface standards as it is in the CDMA2000, it is still suggested that the handset RF designer verifies to see if the components meet the specifications of Table 1.

Table 1. Adjacent Channel Power Rejection

Air Interface	Frequency	Channel Bandwidth	Offset Frequency @ ACPR1	Offset Frequency @ ACPR2	Measurement Resolution Bandwidth
IS-95	824–849 MHz	1.25 MHz	±885 KHz	±1.98 MHz	30 KHz
PCS	1850–1910 MHz	1.25 MHz	±1.25 MHz	±1.98 MHz	30 KHz
ACPR1 = –42 dBc and ACPR2 = –54 dBc					

5 Power Detector

The RF power detector, which uses the RF output signal, generates a rectified DC voltage that determines the output voltage of a DC-DC converter or switcher.

In this application, Texas Instruments LMV225 is chosen as an example since it provides 40 dB linear-in-dB detection range from 0 dBm down to –40 dBm.

RF power control in handsets is essential to ensure that the CDMA system operates smoothly. Since all users share the same radio frequency band, 1.25 MHz in IS-95, then each user appears to others as random noise. The power of an individual user must, therefore, be carefully controlled to prevent any one user from unnecessarily interfering with the others who share the same radio frequency band.

The LMV225, as used in the suggested application block diagram in Figure 5, provides two different functions. The first function is related to the output RF power control as mentioned previously. The second function is to determine the supply voltage of the RF power amplifier. The next section of this article is going to deal with the second function of the LMV225.

6 Switcher or DC/DC Converter

In general, a switcher used for this application has a Pulse Width Modulation (PWM) Mode and a Bypass Mode. The switcher normally operates in PWM mode to improve the efficiency of the handset. In PWM mode, the programmable output voltage is a function of V_{CON}. Equation 3 shows the relationship between the programmable output (SW) and control voltage (V_{CON}) of LM3200.

$$V_{OUT} = 3 \bullet V_{CON} \tag{3}$$

Texas Instruments has switchers for RF Power Amplifiers that are perfect for this application. The LM3200 is capable of generating a dynamically variable output voltage between 0.8V and 3.6V with load currents up to 300 mA in PWM mode and 500 mA in Bypass Mode.

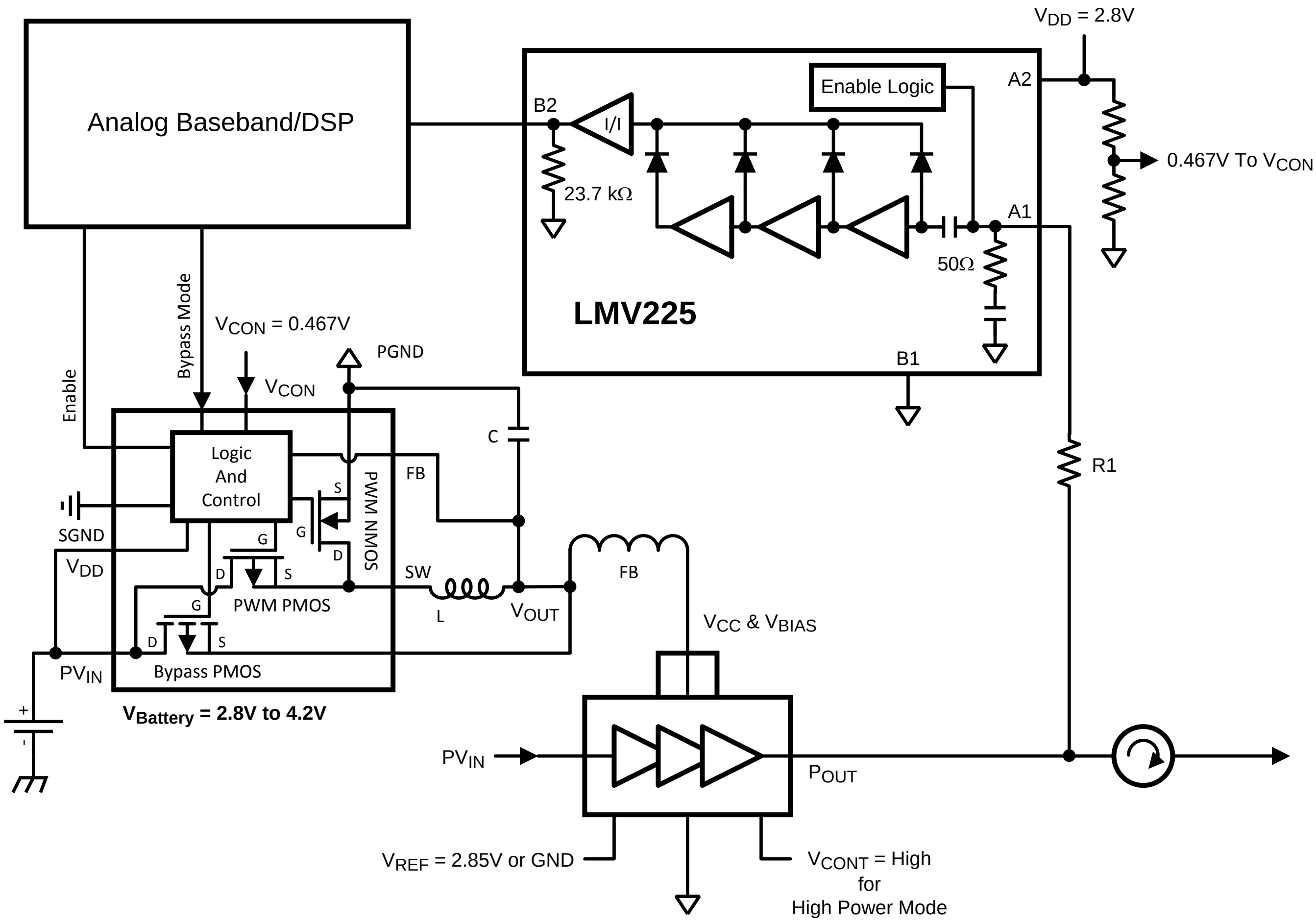

Figure 5. Efficiency Enhancement Circuit Diagram

7 Design Considerations

After a brief discussion of each building block in this application, we are ready to move to an explanation of the design procedure.

Assume that we are requested to design simple efficiency enhancement circuitry for an IS-95 RF power amplifier. The maximum output RF power level is +28 dBm and the LMV225 is used as an RF power detector. The switcher's Programmable Output Voltage equation would be Equation 3.

Figure 3 is the handset PA's probability graph and will be used as the efficiency optimization guideline. This probability graph reveals that the CDMA RF power amplifier operates at +15 dBm output power and below most of the time. If we can reduce the DC power consumption of the CDMA RF power amplifier in this operating range, the handset will save significant battery energy and then talk time will be longer.

The simplest solution is to set the supply voltage, V_{CC}, of the CDMA RF power amplifier to be the lowest level possible when the output RF power is +15 dBm and below.

Figure 2 shows the CDMA RF power amplifier performance at two different supply voltages, V_{CC} = 3.4V and V_{CC} = 1.4V. The 1 dB compression point at V_{CC} = 3.4V is about +28 dBm and at V_{CC} = 1.4V it is about +20 dBm. The graph includes plots of the 3rd order intermodulation distortions for both cases.

A typical CDMA RF power amplifier can pass the ACPR requirements for a small output power level all the way to a +28 dBm power level with V_{CC} = 3.4V as specified in its datasheet. In the case of V_{CC} = 3.4V, the 3rd order intermodulation distortion level is 28 dBc below the fundamental, C/3IM = –28 dBc, at P_{OUT} = +28 dBm. In the case of V_{CC} = 1.4V, the 3rd order intermodulation distortion is 30 dBc below the fundamental, C/3IM = –30 dBc, at P_{OUT} = +15 dBm.

Since ACPR is a function of intermodulation distortion, we can predict that the ACPR at P_{OUT} = +15 dBm with V_{CC} = 1.4V should be as good as that at P_{OUT} = +28 dBm with V_{CC} = 3.4V. Based on this information and the statistics in Figure 3, we can reduce the use of the battery of the CDMA RF power amplifier by setting its V_{CC} = 1.4 for power levels from +15 dBm and below.

Figure 6 shows the DC power consumption of the supply voltage at V_{CC} = 3.4V and V_{CC} = 1.4V and it demonstrates the saving of battery energy. The operating point 'A' is P_{OUT} = +15 dBm when V_{CC} = 3.4V; its P_{DC} can be found to be +27 dBm from the secondary Y-axis. When the supply voltage is changed to V_{CC} = 1.4V, the operating point for P_{OUT} = +15 dBm is 'AA.' Its P_{DC} is +22.5 dBm.

Therefore, the power saving from V_{CC} = 3.4 to V_{CC} = 1.4V is 27 − 22.5 = 4.5 dB. This 4.5 dB power saving corresponds to more than 50% saving in power.

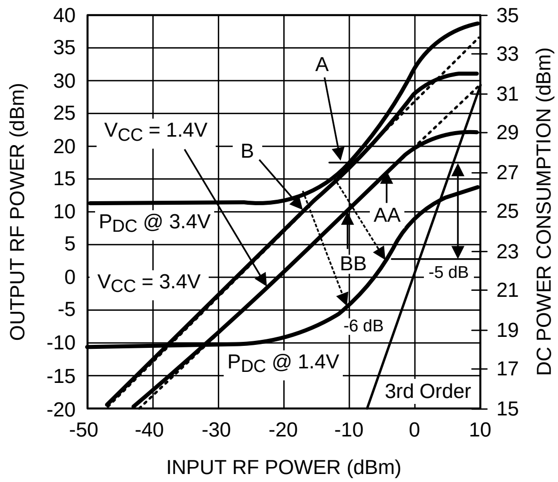

Figure 6. P_{OUT} and P_{DC} vs. P_{IN}

8 Application Circuit

Figure 5 is the proposed application circuit for reducing the use of battery energy in a CDMA RF power amplifier. We set the control voltage of the switcher to be V_{CON} = 0.467V. This 0.467V can be obtained from a voltage divider in the supply voltage of V_{DD} = 2.8V. This 0.467V will generate a V_{OUT} = 3 * 0.467 = 1.4V according to Equation 3. This V_{OUT} = 1.4V is then supplied to the V_{CC} of the RF power amplifier. When P_{OUT} = +15 dBm and below, we need to set the switcher in PWM mode by setting BYPASS = Low.

The LMV225 is used to determine if the switcher needs to be in Bypass mode. We use R1 = 1.8kΩ as a tapping resistor to achieve 31 dB coupling between the output of the RF power amplifier and the input of the LMV225. Figure 4 is the LMV225 response vs. P_{OUT} of an RF power amplifier. At P_{OUT} = +15 dBm, the detected voltage V_{DET} = 1.45V.

In this application circuit, the base-band chip needs to check the value of V_{DET}. When V_{DET} is above 1.45V, the base-band chip will set the switcher in Bypass mode by sending a logic high signal to BYPASS.

9 Power Saving at 10 dBm

Here is another illustration of battery saving. The operating point at 'B' is P_{OUT} = +10 dBm with V_{CC} = 3.4V. At this supply voltage level, the P_{DC} for P_{OUT} = +15 dBm is about 26 dBm. If we lower the supply voltage to V_{CC} = 1.4V, the operating point becomes 'B' and the P_{DC} for P_{OUT} = +15 dBm is about 20 dBm. This shows a 6 dB saving in power or 75% less power in watts.

10 Conclusion

We have demonstrated the flexibility and benefits of using Texas Instruments LMV225 together with a switcher in reducing battery energy consumption in a CDMA RF power amplifier. By adding this simple circuitry, we can save 50% of DC power consumption of the CDMA RF power amplifier at the most common operating points of IS-95 and CDMA2000 handsets.