

Accurate Measurement of LT5514 Third Order Intermodulation Products

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INTRODUCTION

Accurate measurement of the third order intercept point for low distortion IC products such as the LT5514 requires certain precautions to be observed in the test setup and testing procedure. The LT5514 linearity performance is high enough to push the test equipment and test set-up to their limits. A method for accurate measurement of third order intermodulation products, IM3, with standard test equipment is outlined below.

It is also important to correctly interpret the LT5514 specification with respect to R_{OUT} , and the impact of demo-board transmission-line termination loss when evaluating the linearity performance, as explained in the LT5514 Datasheet and in Note 1 of this document.

EVALUATION OF LT5514 LINEARITY PERFORMANCE.

The difficulty in providing an adequate low distortion, two-tone test signal (Note 2) and failure to adjust the spectrum analyzer for maximum resolution (Note 3) are the most common issues when evaluating the LT5514. Below is a description of a test set-up and a method for evaluating high linearity components using standard test equipment. This method makes it easy to identify which section of the set-up limits the measurement, and to optimize the set-up

for the maximum resolution achievable with the available test equipment.

The test equipment required for LT5514 demo board evaluation consists of two signal generators, a 2-way power combiner, a spectrum analyzer, and fixed attenuator pads, as shown in Figures 1 and 2.

Two steps are required for the evaluation of LT5514 intermodulation products.

1. Evaluate and Optimize Test-Setup Performance

Begin by combining the signal outputs of two signal generators (more information is given in Note 2), and connect the resulting two-tone output directly to a spectrum analyzer as depicted in Figure 1. An example initial setting for the spectrum analyzer is: ATTEN = 20dB, SPAN = 100Hz, Resolution Bandwidth = 3Hz to 10Hz, REFERENCE LEVEL = -20dBm, ATTENUATION AUTO (OR MANUAL, 10dB). Each frequency of interest should be inspected, one at a time, with the spectrum analyzer at minimum span. (Spectrum analyzer settings for maximum resolution are discussed in Note 3). The two-tone test signal should be set to a power level corresponding to the desired input level for the LT5514 (-23dBm for optimum maximum output). The signal displayed on the

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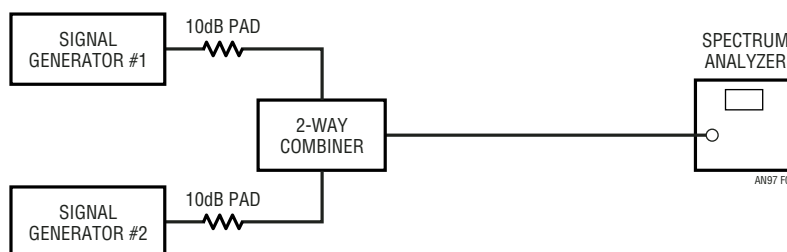


Figure 1. Basic Set-Up for Two-Tone Signal Source IM3 Performance Verification Measurements

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spectrum analyzer should be inspected for:

- a) Intermodulation products. Adjust the spectrum analyzer to obtain the maximum possible resolution (intermodulation product amplitude in dBc relative to tone power).
- b) Second and third harmonic content (which will determine if a lowpass filter is required at the combined signal generator output).

If the observed intermodulation products from the test setup are of comparable size to those expected from the LT5514, then an accurate characterization of the LT5514 is not possible. Likewise, if the observed harmonic content is significant, then it must be reduced in order to avoid generating spurious responses during the LT5514 characterization. Depending on the available test equipment, an adjustment of the spectrum analyzer settings and the signal combiner may be required in order to obtain satisfactory results. The intermodulation product level may be limited by the two-tone signal source or by the spectrum analyzer resolution. The insertion of a small attenuation pad (as described in Note 4) can be used to find which section of the setup limits the intermodulation product level. No results better than this initial measurement can be expected from the LT5514 demo board.

2. Evaluate the LT5514 Demo Board Performance

- Remove matching resistor R7 (255Ω) from the LT5514 demo board when no transmission lines are expected in the LT5514 application (Note 1)
- Program the LT5514 for maximum gain
- Measure the LT5514 demo board gain

- Insert at the LT5514 demo board output (without cables) a combination of attenuator pads, so that the net attenuation cancels the LT5514 board gain. The net gain (LT5514 + attenuator) should be adjusted close to 0dB, so that the spectrum analyzer input level (and settings) from Step 1 are preserved
- Insert the LT5514 demo board with output attenuator between the two-tone source and the spectrum analyzer (Figure 2)
- Evaluate the magnitude of the LT5514 intermodulation products

Even when the input signal quality is marginally adequate, the LT5514 performance can still be evaluated by inspecting the relative degradation of intermodulation products between Step 1 and Step 2.

When testing the LT5514's gain steps, the two-tone test signal level should be increased by an amount equal to the LT5514's attenuation relative to its maximum gain. For example, if the LT5514 gain is decreased 10dB, then the two-tone test signal should be increased by 10dB, correspondingly. No change is required to the Figure 2 test setup. However, in order to maintain the same spectrum analyzer settings, the Figure 1 test setup must be modified: An attenuator pad equal to the increase in the two-tone signal amplitude (10dB in this example) should be inserted in series with the spectrum analyzer input. This pad is not required in the Figure 2 test setup.

Linearity testing at or near the LT5514's minimum gain setting (when the LT5514's IIP3 is very high) is particularly demanding of two-tone signal source quality (see Note 2). Repeating step 1 may help to explain seemingly unsatisfactory results.

An OIP3 measurement example is given in Note 5.

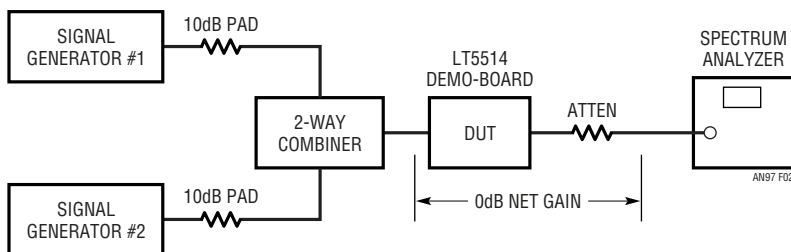


Figure 2. Basic Set-Up for LT5514 Two-Tone IM3 Measurements

NOTE 1. The Demo-Board Output Linearity and the LT5514 Device Linearity

The LT5514 demo board shown in Figure 3, as shipped, will drive 50Ω transmission lines, while providing proper line termination. Figure 4 (reproduced from the LT5514 Datasheet Figure 12) plots the LT5514 demo board OIP3 vs frequency for different measurement conditions. As shown in Figure 4, the LT5514 demo board output linearity as shipped (bottom thick line) is about 6dB lower than the LT5514 device performance specified in the datasheet for $R_{OUT} = 200\Omega$ (top thin line). The transmission line termination loss (due to R7) accounts for 3dB. The lower impedance seen by the LT5514 differential outputs ($R_{OUT} = 100\Omega$ instead of 200Ω) accounts for another 3dB. This explanation is elaborated in the following paragraphs.

LT5514 OIP3 performance is plotted in Figure 4 for two different conditions:

Case 1: The LT5514 demo board output impedance is

50Ω, and is matched to a 50Ω transmission line ($R7 = 255\Omega$ in Figure 4 legend). Resistor R7 provides a transmission line back termination, but dissipates almost half of the LT5514's output power. This situation is appropriate for applications where transmission lines must be driven.

Case 2: The LT5514 demo board output is connected to the load without a transmission line, and the board output impedance is high ($R7 = \text{open}$ in legend). This situation is appropriate for an application where there is a local 50Ω load, and no transmission line back termination is required. No power is lost in the transmission line's back termination in this case.

It is important to note that the differential impedance presented to the LT5514 outputs (R_{OUT}) is different for these two conditions. For $R7 = \text{open}$, $R_{OUT} = 200\Omega$ (50Ω board impedance multiplied by the 4:1 impedance transformation ratio of the on-board transformer). For $R7 = 255\Omega$, this matching resistor in parallel with the 200Ω

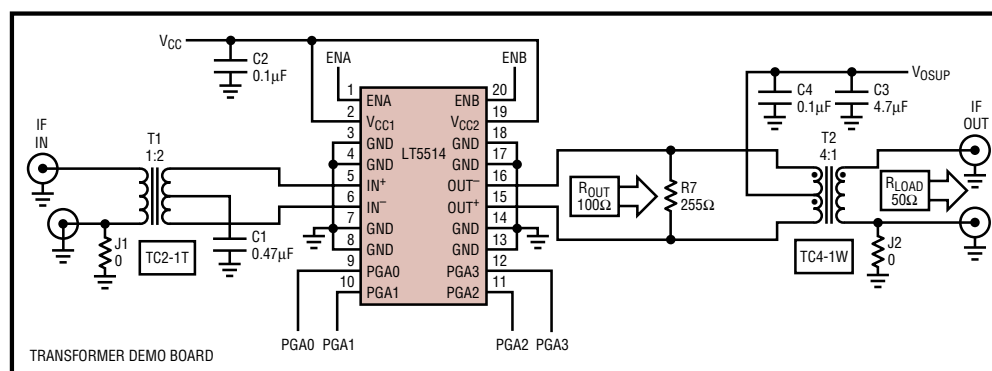


Figure 3. Output Transformer Application Board (Simplified Schematic)

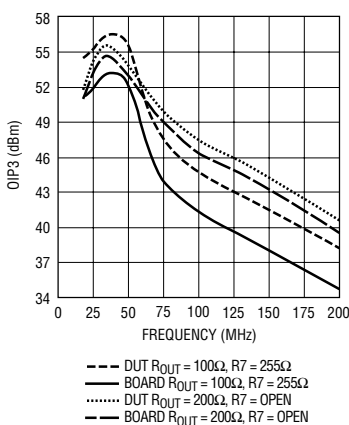


Figure 4. Typical OIP3 for Demo Transformer Board

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transformed impedance gives an approximate $R_{OUT} = 100\Omega$.

Thick lines (BOARD in legend) are the OIP3 figures for the board output power as measured with a spectrum analyzer for both conditions.

Thin lines (DUT in legend) are the OIP3 figures calculated for the actual power the LT5514 part delivers at its differential outputs. These curves depict the LT5514 performance for local load applications.

When comparing the BOARD and DUT OIP3 curves for $R7 = \text{open}$, the difference (about 1dB) is simply the transformer insertion loss. The OIP3 is highest at $R_{OUT} = 200\Omega$. When comparing the BOARD and DUT OIP3 curves for $R7 = 255\Omega$, the difference (about 3dB) increases due to the additional dissipated power in the matching resistor. The OIP3 is reduced when $R_{OUT} = 100\Omega$.

As shipped, the LT5514 demo transformer board is not optimized for the best linearity performance (bottom OIP3 curve in Figure 4, and is only the starting point for LT5514 evaluation. The LT5514 demo board may be customized depending on the application requirements for the best linearity performance.

There are several factors to consider when optimizing the LT5514 for the highest linearity in a particular application that may differ from the default LT5514 demo board setup:

- The transmission line termination resistor, $R7$, (and its associated 3dB power loss) is unnecessary when the LT5514 drives a local load in the application.
- R_{LOAD} (next stage input impedance) may be increased above 50Ω , thereby effectively increasing R_{OUT} . This will increase OIP3.
- A bandpass LC network (instead of the transformer between the LT5514 outputs and the following stage) has the potential to further improve the application linearity above 100MHz, when compared to a 'wide-band' transformer demo board. The bandpass LC network can provide any impedance transformation ratio (thereby increasing R_{OUT}), and can also absorb the LT5514's output capacitance (responsible in part for linearity degradation at high frequencies).

NOTE 2. A Clean Two-Tone Signal Must be Generated to Drive the LT5514

The two most common problems for the two-tone signal source generation are:

- a. Failure to provide adequate isolation between the two signal generators and proper wideband impedance matching.
- b. Insufficient filtering of the two input test signals.

The presence of the signal from one generator at the output of the second generator will modulate the second generator's output. If the unwanted signal is within the signal generator's automatic level control (ALC) bandwidth, the signal generator will try to cancel the "interfering" signal by modulating the amplitude of the desired signal. This results in the signal generator no longer producing a single signal at the required frequency, but also producing side bands at an offset from this signal. These side bands are indistinguishable from intermodulation products generated by the device under test.

There are a number of different ways in which the two generator signals may be combined, in order to minimize these distortion problems:

1. A resistive power combiner is the preferred method for combining the two signal generator outputs. A resistive combiner is well matched, and it presents a constant, power-independent impedance at all three ports. In addition, a resistive combiner is broadband and linear. However, the resistive combiner offers only 6dB isolation between the two signal generators.
2. Reactive combiners give better isolation (>40dB typically) and lower insertion loss (<4dB typically) but over a limited frequency range. In theory, this offers >34dB improvement in isolation over simple resistive combiners. However, the load VSWR must be very good. Otherwise, the benefits of the isolation are lost. Therefore, attenuation pads at the combiner ports are recommended.

When testing at or near maximum gain settings for the LT5514, these simple methods of combining the signal generator tones are adequate. However, when testing the LT5514 at minimum gain, the signal generator levels must

increase to about 10dBm. In this case, methods (1) and (2) fail to provide an adequately clean (low distortion) signal.

3. The best isolation between the two signal generators can be achieved by buffering the individual signal generator outputs with high linearity amplifiers, prior to driving a resistive combiner. This method was used to generate the two-tone test signals for the LT5514 during datasheet characterization.

A lowpass filter may be inserted between the combiner output and the LT5514 board input in order to remove harmonic content from the signal generator output. This precaution is particularly recommended when signal generators with a high second harmonic output are used. When the signal generators' harmonic level is below -40dBc , the LT5514 intermodulation products can be tested without this lowpass filter.

NOTE 3. Dynamic Range of the Spectrum Analyzer

Spectrum analyzers produce significant intermodulation products if operated incorrectly.

As a rule, spectrum analyzers are designed to operate at their best with about -30dBm to -40dBm at the analyzer input. Normally the only device in front of the analyzer is the instrument's input attenuator. Therefore, with tone levels of 10dBm , the (total) input attenuation should be set to about 40dB to 50dB . As the spectrum analyzer attenuation level is increased, the instrument's noise floor rises and potentially hides any intermodulation products.

Attempting to display both the high side and low side intermodulation products simultaneously is the most common problem in making use of the full resolution potential of the spectrum analyzer. For example, a spectrum analyzer span setting of 4MHz is required to observe the intermodulation products with 1MHz tone spacing. This results in unnecessary elevation of the displayed noise floor and reduced resolution.

The spectrum analyzer measurement span and resolution bandwidth must be reduced in order to lower the displayed noise floor, and to increase resolution. The distortion products of the LT5514 should be measured by setting the spectrum analyzer center frequency to that of each individual intermodulation product and tone frequency, one at a time. The spectrum analyzer span is set to a minimum value (100Hz) and resolution bandwidth is set to 10Hz . For

high quality spectrum analyzers, this will be sufficient to exclude the main tones during measurement of the intermodulation products. For some spectrum analyzers, however, the main tones may not be displayed, but their high level may still degrade the performance of the spectrum analyzer. Be careful.

The dynamic range of a typical spectrum analyzer is 70dB . The best spectrum analyzers can accurately measure intermodulation products at about -80dBc . This sets a limit on the LT5514's minimum output power for accurate intermodulation product measurements. For example, the LT5514 specification at 140MHz is $\text{OIP3} = 45\text{dBm}$. When a 70dB dynamic range spectrum analyzer is used, the minimum LT5514 output power can be calculated as $\text{P}_{\text{tone}}(\text{dBm}) = \text{OIP3}(\text{dBm}) - \text{IMD3}(\text{dBc})/2 = 45 - 70/2 = 10\text{dBm}$. The performance at lower LT5514 power levels may be extrapolated from high power level measurements (IMD3 improves with twice the power difference, assuming constant OIP3).

At 50MHz , accurate measurement of the LT5514's OIP3 (54dBm) with this direct method is simply not practical with a 70dB dynamic range spectrum analyzer.

For datasheet characterization and for production testing of the LT5514, two different methods are used to measure the third order nonlinearity. Both methods are based on reduction of the main tone amplitude at the spectrum analyzer input, thereby rendering the intermodulation products more easily detectable by the spectrum analyzer.

1. The first method uses two bandpass filters centered on the frequencies of the 3rd order intermodulation products. These filters provide at least 20dB attenuation of the main tones. The principle limitation of this method is that the tone spacing is limited by the filter out-of-band roll-off, and cannot be lower than 20% to 30% of the center frequency. Availability and insertion loss calibration of these filters are additional difficulties of this method. A lowpass filter for the IMD3^- product and a highpass filter for the IMD3^+ product may allow reduced tone spacing if the resulting out-of-band roll-off is sharper than that of a bandpass filter.
2. The LT5514 datasheet characterization is based on wide band cancellation of the main signal tones at the spectrum analyzer input. This has the advantage that very low tone spacing can be used, limited only by the

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spectrum analyzer filter. This method uses a second, low distortion “reference” signal path that is placed in parallel with the tested LT5514 device path. The outputs of these two paths are subtracted, one from the other, at the input to the spectrum analyzer. The net gain and electrical delay of the two paths are tuned such that the main tone level presented to the spectrum analyzer is reduced by about 40dB typically, while the tested LT5514 output signal intermodulation products are not altered. This method is most accurate, but requires a large amount of hardware. The calibration procedure for this method is also cumbersome, particularly when all gain settings are to be tested.

NOTE 4. Check the Dynamic Range of the Spectrum Analyzer

As a quick check, if the intermodulation products displayed on the spectrum analyzer are real, and not artifacts of the test setup, then their amplitude relative to the main tone level will not be affected by varying the input attenuation on the analyzer (typically in 10dB steps). External attenuator pads (3dB or 6dB) can be used for smaller level variation for this test.

If the IMD product levels relative to the main tone level (dBc) do change when the input attenuation is changed, then the spectrum analyzer is generating internal distortion products. That means that the spectrum analyzer input level is too high to make a valid measurement and more input attenuation is required.

If the IMD (dBc) readings are constant, then the spectrum analyzer resolution is adequate. Adjustments of the two-tone combining method (Note 2) may be required when the two-tone source is applied directly to the spectrum analyzer input (setup calibration step 1).

Whenever the spectrum analyzer’s input attenuator is based on pin-diode attenuators, the spectrum analyzer attenuation should be set to 0dB, and all required input attenuation should be implemented with external attenuator pads. This gives the best dynamic range capability for the spectrum analyzer. There is a simple test to find out if external attenuators are advantageous. Apply a low distortion, two-tone signal to the spectrum analyzer input, and compare the intermodulation product levels observed using only internal attenuation versus those obtained using only external attenuation.

NOTE 5. OIP3 Measurement Example

The example test set-up from Figures 1 and 2 consists of:

- Signal Sources: HP8644B
- Combiner: Mini-Circuits ZFSC2-2 (–25dB isolation, –3.5dB Insertion loss)
- Combiner input attenuation pads: –10 dB
- Spectrum Analyzer: HP8594E (ATTEN = 10dB, Span = 1kHz, $R_{BW} = 300\text{Hz}$, $V_{BW} = 300\text{Hz}$)

This example describes the steps for an actual two tone (at 100MHz) LT5514 Demo Board OIP3 measurement at MaxGain and at –21dB Attenuation Step.

The Max-Gain measurement will start with signal source qualification (step 1) as follows:

- Connect instruments for the test setup depicted in Figure 1
- Set two tone frequencies to 99.9MHz and 100.1MHz
- Adjust Signal Source levels for $Pwr_tone_src = -23\text{dBm}$ at combiner output
- The combined signal measured –45dBc 2nd harmonic, –64dBc 3rd harmonic. These levels are considered satisfactory, and no lowpass filter is used
- Record the Spectrum Analyzer readings for tone and intermodulation products in the SOURCE column of the LT5514 Max-Gain Measurement Table 1

The Max-Gain measurement will continue according to the Figure 2 test setup (step 2) as follows:

- The LT5514 demo board has $R7 = 255\Omega$ resistor removed and the measured demo board Gain is 29.8dB
- The LT5514 demo board drives an Ext_Atten = 30.1dB attenuator pad (at the LT5514 demo board output connector)
- Record the Spectrum Analyzer levels in the LT5514 column of the LT5514 Max-Gain Measurement Table 1 (bold face fields)

The LT5514 demo board OIP3 calculation formula is:

$$\text{OIP3} = Pwr_tone_board + (\text{IMD3})/2 = Pwr_tone_sa + \text{Ext_Atten} + |(\text{IMD3})/2|$$

For the previous example, the OIP3 at demo board output when LT5514 is set at Max-Gain is:

$$\text{OIP3} = -23.3 + 30.1 + (77.4)/2 = 45.5\text{dBm}$$

Note that the higher (worst) sidetone measurement is used for this calculation.

The OIP3 measurement for the LT5514 Demo Board at -21dB Attenuation Step follows a similar sequence.

The set-up changes for step 1 only (source qualification, Figure 1) are:

- Insert about 21dB pad at the combiner output
- Increase by 21dB the signal generator output levels
- Fill in the SOURCE column in Table 2

The set-up changes for step 2 only (Demo Board measurement, Figure 2) are:

- Set LT5514 PGA0 high and PGA1 = PGA2 = PGA3 inputs low
- Remove the 21dB pad from the combiner output in step 1

- Insert the LT5514 Demo Board driving the same Ext_Atten = 30.1dB attenuator pad used in the Max-Gain measurement previously

- Fill in the *LT5514* column in Table 2

The Spectrum Analyzer measured power levels are given in Table 2 (in bold face).

Then, for the demo board output when the LT5514 is set at the -21dB Attenuation Step:

$$\text{OIP3} = -23.1 + 30.1 + (74.7)/2 \cong 44.4\text{ dBm}$$

This calculation is accurate provided the relative difference between the IMD3 levels for step 1 and step 2 ($\text{IMD3}_{\text{LT5514}} - \text{IMD3}_{\text{SOURCE}}$ Difference) is high enough.

A cascaded OIP3 system calculation (valid only for this 0dB net gain method) was used to generate the OIP3 error curve as a function of IMD3 relative difference, shown in Figure 5. The result of this calculation is plotted there as the thick top curve, and applies whenever the $\text{IMD3}_{\text{SOURCE}}$ (from step 1) is well above the spectrum analyzer noise floor. Since this may not be the case, Figure 5 presents a family of OIP3 error curves, where the legend dB value represents the $\text{IMD3}_{\text{SOURCE}}$ elevation above the spectrum analyzer noise floor.

Table 1. LT5514 Max-Gain Measurement

| FREQUENCY (MHz) | PARAMETER | UNIT | SOURCE (STEP1) | LT5514 (STEP2) | IMD3LT5514 – IMD3SOURCE DIFFERENCE |
|-----------------|-----------------------|------|----------------|----------------|------------------------------------|
| | Column Suffix: | | _src | _sa | |
| 99.7 | Pwr_IMD3 ⁻ | dBm | -116.5 | -101.3 | 15.2dB |
| 99.9 | Pwr_tone | dBm | -23 | -23.3 | |
| 100.1 | Pwr_tone | dBm | -23 | -23.3 | |
| 100.3 | Pwr_IMD3 ⁺ | dBm | -116.0 | -100.7 | 15.3dB |
| | IMD3 ⁻ | dBc | -93.5 | -78 | |
| | IMD3 ⁺ | dBc | -93 | -77.4 | |

Table 2. LT5514 -21dB Attenuation Step Measurement

| FREQUENCY (MHz) | PARAMETER | UNIT | SOURCE (STEP1) | LT5514 (STEP2) | IMD3LT5514 – IMD3SOURCE DIFFERENCE |
|-----------------|-----------------------|------|----------------|----------------|------------------------------------|
| | Column Suffix: | | _src | _sa | |
| 99.7 | Pwr_IMD3 ⁻ | dBm | -116.5 | -98.5 | 18dB |
| 99.9 | Pwr_tone | dBm | -23 | -23.1 | |
| 100.1 | Pwr_tone | dBm | -23 | -23.1 | |
| 100.3 | Pwr_IMD3 ⁺ | dBm | -114.5 | -97.8 | 16.7dB |
| | IMD3 ⁻ | dBc | -93.5 | -75.4 | |
| | IMD3 ⁺ | dBc | -91.5 | -74.7 | |

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One final word of caution should be noted when using the Figure 5 OIP3 correction factor. This correction is valid only when the two-tone source quality is limiting. When the Spectrum Analyzer is limiting the step 1 intermodulation product reading, the Figure 5 OIP3 correction factor does not apply. In this case, we have found that the step 2 intermodulation product readings may be optimistic. The reason is that comparable levels of LT5514 generated intermodulation products and Spectrum Analyzer intermodulation products may have an arbitrary phase relationship. If these intermodulation products are in opposite phase, the Spectrum Analyzer readings may be lower than the actual values (due to intermodulation product cancellation).

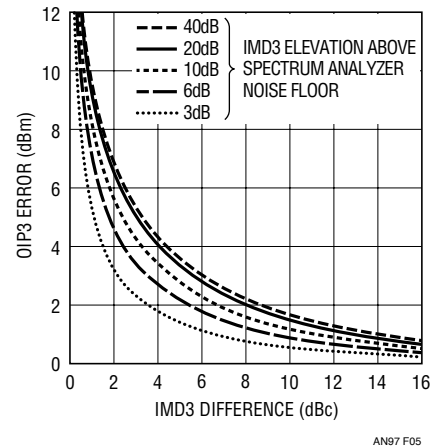


Figure 5. OIP3 Correction Factor vs Relative Difference Between IMD3 Levels for Step 1 (Source Only) and Step 2 (Device Under Test)