

# Measuring the RF Power in CDMA2000 and W-CDMA High Power Amplifiers (HPAs)

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## Introduction

Designers of high-power amplifiers (HPAs) used in CDMA2000 and W-CDMA base stations encounter many challenges in achieving accurate transmit power measurements. Complications include high peak-to-average ratios, peak-to-average ratios that change with base station call loading, large operating temperature ranges, and large transmit power ranges. Taking advantage of accurate RMS output power measurement allows HPA manufacturers to reduce the maximum power for which they design. This article describes several ways to accurately measure and control RMS power over temperature.

Complex modulation schemes like CDMA2000 and W-CDMA have large peak-to-average ratios. For a given maximum average-output-power requirement, the maximum designed-for power requirement will generally increase (or the linearization requirements increase) as the peak-to-average value increases due to base station spectral mask and EVM requirements. If the peaks of the modulated signal are clipped, third order distortion will increase, causing the base station to fail its spectral mask requirements. Clipping the peaks of a modulated signal can also cause a loss of data, making the system fail its EVM requirements. Designing an HPA based on peak power transmission requirements is expensive but necessary. The added expenses are due to both an increased cost in the electrical components and a decreased efficiency of the HPA. There is always a \$/Watt associated with the maximum designed for power of an HPA and running a HPA well below its saturation point is inefficient. A decrease in efficiency will increase the cost of an HPA module because it increases the cost, size, and weight of the mechanical structure used to dissipate the heat, reduces the HPA's reliability, and increases its operating cost.

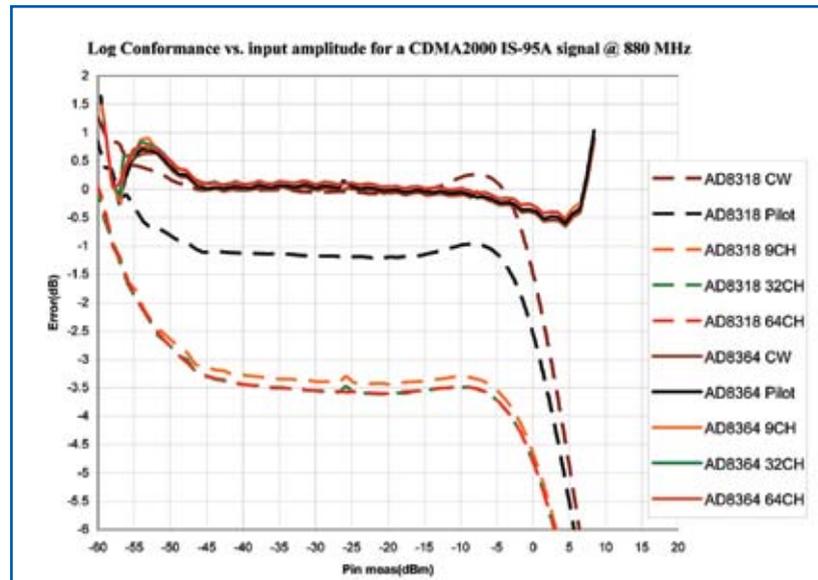


Figure 1: The errors in a RMS-responding RF detector (AD8364) vs. a non-RMS-responding RF detector show the effect of peak-to-average ratio on power detection. While a non-RMS-responding RF detector (AD8318) exhibits significant measurement error as the peak-to-average ratio of its input signal varies, an RMS-responding RF detector (AD8364) is largely immune to changes in peak-to-average ratio.

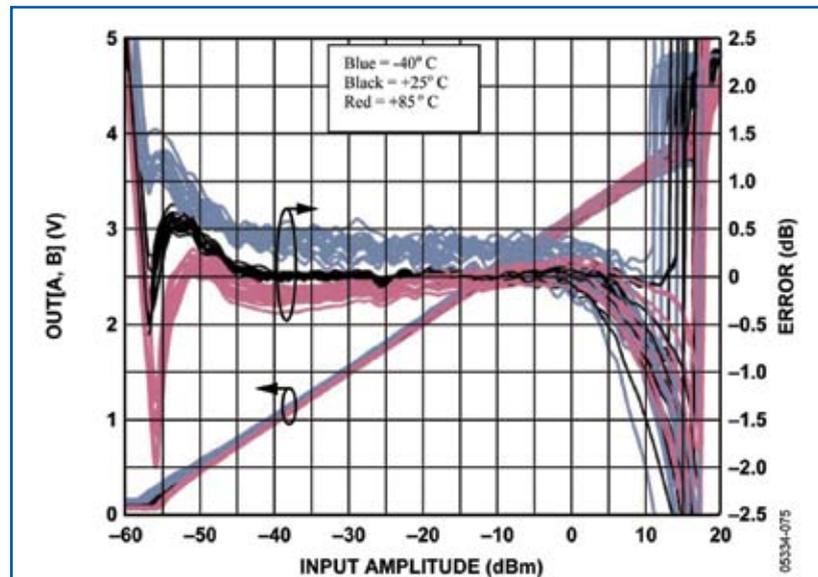


Figure 2: The Analog Devices AD8364 output voltage and log conformance error vs. Pin (@ 450 MHz) shows very little change when temperature is cycled from  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ . This remains true for 30 devices taken from different production lots, even though the performance is slightly different over temperature.

Reducing the maximum designed-for power of an HPA is important to HPA manufacturers. The closer an HPA's saturation point can get to its average power, the more efficient and cost effective the HPA will be. There are many techniques used to get a HPA's saturation point as close as

possible to the average transmitted power, but these techniques are all limited by the system's ability to measure the output power. The maximum designed-for power of the HPA needs to be increased by the RF power measurement tolerance (including variation vs. temperature and peak-to-aver-

age ratio) to ensure spectral mask and EVM compliance. This makes the accuracy of the RF Power Measurement System critical to reducing the cost and efficiency of an HPA.

Not only do CDMA2000 and W-CDMA modulation schemes have large peak-to-average values but the peak-to-average value changes with the call volume of a particular base station. In CDMA2000 IS-95A, for example, the forward link crest factor is 6.6 dB for pilot only, and 12 dB for 64 channels (using no CF reduction techniques). Large peak-to-average values cause errors in non-RMS-responding RF power detectors. A modulation scheme's large peak-to-average ratio can be calibrated out in production if it stays constant but variation in the peak-to-average ratio based on the amount of users in the system, tight control of which Walsh codes are being used, and a very large look up table in order to know the peak-to-average ratio of the signal at a particular time. A better option is the use of a RMS-responding detector. Unlike diode detectors or log amps, RMS-responding detectors are largely immune to variations in crest factors. Figure 1 shows the error of a high performance Log Amp (AD8318) compared to that of an RMS-responding detector (AD8364) as a result of the crest factor change (user loading) in the TX section of a CDMA2000 IS-95A base station. Note that the AD8318's output changes by 3.5 dB (or 86 mV) between CW and 64 channel CDMA2000 IS-95A and 2.4 dB between Pilot only and 64 channel CDMA2000 IS-95A, while the AD8364's output only changes by 0.1 dB (or 5 mV). A diode detector behaves similarly to a Log Amp in that its output voltage changes with respect to the crest factor of the detected signal. If a Log Amp were used for power detection in this system, the 2.4 dB variation

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in detected power would need to be removed through signal processing or added to the maximum designed-for-power in the HPA.

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Being able to accurately measure the RMS power across the operating temperature range of the HPA is also critical in determining the maximum designed-for power of the HPA. The accuracy of this measurement (or lack thereof) will need to be added directly to the maximum designed-for power, unless the difficult and costly process of calibration over temperature is performed. All components involved with the detection of the HPA's output power (e.g. directional coupler, attenuator, etc.) can add errors over temperature, but most change very little over the HPA's operating temperature. Generally, the accuracy of measuring the HPA's output power over temperature is directly related to the temperature performance of the detector. In recent years RF detection technology has made large strides in creating devices with responses that are very stable over temperature (better than  $\pm 0.5$  dB from  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ ). Figure 2 shows the temperature performance of the AD8364 dual RMS-responding power detector. This data was taken at  $+25^{\circ}\text{C}$  (black),  $-40^{\circ}\text{C}$  (blue), and  $+85^{\circ}\text{C}$  (red) @ 450 MHz. It includes voltage and error over temperature (after ambient calibration) vs. input power for at least 30 devices from multiple production lots. Each part behaves slightly different over temperature.

The Analog Devices AD8364 output voltage and log conformance error vs. Pin (@ 450 MHz) shows very little change when temperature is cycled from  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ . This remains true for 30 devices taken from different produc-

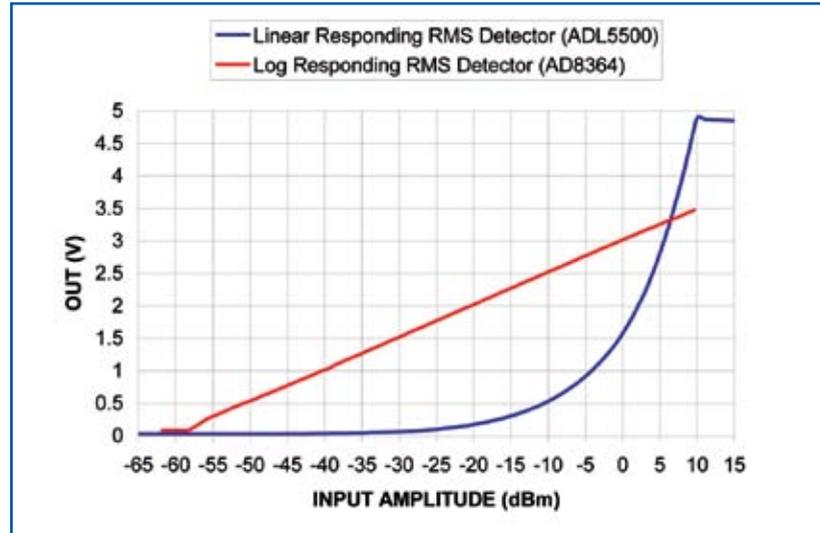


Figure 3: A comparison of a detector whose output is linear to the input RMS power in dBm (Analog Devices AD8364) to a detector whose output is linear to the input RMS volts (Analog Devices ADL5500) shows the difference in dynamic range and emphasizes the necessity of choosing an ADC with the proper resolution.

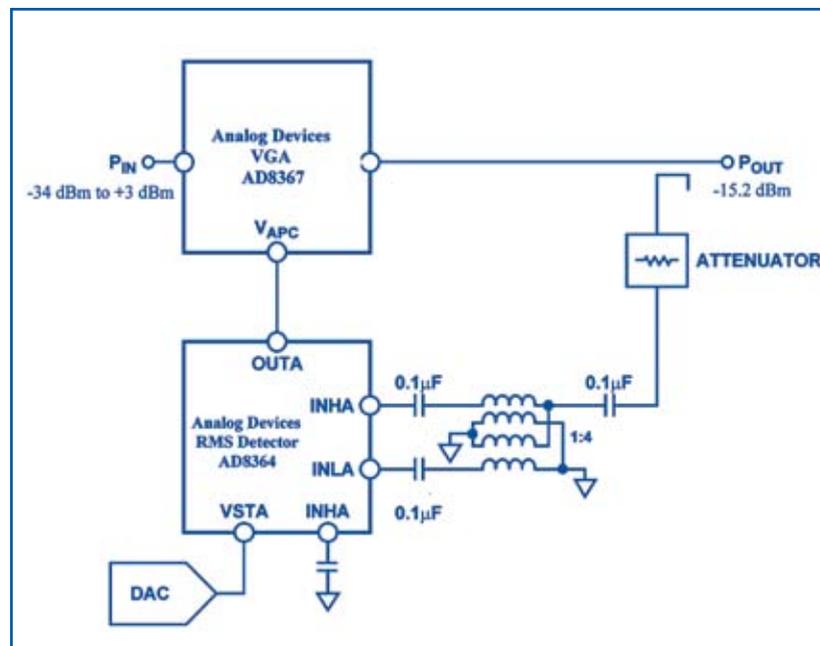


Figure 4: In Controller Mode the detector determines the power at its input and adjusts a VGA (or variable attenuator) until the detected power coincides with the level set by the power control input voltage (VSTA).

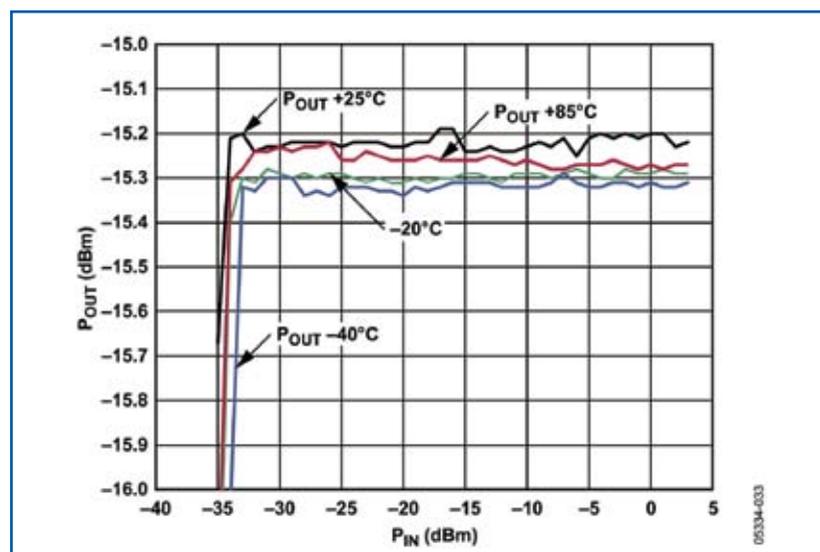


Figure 5: When one side of Analog Devices AD8364 dual RMS-responding detector is used to control the power of a system, the power at the input of the detector (and at Pout) stays constant vs. input power and temperature (less than  $\pm 0.1$  dB).

tion lots, even though the performance is slightly different over temperature.

It is not only essential to accurately measure an HPA's maximum output power but it is also necessary to measure the output power over the entire transmit power range of the HPA, though the accuracy at lower power levels is sometimes not as critical. However, the accuracy of measuring over a large dynamic range is related to both the detector and the ADC resolution. Figure 3 shows the output of two RMS-responding detectors, the AD8364 and ADL5500. The ADL5500 is linear in RMS volts to the input RF signal, and the AD8364 is linear in RMS power (dB) to the input RF signal. Based on the requirements for dynamic range and accuracy at lower power levels, the required resolution of the ADC used with the ADL5500 could be much greater than it would be for the AD8364. System requirements will dictate which detector/ADC will provide the most cost-effective and easiest-to-implement solution based on accuracy at lower power levels and dynamic range requirements.

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In some instances, accurately controlling the power or gain of a system using an analog feedback loop can improve the performance and replace simple power detection. Many currently offered detectors can control power using an analog feedback loop (i.e. a detector used in Controller Mode) in addition to detecting it. If an RMS-responding detector is used in Controller Mode, power can be set very accurately vs. input power, temperature, and crest factor. This power can be set very accurately, and its level can be changed using an analog voltage controlled by an ADC. Using a power detector in Controller Mode to accurately control the input

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or output power of an HPA would be an ideal application, as it would remove the need to detect the input or output power. In Controller Mode the detector determines the power at its input and adjusts a VGA (or variable attenuator) until the detected power coincides with the power set by the Power Control input voltage.

Figure 4 shows a basic schematic of an RMS-responding detector (AD8364) used in Controller Mode to control the output power. Figure 5 shows the overall circuit performance vs. input power and temperature when the VGA is controlled by one side of an AD8364 (dual RMS-responding log detector). Note that an HPA can be put between the VGA and coupler as long as the power level is set correctly into the AD8364, and that any VGA (or variable attenuator) can be used if the control voltages are set properly between it and the AD8364 (an op-amp may be needed to invert and/or level shift the control voltage). If the control levels between the detector and VGA are set properly and power levels are properly designed, the power control range/usable

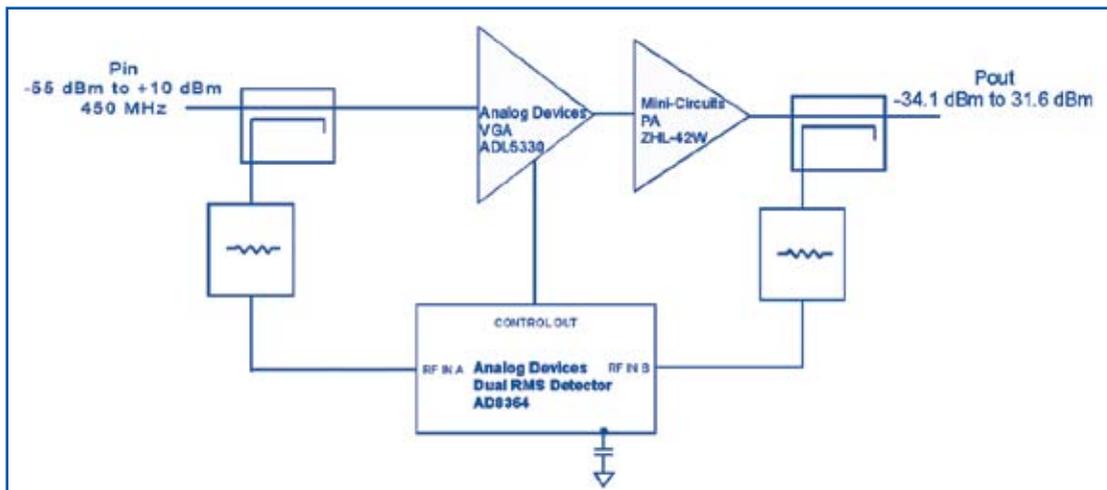


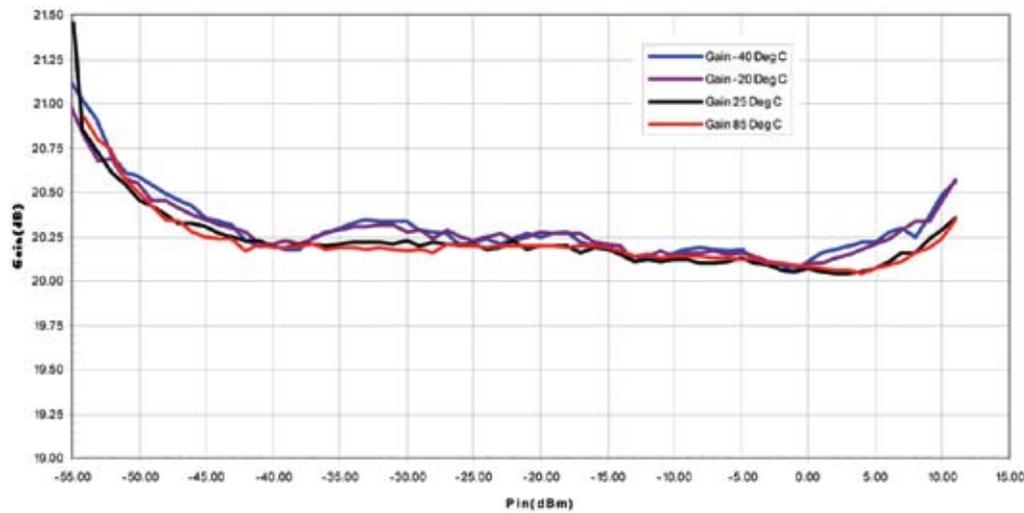
Figure 6: When both inputs of a dual detector are used in Controller Mode, the detector will control a VGA (or VVA, etc.) in such a way as to equalize the power it detects at both RF inputs. The gain of the system will be determined by the couplers and attenuators used to set the power being detected by the dual detector.

input power range will be close to the detectable power range of the detector (60 dB, in the case of the AD8364).

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When one side of Analog Devices AD8364 dual RMS-responding detector is used to control the power of a system, the



*Figure 7: When both inputs of Analog Devices dual RMS detector (AD8364) are put in Controller Mode, the gain is controlled to better than  $\pm 0.15$  dB vs. temperature and input power, with a dynamic range almost equal to the dynamic range of the RMS detector.*

power at the input of the detector (and at  $P_{out}$ ) stays constant vs. input power and temperature (less than  $\pm 0.1$  dB).

A dual RMS-responding detector operating in Controller Mode can also be used to control the gain of an HPA very accurately vs. input power, temperature, and crest factor. If the gain of an HPA module is controlled with enough accuracy over input power, temperature, and crest factor, the HPA module's output power would not have to be reported but would be directly related to the power feeding it. If both inputs of a dual detector are put in Controller Mode, the detector determines the power at each input and adjusts the gain of a VGA until the power detected on one input is equal to the power on the other. Figure 6 shows a basic schematic of the AD8364 (dual RMS detector) used to control the gain of a system. Figure 7 shows the performance of this setup. Everything that needs to be accurately controlled should be included between the two couplers. Note that a VGA, variable attenuator, or even the bias of the HPA can be used to control the gain. If the control levels between the detector and VGA are set properly and power levels are properly designed for, the usable input power range will be close to the detectable power range of the detector (60 dB, in the case of the AD8364).

When both inputs of a dual detector are used in Controller Mode, the detector will control a VGA (or VVA, etc.) in such a way as to equalize the power it detects at both RF inputs. The gain of the system will be determined by the couplers and attenuators used to set the power being detected by the dual detector.

When both inputs of Analog Devices dual RMS detector (AD8364) are put in Controller Mode, the gain is controlled to better than  $\pm 0.15$  dB vs. temperature and input power, with a dynamic range

almost equal to the dynamic range of the RMS detector.

Many of the challenges associated with RF power detection for HPAs used in CDMA2000 and W-CDMA systems can be solved using RMS-responding RF detectors. Variations in detected power due to large peak-to-average values that change with base station loading, large operating temperature ranges, and large transmit power ranges, are now manageable. New ways to control power and gain accurately enough to remove the need for detect power are now available. All of these things allow HPA manufacturers to reduce the cost and improve the reliability of their HPAs.

## ANALOG DEVICES

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