Base Station Closed-Loop RF Power Control with LMV232 Crest-Factor Invariant Detector

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Introduction

Thanks to the rapid growth in data application customers of CDMA2000 and other 3G cellular phone networks, it becomes very critical to optimize the systems throughput performance of these cellular systems.

The main goal of optimization in CDMA2000 cellular systems is to increase the established call rate, reduce the drop call rate, remove blind spots in the coverage areas and, at the same time, increase the transmission data rate.

In order to keep the drop call rate low and tune up the established-call rate, the coverage area of adjacent base stations must have some overlap. In this overlap coverage area, the RF power level of the pilot channel from each base station is about the same but the RF power level of the load channel from each base station may be much different.

Since the transmitted RF power level from the base station will affect the transmission data rate and the quality of services, precise control the RF transmitted power will be one of the key tasks for optimization in CDMA2000.

This article is going to provide a solution with the LMV232 crest-factor-invariant RF power detector. The LMV232 can accurately measure the average transmit power level in base stations so that quality of service and better system's throughput in the corresponding cell can be achieved.

CDMA2000 Cellular Base Station

As shown in Figure 1, each base station has its own coverage area. In a cellular phone network, each base station need to maintain the maximum required transmit RF power level in order to maintain stable and reliable communication links to mobile units. The maximum transmitted RF power for microcell is 10W. For macrocell, it could be either 20W or 40W depending upon the network specification.

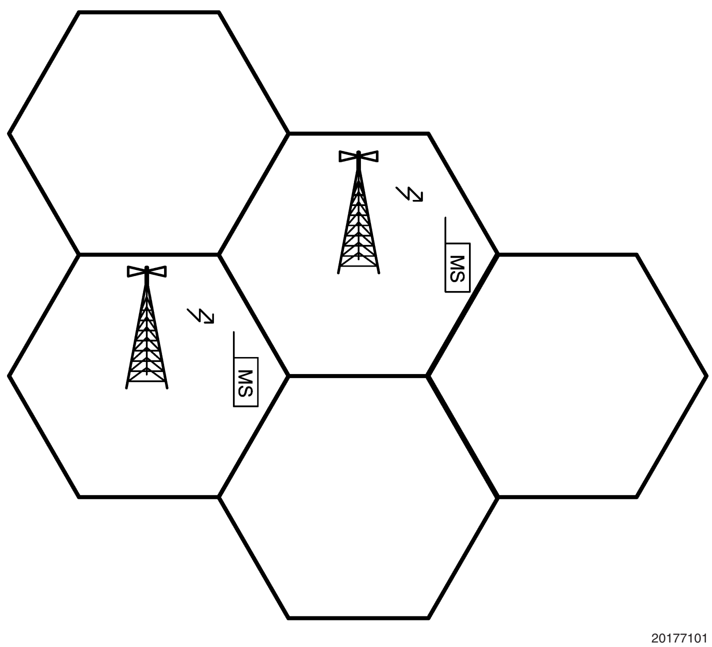

FIGURE 1.

In a CDMA system, every cell uses the same frequency, at least for the same service provider in the same region. If the transmitted RF power is too high, it will cause unwanted interference to the adjacent cells. If the transmitted RF power is too low, the coverage area would be reduced. This will make mobile units far away from the base station have weak communications and more chances of dropped calls.

In the next sections, we are going to address the mentioned issues of inaccuracy in transmission RF power from the base station. We will provide a solution for closed-loop RF power control so that the base station can transmit the right RF power level accurately. By doing so, we aim at improving the communications quality.

Coverage Area and Transmit RF Power Level

This section is to discuss one of the most important parameters in digital communications technology, namely, carrier-to-noise ratio, C/N. We will derive the coverage area of a base station by using a first order radio wave propagation model and then observing how errors in transmitter RF power affect the coverage area.

The Carrier-to-Noise, C/N ratio, can be found from equation (1):

Equation (1):

$$\frac{C}{N} = \frac{P_E}{N} \times G_{RX} \times L_{PATH}$$

Where

P_E: effective transmit RF power

N: effective noise power

L_{PATH}: loss of transmission path from base station to mobile unit

G_{RX}: antenna gain of mobile unit

And,

Equation (2):

$$P_E = P_{PA} \bullet L_{CABLE} \bullet G_{TX}$$

Where,

P_{PA}: output RF power from base station power amplifier

L_{CABLE}: cable loss from power amplifier to antenna

G_{TX}: antenna gain of base station

If we use a free space model for analysis and assume that the cell forms a circle, the transmission path loss will be,

Equation (3):

$$L_{PATH} = \frac{4\pi\lambda^2}{d^2}$$

Where,

λ: wavelength of RF signal

d: radius of cellular base station's coverage area

We can re-write equation (1) as the following,

Equation (4):

$$\frac{C}{N} = \frac{1}{N}\left[P_{PA} \times L_{CABLE} \times G_{TX}\right] G_{RX}\left[\frac{4\pi\lambda^2}{d^2}\right]$$

Or,

Equation (5):

$$d^2 = P_{PA} \times L_{CABLE} \times \frac{G_{TX}G_{RX} \times 4\pi\lambda^2}{\left[\frac{C}{N}\right]}$$

In a well planned base station design, d^2, λ and P_{PA} are fixed values; therefore, we can conclude that

d^2 is proportional to P_{PA}.

Or,

Coverage area is proportional to the transmitted RF power level in base station.

Assume that P_{PA0} is the required transmitted RF power from the base station, d_0 is its corresponding radius of coverage area; P_{PA1} is the actual measured RF power level from the base station and then d_1 is its corresponding radius of coverage area.

Equation (6):

$$\frac{d_1^2}{d_0^2} = \frac{P_{PA1}}{P_{PA0}}$$

Equation (7):

$$\Rightarrow 10 \times \log\frac{d_1^2}{d_0^2} = 10 \times \log\frac{P_{PA1}}{P_{PA0}}$$

In general, a microcell base station can transmit 10 watts or 40 dBm RF energy. If this base station has −1 dB error in transmit power, the actual transmitted RF power level will be 40−1 = 39 dBm.

In order to demonstrate how transmit power error affects the coverage area, we substitute the −1 dB into equation (7), and then we get,

Equation (8):

$$10 \times \log\frac{P_{PA1}}{P_{PA0}} = -1\text{dB}$$

Or,

Equation (9):

$$10 \times \log\frac{d_1^2}{d_0^2} = -1\ \text{dB} \Rightarrow \frac{d_1^2}{d_0^2} = 10^{-0.1} = 0.795$$

Equation (10):

$$\frac{d_0^2 - d_1^2}{d_0^2} = 1 - 0.795 = 0.205 = 20.5\%$$

We can observe the following from equation (10).

If the coverage area is πd^2 and the transmitted RF power has −1 dB error. This error in transmit RF power level will effectively shrink the coverage area by 20.5%. In order to keep the base station's coverage area from shrinking, we need to minimize the transmit error of the RF power amplifier in the base station.

The RF Power Amplifier in the Base Station

The RF Power Amplifier in the Base Station (Continued)

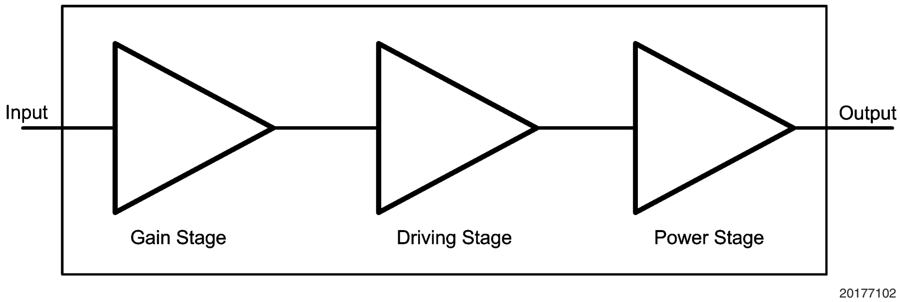

FIGURE 2.

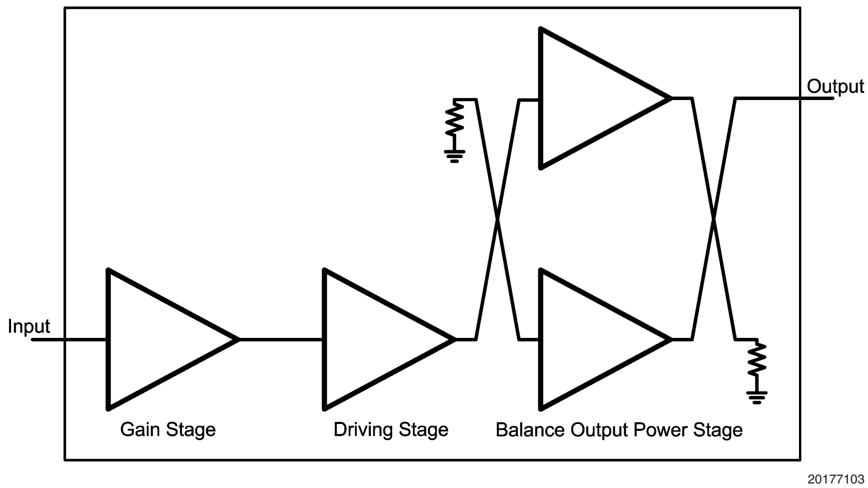

FIGURE 3.

Figure 2 and Figure 3 are the block diagrams for CDMA2000 RF power amplifiers used in base stations. In general, there are three stages in the RF power amplifier module. The first stage is a gain stage, the second stage is a driving stage and the third stage is the output power stage.

In Figure 3, a balanced output stage is used in the RF power amplifier. The advantage of a balanced output stage is that the output impedance of the RF power amplifier module would be easily kept at 50Ω because any reflected RF power will be absorbed by the 50Ω termination at the hybrid coupler.

In a CDMA microcell base station, the peak RF power specification for the power amplifier is 100W; however, the average power is only 10W. Since CDMA signals have 6 dB to 10 dB crest factor, the RF power amplifier needs to work on 6 dB to 10 dB back off from its peak power to maintain the linearity. Moreover, there are also cable losses between the antenna and the power amplifier module. The RF power amplifier has to deliver more power to compensate for the cable loss.

Over Temperature Characteristics of LMV232

Figure 4 demonstrates the temperature characteristics of the LMV232 at +25˚C, −30˚C and +85˚C. The measurement frequency is set at 1.9 GHz. The input power range is taken from −15 dBm to +10 dBm (or 0.032 mW to 10 mW). These test conditions represent typical application and system requirement of CDMA2000 and W-CDMA.

Over Temperature Characteristics of LMV232 (Continued)

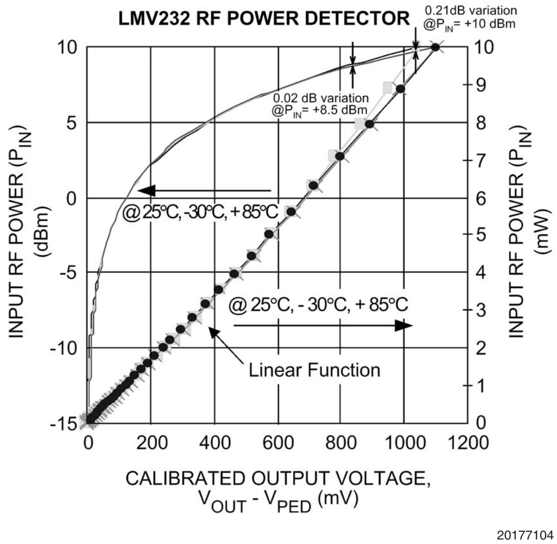

FIGURE 4.

In this figure, the X-axis is the calibrated output voltage from the LMV232. It is the difference between actual output DC voltage and pedestal voltage, i.e., $V_{OUT} - V_{PED}$. The primary Y-axis on the left hand side is the input RF power in dBm to the LMV232. The secondary Y-axis on the right hand side is the same input RF power, but, its units are in mW.

In Figure 4, we can see the over temperature response of the LMV232. The test data are clustered into two groups. One of the groups is close to the primary axis on the left. These curves are plotted with input power level in dBm and they follow an exponential response. At the same time, this set of curves is almost overlapped in any place. This can easily be explained; the calibrated DC output voltage from the LMV232 has a very insignificant change over temperature.

We can also see a set of curves near the secondary Y-axis on the right. These curves are plotted with input power level in mW and they follow closely a linear function. Because of the property in linear function, we can use the two points test method in system calibration.

LMV232 Small Drift over Temperature

We can use some of the data in Figure 4 to demonstrate the precision RF power measurement from the LMV232. Assume that the input RF power to the LMV232 is +10 dBm or 10 mW. The calibrated output voltage from the LMV232 will be 1V as shown in Figure 4. If we use this 1V to predict the measured RF power from −30˚C to +85˚C, we can see that the maximum error would be 0.21 dB. Moreover, if the input RF power to the LMV232 is 8.5 dBm or 7 mW, the calibrated output voltage will be 800 mV. Again, if we use this 800 mV to predict the measured RF power in any temperature range from −30˚C to +85˚C, the maximum prediction error will be 0.02 dB. We can easily find applications in CDMA base stations for such precise RF power detection as provided by the LMV232.

LMV232 Base Station Application Example

In this section, we are going to explain how the LMV232 and an RF power amplifier can work together in a CDMA base station to provide an accurate transmit RF power level. Figure 5 is the application block diagram.

LMV232 Base Station Application Example (Continued)

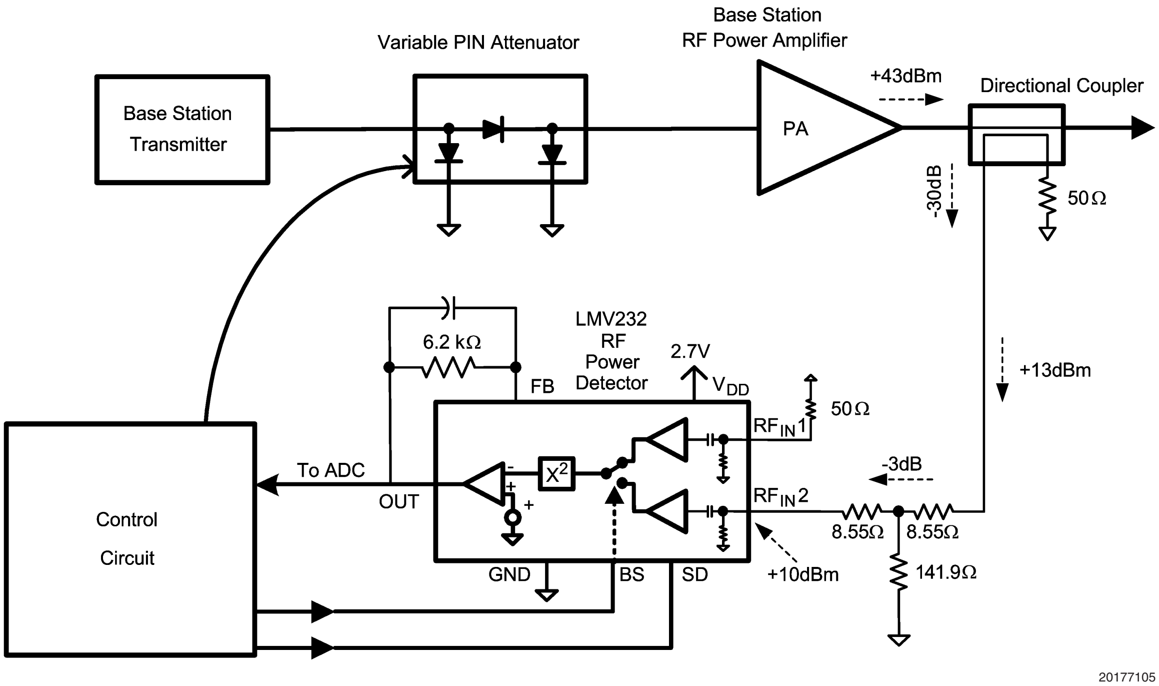

FIGURE 5.

In Figure 5, we use an RF power detector LMV232 to measure the transmit RF power in a CDMA2000 base station. In this application example, the average RF output power level is set to 20W or +43 dBm. We also set the corresponding input RF power level for LMV232 to be +10 dBm or 10 mW.

Accordingly, we need a directional coupler between the output of the RF power amplifier and the input of the LMV232.

We can compute the needed coupling factor by 10 dBm – 43 dBm = –33 dB. That is to say we need a –33 dB directional coupler.

For your information, the maximum coupling factor for an off-the-shelf directional coupler is –30 dB. In order to achieve the –33 dB coupling factor, we have to add another –3 dB attenuator between the input of the LMV232 and the coupling port of the directional coupler. In Figure 5, we have added a –3 dB T network attenuator.

At this point, we can use the test result in Figure 4 to verify the design in Figure 5. When the calibrated output DC voltage from the LMV232 is at 1V, it means the input RF power level is +10 dBm. Since there is a 33 dB coupling between the output of the RF power amplifier and the input of the LMV232, the measured RF output power level from the PA is +10 + 33 = +43 dBm. As we have seen from Figure 4, the maximum measurement error is only 0.21 dB if the ambient temperature is changed from –30˚C to +85˚C.

In normal operation, the base station may need to lower its output RF power to meet the requirement of the wireless network. As shown in Figure 5, we can have an adjustable PIN diode attenuator at the input of the RF power amplifier. We can use this variable attenuator to lower the input RF signal level to the RF power amplifier. Since the RF power amplifier has a fixed gain, the RF power amplifier output level will be reduced when its input signal level reduces.

In this power level adjustment process, the LMV232 detects the output signal level of the RF power amplifier, and then sends back this information to the control system. The control hardware or software will then compare the measured output RF power level to the needed RF power level. Any difference will be computed, the control systems will operate on the difference and provide a DC signal to adjust the variable PIN attenuator to correct the input RF signal level.

Conclusion

The LMV232 is optimized for non-constant envelope RF power detection application. It has very small over temperature drift characteristics. The cellular base station can implement a closed-loop RF power control from the LMV232 together with a directional coupler, variable RF attenuator and RF power amplifier. With accurate transmit power level from the base station, the cellular network can provide high quality service and better transmission rates to the mobile users.

Notes

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