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[Test & Measurement]

Make Precise Base-Station Power Measurements

A highly integrated device with a pair of logarithmic amplifier detectors operating to approximately 3 GHz can be useful in making amplitude and phase measurements on two input signals.

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Measurements of gain and phase are vital to the operation of many radio systems. At one time, this capability required complex and expensive instruments or circuitry. Fortunately, now this capability can be incorporated into wireless infrastructure subassemblies through a compact, single-chip integrated circuit (IC) that enables the direct measurement and comparison of two independent RF or intermediate-frequency (IF) signals.

Circuits used to measure power levels are generally referred to as detectors. The most common form of detector is the diode, which typically requires extensive calibration, linearization, and temperature compensation to accurately measure RF power over the normal range of temperature where a radio must meet its specifications. Discrete diode circuits can now be replaced with a single, highly integrated circuit which contains demodulating logarithmic amplifiers, enabling the measurement of alternating RF signals over a wide dynamic range, into a continuously varying low-frequency output voltage that corresponds to the ratio of the magnitudes of the envelopes of the RF input signals. More detailed information on demodulation logarithmic amplifiers is available in the AD8307 datasheet (available at www.analog.com/productSelection/pdf/AD8307_a.pdf).

The need to measure signal levels in wireless infrastructure equipment is critical to adjust transceiver automatic-gain-control (AGC) circuits, in the receiver (Rx) for maximum sensitivity to the varying inputs from the mobile users and in the transmitter (Tx) so that the output power is maintained at its optimum level for performance mask, power-amplifier (PA) efficiency and linearity, and government regulations.

As a result many different logarithmic amplifier circuits have been developed, and optimized for specific applications. Within an Rx, the received-signal-strength indication (RSSI) is used to adjust the gain of the Rx to extend dynamic range to 100 dB. For the Tx, accurately controlling the transmit signal power with a transmitted-signal-strength indication (TSSI) at RF frequencies at the higher power levels significantly eases the implementation of controls for PA operating level for maximum efficiency. As a sampling of available power-detector/logamp circuits, the models AD8309 and AD8310 from Analog Devices (Wilmington, MA) operate with maximum input frequencies of 500 and

440 MHz, respectively and dynamic ranges of 100 and 95 dB, respectively, while the company's models AD8313 and 8314 operate to 2.5 GHz, with dynamic ranges of 70 and 45 dB, respectively. The AD8309 and AD8310 log detectors are designed for RSSI applications, while the AD8313 and AD8314 are suitable for TSSI applications.

All of these detectors provide an output that is proportional to the logarithm of the amplitude of the incoming signal. In many applications, it is necessary to detect and compare power levels at different points within the circuit so that adjustments for optimal performance can be made. Temperature drift causes changes in PA gain and every decibel of power must be preserved for maximum efficiency and minimum power consumption. To measure the differences between two input signals, a new circuit was developed as embodied by the company's model AD8302 Gain and Phase Detector. This function allows users to effectively calibrate their PA gain and radio-transceiver AGC chains by computing the gain or attenuation between the input and output of a system or subsystem.

The AD8302 integrates two identical logarithmic detectors on a single chip, each having dynamic range of 60 dB, a digital phase detector, and circuits used for amplitude and output scaling ([Fig. 1](#)). With both logamps fabricated on the same die, their performance is matched very accurately as errors associated with each stage track each other, thereby effectively canceling each other. Two independent input signals, one of which might be a known reference signal, are applied to the Channel A and Channel B inputs. The outputs from the AD8302 are voltages proportional to the relative amplitude (i.e., gain or loss) and relative phase of the two input signals.

The AD8302 is the first integrated circuit (IC) to enable a direct ratio measurement between two independent RF input signals. The AD8302 enables designers to build accurate, low-cost system diagnostics and calibration into their final product.

A user can measure an amplitude difference range of up to 60 dB, which corresponds to input range from 0 to –60 dBm. Measurements at the center point at –30 dBm can be performed with exceptional accuracy. The phase measurement can be simultaneously measured over 180-deg. range. A full 360-deg. measurement range is possible when it is known *a priori* which channel leads or lags the other in phase.

The amplitude-signal output is scaled to 30 mV/dB and the phase output is scaled to 10 mV/deg. through on-chip output amplifier circuits. It is possible to adjust the scaling so that the user may, to a reasonable extent, customize these slopes. These output voltages may be fed to an analog-to-digital converter (ADC) or they can be used to drive analog circuits.

The performance and accuracy of the AD8302 is dependent on a multitude of factors: the relative difference between the two input signals in amplitude and phase at the frequency of interest (RF or carrier frequency), the signal bandwidth at the carrier frequencies, and the device operating temperature. In characterizing the AD8302, the development team chose to provide accuracy and performance data over the popular cellular radio frequencies: 900 MHz, 1.8 GHz, and 2.2 GHz. However, the IC performs accurate amplitude measurement to 3 GHz and phase accuracy over a somewhat reduced range to 2.7 GHz. In addition, the AD8302 operates exceptionally well at low frequencies, so it is well-suited for baseband and IF and RF applications.

For gain measurement, the AD8302 offers excellent accuracy of better than 0.2-dB error beyond a 40-dB dynamic range at 900 MHz and better than 1 dB over a 60-dB dynamic range at 900 MHz. For

phase measurements, the AD8302 offers better than 1-deg. error at 900 MHz over the full 0-to-180-deg. range. However, at the higher frequencies, the accuracy is reduced as 0- or 180-deg. relative phase is approached.

The AD8302 can measure the relative phase and magnitude of two input signals and operate in one of two modes: measurement or controller. In measurement mode, shown in [Fig. 2](#), the gain and phase outputs are continuously variable as the corresponding relationships between the input signals are varied. The slope of the gain output is linear in decibels, at the rate of 30 mV/dB. The slope of the phase output is linear in degrees, and is nominally 10 mV/deg. These transfer functions are shown in [Fig. 3](#). The measurement mode is enabled by connecting the VMAG output to the MSET pin for the magnitude measurement function, and by connecting the VPHS output to the PSET input pin for the phase-measurement function.

The gain-transfer function, available at the VMAG pin, can continuously measure gains from –30 to +30 dB when the input power to the reference channel, pin INPB, is held at –30 dBm. The phase-transfer function, available at pin VPHS, can unambiguously measure relative phase from 0 to 180 deg. If the total relative phase excursion exceeds 180 deg., then the VPHS output is less definitive, since the sign of the slope of the transfer function changes from negative to positive as relative phase passes through 180 deg. For the gain- and phase-measurement functions, optimal accuracy is obtained for mid-scale output voltages, i.e., 0-dB gain and 90-deg. relative phase, and for absolute signal amplitudes at approximately –30 dBm.

In the controller mode, the open-loop operation of the VPHS and VMAG outputs are analogous to comparators. This mode is enabled by breaking the external connections between VMAG and MSET, and VPHS and PSET, and applying control voltages to MSET and PSET that correspond to the conditions for which the AD8302 is testing. This configuration is shown in [Fig. 4](#). For example, to set the AD8302 to indicate if gain is greater than or less than +10 dB, a reference voltage that corresponds to +10-dB gain (nominally +1.2 VDC) is applied to pin MSET. Then, if the magnitude of the signal applied to pin INPA is 10 dB (or more) larger than that of the signal applied to pin INPB, the voltage at pin VMAG will go to its most positive value, which is approximately +2 VDC. Otherwise, the voltage at pin VMAG will go to its minimum value, which is approximately 0 VDC. The controller mode for the phase-measurement output operates in a similar way. The voltage that corresponds to the condition for which the AD8302 tests is simply the same voltage that would be produced by the AD8302 in measurement mode when that condition is applied to the INPA and INPB inputs. The gain- and phase-measurement functions are independent of each other, so it is possible to operate one of these functions in measurement mode while operating the other in controller mode.

The AD8302 offers the ability to continuously measure the gain distribution or variation across a section of circuitry. Within a cellular base-station radio transceiver, ensuring that the AGC circuits in the Tx and Rx signals are adjusted to meet the needs of the cell-site capacity and compensated for drift over their operating temperature and lifetime are important considerations. The AD8302 can be set up as a monitor circuit continuously measuring the difference between signals, which can then be digitized, or set for alarm indication when used in the controller mode. The AGC or cell site can thus be dynamically adjusted over the life of the base station.

Another key application for the AD8302 is to control the gain across a PA or to build simple linearization circuits ([Fig. 5](#)). The AD8302 can be used in either mode in feedback and controller-

based linearization architectures, as part of either active or passive circuitry within a PA system.

Cell-site operators are now deploying multicarrier PAs (MCAs) that can handle multiple RF carriers simultaneously. An MCA requires extensive linearization to remove intermodulation (IM) products. The AD8302 is suited to all forms of linearization architectures, including feedforward and predistortion. In a feedforward system, the AD8302 can be used to monitor the carrier cancellation within the first PA loop and distortion cancellation within the error-amplifier loop. The output response in both can be compensated within the gain and phase shifters.

Other key applications include adaptive antenna circuits where the dual matching of both log amplifiers eases the design in measuring the forward and reflective power or voltage standing-wave ratio (VSWR).

Along with a dual directional coupler and one or two attenuators, the AD8302 can be used to form a wideband VSWR/reflection-coefficient meter (figure not shown; contact author for details). The AD8302 compares the magnitude and phase of the incident signal, supplied by a generator, to that of the signal reflected from the load. For a perfect impedance match between the source, load, and transmission lines, the magnitude of the reflected signal would be 0 and the resultant SWR would be unity. As the impedance of any of these components is changed from this optimal value, the magnitude of the reflected signal will increase, increasing the SWR.

Since the AD8302 provides optimal accuracy when the magnitudes of the input signals are both –30 dBm, the coupling factors of the directional couplers and the attenuation factors of the attenuators are selected to provide these levels under nominal operating conditions. As a result, the AD8302 can accurately resolve variations in reflected signal magnitude of ±30 dB from the nominal conditions. The reflection coefficient, Γ , which is a vector quantity, is defined as:

$$\Gamma = \text{reflected voltage/incident voltage} = (Z_L - Z_0) / (Z_L + Z_0)$$

The SWR, in terms of the reflection coefficient, is:

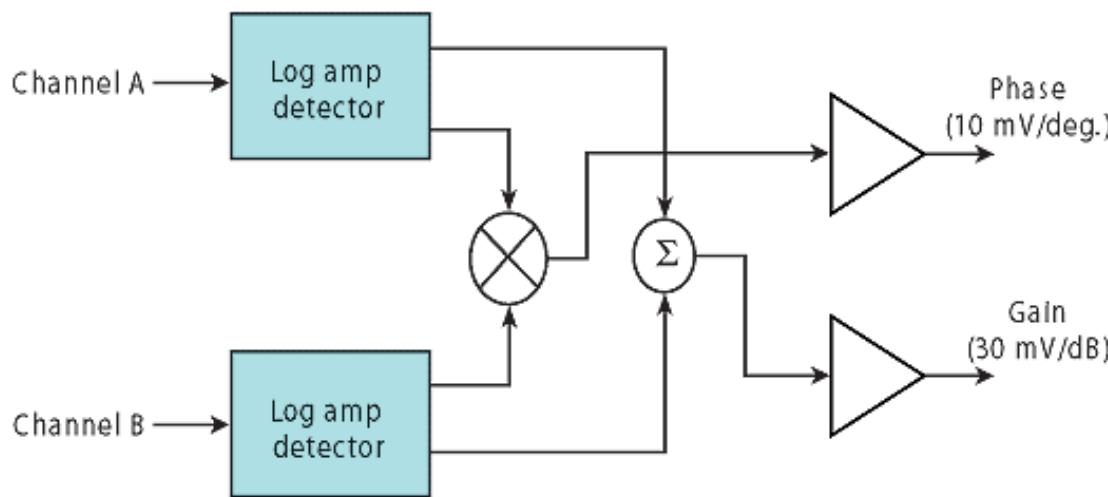
$$\text{SWR} = (1 + |\Gamma|) / (1 - |\Gamma|)$$

If one arbitrarily selects the coupling factors of both directional couplers to be 20 dB, then the attenuation factors of the attenuators are selected as follows. The attenuator that drives pin INPB, ATTEN_B, is selected to ensure that the signal level at the termination resistor R_B is –30 dBm under nominal conditions. Then, the attenuation factor of the other attenuator, ATTEN_A, is selected to also deliver –30 dBm to pin INPA under nominal conditions. If one assumes that the return loss of the load is nominally 20 dB, then the reflected signal from the load coupled towards pin INPB is 20 dB lower than the incident signal amplitude, so the value of ATTEN_B that would deliver –30 dBm to pin INPB is 20 dB smaller than the value selected for ATTEN_A. For example, if ATTEN_B is selected to be 23 dB and the nominal return loss of the load is 20 dB, then ATTEN_A should be 23 – 20 = 3 dB. The measured reflection coefficient can be used to calculate the level of impedance mismatch or SWR of a particular load condition. This configuration proves particularly useful in diagnosing varying load impedances within antenna systems.

In a test instrument such as a vector-network analyzer (VNA), the AD8302 can be configured to measure the reflection coefficient of a device under test (DUT) to determine the complex impedance of the DUT.

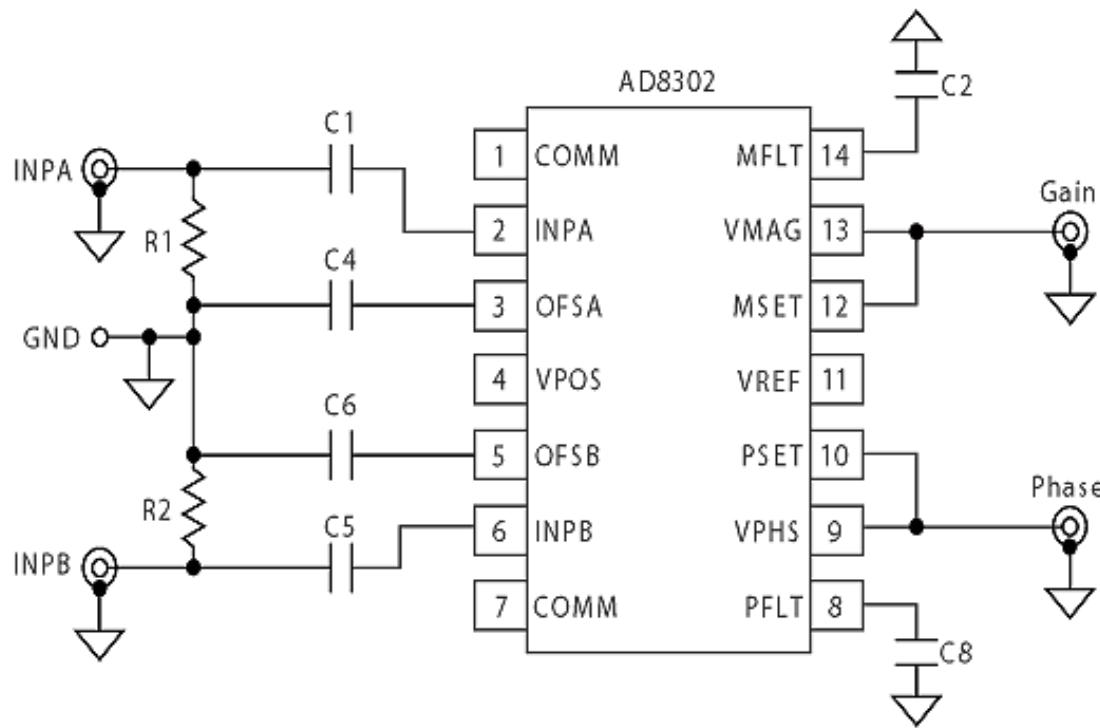
The AD8302 is fabricated with a high-performance silicon (Si) bipolar-process transistors with cutoff frequencies to 25 GHz. The device, which is packaged in a 14-lead thin-shrink, small-outline package (TSSOP), is specified over the –40 to +85°C temperature range. The AD8302 has a power-measurement range of –60 to 0 dBm to 3 GHz. It has a gain-measurement range of 60 dB (0 to +1.8 VDC) and phase-measurement range of 180 deg. (0 to +1.8 VDC). The amplitude accuracy is better than 0.2 dB across the 60-dB range and the phase accuracy is better than 1 deg. across the 180-deg. range. The small-signal envelope bandwidth is 30 MHz. The device typically consumes 19-mA current from a supply voltage of +2.7 to +5.5 VDC.

Figure 1



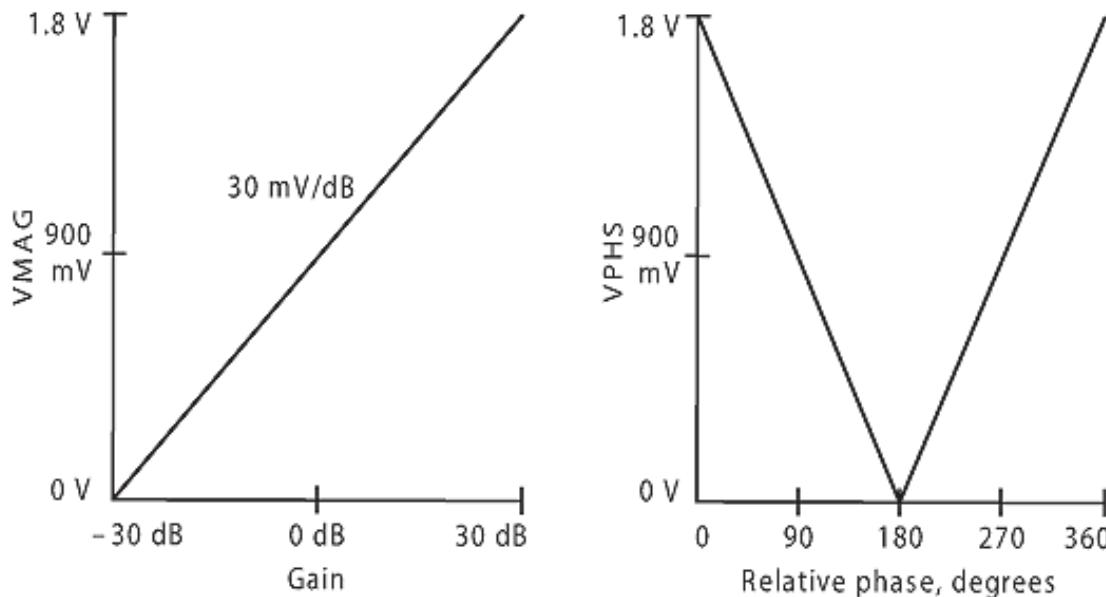
1. This functional block diagram of the AD8302 shows the pair of logarithmic detectors integrated on a single chip.

Figure 2

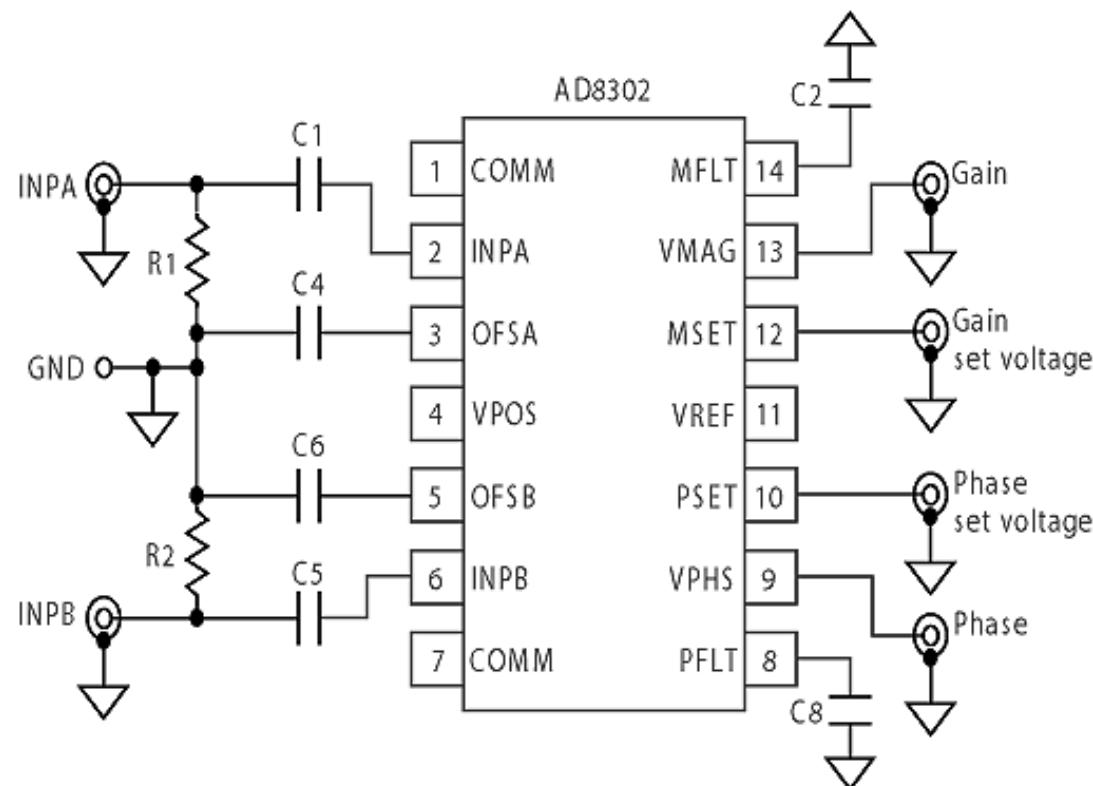


2. In the measurement mode, the AD8302's gain and phase outputs vary as a function of the gain and phase relationships between the input signals.

Figure 3

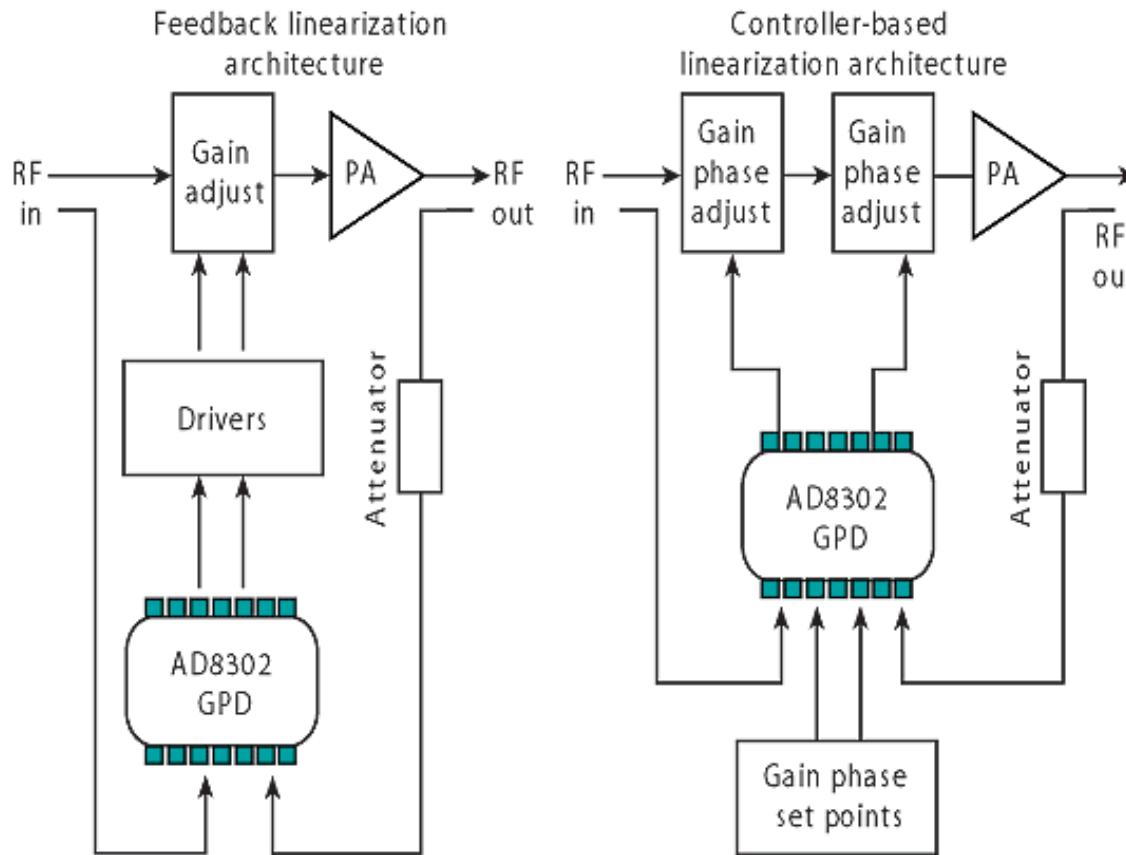


3. The AD8302 provides linear transfer functions for gain (left) and phase (right).

Figure 4

4. In the open-loop controller mode, the amplitude and phase outputs of the AD8302 are analogous to comparators.

Figure 5



5. The AD8302 can be used in a variety of linearization configurations for minimizing IM products in multicarrier cellular PAs.

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