Crest Factor Invariant RF Power Detector

Introduction

Over the past few years cellular phone system have made a major transition from power efficient digital modulation schemes to bandwidth efficient digital modulation techniques. This is because new cellular phone systems need to provide a high transmission rate capability to satisfy the needed broadband applications.

Power efficiency modulation schemes provides reliable transmission of information in a communications system at the lowest practical power level. One of the very successful examples is the GSM/GPRS network. The binary signaling GMSK modulation is used in the GSM/GPRS network.

A bandwidth efficient modulation scheme delivers a higher data rate within a limited spectrum bandwidth. All the initial phases of 3G networks take advantage of this kind of modulation. A Sixteenth-ary Quadrature Amplitude Modulation (16QAM) scheme is even used in the latest High Speed Downlink Packet Access (HSDPA) of W-CDMA air interface. The 16QAM is used in the downlink to provide mobile users with the capability to download information much quicker. The move to bandwidth efficient modulation provides more information capacity with varieties of 3G cellular phone services, higher data security, better quality of services (QoS), and quicker system availability.

The high level M-ary modulation schemes, like 8PSK, 16QAM, etc, have a greater capacity to convey large amounts of information than low level binary modulation schemes, like GMSK.

The gain of greater capacity comes at the expense of more complex hardware in the radio and DSP. Alternatively, more complex transmitters and receivers can be used to transmit the same information over less bandwidth.

In summary, the transition to more and more spectrally efficient transmission techniques requires more and more complex hardware. This complex hardware may include a better DSP, faster signal processing algorithms, high linear RF power amplifiers, and more accurate RF power detectors, etc.

The objective of this article is to demonstrate and briefly explain how the LMV232 Mean Square Power Detector from National Semiconductor can be used as an accurate RF power detector for bandwidth efficiency modulated RF transmission in a handset or mobile unit.

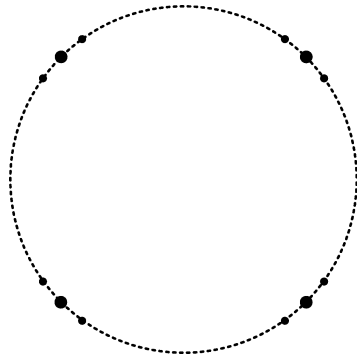## Overview of Digital Modulation in Cellular Phones

A digital modulation scheme is more spectral efficient if it can transmit a greater amount of data or bits per second in a given bandwidth. Therefore, we define the bandwidth or spectral efficiency of a modulation to be "transmission bit rate divided by the occupied channel bandwidth, bit/second/ Hz." *Table 1* indicates that a higher M-ary modulation scheme has a large number of output levels and, therefore, has better spectral efficiency.

TABLE 1. Theoretic Bandwidth Efficiency

| Modulation Scheme	Theoretical Bandwidth/Spectral Efficiency (bit/second/Hz)	Comments
GMSK	1	Constant Envelope
QPSK	2	Non-constant Envelope
8PSK	3	Non-constant Envelope
16QAM	4	Non-constant Envelope

Figure 1 shows the constellation diagram of each modulation. In these diagrams, we can see that only the GMSK has a constant RF envelope.

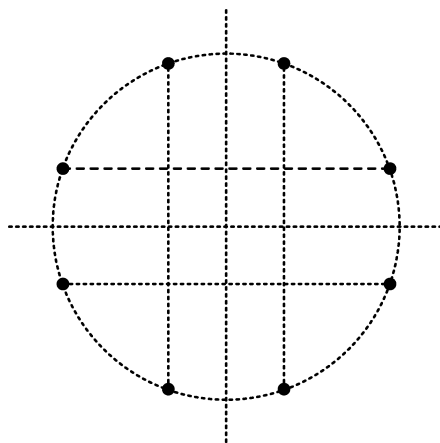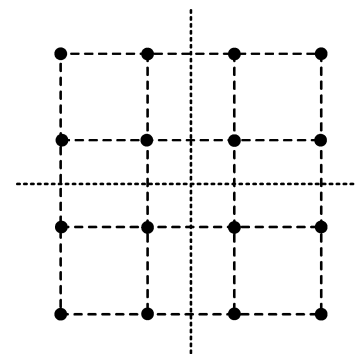# Overview of Digital Modulation in Cellular Phones (Continued)

GMSK
1 bits per symbol
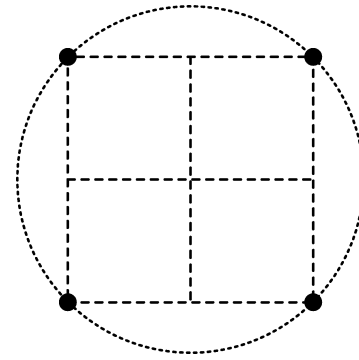
QPSK
2 bits per symbol

8PSK
3 bits per symbol

16QAM
4 bits per symbol

FIGURE 1. Constellation Diagram of Digital Modulation Used in Cellular Phones

The other way to look at the bandwidth efficiency is the symbol rate (or Baud Rate) because the signal bandwidth for the communications channel needed depends on the symbol rate, not on the bit rate.

Symbol rate = bit rate / the number of bits transmitted with each symbol

Bit rate is the frequency of a system bit stream or raw data stream. The symbol rate is the bit rate divided by the number of bits that can be transmitted with each symbol on each time interval.

If one bit is transmitted per symbol, as in MSK, then the symbol rate would be the same as the bit rate. If two bits are transmitted per symbol, as in QPSK, then the symbol rate would be half of the bit rate. In comparing the MSK and QPSK, we can easily find that the symbol rate of QPSK is lower for transmitting the same amount of information. This is why modulation formats that are more complex and use a higher number of states can send the same information over a narrower piece of the RF spectrum.

GMSK Modulation in GSM/GPRS

The GSM/GPRS cellular phone network uses a variation of the constant-envelope modulation format called 0.3 GMSK (Gaussian Minimum Shift Keying with BT = 0.3). In this modulation format, the amplitude of the modulating carrier is kept constant (as shown in *Figure 1*) while its frequency is varied by the modulating message signal. This is a desirable characteristic for using a power efficient RF amplifier in the transmitter.

Amplitude variations can exercise nonlinearities in an amplifier's amplitude-transfer function, generating spectral regrowth and unwanted adjacent channel power. Since there is no amplitude variation in MSK, more efficient amplifiers (which tend to be less linear) can be used with constant envelope signals. This reduces power consumption.

In the GSM/GPRS standard, the modulated waveforms are filtered with a Gaussian filter, which results in a narrow spectrum. In addition, the Gaussian filter has no time-domain overshoot and therefore the peak deviation is not increased.
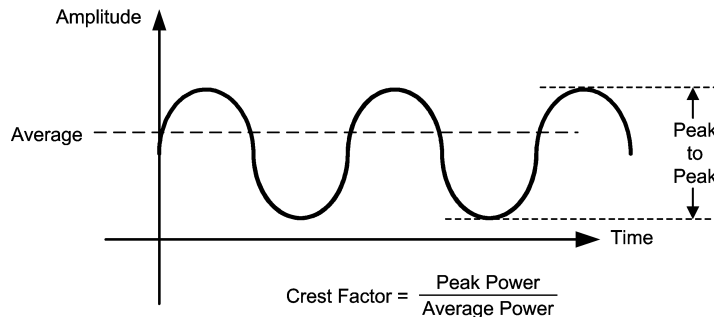
QPSK and 16QAM Modulation in 3G CDMA

16-ary Quadrature Amplitude Modulation (16QAM) is going to be used in the HSPDA of the W-CDMA standard. The

QPSK and 16QAM Modulation in 3G CDMA (Continued)

symbol rate is one fourth of the bit rate for 16QAM because $16 = 2^4$ as seen in *Figure 1*. So this modulation format produces a more spectrally efficient transmission. It is more efficient than MSK, QPSK or 8PSK. Note that QPSK is the same as 4-ary Quadrature Amplitude Modulation.

In linear schemes, the amplitude of the transmitted signal varies with the modulating digital signal as in BPSK or QPSK. In systems where bandwidth efficiency is more important than power efficiency, constant envelope modulation is not as well suited.

Crest Factor (CF) or Peak-to-Average Ratio (PAR) in Digitally-Modulated RF

The crest factor is defined as the ratio of peak amplitude to average amplitude (Peak-to-Average Ratio) as shown in *Figure 2*. For narrow band QPSK modulation, the crest factor is 6 dB and for offset QPSK modulation, the crest factor is 5.1 dB.

$$\text{Crest Factor} = \frac{\text{Peak Power}}{\text{Average Power}}$$

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FIGURE 2. Crest Factor Definition

In cellular phone systems, the Complementary-Cumulative-Probability-Distribution Function (CCDF) is used to measure the statistics of a transmitted radio frequency signal. The CCDF statistically represents how often a radio frequency signal is above a specific power level or threshold. This CCDF is the authentic method to characterize the crest factor (CF) or peak-to-average (PAR) of WCDMA or CDMA2000 signals in the 3G network.

In IS-95, the PAR is found to be 3.9 dB and the PAR in CDMA 1X RTT can be as high as 5.4 dB. In W-CDMA, the PAR can vary from 2 dB to 11 dB. In summary, the PAR in CDMA2000 or W-CDMA depends on the radio configurations, spreading code combinations and channels used. Sometimes, crest factor reduction techniques are used to reduce the effective PAR in base station transmitters.

Power Definition and Measurement in Cellular Phone Systems

In the DC world, the power dissipating through a circuit element is calculated by taking the product of the current through this element and the voltage drop across the element,

$$P_{DC} = V \cdot I \text{ (Watts or mW)}$$

In the analog and RF world, either peak power or average power could be used to represent the transmitted or received energy level. *Figure 3* show a typical RF signal with amplitude variation on its envelope. The power level of the signal is defined by:

$$P_{RF/Analog} = \frac{V_{average}^2}{R} \text{ (Watts or mW)}$$
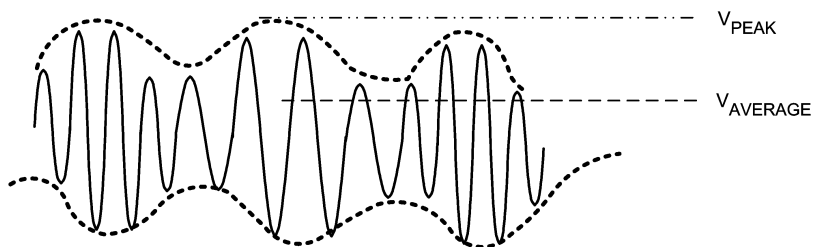
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FIGURE 3. Peak Power and Average Power Measurement in a Digitally-Modulated RF Signal

Peak Power Detector

Peak power measurement has been successfully used in GSM and AMP cellular phone networks. Typically, peak RF power measurement is performed by circuits with a pair of Schottky diodes, where one diode is used for RF rectification and the other is used for temperature compensation.

As we mentioned in the previous section, 3G CDMA RF signals have high crest factors and peak power measurement will result in values that are higher than the average power of the CDMA signal by a factor of PAR. Using a peak power detector requires a proprietary calibration approach to correct the measurement uncertainties caused by the varying crest factor.

Average Power Detector

Average power measurement is to measure the average power of the RF signal. This method can handle signals with changing modulation envelopes such as QPSK or 16QAM. The measurement result provides a true measure of the average power in the signal, regardless of modulation type and peak-to-average ratio (PAR or CF). As a result, average power measurement is ideal to handle signals in which the amplitude of the envelope of modulation changes with time such as IS-95, CDMA2000, W-CDMA or TD-sCDMA.

As mentioned in the previous section, 3G CDMA RF signals have high crest factors and the peak power measurement will result in values that are higher than the average power of the CDMA signal by a factor of PAR.

To resolve these uncertainties caused by the crest factor, a mean square radio frequency power detector, like the LMV232, can be used to measure the average power of a changing modulation signal.

Mean Square Detection

The LMV232 is a trans-linear device and makes use of the exponential Ic-V_{be} relation of a bipolar transistor:

$$y = e^{2 \cdot 1n(x)} = x^2$$

Since the LMV232 follows the square law, we can observe that the output voltage V_{OUT} (Volts) of the LMV232 is proportional to the input power P_{IN} (Watts or miliWatts).

$$V_{OUT} \text{ (Volts)} = k \cdot P_{IN} \text{ (mW)}$$

3G Cellular Phone Applications

In today's market, the maximum output power of a 3G RF power amplifier is slightly higher than +28 dBm and the maximum output power of a 3G mobile unit is +27 dBm. One extra decibel of power is needed to compensate for the intrinsic loss of circuits between the antenna and power amplifier. A 3G RF power amplifier usually has two modes; a high power mode recommended for use from +16 dBm and above; and a low power mode recommended for use from +16 dBm and below.

Figure 4 is the estimated curve of output power probability in a 3G mobile unit. Since the highest probability of output power occurrence in 3G is from +10 dBm and above in a 3G mobile unit, it is very critical to tightly control its output RF power from +10 dBm to a maximum output signal level of +27 dBm.
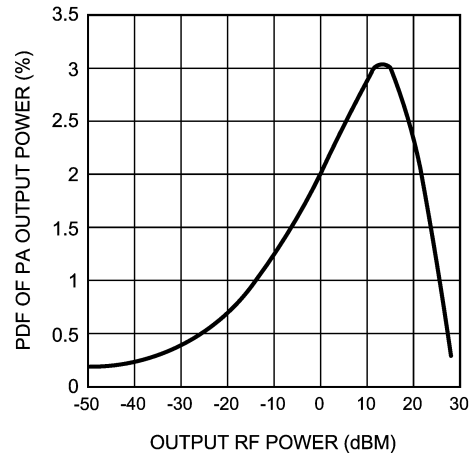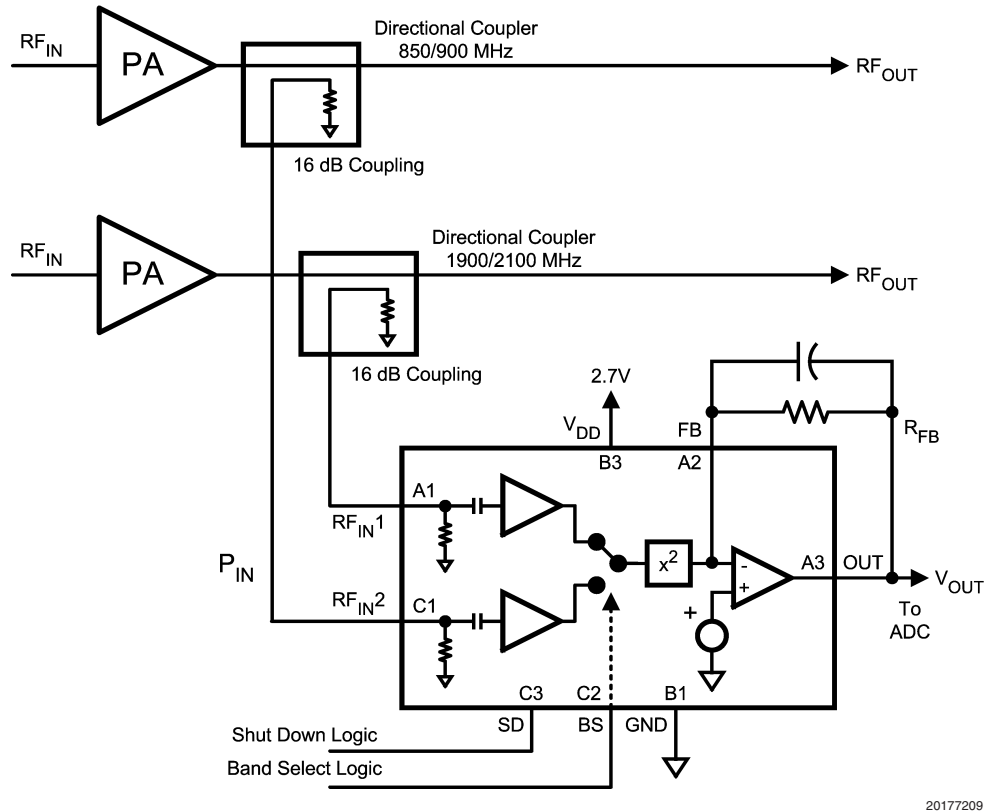

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FIGURE 4. Probability of PA Output Level in a 3G CDMA Mobile Unit

The LMV232 has a 20+dB linear detection range from +13 dBm and below. *Figure 5* is a recommended application block diagram for use in detecting the transmitted RF signal level in a multi-band 3G mobile unit.

3G Cellular Phone Applications (Continued)

FIGURE 5. Applications Block Diagram for the LMV232 in a 3G Multi-band Handset

In this design, a 16 dB directional coupler is used at the output of the power amplifier (PA). This sets the maximum input RF power to the LMV232 to

$$P_{IN} \text{ (dBm)} = +28 \text{ dBm} - 16 \text{ dB} = +12 \text{ dBm}$$

When the output power of PA is +11 dBm, the input power of the LMV232 would be:

$$P_{IN} \text{ (dBm)} = +11 \text{ dBm} - 16 \text{ dB} = -5 \text{ dBm}$$

In this design example, we have set the operating range of the LMV232 to be from −5 dBm to +12 dBm so that we have enough room for coupling factor variations.

Detection Error Over Temperature

The LMV232 mean square RF power detector is used to detect the transmit power in a 3G mobile unit. In a real application, the detected voltage $V_{DETECTED}$ has to be calibrated to a known reference before the detection method can be used in normal phone operation.

Because of

$$V_{DETECTED} \propto P_{IN} \text{ (mW)} = P_{OUT} \text{ (mW)} - \text{Coupling (dB)}$$

There is a linear response from −7 dBm to +13 dBm when the power is represented in mW. This linear characteristic provides an added advantage for power amplifier detection voltage calibration.

In the production process, $V_{DETECTED}$ is measured at two different power levels (2-Point), say at the power amplifier's P_{OUT} = +14 dBm and P_{OUT} = +24 dBm. (This corresponds to P_{IN} = −2 dBm and P_{IN} = +8 dBm respectively with a 16 dB coupler.) Based on this measurement data, we can create a linear equation for $V_{DETECTED}$ and the PA's P_{OUT}.

Figure 6 is the measurement results based on the applications circuit in *Figure 5*. We also tested the RF power detector circuit through −40˚C to +85˚C. The 2-Point test data was taken at room temperature and its estimated equation is used to predict the PA's P_{OUT} at any temperature.

If $V_{DETECTED}$ = 1V, then the mobile unit will estimate that its PA's P_{OUT} = +12.3 dBm disregarding the temperature condition. In a hypothetical situation, the power amplifier's output power would be P_{OUT} = +12.65 dBm if the mobile unit was at a temperature of −40˚C.

The detection error in the previous prediction would be 12.65 dBm − 12.3 dBm = 0.35 dB.

Figure 7 is the same kind of measurement results as *Figure 6*, but the graph is zoomed into the small signal region. Again, the detection error based on the 2-Point test equation will be less than 0.65 dB over the temperature range from −40˚C to +85˚C.
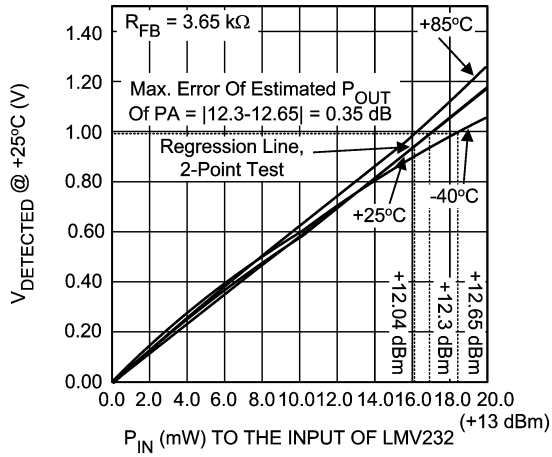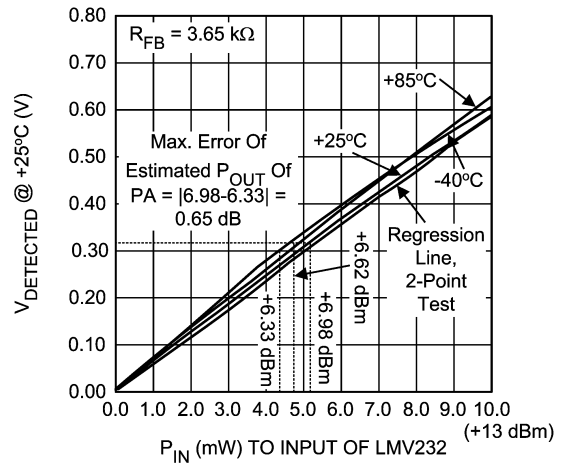
FIGURE 6. Over Temp Data of the LMV232 in a Handset to Demonstrate Measurement Accuracy

FIGURE 7. Over Temp Data to Show the LMV232's Accurate Performance at Small Signals

Summary

The LMV232 is optimized for applications in 3G mobile units. Together with a directional coupler, the LMV232 can be used to detect accurately the handset's transmit power level at the most often used range of +10 dBm and above. This is shown in the probability curve. Its crest factor invariant detection characteristic eliminates the need for the proprietary peak-to-average ratio correction process.

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