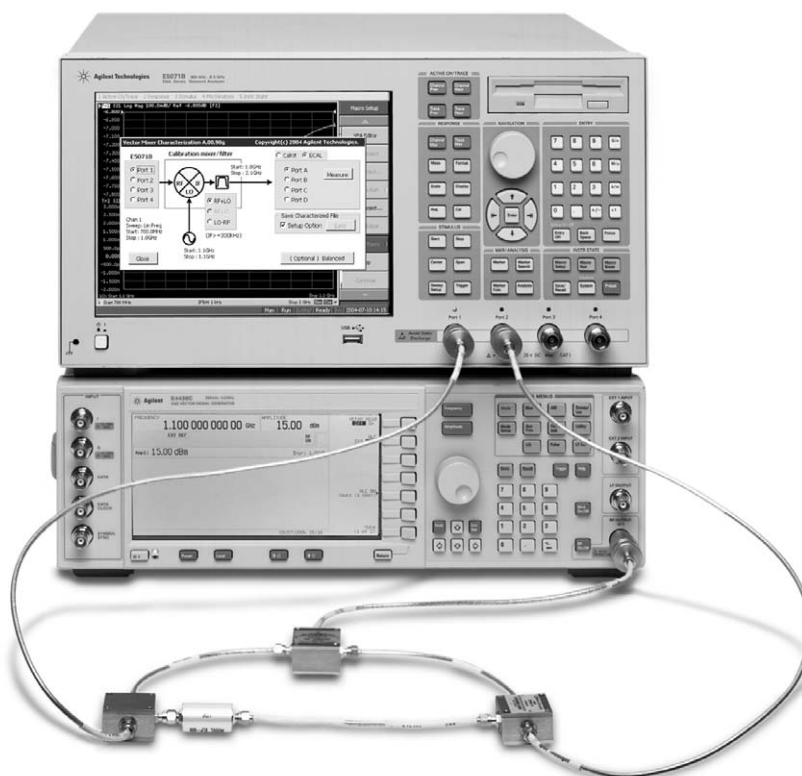
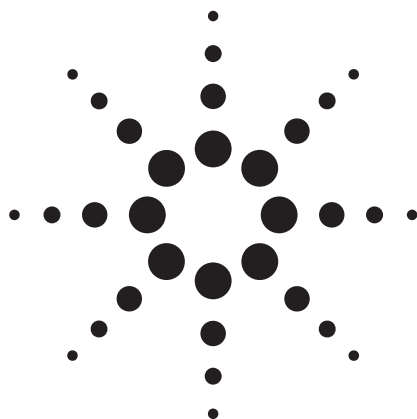


Agilent ENA RF Network Analyzers

Application Note 1463-6

Accurate Mixer Measurements
Using the Frequency-Offset Mode



Agilent Technologies

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Introduction

Frequency-translating devices such as mixers are critical components in most RF communication equipment. New and advanced modulation techniques have resulted in more complex mixer designs, with more stringent test requirements. Evaluations need to be more accurate with tighter specifications, and now more than ever, there is the necessity to reduce cost.

Traditional vector network analyzers working at a single stimulus and response frequency have a limited ability to evaluate the characteristics of mixers. The ENA RF network analyzers feature the frequency-offset mode (FOM)¹, which enables you to independently set the source and receiver frequencies for measuring mixers. Therefore you can stimulate a device over one frequency range and observe its response over another.

This application note discusses the recommended measurement procedure for evaluating mixers by employing factors such as conversion loss, return loss, isolation, and intermodulation distortion with the ENA FOM, taking advantage of Agilent's patented scalar- and vector-mixer calibration techniques.

To derive the full benefit from this application note, you should have an understanding of fundamental network analysis and the scalar- and vector-mixer calibrations. Agilent application notes 1408-1, 1408-2, and 1408-3 offer in-depth material regarding mixer measurements and calibration techniques. See the Related Literature section for more information.

Legend

For this document:

- Hardkeys are formatted as **[EXAMPLE]**
- Softkeys are formatted as **[Example]**

1. Option E5070B-008 or E5071B-008 is required.

1 Measurement Parameters of the Mixer

The ENA FOM offers two advanced mixer calibration techniques: scalar-mixer calibration (SMC) and vector-mixer calibration (VMC).

The measurement parameters for the mixer can be evaluated accurately by properly applying these two calibration techniques. In addition, ENA's FOM supports not only swept-IF measurements

but also fixed-IF and fixed-RF measurements. Table 1 shows measurement parameters of the mixer. As the table shows, the ENA's mixer measurement solution covers various types of measurement parameters. Moreover, conversion compression, isolation, and intermodulation distortion can be measured by using the ENA.

Table 1. Mixer measurement parameters (two-port configuration)

	Scalar-Mixer Calibration (SMC)			Vector-Mixer Calibration (VMC)		
	Swept-IF	Fixed-IF	Fixed-RF	Swept-IF	Fixed-IF	Fixed-RF
Conversion loss						
RF -> IF	O	O	O	O	O	-
IF -> RF	O	O	O	O	O	-
Return loss						
RF	O	O	O	O	O	-
IF	O	O	O	O	O	-
Group delay						
RF -> IF	-	-	-	O	-	-
IF -> RF	-	-	-	O	-	-

2 Vector-Mixer Calibration (VMC)

VMC offers measurements of conversion loss, phase, and absolute group delay of mixers by using a combination of calibration standards (such as open, short, load, or ECal), a "calibration mixer/IF-filter pair", and a network de-embedding function. VMC is the only solution that can measure absolute group delay of mixers. In addition, Agilent's patented VMC enables you to perform accurate balanced mixer measurements¹.

As shown in Figure 1, ENA's VMC adopts the up/down conversion technique, and therefore the calibration procedure is different from that of the microwave PNA².

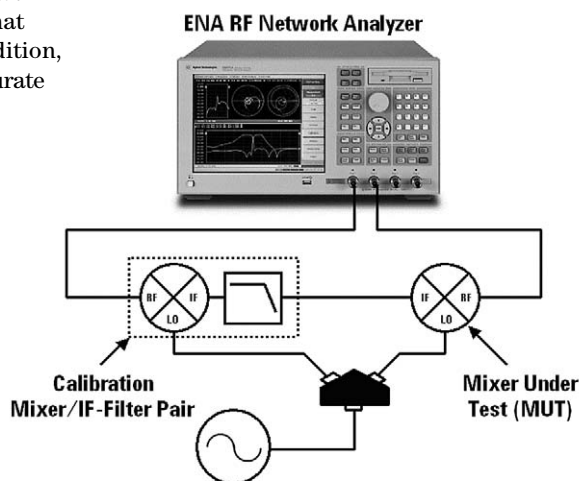


Figure 1. Up/down conversion technique

1. For detailed information on balanced mixer measurements, see Appendix 2, "Calibration Mixer Characterization for Balanced Mixer Measurements".
2. For detailed information on the mixer-calibration procedure for the MW PNA Series, see application note 1408-3, literature number 5988-9642EN.

2.1 Calibration mixer/IF-filter pair and MUT

VMC requires two mixers and a filter: a calibration mixer/IF-filter pair, and a mixer-under-test (MUT). In this section, we explain the difference between these two mixers. For more detailed information on the calibration mixer, see Appendix 1, “Calibration Mixer Attributes and Considerations”.

Calibration mixer/IF-filter pair: The purpose of the calibration mixer is to enable the up/down conversion configuration, which provides the same frequency sweep range between test ports 1 and 2, even for mixer measurements. The IF filter is used to select the desired mixing product: RF+LO, RF-LO, or LO-RF. This filter should have low loss in the passband region to minimize measurement uncertainty, and should be highly

reflective to all other mixing products. The calibration mixer/IF-filter pair can be considered part of the test system setup, like the network analyzer or test cables. The calibration mixer does not need to be moved, connected, or disconnected during the calibration or measurement process; it remains in place all the time. As explained in Appendix 1, “Calibration Mixer Attributes and Considerations” section, there are very few requirements for the calibration mixer and the filter.

MUT: The MUT is separate from the calibration mixer. It is the unknown device to be measured. However, if your MUT meets the requirements of a calibration mixer, you can actually use one of your MUTs as the calibration mixer.

2.2 Overview of vector-mixer calibration

The ENA’s VMC concept is explained in Figure 2.

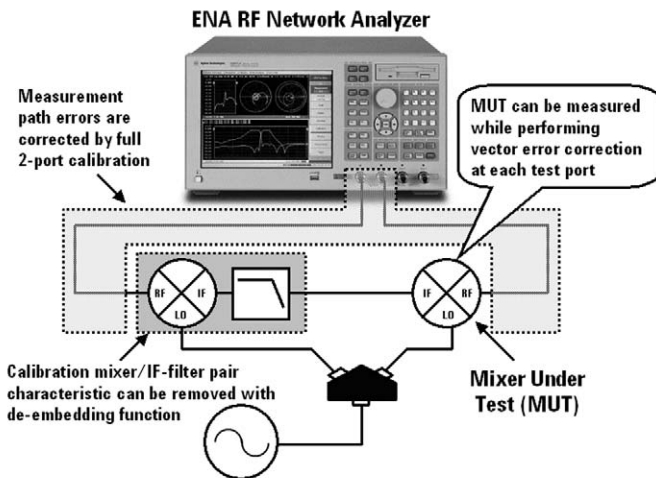


Figure 2. Overview of vector-mixer calibration

VMC is implemented by eliminating the characteristics of the calibration mixer/IF-filter pair using the network de-embedding function after performing a full two-port error correction. As shown in Figure 1, employing the up/down conversion technique allows you to specify the same sweep frequency range for both output and input ports, enabling you to perform full two-port error correction at the test ports. Consequently, only the MUT’s characteristics remain, after eliminating the characteristics of calibration mixer/IF-filter pair from all of the measurement results using the network de-embedding function.

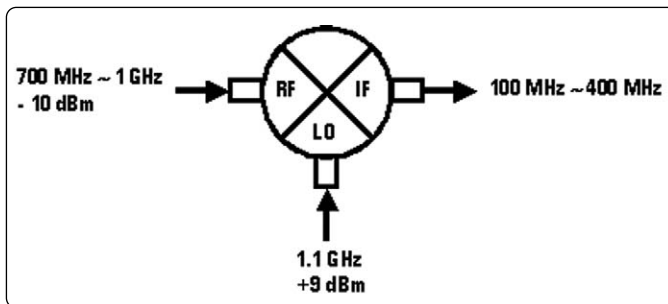
In addition, the up/down conversion technique means the frequency-offset sweep function does not need to be used. Hence, VMC requires characterization data for the calibration mixer/IF-filter pair.

2.3 Procedure for vector-mixer calibration

The vector-mixer calibration procedure is explained by using the mixer measurement setup example in Table 2. This document does not include an explanation of the general network analyzer's operating procedure.

Table 2. Setup example of swept-IF measurements

	Frequency range	Mixer input power level
RF signal	700 MHz to 1 GHz	-10 dBm
LO signal	1.1 GHz (fixed)	+9 dBm
IF signal	100 MHz to 400 MHz	-



Note: The external signal source power level should be set to +15 dBm to compensate for the loss of the power splitter.

Step 1. Setup for the network analyzer

Before performing the VMC, the RF signal frequency range (700 MHz to 1 GHz), mixer input power level (-10 dBm), and IF bandwidth should be set in advance. It is recommended that you perform a calibration with narrow IF bandwidths (1 kHz or less) to ensure low noise levels.

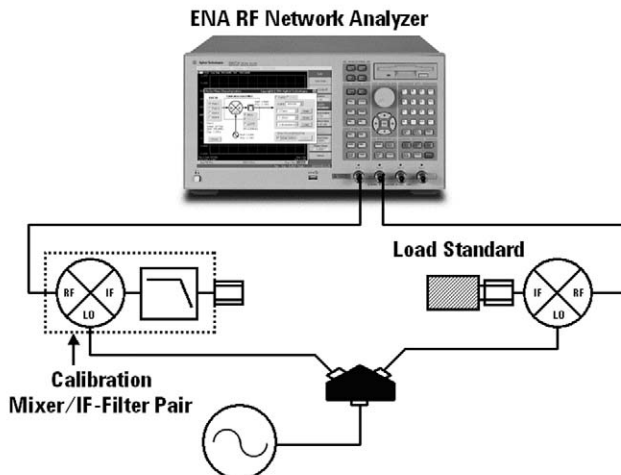


Figure 3. Setup for the vector mixer characterization

Step 2. Setup for the external signal source

The ENA allows you to control the external signal source connected to the USB/GPIB interface¹. For the external signal source setting, see Appendix 3 "Setup for the External Signal Source".

Step 3. Perform full two-port calibration

Perform the full two-port calibration at the test ports before connecting the calibration mixer/IF-filter pair and MUT.

Step 4. Setup for the vector-mixer characterization VBA macro

In VMC, the calibration mixer/IF-filter pair must be characterized. In this step, the calibration mixer/IF-filter pair is characterized by using the vector-mixer characterization VBA macro, which is pre-installed in the ENA. This VBA macro (program) is saved as "MixerCharacterization.vba" in the "Agilent" directory on the User [D:] drive.

From the front panel of the ENA, set this VBA macro by using [MACRO SETUP]. Press [Load Project] and select this VBA macro from the file explorer. Finally, you can run this VBA macro just by pressing [MACRO RUN].

To run this macro more easily, there is a method for registering the VBA macro in the [Load & Run] menu under [Select Macro]. Because it is easy to register this VBA macro and move it to the "VBA" directory on the [D:] drive, you can run this VBA macro from the [Load & Run] menu directly.

Step 5. Setup for the vector-mixer characterization

Figure 3 shows an example of the setup for vector-mixer characterization. We recommend characterizing the calibration mixer/IF-filter pair under the conditions where the power splitter for distributing the LO signal to the calibration mixer/IF-filter pair and the MUT are connected. During the evaluation of the calibration mixer/IF-filter pair, the LO power level should be the same as when the MUT is measured. This is because the mixer's conversion loss and reflection coefficient are significantly affected by the power level of the LO signal. In addition, the reflection signal between the external signal source, the power splitter, and the RF signal leakage are also critical issues for mixer measurements. For more information about these issues, see Appendix 1, "Calibration Mixer Attributes and Considerations".

1. A USB/GPIB interface is necessary to control ENA peripherals, such as power meters or source generators for mixer measurements. Agilent's 82357A USB/GPIB interface is recommended.

Step 6. Calibration mixer/IF-filter pair characterization

The vector-mixer characterization, which is provided as the VBA macro, assists the whole process of your calibration mixer/IF-filter pair characterization¹. As shown in Figure 4, connect the calibration mixer/IF-filter pair to the test port of the network analyzer with which the vector calibration has been performed, then connect an ECal module or mechanical calibration standards (open, short, load) to the end of the IF-filter to start the reflection measurements. From these three reflection measurements, the characteristics of the calibration mixer/IF-filter pair can be determined (input match, output match, and transmission response).

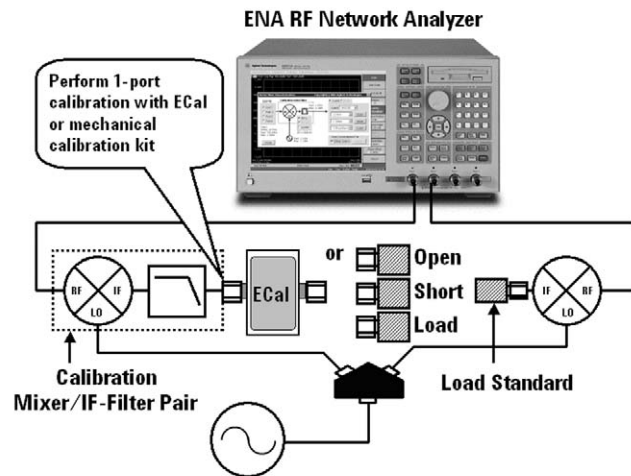


Figure 4. Calibration mixer/IF-filter pair characterization

The calibration mixer/IF-filter pair characterization employing the vector-mixer characterization VBA macro (Figure 5) can be performed in accordance with the following procedure:

- a. Connect the calibration mixer/IF-filter pair to test port 1, which has been calibrated in step 3, and check **[Port 1]** in this program.
- b. Set the IF frequency to be measured: $IF = RF + LO$, $IF = RF - LO$, or $IF = LO - RF$.
- c. Choose the mechanical calibration kits (open, short, and load) or ECal in this program. Connect the calibration kit, and press **[Measure]** to perform three reflection measurements. The mechanical calibration kits, test ports and external-signal-source frequencies, which are preset values in ENA, are automatically imported to this software.
- d. After completing the three reflection measurements, characterized data is saved as a Touchstone-format file. If you check **[Setup Option]** in this program, the saved Touchstone file is automatically applied to port 1 as the de-embedding data. The fixture simulator also automatically turns on in order to remove the characteristics of the calibration mixer/IF-filter pair from all of the measurement results.

After completing the VMC, connect the MUT to perform the vector-mixer measurements (see Figure 1).

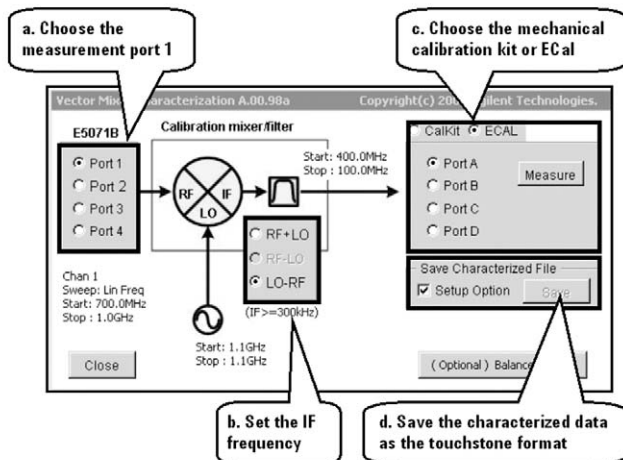


Figure 5. Vector-mixer characterization VBA macro

1. For detailed information on the characterization of the calibration mixer/IF-filter pair, see the "application note 1408-1, literature number 5988-8642EN.

3 Scalar-Mixer Calibration (SMC)

The SMC can be used to characterize the conversion loss and reflection parameters of mixers with very high accuracy, by performing

error correction using a combination of calibration standards (Ecal or open, short, load) and a power meter.

3.1 Overview of scalar-mixer calibration

For the measurement of the conversion loss in frequency-translating devices, normal full two-port calibration is not available because of the frequency difference between the stimulus and response ports. SMC allows you to correct the error terms that reside in a full two-port error model, by using the error model and the expression based on a new concept¹. The scalar-mixer calibration can correct the following error terms:

- The reflection between the output (stimulus) port of the network analyzer and the input port of the MUT (vector error correction).
- The reflection between the input (response) port of the network analyzer and the output port of the MUT (vector error correction).
- Transmission frequency characteristics in different frequencies (scalar error correction).

In a traditional power-meter calibration, the analyzer source power is calibrated for flatness and linearity over the input frequency range, while the receiver is calibrated for flatness and linearity over the output frequency range. The analyzer is calibrated in the presence of the impedance of the power sensor. In other words, the measurements will have optimal accuracy if the MUT has the same input match as the power sensor. In this method, the mismatch that exists between the MUT and the network analyzer cannot be corrected.

By using the network analyzer's one-port calibration ability, the port and MUT input and output reflection coefficients can be measured. Using the known vector reflection coefficients of the test port, the MUT, and the power sensor, SMC corrects for mismatch loss. Since SMC is referenced to a traceable standard (power sensor/ meter measurements), it provides the specified measurements for conversion loss magnitude.

3.2 Procedure for scalar-mixer calibration

The scalar-mixer calibration procedure is explained by using the configuration shown in Figure 6. Unlike VMC, SMC does not use the calibration mixer, however the IF-filter is required to select the required IF frequency such as RF+LO, RF-LO, or LO-RF.

ENA RF Network Analyzer & Power Meter

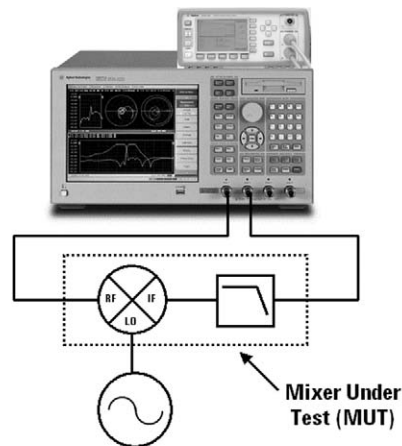


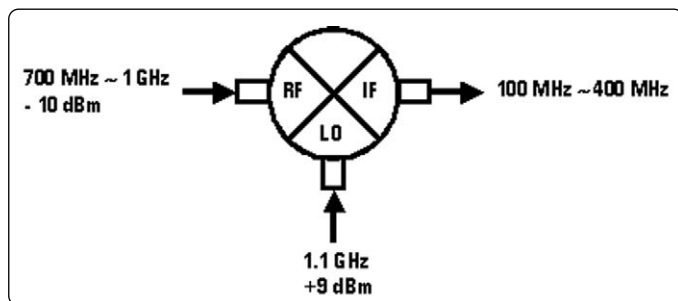
Figure 6. Configuration of the scalar-mixer calibration

1. For detailed information on the scalar-mixer calibration (SMC) theory, see the application note 1408-1, literature number 5988-8642EN.

Table 3 shows the swept-IF measurement setup example.

Table 3. Example of setup for swept-IF measurement

	Frequency range	Mixer input power level
RF signal	700 MHz to 1 GHz	-10 dBm
LO signal	1.1 GHz (fixed)	+9 dBm
IF signal	100 MHz to 400 MHz	-



Measurement parameters of the external signal source and the power meter should be set in advance. For the external signal source setting, see Appendix 3 "Setup for the External Signal Source". For the power-meter setting, see Appendix 4 "Setup for the Power Meter".

Step 1. Setup for the network analyzer

First, the frequency-offset sweep setup is explained. As it is described in the following equation, the frequency range of each test port can be set using a multiplier (M_n), a divisor (D_n), and offset (O_n) for the basic frequency¹.

$$\text{Port (n) frequency} = \text{Basic frequency} \times M_n \div D_n + O_n$$

Therefore, you can set the test port frequency, which is shown in Table 3, in accordance with the following procedure:

From the front panel of the ENA, set the basic frequency by using [START] and [STOP].

Basic frequency setting: [START] = 700 MHz, [STOP] = 1.0 GHz

Press [SWEEP SETUP] and select [Frequency Offset] then press [Frequency Offset] to turn it [On]. Also, each test port frequency can be set under the [Port 1] and [Port 2] menu.

RF-port frequency setting:

[Multiplier] = 1, [Divisor] = 1, [Offset] = 0 Hz

IF-port frequency setting:

[Multiplier] = -1, [Divisor] = 1, [Offset] = 1.1 GHz

Step 3. Perform the scalar-mixer calibration

You can perform SMC by using the mechanical calibration kit or the ECal module. In this example, the mechanical calibration kit is used.

Before starting SMC, verify whether [Frequency Offset] is turned [On]. Press [CAL] and then choose [Scalar Cal (Manual)] under [Mixer/Converter Calibration]. Choose [2-1 (fwd)] under [Select Ports], then perform the error correction to measure the transmission characteristic from the RF to the IF of the MUT. In addition, ENA's SMC provides the error correction not only for the RF to IF transmission measurement, but also for the IF to RF [1-2 (rev)] and the bidirectional [1,2 (both)] transmission measurements. This enables you to measure these parameters without changing the connection.

Perform the error correction at each test port using the mechanical calibration kit or ECal module in accordance with the instruction under [Reflection] and [Transmission] menus.

When performing SMC, we recommend you use the ECal module rather than the mechanical calibration kit. The ECal module can perform all the necessary ratioed error corrections with a single pair or connections. This enables you to drastically improve your operating efficiency.

Finally, error correction with a power meter is performed under Power Meter. Choose the power sensor from [Use Sensor] and then perform the power calibration by connecting the power sensor to the RF test port.

Step 4. Setup for the mixer measurements

After performing the calibration, connect the MUT to execute the scalar-mixer measurements (see Figure 6).

1. The basic frequency is a frequency range set by [START] and [STOP] keys.

4 Mixer Measurements

There are several measurement parameters involved with mixer measurements, such as conversion loss, return loss, conversion compression, isolation, and intermodulation

distortion. This section describes several procedures and hardware setups for measuring these parameters.

4.1 Conversion loss

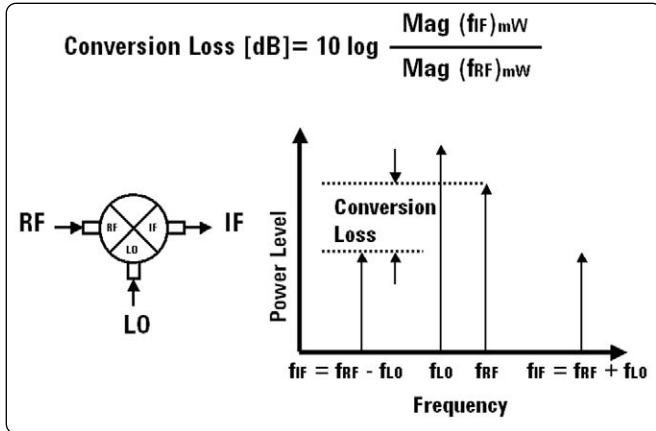


Figure 7. Conversion loss

This section explains conversion loss measurements. As shown in Figure 7, conversion loss is the measure of a mixer’s efficiency. It is identified as the ratio of the output power to the input power at a given LO power and is usually expressed in dB.

While conversion loss by a mixer is usually very flat within the frequency span of its intended operation, the average loss will vary with the level of the LO. As shown in Figure 8, conversion loss is usually measured versus frequency, either the IF frequency (with a swept-IF) or the RF frequency (with a fixed-IF). The ENA’s FOM supports the external-signal-source control, so you can easily perform swept-IF, fixed-IF, and fixed-RF¹ measurements.

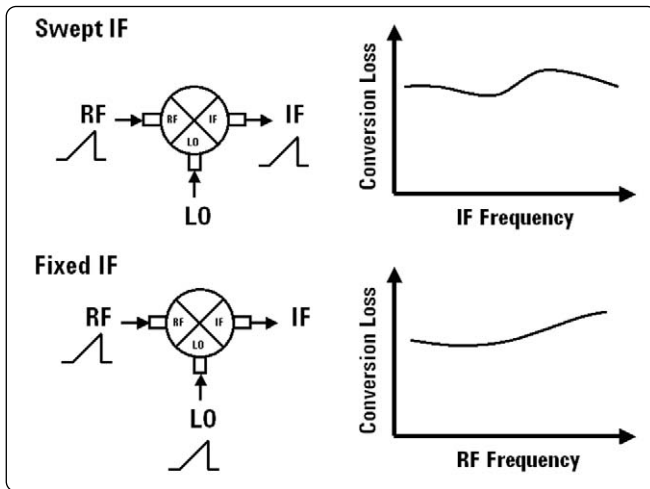


Figure 8. Conversion loss measurements

4.1.1 Measurement procedure of conversion loss

Conversion loss can be measured by using VMC and SMC, which are explained in Section 2 and 3. For detailed procedures of the VMC, see the

“Vector-Mixer Calibration (VMC)” section. For detailed procedure of the SMC, see the section “Scalar-Mixer Calibration (SMC)”.

1. Some of mixer parameters cannot be measured by using the fixed-IF or fixed-RF setup with the vector-mixer calibration. For more information, see Table 1.

4.1.2 Example of conversion loss measurements (VMC/SMC)

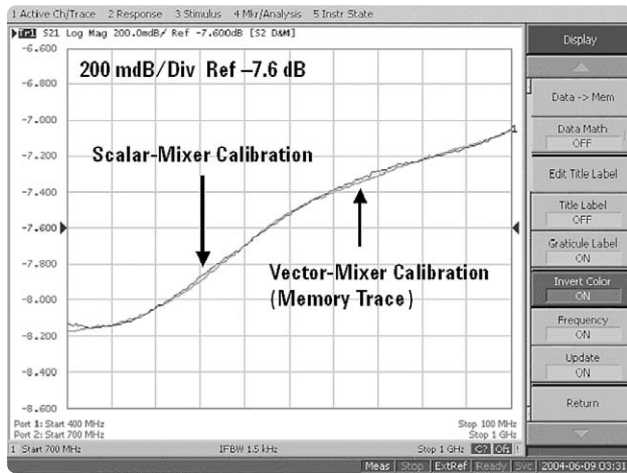


Figure 9. Comparison of conversion loss measurement results (VMC vs. SMC)

Figure 9 shows an example of conversion loss measurements made with VMC and SMC. These measurements can be performed with the operations that are explained in sections 2 and 3. As shown in this figure, both data correlate well; hence you can perform highly accurate conversion loss measurements using either the VMC or the SMC technique.

VMC allows you to measure phase and absolute group delay of conversion loss, which traditionally has been a very difficult and noisy measurement. Figure 10 shows the measurement results of magnitude, phase, and group delay of conversion loss.

Figure 11 shows the conversion loss measurement data comparison made with SMC versus a traditional power-meter calibration. This figure clearly reveals that a simple power-meter calibration cannot remove error terms such as source match, load match, and directivity; therefore, the measurement trace has ripple due to the effects of these error terms.

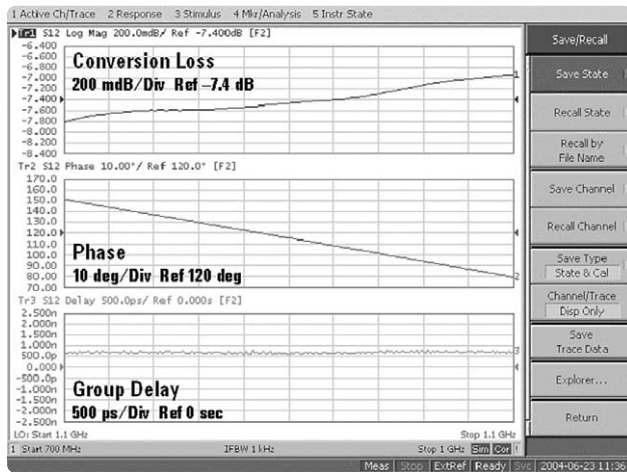


Figure 10. Conversion loss measurement example with VMC

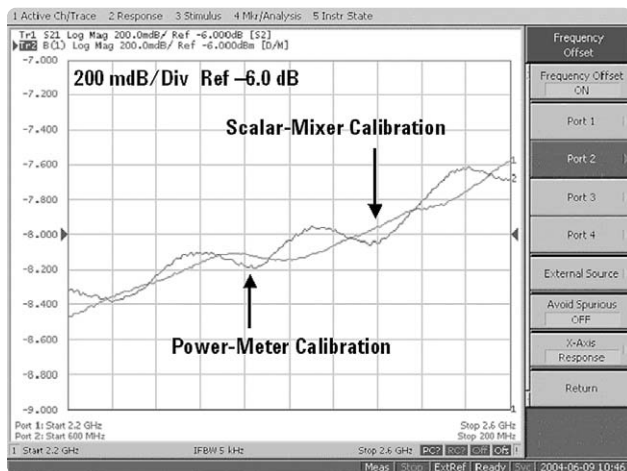


Figure 11. Conversion loss measurement comparison (SMC vs. Power Cal.)

4.2 Return loss/SWR

This section explains return loss/SWR measurements. Return loss/SWR are reflection parameters (S_{11} or S_{22}) that are linear even when testing frequency-translating devices, since the reflected signal does not undergo a frequency shift. Therefore, these measurements are essentially standard S-parameter measurements.

Mixers are three-port devices, and the reflection from any one port depends on the condition of the other two

ports. When measuring a mixer's return loss, it is important to terminate the ports not being tested with characteristic impedance (50 ohms) or the impedance that they would see during actual operation. If the IF-port of the mixer will be directly connected to a filter, then this filter should be used when testing RF- or LO-port reflection measurements. Also, the LO signal should be applied at the power level that will be used in actual operation.

4.2.1 Measurement procedure for return loss/SWR

Table 4. Example of setup for return loss/SWR measurements

	Frequency range	Mixer input power level
RF signal	700 MHz to 1 GHz	-10 dBm
LO signal	1.1 GHz (fixed)	+9 dBm
IF signal	100 MHz to 400 MHz	-

Table 4 shows an example of the return loss/SWR (RF-port) measurements setup.

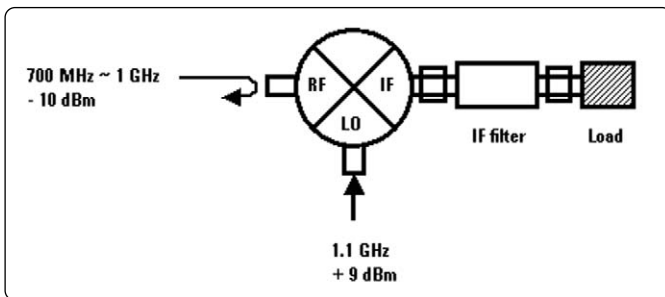
Measurement parameters of the network analyzer and the external signal source should be set in advance, prior to performing the return loss/SWR measurements. For the external signal source setting, see Appendix 3, "Setup for the External Signal Source".

Step 1. Perform one-port calibration

Perform one-port calibration at the point to be connected to the mixer's RF-port.

Step 2. Setup for the mixer measurements

After performing one-port calibration, connect the MUT and then measure the SWR (S_{11}).



4.2.2 Example of SWR measurement

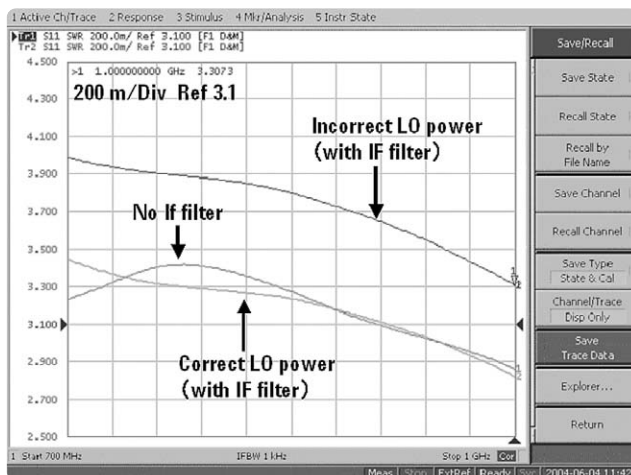


Figure 12. SWR measurement example

Figure 12 shows an example of the SWR measurements on the input port of an RF mixer. The figure compares the measurement results of a LO drive with the correct power level (+9 dBm), a LO drive with an incorrect power level, and a LO drive with a correct power level but without an IF-filter. As shown in this figure, SWR varies dramatically due to a change of LO power level and with or without the IF-filter.

4.3 Conversion compression

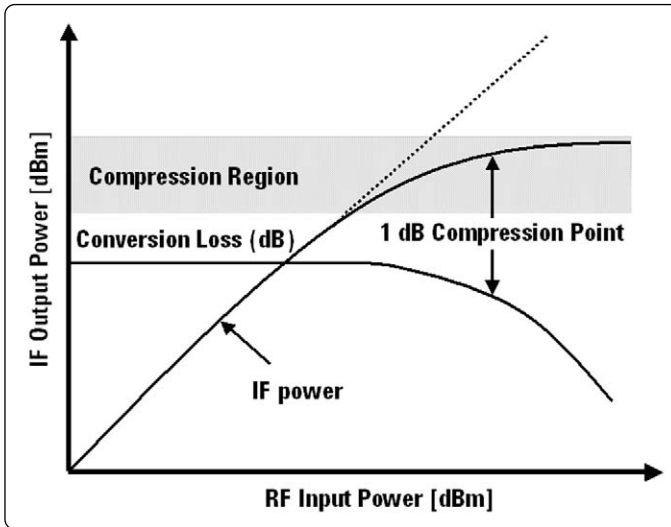


Figure 13. Conversion compression

This section explains the conversion compression measurements. Conversion compression is a measure of the maximum RF input signal level for which the mixer will provide linear operation (Figure 13). Conversion loss is the ratio of the IF output level to the RF input level, and this value remains constant over a specified input power range. When the input power level exceeds a certain maximum, the constant ratio between IF and RF power levels will begin to change. The point at which the ratio has decreased by 1 dB is called the 1-dB compression point.

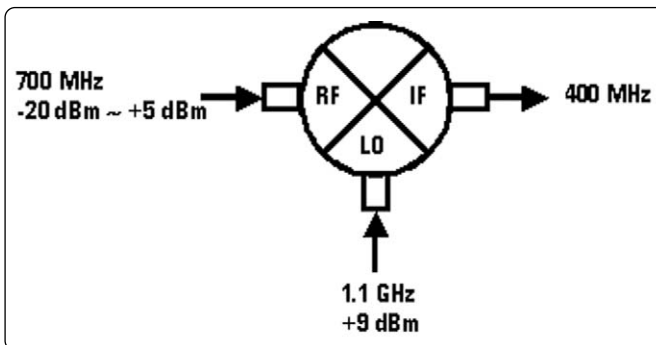
4.3.1 Measurement procedure for conversion compression

The conversion compression can be measured by using the power sweep function on the ENA.

Table 5 shows an example of conversion compression measurements setup.

Table 5. Example of setup for conversion compression measurements

	Frequency range	Mixer input power level
RF signal	700 MHz (fixed)	-20 dBm to +5 dBm
LO signal	1.1 GHz (fixed)	+9 dBm
IF signal	400 MHz (fixed)	-



Measurement parameters of the network analyzer, the external signal source, and the power meter should be set in advance, prior to performing the conversion compression measurement. For the external signal source setting, see Appendix 3, “Setup for the External Signal Source”. For the power meter setting, see Appendix 4, “Setup for the Power Meter”.

Step 1. Setup for the network analyzer

The setup procedure of power sweep is explained as follows:

From the front panel of the ENA, set the carrier-wave (CW) frequency by using [SWEEP SETUP] and set [CW Freq] (700 MHz) under [Power]. Then, press [Sweep Type] under [SWEEP SETUP] and choose [Power Sweep]. Set the power range (-20 dBm to +5 dBm) by using [START] and [STOP].

As shown in Table 5, RF and IF frequencies are different so each test port frequency needs to be set independently with the frequency-offset function. For the frequency-offset sweep setting, see the “Procedure for scalar-mixer calibration” section.

Step 2. Perform the SMC

SMC should be performed before measurements. For the SMC procedure, see “Procedure for scalar-mixer calibration”.

Step 3. Setup for the mixer measurements

After performing SMC, connect the MUT and then measure the conversion compression (See Figure 6). The 1-dB conversion compression point can be obtained with the following operation: From the front panel of the ENA, set the marker to the left end of the trace, which is in a linear

area, by using [Marker 1] under [MARKER]. Set marker 1 as the reference marker by pressing [Ref Marker Mode]. Then press [Target] under [MARKER SEARCH] and set the target value (-1 dB) at [Target Value]. Finally, you can easily find the 1 dB compression point by pressing [Search Target]. The compression point is in absolute power, so the delta stimulus value must be added to the reference marker’s absolute stimulus value. In the following example, 1-dB compression occurs at 1.2 dBm: -15 dBm + 16.2 dBm = 1.2 dBm.

4.3.2 Example of conversion compression measurement

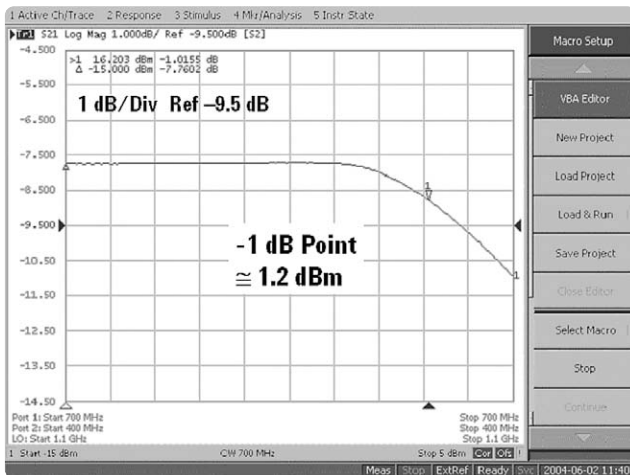


Figure 14. Example of conversion compression measurement

Figure 14 shows an example of the conversion compression measurement.

4.4 Isolation

This section explains the isolation measurements. Isolation is the measure of signal leakage in a mixer, and it is measured using normal S-parameters without the frequency-offset mode. The feed through is specifically the forward signal leakage to the IF-port, and it is one of the most important parameters in mixer measurements. High isolation means that the amount of leakage

or feed through between the mixer’s ports is very small. The LO to RF isolation and the LO feed through are typically measured with the third port terminated at 50 ohms. The RF feed through measurement is made as the LO signal is being applied to the mixer. The ENA can supply up to +10 dBm¹ output power for the LO isolation measurements.

1. This is specified in the range of 300 kHz to 3 GHz.

4.4.1 Procedure for isolation measurement

Table 6 shows an example of the isolation measurements setup.

Table 6. Example of setup for isolation measurements

Parameters	Measurement setup
LO to RF isolation	
LO feed through	
RF feed through	

Measurement parameters of the network analyzer and the external signal source should be set in advance, prior to performing the isolation measurements. For the external signal source setting, see Appendix 3, "Setup for the External Signal Source".

Figure 15 shows an example of the isolation measurement configurations.

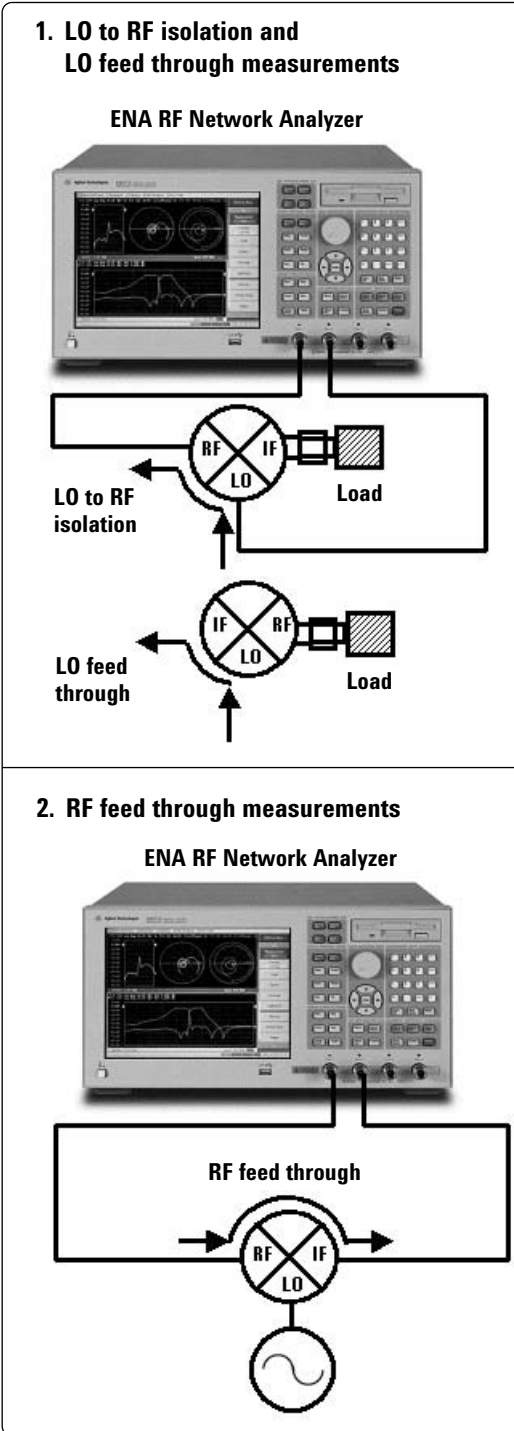


Figure 15. Examples of isolation measurement configurations

4.4.2 LO to RF isolation and LO feed through measurements

Setup the instrument for the LO to RF isolation and the LO feed through measurements based on Figure 15-1.

Step 1. Setup for the network analyzer

From the front panel of the ENA, set the RF frequency range (10 MHz to 1 GHz), output power level (+9 dBm) to the appropriate level.

Step 2. Setup for the mixer measurements

After performing one-port calibration, connect the MUT, then measure the LO to RF isolation and the LO feed through.

4.4.3 Isolation measurement example one

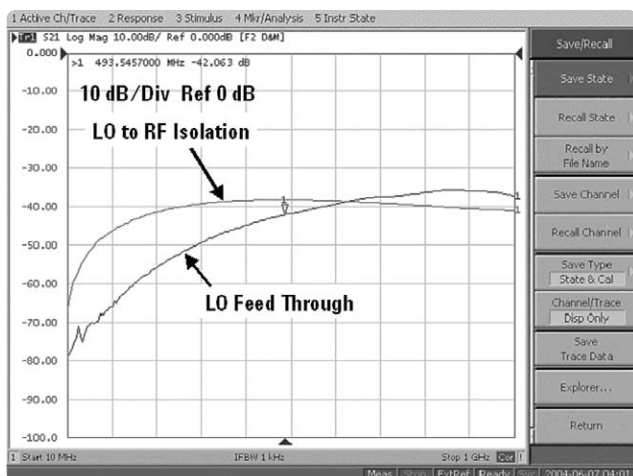


Figure 16. Example of LO to RF isolation and LO feed through measurements

Figure 16 shows measurement results of the LO to RF isolation and the LO feed through.

4.4.4 RF feed through

Setup the instrument for the RF feed through measurement based on Figure 15-2.

Step 1. Setup for the network analyzer

In this measurement, the ENA uses the same frequency range of the previous isolation measurements. The external signal source frequency (1.1 GHz) and output power level (+9 dBm) need to be set here.

4.4.5 Isolation measurement example two

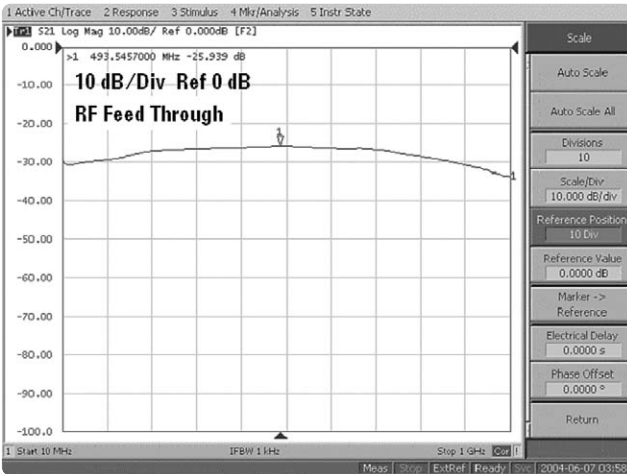


Figure 17. Example of RF feed through measurement

Figure 17 shows the measurement result of the RF feed through.

4.5 Two-tone third-order intermodulation distortion

This section explains the two-tone third-order intermodulation distortion measurements. Intermodulation distortion is a common problem in narrowband systems. It is the unwanted frequency components resulting from the interaction of two (f_1 and f_2) or more spectral components passing through a device with non-linear behavior such as a mixer. The unwanted components are related to the fundamental components by sums and differences of the fundamentals and various harmonics: $nf_1 \pm mf_2$.

$|n| + |m|$ is called the order of intermodulation products, so $2f_1 - f_2$ and $2f_2 - f_1$ are called third-order intermodulation products.

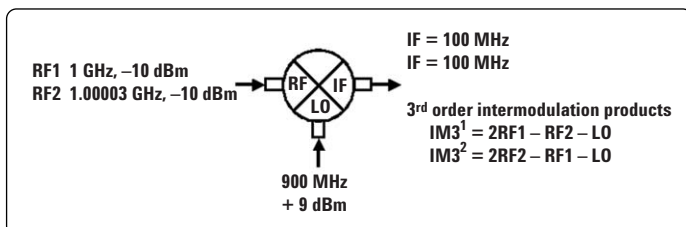
In this measurement, two closely spaced fixed frequencies of equal amplitude are input at the mixer's RF-port, while a single frequency is used to drive the mixer's LO port.

4.5.1 Procedure for intermodulation distortion measurement

Table 7. Example of setup for intermodulation distortion measurement

	Frequency range	Mixer input power level
RF1 signal	1 GHz (fixed)	-10 dBm
RF2 signal	1.00003 GHz (fixed)	-10 dBm
LO signal	900 MHz (fixed)	+9 dBm
IF1 signal	100 MHz	-
IF2 signal	100.03 MHz	-

Table 7 shows an example of intermodulation distortion measurement setup.



The third-order intermodulation products can be calculated with the following equations:

$$IM3^1 = 2RF1 - RF2 - LO = 99.97 \text{ MHz}$$

$$IM3^2 = 2RF2 - RF1 - LO = 100.06 \text{ MHz}$$

Measurement parameters of the network analyzer and the external signal source should be set in advance, prior to performing an intermodulation distortion measurement. For the external signal source setting, see Appendix 3 “Setup for the External Signal Source”.

The intermodulation distortion measurement requires two external signal sources, however the ENA’s frequency-offset mode supports only one external signal source. Therefore, the second external signal source needs to be manually controlled. Figure 18 shows an example of the intermodulation distortion measurement configuration.

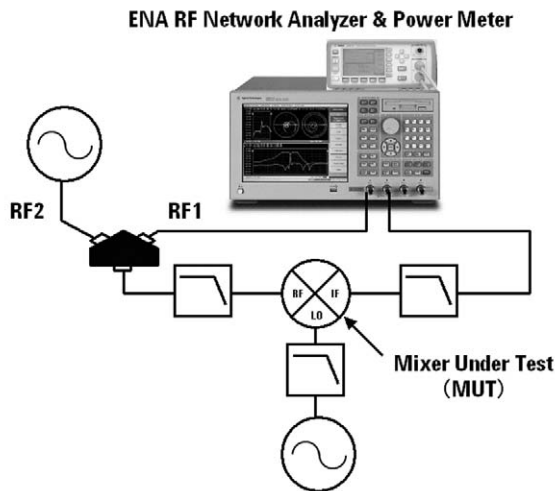


Figure 18. Example of intermodulation distortion measurement configuration

Step 1. Setup for the network analyzer

When you measure the intermodulation distortion, we recommend the use of a narrow IF bandwidth (100 Hz or less) in order to increase the dynamic range. The intermodulation distortion is measured with a combination of frequency-offset sweep and absolute (non-ratioed) measurement functions.

- a. **RF-port frequency setup:** Set the RF-port frequency by using [SWEEP SETUP]. Choose [Frequency Offset] and press [Frequency Offset] to turn [ON] the frequency-offset sweep. Select [Port 1] and then set the RF-port frequency as follows:

RF-port frequency:
[Multiplier] = 0, [Divisor] = 1, [Offset] = 1 GHz

- b. **Sweep mode setup:** In this case, the segment sweep function is used to perform a faster measurement.

Set the segment sweep table by using [SWEEP SETUP]. Choose [Edit Segment Table] and set [Freq Mode] to [Center/Span]. Then, create the segment sweep table in accordance with Table 8.

Table 8. Example of setup for segment sweep table

	Center	Span	Points
1	99.92 MHz	2 kHz	5
2	99.97 MHz	2 kHz	5
3	100.00 MHz	2 kHz	5
4	100.03 MHz	2 kHz	5
5	100.06 MHz	2 kHz	5
6	100.11 MHz	2 kHz	5

Press [SWEEP SETUP] and then select [Segment] under [Sweep Type]. Finally, choose [Freq Base] under [Segment Display].

- c. **Absolute measurement setup:** Set the absolute measurement by using [MEAS] and then choose the measurement port from [Absolute]. In the case of an absolute measurement, the receiver of port 1 is designated “A”, the receiver of port 2 is designated “B”, and the reference receiver is designated “Rn” (n = port number). Also, a numeric in the parentheses indicates the stimulus port number. In this case, port 1 is assigned as the stimulus port, while port 2 is assigned as receiver port (B). Therefore, the B(1) should be selected.

Step 2. Calibration of the network analyzer

To achieve accurate absolute measurements, both power and receiver calibrations need to be performed. In order to perform both calibrations in the entire receiver’s frequency range, the RF-port (stimulus) should be set at the same frequency range as the IF-port (receiver).

In the case of Table 8, reset the RF-port (RF1) frequency in the range of 99.92 MHz to 100.11 MHz then perform the power calibration with power meter.

Press [CAL] and choose [Power Calibration]. Select [1] under [Select Port] then press [Take Cal Sweep] to perform a power calibration. When you perform the power calibration, please confirm that the power meter is connected to the ENA via the USB/GPIB interface.

Next, calibrate the receiver. Press [CAL] and choose [Receiver Calibration]. Select [2] under [Select Port] then connect the RF-port and IF-port with a low loss cable. Following that, perform the receiver calibration with [Take Cal Sweep]. Finally, corrected RF power gain data is transferred to the IF-port in order to correct the receiver’s gain.

After performing the receiver calibration, the RF-port (RF1) frequency should be set to 1 GHz as it is described in Step 1 (a).

Step 3. Setup for the second external signal source

Set the RF 2 frequency (1.00003 GHz) and power level (-10 dBm) of the second external signal source manually. After finishing the setup, connect the MUT to execute the intermodulation distortion measurement using the absolute measurement function (see Figure 18).

4.5.2 Example of intermodulation distortion measurement

Figure 19 shows the measurement result of the two-tone third-order intermodulation distortion.

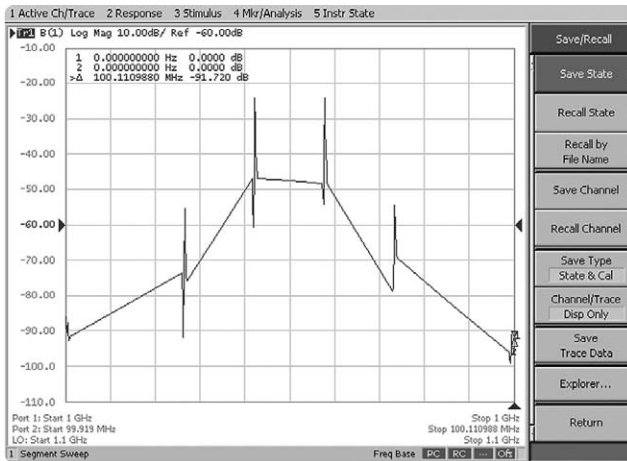


Figure 19. Example of two-tone third-order intermodulation distortion measurement)

The third-order intercept (TOI) can be calculated from this measurement result. TOI is the mixer’s input level where the amplitudes of the fundamental signals and the third-order products would be equal (see Figure 20) and it can be calculated using the following equation.

$$TOI [dBm] = \text{Input signal levels [dBm]} - \text{Distortion products [dBc]}/2$$

In this case, TOI is approximately 5 dBm.

$$TOI [dBm] = -10 \text{ dBm} - (-30\text{dBc}/2) = 5 \text{ dBm}$$

TOI is a constant value independent of input power, and can be used to predict the level of distortion products at any input power level.

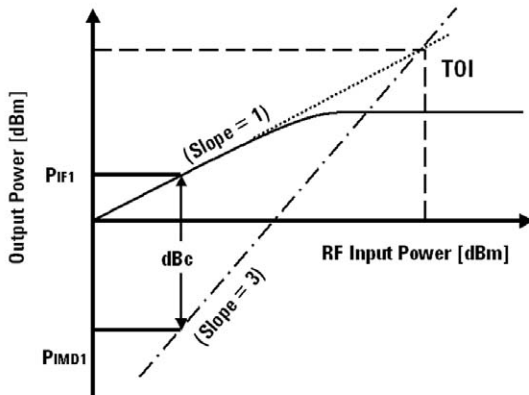


Figure 20. Concept of the third-order interception (TOI)

Summary

There are many challenges associated with making measurements on non-linear frequency-translating devices such as mixers. It is difficult to accurately evaluate mixers due to complex measurement configurations and to account for unwanted error signals.

The FOM on the ENA RF network analyzers provides various kinds of functions that can solve these typical issues. In particular,

advanced mixer-calibration functions such as VMC and SMC permit highly accurate mixer measurements. In addition, the absolute measurement function with the power and the receiver calibration enables you to perform accurate intermodulation distortion measurements. Hence, the ENA's FOM makes all required mixer measurements fast and easy, while giving you more confidence in the measurement results.

Appendix 1: Calibration Mixer Attributes and Considerations

Frequency range: The frequency range of a calibration mixer should be the same or wider than the frequency range of the MUT. If you want to test multiple MUTs with a single calibration mixer, this calibration mixer should cover the frequency range of all the MUTs to be tested.

Return loss: VMC corrects for the mismatch errors associated with the reflected signal of the fundamental frequency. However, the harmonic and spurious products can reflect off the mixer and network analyzer test ports and create error terms. Therefore a device with better return loss will yield lower uncertainty. If RF- and IF-filtering are used before and after the mixer respectively, the effects of poor return loss can be reduced, and if the conversion loss of the mixer is low enough, attenuators can be used to improve mismatch errors.

Conversion loss: To obtain accurate calibration results, the one-way conversion loss of the calibration mixer/IF-filter pair should be less than 10 dB. If the one-way conversion loss of the calibration mixer exceeds 15 dB, the accuracy of the calibration is severely degraded.

Conversion loss reciprocity: The main requirement of a calibration mixer is that it should be reciprocal. Reciprocity means that the forward and reverse conversion loss magnitude and phase are equal. Forward conversion loss is defined as the loss that occurs when an RF signal is incident upon port 1 and an IF signal is measured at port 2. On the other hand, reverse conversion loss is defined as the loss that happens when an IF signal is incident upon port 2 and an RF signal is measured at port 1. The reason for the reciprocity requirement is that the calibration process calculates the net response of the forward and reverse mixer conversion loss by measuring the portion of the signal that travels through the filter and reflects off the calibration standards. In calculating the error terms, the assumption is made that the forward and reverse conversion losses are the same, and from here, the one-way characteristic of the calibration mixer is determined¹.

1. For detailed information on the vector-mixer calibration (VMC) theory and frequency-offset error models, see application note 1408-1, literature number 5988-8642EN.

High-order mixing products (spurious products): The spurious generation of a calibration mixer should be low, as spuriousness can result in measurement errors. The FOM includes the avoid spurious function, which can reduce the effects of various spurs during the calibration and measurement process (see Figure 21). Another practical technique is to slightly change the stimulus or response frequencies or number of points to avoid spurs.

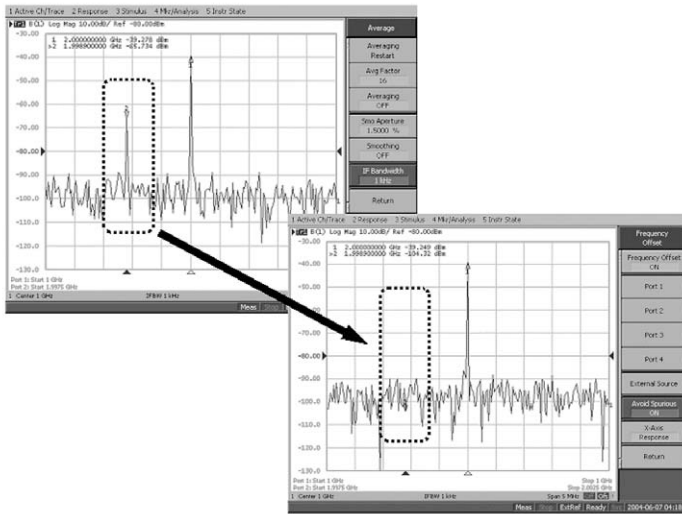


Figure 21. Avoid spurious function

Isolation: There are six mixer isolation terms; RF to IF and LO, LO to RF and IF, IF to RF and LO. The LO leakage term can be a significant error causing a spurious response, due to the high power levels of the LO. Thus, it is critical to reduce the amount of LO leakage in order to achieve an accurate VMC. A good calibration mixer has at least 20 dB of LO to RF and LO to IF isolation. The LO leakage problem is that the LO signal leaking through the RF or IF port can reflect off the network analyzer port and re-enter the mixer and mix with the other products to create a mismatch error signal. It also can leak to the reference channel path and create additional errors.

RF power level: The calibration mixer should be operated in its linear region to ensure linear reflections, which generally implies an RF power that is at least 30 dB less than the LO power. The reason for this is that the

calibration model assumes linear reflections. If the mixer is operating in the linear region, the IF port reflection coefficient does not change with the RF input power level. However, in the nonlinear region, the reflection term is dependent on the input power level. Figure 22 shows a graph of the S_{11} of a mixer, over various RF power levels. The LO power of this mixer was set a nominal value of +7 dBm, and we increased the RF power level. The figure shows that S_{11} remains relatively constant until the RF power goes to -10 dBm. With -5 dBm and higher RF input power, S_{11} changes significantly.

Too much RF power will result in a VMC with significant errors, hence it is recommended that users perform a test similar to the measurement described above to ensure that the calibration mixer is operating in its linear region.

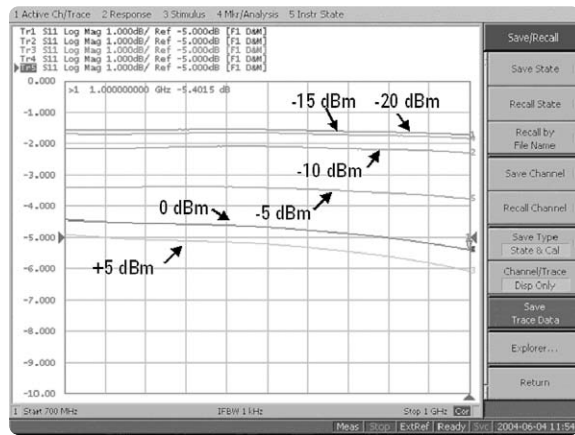


Figure 22. Effects of RF power level variation on S_{11} measurements

LO power level: The ENA uses the up/down conversion technique to perform VMC; therefore, the power of the LO signal is distributed to the calibration mixer and MUT by a power splitter. During a characteristics evaluation of the calibration mixer/IF-filter pair, the LO power level used by the drive of the calibration mixer must be equal to the LO power level with the MUT connected. This is because the calibration mixer's performance depends heavily on the LO signal power level. Consequently, we recommended characterizing the calibration mixer/IF-filter pair under the conditions where the power splitter for distributing the LO signal and the MUT are connected.

Appendix 2: Calibration Mixer Characterization for Balanced Mixer Measurements

By using the vector-mixer characterization VBA macro, it is easy to perform calibration mixer characterization for balanced mixer measurements. The characterization procedure for the calibration mixer/IF-filter pair, which is used for balanced mixer measurements, is basically the same as those used for normal mixer measurement. However, two sets of characteristic data of calibration mixer/IF-filter pairs are required for balanced mixer measurements (see Figure 23).

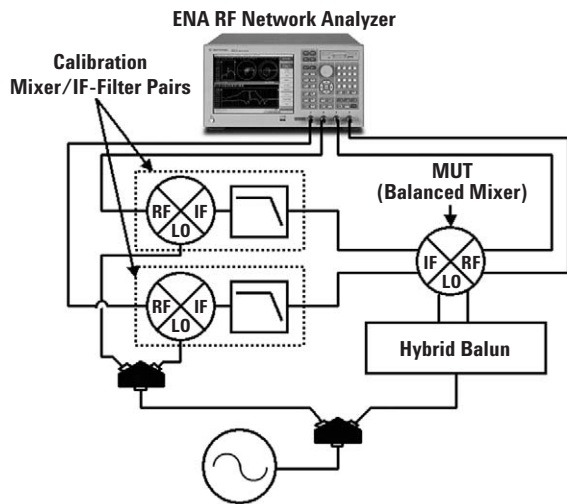


Figure 23. Balanced mixer measurement configuration

Connect the calibration mixer/IF-filter pair to the test port of a network analyzer with which calibration has been performed. Then connect the open, short, and load standards to the end of the IF-filter to begin the reflection measurement. For a balanced mixer, the phase difference of the LO signal between the calibration mixer/IF-filter pairs will remain as an error, because each calibration mixer/IF-filter pair is characterized independently. Therefore, you need to correct the phase difference between the two characterized calibration mixer/IF-filter pairs.

Before you perform the LO phase error correction with the following procedure, each characteristic data of the calibration mixer/IF-filter pair should be configured in the fixture simulator in advance.

- Press **[(Optional) Balanced Mixer]** on the vector-mixer characterization VBA macro menu and launch the balanced mixer characterization menu as show in Figure 24.
- The data file for a pre-measured calibration mixer/IF-filter (MIXER_1.s2p, MIXER_2.s2p) will be automatically imported to the VBA macro.
- Select the measurement port. Then connect a through cable between the IF-ports of the calibration mixers to correct the phase difference of the LO signals for the calibration mixer/IF-filter pairs.
- Press **[Execute]** to perform a phase error correction and overwrite the results on the original data files.

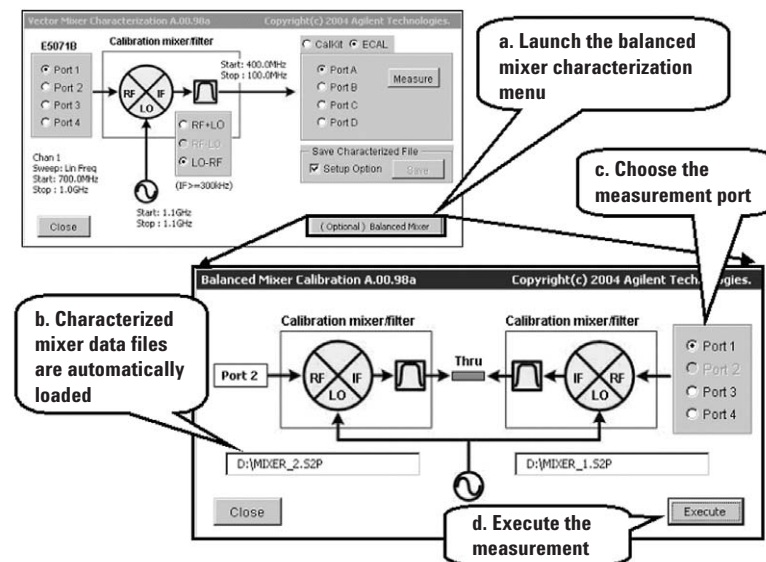


Figure 24. Balanced mixer characterization menu

Appendix 3: Setup for the External Signal Source

The ENA allows you to control the external signal source connected to the USB/GPIB interface¹. Typical Agilent signal sources such as ESG, PSG, and the 86xx Series are supported by the ENA as the standard.

To use an external signal source, we recommend that the external signal source's internal-reference signal output connector (Ref. Out) and the ENA's external-reference signal input connector (Ref. In) should be connected to each other with a BNC cable. This ensures a stable measurement because the ENA is phase-locked to the external signal source's frequency reference signal.

From the front panel of the ENA, set the GPIB address of the external signal source by using the **[SYSTEM]**. Press the **[Misc Setup]** and choose **[GPIB Setup]** and then enter the external signal source address at **[Signal Generator Address]**. Additionally, the desired signal source can be selected under this menu.

Next, set the power level and frequency range of the external signal source. In the case of VMC, the output power of the external signal source is distributed to the calibration mixer and MUT by a power splitter. Consequently, the power level needs to be set in consideration of the power splitter's loss (about 6 dB).

From the front panel of the ENA, set the power level by using **[SWEEP SETUP]**.

Press **[Frequency Offset]** and choose **[Power]** under **[External Source]** and then set the power level.

As described in the following equation, the external source frequency range can be set using a multiplier (M_{LO}), a divisor (D_{LO}), and offset (O_{LO}) for the basic frequency².

$$\text{External signal source frequency (LO)} = \text{Basic Frequency} \times M_{LO} \div D_{LO} + O_{LO}$$

For example, 1.1 GHz fixed LO frequency can be set using the following values.

External signal source (LO) setting: **[Multiplier]** = 0, **[Divisor]** = 1, **[Offset]** = 1.1 GHz

The external signal source frequency can also be set with **[Start]** and **[Stop]**, although the setting mentioned above is recommended. This allows you to automatically retain the offset value even if you have changed the setting range of the basic frequency, since the external signal source frequency is defined as a formula.

Finally, the control of an external signal source is explained. The LO frequency (LO) setting can be displayed under the screen of the ENA by using **[LO Frequency]** to turn it **[On]**. Then press **[Control]** to turn the external signal source control **[On]**, which allows you to send parameters such as frequency range and power level to the external signal source and start the control.

Appendix 4: Setup for the Power Meter

The ENA allows you to control the power meter connected to the USB/GPIB interface. From the front panel of the ENA, set the GPIB address of the power meter by using **[SYSTEM]**. Press **[Misc Setup]** and choose **[GPIB Setup]** and then enter the power meter address at **[Power Meter Address]**.

-
1. A USB/GPIB interface is necessary to control ENA peripherals, such as power meters or source generators for mixer measurements. Agilent's 82357A USB/GPIB interface is recommended.
 2. The basic frequency is a frequency range set by **[START]** and **[STOP]** keys.

Related Literature

These documents are available from the library on Agilent's website: www.agilent.com

1. *Mixer Transmission Measurements Using The Frequency Converter Application*, application note 1408-1, literature number 5988-8642EN
2. *Mixer Conversion-Loss and Group Delay Measurement Techniques and Comparisons*, application note 1408-2, literature number 5988-9619EN
3. *Improving Measurement and Calibration Accuracy using the Frequency Converter Application*, application note 1408-3, literature number 5988-9642EN
4. *Novel Method for Vector Mixer Characterization and Mixer Test System Vector Error Correction*, white paper, literature number 5988-7826EN
5. *Comparison of Mixer Characterization using New Vector Characterization Techniques*, white paper, literature number 5988-7827EN
6. *Improving Network Analyzer Measurements of Frequency-translating Devices*, application note 1287-7, literature number 5966-3318E

Web Resources

For additional information on the ENA visit: www.agilent.com/find/ena

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