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APPLICATION NOTE 3629

Techniques for Measuring RF Gain Using the MAX2016

This application note discusses how to implement the MAX2016 RF detector into an automated test system for gain measurements in heterodyne transceiver applications. The article compares the quality and measurement accuracy from three different approaches: gain measurement and calibration; gain measurement with offset only; and gain measurement with offset and slope calibration.

Introduction

As a dual RF power detector, the MAX2016 is quite capable of performing gain measurements for single RF blocks or more complex heterodyne transceiver lineups. One of the part's key features is the inclusion of an on-chip comparator circuit, which computes the difference between the two applied power levels.A simple gain calculation of gain = P_{OUTPUT} - P_{INPUT} = P_{OUTA} - P_{OUTB} = P_{OUTD} is easily realized through this circuitry. Care must be taken, however, to ensure that the accuracy requirements of the measurement are adequately met.

Depending on the application, a one-time calibration may be needed to counter any differences in line and coupler losses, as well as part-to-part variations. The following application note outlines some basic calibration methodologies employed in RF gain measurements. Two common applications are presented. The first example is a detailed look at measuring the gain of a heterodyne transceiver. The second example shows how the calibrated MAX2016 can replace slow and expensive power meters in factory Automated Test Equipment (ATE) applications. In the ATE example, a comparison of the accuracy achieved with and without calibration is provided for reference. Both examples demonstrate the importance of adequately calibrating the measurement setup.

Typical RF Transceiver Gain Measurements

Because the MAX2016's power detectors possess an extended frequency range of DC to 2.5GHz, the device can easily be configured to measure the gain of either a single gain block (**Figure 1a**) or a complete heterodyne receive/transmit lineup (**Figure 1b**).

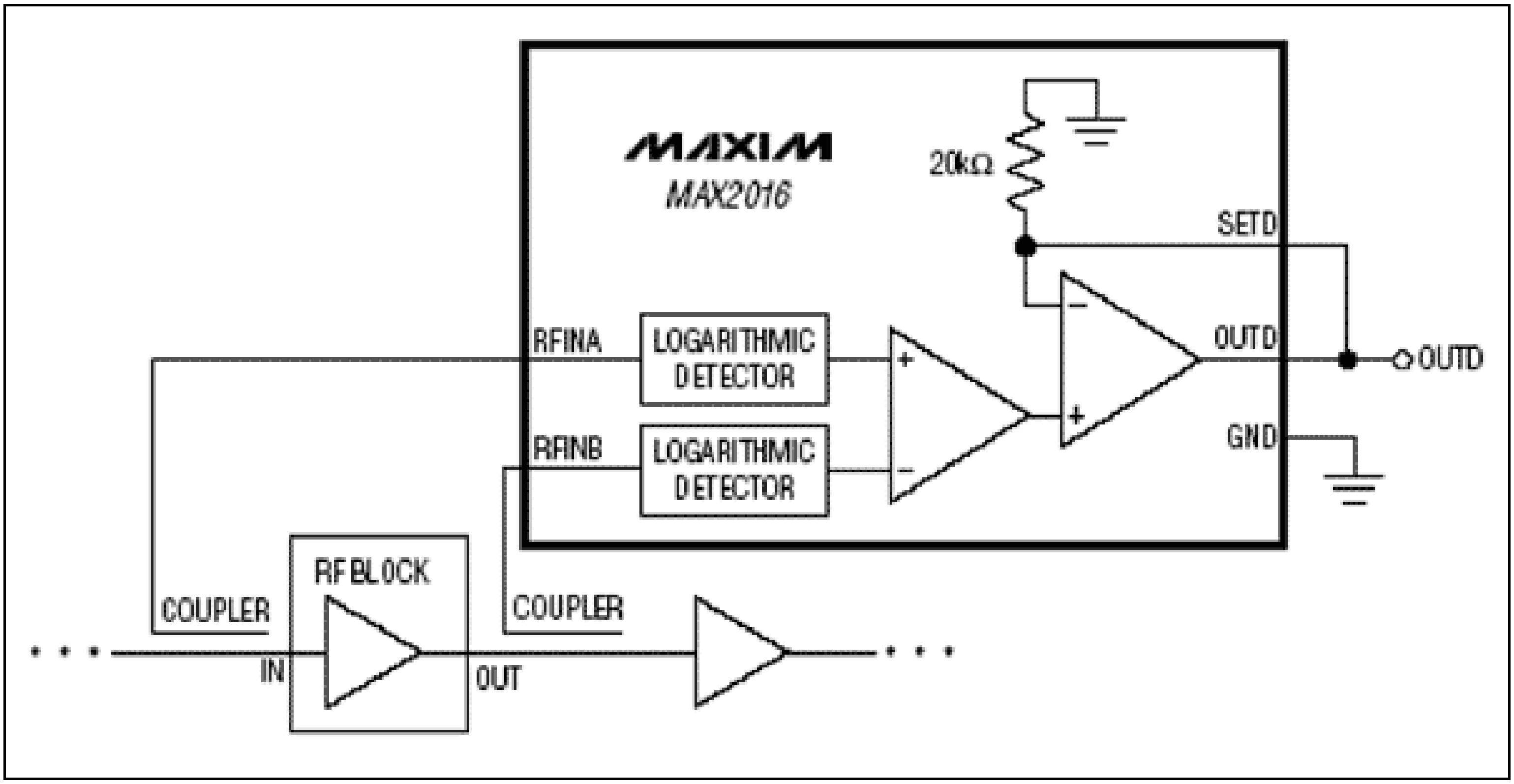


Figure 1a. Gain measurement for a single RF gain block.

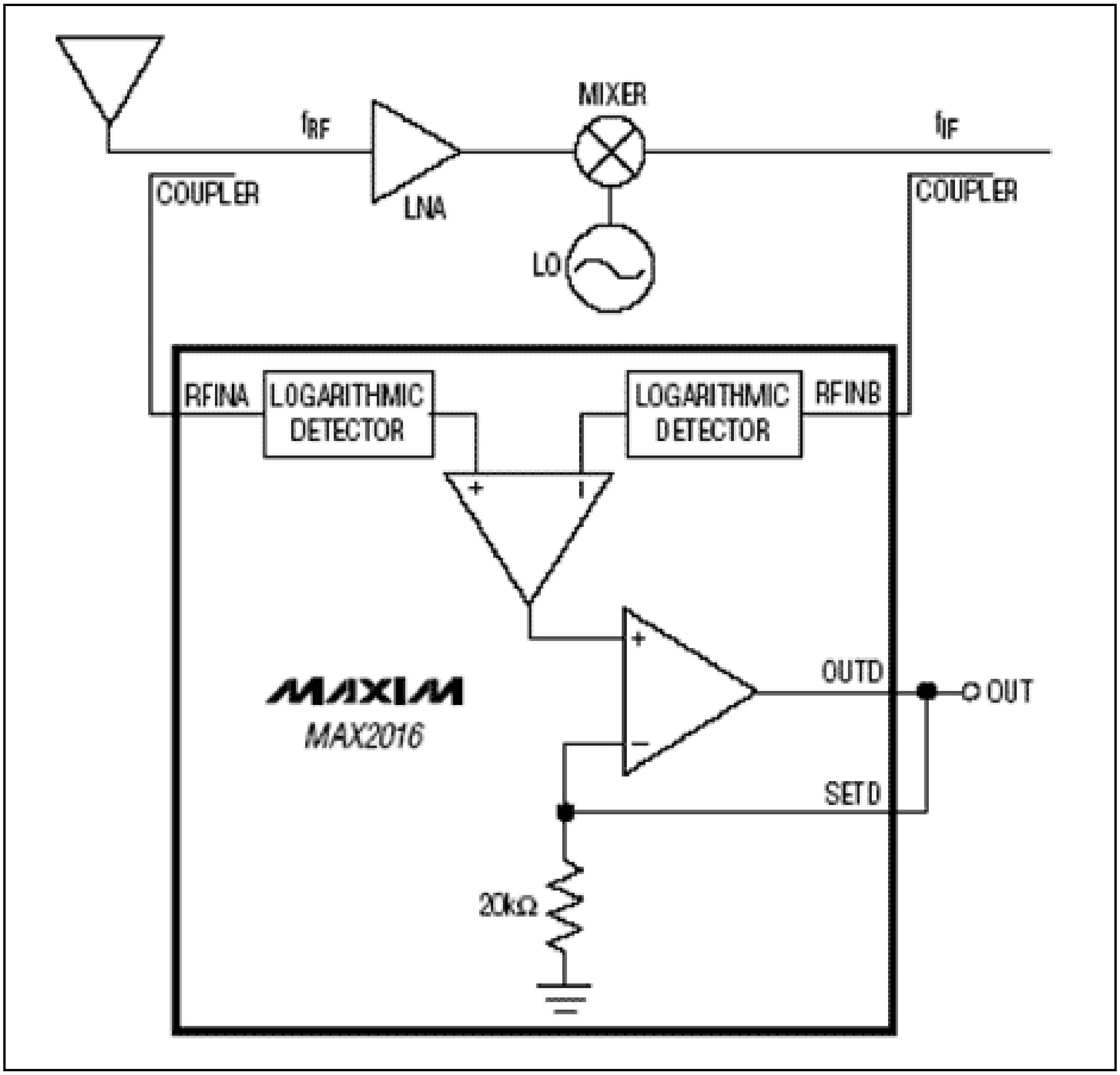


Figure 1b. Gain measurement for a heterodyne receiver.

In both the above configurations measurement uncertainties can affect the accuracy of the gain measurement. Absolute gain measurements can be compromised by line differences and coupler losses, as well as part-to-part variations in the MAX2016. Although the MAX2016 includes two identical, integrated log detectors, minor differences in the slope and intercept point can lead to small errors on the difference output.

A simple way to compensate for these variations is to implement a one-time slope and intercept calibration during factory test. **Figure 2** outlines such a test configuration for a heterodyne receiver. As shown, an RF signal with a known power level is injected into the front-end of the receiver. An external power detector is then used to determine the received power level of the down-converted signal. If the down-converted signal cannot be readily sampled, the transceiver's on-board high-speed ADC can be used to approximate the received power level. Since most receivers employ some sort of variable gain amplifier/variable voltage amplifier (VGA/VVA) for enhancing dynamic range, the lineup's gain can be altered in test and subsequent measurements made to determine the slope and intercept of the gain vs. V_{OUTD} response. The slope and intercept of the response is stored into the transceiver's nonvolatile memory (NVM), allowing subsequent V_{OUTD} measurements to be mapped into an absolute gain value. For additional accuracy, a complete matrix with multiple values of V_{OUTD} vs. gain can be created and stored in the NVM. An interpolating algorithm can then be implemented to calculate the gain for any measured value of V_{OUTD}. **Figure 3** depicts these two alternative approaches.

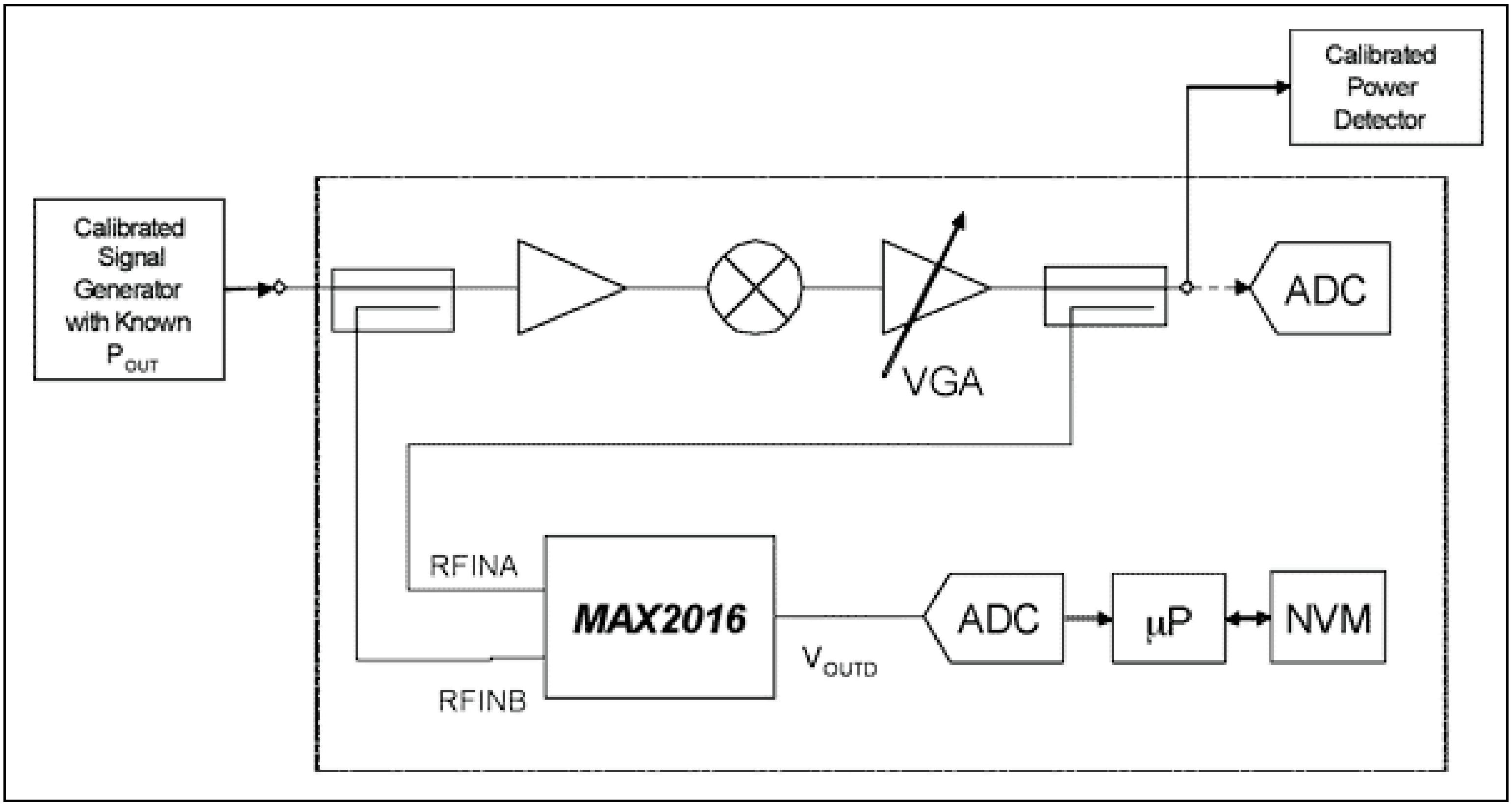
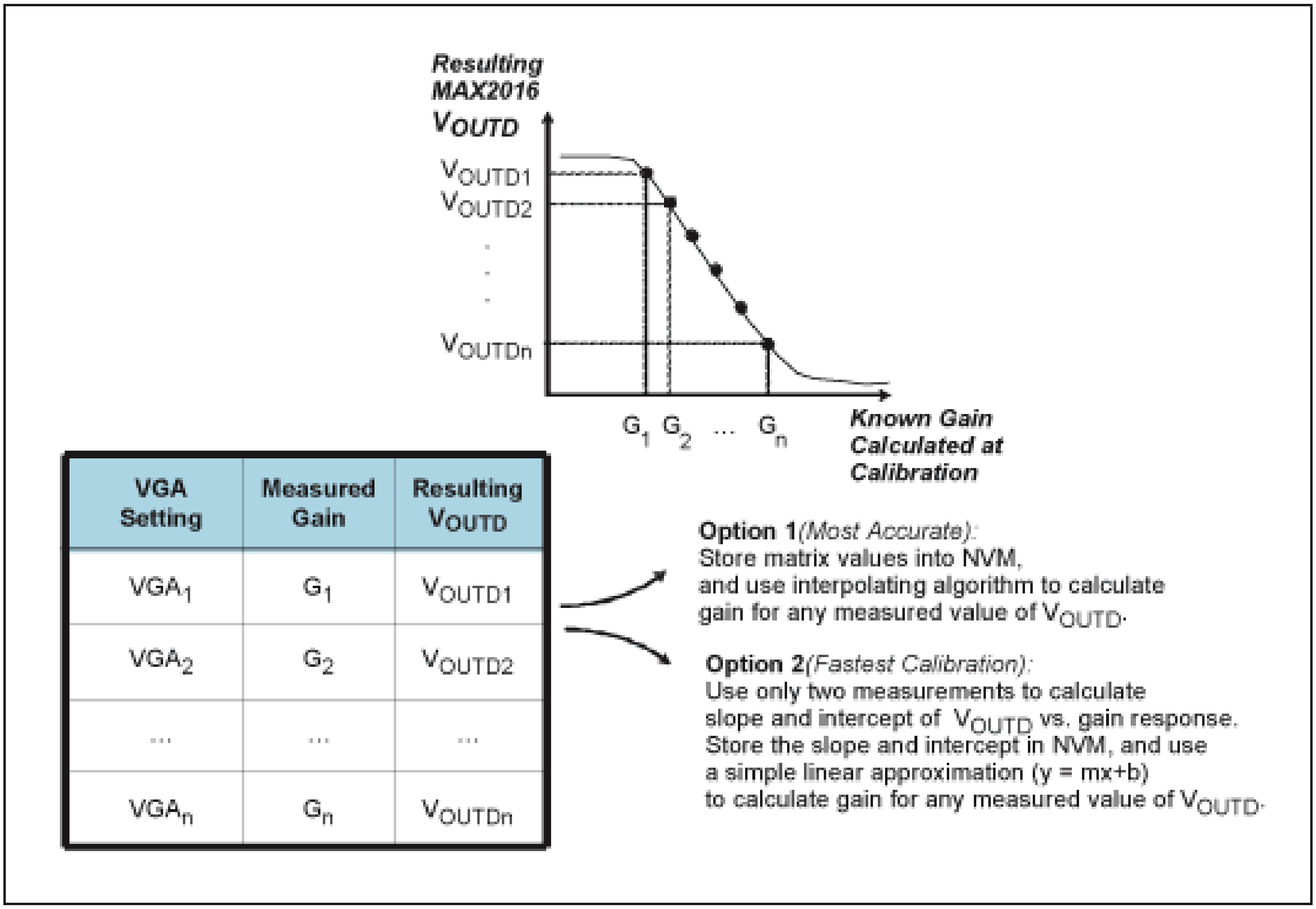


Figure 2. Factory gain calibration setup—receiver under test.



VGA Setting	Measured Gain	Resulting V_{OUTD}
VGA_1	G_1	V_{OUTD1}
VGA_2	G_2	V_{OUTD2}
...	...	...
VGA_n	G_n	V_{OUTDn}

Option 1 *(Most Accurate):*
Store matrix values into NVM,
and use interpolating algorithm to calculate
gain for any measured value of V_{OUTD}.

Option 2 *(Fastest Calibration):*
Use only two measurements to calculate
slope and intercept of V_{OUTD} vs. gain response.
Store the slope and intercept in NVM, and use
a simple linear approximation (y = mx+b)
to calculate gain for any measured value of V_{OUTD}.

Figure 3. Gain calibration scheme for a heterodyne receiver.

Note that the MAX2016's two internal log detectors map well together over temperature, eliminating the need to compensate for temperature offsets in the calculation of the transceiver's absolute gain. If additional accuracy is desired, typical temperature offsets can, of course, be measured and entered into the NVM. The gain vs. V_{OUTD} algorithm can add in these offsets by measuring the current operating temperature and interpolating between the temperature extremes.

Using the MAX2016 as an Alternative to Two Power Meters in ATE Applications

As mentioned above, the most straightforward way to measure the gain of a Device Under Test (DUT) is to directly measure its input and output power in dBm, and then subtract the input power from the output power to obtain the gain. Traditionally, the only way to obtain a very accurate wideband power measurement was by using a power meter. However, a power meter's slow measurement speed precluded it from being used in a production environment where short test times are critical. Since the MAX2016's dual log detectors have a rather short response time (~100ns), rapid gain measurements are now feasible in a production environment. As demonstrated in the example above, a simple gain measurement can be made by coupling the input power of a DUT to one port of the MAX2016 while simultaneously coupling the DUT's output power to the MAX2016's second port. A DC voltage (V_{OUTD_MEAS}) proportional to the gain of the device can be captured at the V_{OUTD} pin. The gain can be calculated from the following expression:

Gain (dB) = (V_{OUTD_OFFSET} - V_{OUTD_MEAS}) / V_{OUTD_SLOPE} (Eq 1)

Using no calibration and typical values for V_{OUTD_OFFSET} and V_{OUTD_SLOPE} from the MAX2016's data sheet, this equation can be simplified as gain (dB) = (1.0 - V_{OUTD_MEAS}) / 0.025. Refer to the MAX2016 data sheet for more detailed information.

Although this simplified expression for calculating gain is useful, a more thorough calibration is recommended to enhance the accuracy of the gain measurement. Multiple calibration steps can be implemented to yield varying degrees of absolute accuracy. The following text details a calibration approach which involves measuring the exact values of V_{OUTD_OFFSET} and V_{OUTD_SLOPE}. The user can choose to implement one or both calibration types, depending on the desired level of accuracy. A comparison is provided (see below) which outlines the expected precision obtained using only a V_{OUTD_OFFSET} calibration vs. V_{OUTD_OFFSET} *and* V_{OUTD_SLOPE} calibrations.

General Test Setup

To obtain a more precise value for V_{OUTD_OFFSET}, both input ports of the MAX2016 must be driven with the same power level. The DC level on the V_{OUTD} pin is equal to V_{OUTD_OFFSET}. Using a calibrated attenuator in series with one of the MAX2016 input ports and measuring the V_{OUTD} value, allows the user to find V_{OUTD_SLOPE}. V_{OUTD_SLOPE} can then be solved for a given V_{OUTD_OFFSET} and the loss of the attenuator. **Figure 4** outlines the test setup for this characterization. A MAX2016EV kit was used as part of the gain measurement/calibration technique.

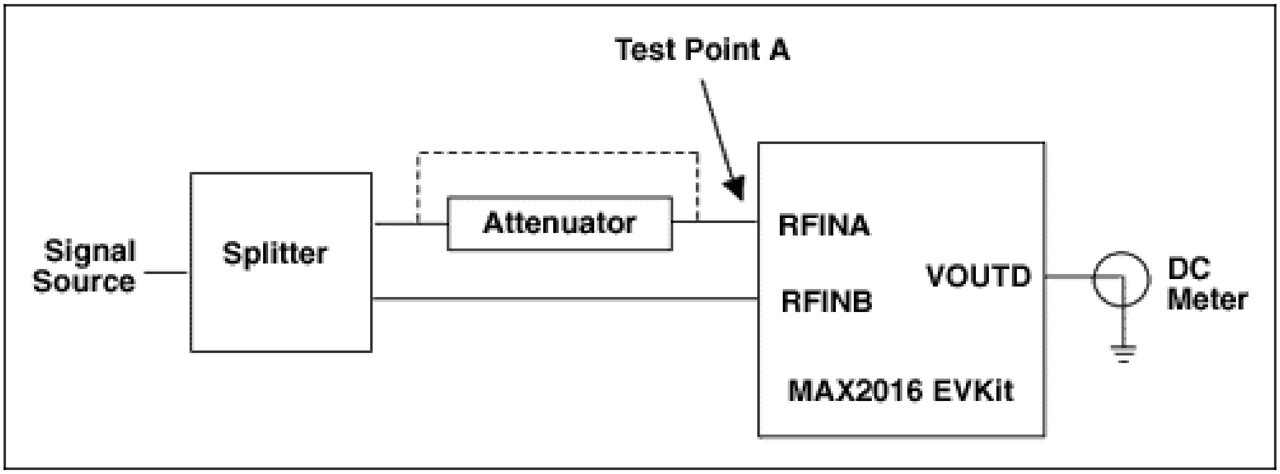


Figure 4. Lab evaluation setup.

For this evaluation, fixed-power attenuators were used for calibrating V_{OUTD_SLOPE}. However, note that the results obtained are equally applicable to devices having gain. The selected frequencies and exact attenuations were driven by the test requirements of the MAX3654 VGA: a CATV transimpedance amplifier with AGC that varies the gain over a 0dB to 20dB range. Different frequencies and attenuator values can be chosen to meet the requirements of other applications.

Calibrating V_{OUTD_OFFSET} and V_{OUTD_SLOPE}

Various attenuators were first characterized using a URV5 RF power meter. This measurement was performed at point A in Figure 4 to ensure that it represents the true attenuation, taking into account any cable losses.

Next, the values for V_{OUTD_OFFSET} and V_{OUTD_SLOPE} were measured at each test frequency.

- To measure V_{OUTD_OFFSET}, the attenuator was bypassed and both ports to the MAX2016 were driven with the same signal level. The resulting DC voltage at V_{OUTD} is the calibrated value for V_{OUTD_OFFSET}.
- To measure V_{OUTD_SLOPE}, a calibrated 10dB attenuator was inserted and the DC voltage at V_{OUTD} was again measured. (Call this value V_{OUTD_MEAS}.) The value of V_{OUTD_SLOPE} can now be calculated using Equation 1, given V_{OUTD_OFFSET}, V_{OUTD_MEAS}, and the known attenuator value of 10dB. Note that the attenuator value is represented as a gain of -10dB in Equation 1. The 10dB attenuator was chosen because it is in the middle of the MAX3654's gain range. **Table 1** shows the corresponding values for V_{OUTD_OFFSET} and V_{OUTD_SLOPE}.

Table 1. Offset and Slope Calibration Numbers

	V_{OUTD_OFFSET} (V)	V_{OUTD_SLOPE} (mV/dB)
At 50MHz	1.044	27.8
At 900MHz	1.043	26.3

Calibration Accuracy Comparison

V_{OUTD} was measured for six separate attenuators (1, 2, 8, 10, 12, and 20dB) at each test frequency. Calculations were performed to determine the measured attenuation and the resulting accuracy for three cases:

1. No calibration
2. Offset-only calibration
3. Offset and slope calibration

The results are given below in **Tables 2** through **Table 6**.

Table 2. MAX2016 Measurement Error Using Typical Values from the Data Sheet (V_{OUTD_OFFSET} = 1.0V, V_{OUTD_SLOPE} = 25mV/dB)

V_{OUTD} (V)	CALIBRATED ATTENUATION (dB)	MEASURED ATTENUATION (dB)	MEASUREMENT ERROR (dB)
1.022	0.9	0.9	0.0
0.993	2.0	0.3	-1.7
0.827	7.9	6.9	-1.0
0.763	10.1	9.5	-0.6
0.713	11.9	11.5	-0.4
0.481	20.2	19.2	-1.0

Table 3. MAX2016 50MHz Measurement Error Using an Offset-Only Calibration (Typical V_{OUTD_SLOPE} = 25mV as stated in the data sheet.)

V_{OUTD} (V)	CALIBRATED ATTENUATION (dB)	MEASURED ATTENUATION (dB)	MEASUREMENT ERROR (dB)
1.022	0.9	0.9	0.0
0.993	2.0	2.0	0.0
0.827	7.9	8.7	0.8
0.763	10.1	11.2	1.1
0.713	12.0	13.2	1.2
0.481	20.2	22.5	2.3

Table 4. MAX2016 50MHz Measurement Error Utilizing Both the Offset and Slope Calibrations

V_{OUTD} (V)	CALIBRATEDB ATTENUATION (dB)	MEASURED ATTENUATION (dB)	MEASUREMENT ERROR (dB)
1.022	0.9	0.8	-0.1
0.993	2.0	1.9	-0.1
0.827	7.9	7.8	-0.1
0.763	10.1	10.1	0.0
0.713	12.0	12.0	0.0
0.481	20.2	20.2	0.0

Table 5. MAX2016 900MHz Measurement Error Using an Offset-Only Calibration (Typical V_{OUTD_SLOPE} = 25mV as stated in the data sheet.)

V_{OUTD} (V)	CALIBRATED ATTENUATION (dB)	MEASURED ATTENUATION (dB)	MEASUREMENT ERROR (dB)
1.021	0.9	0.9	0.0
0.994	2.0	2.0	0.0
0.834	7.9	8.4	0.5
0.774	10.1	10.8	0.7
0.720	12.0	12.9	0.9
0.509	20.2	21.4	1.2

Table 6. MAX2016 900MHz Measurement Error Utilizing Both the Offset and Slope Calibrations

V_{OUTD} (V)	CALIBRATED ATTENUATION (dB)	MEASURED ATTENUATION (dB)	MEASUREMENT ERROR (dB)
1.021	0.9	0.9	0.0
0.994	2.0	1.9	-0.1
0.834	7.9	8.0	0.1
0.774	10.1	10.1	0.0
0.720	12.0	12.1	0.1
0.509	20.2	20.3	0.1

Conclusions for Implementing the MAX2016 as a RF Detector in Production Test

A few observations can be made from the data presented above.

First, the errors associated without calibrating (Table 2) are significant. If the gain on a device like the MAX3654 VGA was tested in production using an uncalibrated MAX2016, then the VGA test limits would need to be very wide to allow for these large errors. This would, in turn, translate into a wider gain specification in the data sheet, thus making the part less attractive to designers.

Secondly, the errors are manageable for the 0.9dB and 2.0dB attenuators with only an offset calibration (Table 3 and Table 5). This becomes useful when only one value of DUT gain is to be measured. If the DUT board is designed so the attenuation at the DUT's output equals the typical expected DUT gain, then the input levels to the power detector ports will be approximately equal. Assume that the spread in gain specification is less than about 2dB. Then the accuracy data for the 0.9dB and 2.0dB attenuators would imply that only an offset calibration is required to precisely measure small deviations from the typical gain. However, note how the accuracy quickly degrades as the attenuation values increased. Hence, this technique will exhibit problems for large-gain deviations common in VGAs like the MAX3654.

The data in Table 4 and Table 6 shows that performing *both* an offset and slope calibration provides the best results when measuring gains over a large range. To execute the calibrations, the DUT board hardware must be able to drive both the MAX2016 power detectors to the same level and also switch in a calibrated attenuator.

Figure 5 shows one possible implementation of the required RF switching on the input to the MAX2016. The DUT gain measurement is performed with the switches in position A. The offset calibration is performed with the switches in position B. The slope calibration is performed with the switches in position C. The attenuator value used for the slope calibration is equal to the typical value of the DUT gain specification. Note that the error is still minimal for attenuations far from the value at which the slope calibration was executed (10dB). The data supports the assumption that the nonlinearity of gain vs. V_{OUTD} curve is minimal, and also suggests that only a single slope calibration is required.

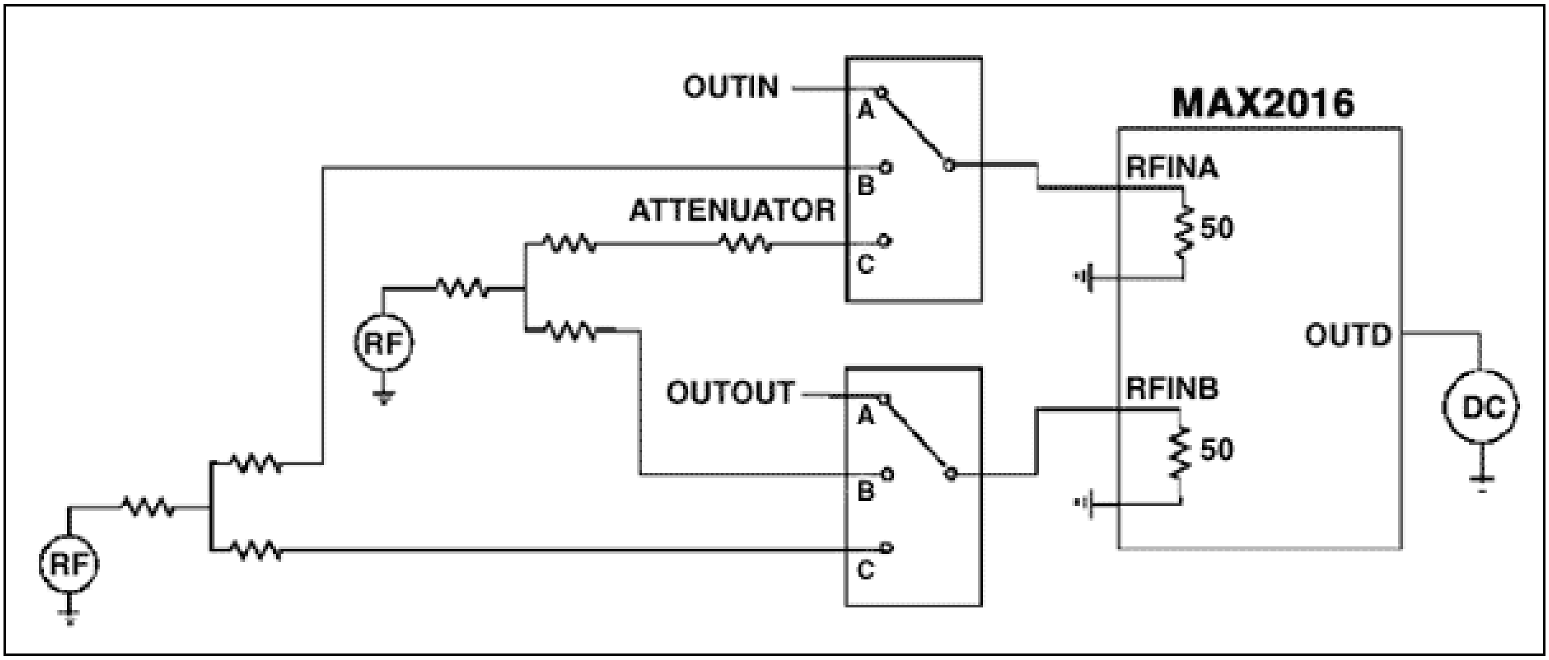


Figure 5. MAX2016 RF input calibration switching.

Application Note 3629: http://www.maxim-ic.com/an3629

More Information

For technical questions and support: http://www.maxim-ic.com/support

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Related Parts

MAX2016: QuickView -- Full (PDF) Data Sheet -- Free Samples

AN3629, AN 3629, APP3629, Appnote3629, Appnote 3629