MS462xx Series

SCORPION™

Vector Network Measurement Systems

APPLICATION GUIDE

Anritsu

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Table of Contents

Chapter 1 - General Information

Scope of This Manual 1-1
Introduction 1-1
System Description 1-2
Related Manuals 1-2

Chapter 2 - 3-Port Calibration

Introduction 2-1
Two Port Cals 2-1
Three Port Calibration Types 2-2
Example SOLT Calibration 2-4
LRM/TRX-Based Calibration 2-7
3-Port Cal Method Details 2-10

Chapter 3 - Noise Figure Measurement

Introduction 3-1
Noise Figure Fundamentals 3-1
Uncertainties Overview 3-3
Noise Figure Measurements 3-9

Chapter 4 - Intermodulation Distortion

Introduction 4-1
Two-Tone IMD 4-1
Measurement Flow 4-4
Measurement Variables/Receiver Cals 4-8
Flat Port Power Calibrations 4-8
Input Referrals 4-8
Measurements 4-9
Offset Frequency Selection 4-12

Chapter 5 - Harmonic Measurements

Introduction 5-1
CW RCVR vs. Swept Measurements 5-1
Uncalibrated Measurements 5-1
Enhancement Calibrations 5-5
Phase Calibration 5-9
Accuracy and Uncertainty Issues 5-11
Summary 5-11

Chapter 6 - Mixer Measurements

Introduction 6-1
Manual Conversion Loss 6-1
Other Measurements 6-6
Noise Figure Measurements 6-7
Mixer IMD Measurements 6-13

Chapter 1
General Information

1-1 SCOPE OF THIS MANUAL

This Application Guide details information on many of the special measurement capabilities of the MS462xx Vector Network Measurement System. The application information included herein specifically addresses the following MS462xx innovations:

- Three-port, error-corrected measurements of devices such as duplexers, mixers, power dividers, circulators, and couplers. A single connection provides all 9 S-parameters simultaneously for each of these three-port devices.
- Noise figure measurements where S-parameters can be included in the calculations to compensate for mismatches during the measurement. This is a vector error-corrected measurement rather than just a scalar measurement.
- Intermodulation distortion (IMD) measurements versus frequency. CW-type measurements are simple for the MS462xx, but it can also measure IMD, calculate third-order intercept (TOI), and display the results versus frequency referenced to input or output and relative to upper or lower tones.
- Vector Harmonic measurements where S-parameters are used to correct for source harmonics. Similar to IMD measurements, the harmonic measurements can be displayed versus frequency referenced to input or output.
- Simplified mixer measurements for Fixed LO and Fixed IF measurements, including conversion loss, noise figure, and (with an external Anritsu synthesizer) IMD.

This single connection, multiple measurement capability is the reason the MS462xx is named a Vector Network Measurement System instead of a Vector Network Analyzer.

1-2 INTRODUCTION

This chapter provides information to familiarize the user with the basic description of the MS462xx Vector Network Measurement System. Included is information about related manuals.

1-3 SYSTEM DESCRIPTION

The MS462xx is primarily a high performance, innovative Vector Network Analyzer (VNA) that readily, efficiently, and accurately performs S-parameter measurements. The MS462xx is especially innovative because it can also perform measurements not typically associated with a VNA. These measurements include noise figure, intermodulation distortion (IMD), and harmonics. The ability to perform these other measurements typically requires four additional instruments besides the VNA; namely, a noise figure meter, two synthesizers, and a spectrum analyzer. The MS462xx can integrate these five instruments into a single system: a Vector Network Measurement System.

In this way, the MS462xx can replace systems that require multiple instruments, test fixtures, and connections with a more straightforward integrated approach where a single connection can yield multiple useful measurements.

The innovative measurement capability of the MS462xx Vector Network Measurement System provides the outline for the following Application Guide discussions:

- 3-Port Calibration
- Noise Figure
- Intermodulation (IMD)
- Harmonic
- Mixer
  Conversion Loss
  Noise Figure
  IMD

1-4 RELATED MANUALS

This manual is one of a six manual set consisting of this Application Guide, the *MS462xx Quick Start Measurement Guide* (Anritsu part number 10410-00213), the *MS462xx Operation Manual* (Anritsu part number 10410-00203), the *MS462xx Programming Manual* (10410-00204), the *MS462xx Maintenance Manual* (10410-00205), and the *MS462xx GPIB Quick Reference Guide* (10410-00206).

Chapter 2
3-Port Calibration

2-1 INTRODUCTION

The need to quickly and accurately measure the S-parameters of three port devices is ever increasing. Production volumes of components such as duplexers, combiners, distribution amplifiers, circulators and others have increased to the point where measurement speed and simplicity are as critical as accuracy. An integrated three port measurement system, as is available in the MS462xx Vector Network Measurement System, can help achieve these goals.

An important part of these S-parameter measurements is in the calibration techniques. This chapter provides information and guidance on the use of these calibrations and how they differ from those used in standard two port measurements.

2-2 TWO PORT CALS

Why not just use two port cals? An S-parameter, on a simple level, involves only two ports at a time: in S23, the receive port is port 2 and the transmit port is port 3. One might therefore think that a collection of two-port cals might suffice for the measurement of a three port device (i.e., two port cals between ports 1 and 2, between 1 and 3, and between 2 and 3). This approach has been implemented by many users of external test sets that try to mimic a three port test set. A few problems, however, exist:

- Many calibration steps. With a standard SOLT (short open load thru) cal, this will require the connection of at least 7 cal standards for each two port cal (assuming isolation is not being corrected) for a total of 21 standards connections. While a technique such as AutoCal will help, three separate AutoCal procedures are still required and will still be fairly time-consuming. In either case, a group of 30-36 correction coefficients will usually be generated for these measurements.

- Third port effects. The collection-of-two-ports approach neglects the effect of the unused port and assumes that it is perfectly terminated. It is likely that the third port of the test set is not perfect and has some finite load match (probably no better than –20 dB over any sizable frequency range). This could cause substantial errors, particularly on devices that are quite trilateral (for example, combiners, some couplers, etc.).

- Data handling complexity. Three two-port cals now must normally be repeatedly recalled during a measurement. Since cal files are typically fairly large (particularly if many measurement points are used), this continual file transfer could noticeably increase measurement overhead.

A full three-port cal, on the other hand, treats the test set as an integrated unit and applies full correction with one unified set of calibration coefficients. In contrast to the 30-36 error coefficients needed before, the global three-port calibration will only need 18-24 coefficients (again depending on if isolation is included or not). The number of standards connections is also reduced: down to 11-12 for SOLT calibrations or even 7 for a TRM/TRX calibration (assuming isolation is excluded). The time savings from this reduction, and from only processing a single calibration file, can be significant. Also since the load match of the third port is automatically included, another potential inaccuracy is avoided.

2-3 THREE PORT CALIBRATION TYPES

While there are many ways that the three-port calibration sequence could have been implemented, a path was chosen to maximize flexibility with which different types of calibrations and calibration components are used. Presently, all three port calibrations start with a two port calibration. This two port calibration can be done using any of the available techniques:

SOLT (standard) Uses a short, open and load on each port together with a thru line between ports 1 and 2. The load may be fixed or sliding. This is the most common calibration selection and usually works well for coaxial systems.

LRL Uses a reflect standard (often a short) at each port together with two different line lengths connected between ports 1 and 2. This method is particularly valuable for on-wafer and other testing where open standards are difficult to implement. It is somewhat band-limited and may require additional line standards for wider bandwidths.

LRM Uses a reflect standard and a fixed load at each port together with a thru line between ports 1 and 2. Similar to LRL in its value for on-wafer test but simpler to implement and more broadband.

Offset Short Uses a load and two shorts (different offset lengths) at each port together with a thru line between ports 1 and 2. This method is often used for waveguide systems.

TRM A simplified version of LRM using similar standards.

AutoCal An automated calibration system that requires connecting the AutoCal box to ports 1 and 2 (as well as connecting power and serial communications cables). The box contains internal impedance and thru standards that enable a transfer calibration in 1 step. The primary advantage is improved time efficiency in a higher measurement throughput environment.

Further details on all of these calibration methods are available in the *MS462xx Operation Manual* (Anritsu part number 10410-00203).

The user must select a calibration appropriate to the hardware involved. The number of calibration steps required for this two-port phase will vary with the calibration type selected. An isolation step is optional in all two port calibrations, and if an isolation step is used for the two port calibration, it must also be used for the three port completion step. Similarly, if isolation is omitted during the two port calibration, it will not be performed during the three port completion step.

Once the two port calibration has been successfully performed, the user may select one of two varieties of three port calibration completion steps.

SOLT Very similar to the standard two port method and requires connecting an open, a short, and a load to port 3 as well as a thru line between port 1 and 3 (and possibly between 2 and 3). The connector type on port 3 must also be specified since open standard coefficients must be applied (in some cases, it is quite critical to load the coefficient data corresponding to the particular cal kit being used). The connector type need not be the same as for port 1 or for port 2. The SOLT calibration is quite stable for coaxial systems and will almost always perform adequately.

TRX Very similar to the LRL/LRM/TRM family of calibrations and requires connecting a short to port 3 (presently not allowed to be an ambiguous reflection) and a thru line between port 1 and port 3. The offset of the short plane must be specified as in LRL/LRM/TRM and the length of the thru must be specified as well. Fewer connections are required for this cal and it is more amenable to on-wafer calibrations. The required care and quality of calibration is somewhat higher as is the case with the LRL/LRM/TRM family.

Once the calibration method is selected, some attention must be paid to where the reference planes are located. With larger DUTs, cables are commonly connected to all three ports and the reference planes are established at each of the cable ends. The only important requirement is if the port 3 reference plane is not connected to the port 1 reference plane (that defined during the two port calibration) during the 3 port thru step, then the appropriate length of the thru line must be entered. The scenario just described does not fall into the common ‘zero-length-thru’ category.

2-4 EXAMPLE SOLT CALIBRATION

This section contains an example of a SOLT-based calibration sequence and measurement. The device to be tested is a PCS duplexer with a selected frequency range of 1800-2100 MHz and 201 points. The connectors are all SMA and the power level will be the default 0 dBm. Cables were connected to all three ports and the reference planes will be established at the end of each cable.

1. Perform a 12-term two-port cal.

The standard SOLT cal is used with the above frequency range. Isolation is excluded (for both this and the three port completion). The connector types are SMA (F) on port 1 and SMA (M) on port 2. A standard SMA/3.5 cal kit was used without the sliding load and with mixed components

- ❑ Connect broadband loads to port 1 and 2 cable ends. Measure.
- ❑ Connect an open to port 1 cable end and a short to port 2 cable end. Measure.
- ❑ Connect a short to port 1 cable end and an open to port 2 cable end. Measure.
- ❑ Connect a thru line between ports 1 and 2 (zero length in this case since the cables are simply connected together). Measure.

This completes the steps for the two port calibration. The reference planes for ports 1 and 2 have been established at the ends of their cables.

2. Perform the three port completion.

The SOLT method was selected for this step also. Since isolation was excluded during the two port cal, it will also be excluded here automatically. The port 3 connector type is SMA (M). The same cal kit components were used for these substeps as in step 1.

- ❑ Connect a thru line between ports 1 and 3 (zero length in this case since the cables are simply connected together). Measure.
- ❑ Connect an open to port 3 cable end. Measure.
- ❑ Connect a short to port 3 cable end. Measure.
- ❑ Connect a broadband load to port 3 cable end. Measure.

This completes the steps for the three port calibration. The ‘cal plus front panel setup’ may now be saved to disk or to memory

3. Perform the measurement.

The duplexer was connected to the system. Four of the most pertinent of the nine S-parameters for the DUT are shown in Figure 2-1 (port 1 is the common port of the DUT) .

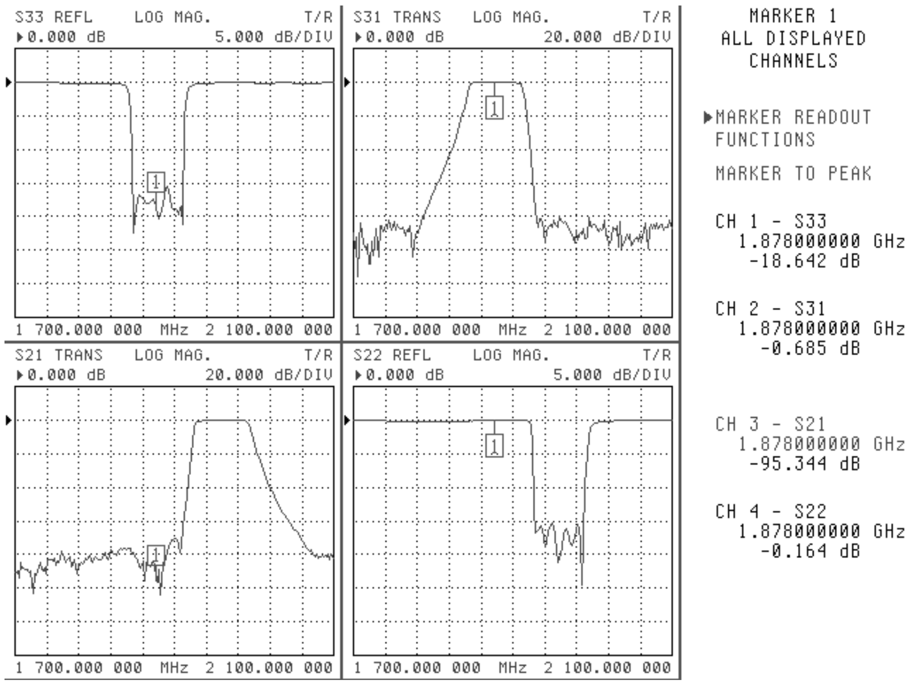


Figure 2-1. *S33, S31, S21, and S22 for a PCS Duplexer*

The filter responses and isolation levels are what one might expect for a commercial PCS duplexer. All of these measurements were performed with the single unified calibration sequence described above and any of the nine S-parameters can be combined onto any screen. A 1 kHz IF bandwidth with one average was used for all of these measurements. With 201 points, the sweep time was between 200 and 300 ms with an observed dynamic range in excess of 95 dB (see Figure 2-1).

Since the source power of 0 dBm was used, greater dynamic range or lower sweep times are possible while still observing the required performance of this DUT. Another S-parameter, S11, for this DUT was segregated to illustrate an earlier point about the danger of trying to measure a three port DUT with a two port calibration. The plot in Figure 2-2 shows the |S11| obtained using a full three port calibration and one obtained with just a two port calibration.

The two traces (one saved using trace memory) show the result using a global three port cal and the result using just the base 2 port cal while leaving port 3 connected to the instrument. The neglect of load match can lead to errors in the latter case.

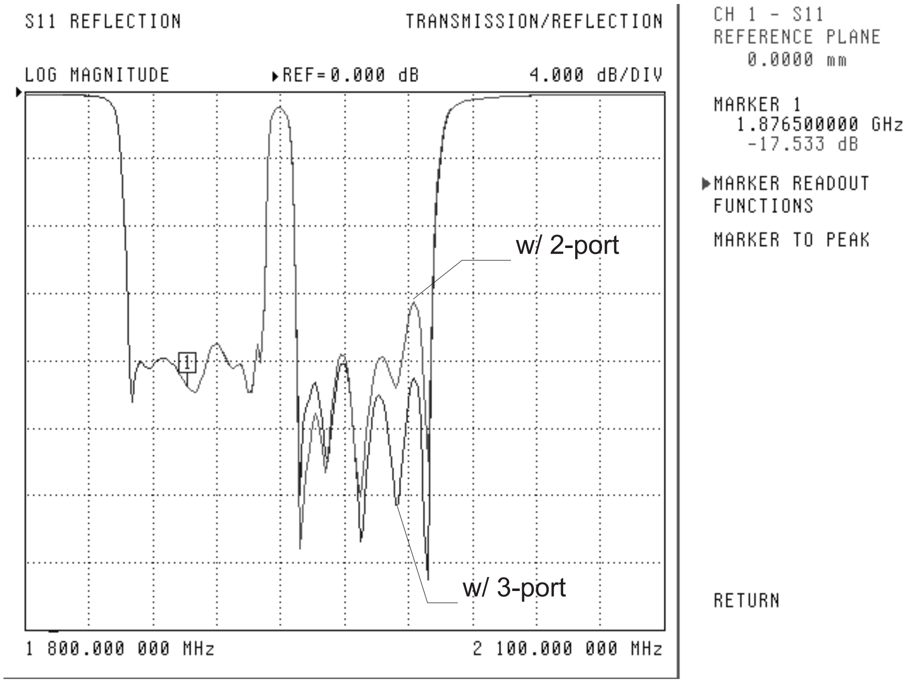


Figure 2-2. *Plot of S11 of the Duplexer Comparing 3-port and 2-port Calibration Results*

As one can see, the errors in measurement can sometimes be severe if an inappropriate cal is not used. In this case, the two port cal (performed between ports 1 and 2) does not take into account the load match at port 3 (on the order of –18 dB). The resulting problems are most severe in the passband of the path between ports 1 and 3 (from about 1930 MHz to 1990 MHz). Here, the measured S11 is affected not only by the DUT filter but also by the terminating port impedance.

2-5 LRM/TRX-BASED CALIBRATION

This section contains an example of an LRM/TRX-based calibration sequence and measurement. The device to be tested is a simple Wilkinson combiner with a selected frequency range of 1000-2000 MHz and 201 points to be measured with a 1 kHz IF BW. The connectors are all SMA and the power level will be the default 0 dBm. This cal type might not normally be used with such a simple device and connector structure but it is done here primarily to illustrate another calibration sequence. Cables were connected to all three ports and the reference planes will be established at the end of each cable.

1. Perform a 12 term two-port cal

The LRM cal is used with the above frequency range. Isolation is excluded (for both this and the three port completion). The connector types are SMA (F) on port 1 and SMA (M) on port 2. A standard SMA/3.5 cal kit was used without the sliding load. A short will be used as a reflection standard (with a 5 mm offset as in this cal kit) and a zero-length thru will be employed for the thru line step of the calibration.

- ❑ Connect a thru line between ports 1 and 2. (zero length in this case since the cables are simply connected together). Measure.
- ❑ Connect fullband matches to the cable ends from ports 1 and 2. Measure.
- ❑ Connect a short to the port 1 cable end. Measure.
- ❑ Connect a short to the port 2 cable end. Measure.

This completes the steps for the two port calibration. The reference planes for ports 1 and 2 have been established at the ends of their cables.

2. Perform the three port completion.

The TRX method was selected for this step. Since isolation was excluded during the two port cal, it will also be excluded here automatically. The port 3 connector type is SMA (M). The same calibration kit components were used for these substeps as in step 1. As in that previous step, a zero-length thru is used and the reflective device offset is 5mm.

- ❑ Connect a thru line between ports 1 and 3. (zero length in this case since the cables are simply connected together). Measure.
- ❑ Connect a short to port 3 cable end. Measure.

This completes the steps for the three port calibration. The ‘cal plus front panel setup’ may now be saved to disk or to memory

3. Perform the measurement.

The combiner was connected to the system (port 1 connected to the summing port of the combiner). Four of the most pertinent of the nine S-parameters for the DUT are shown in Figure 2-3, and the results conform to expectations.

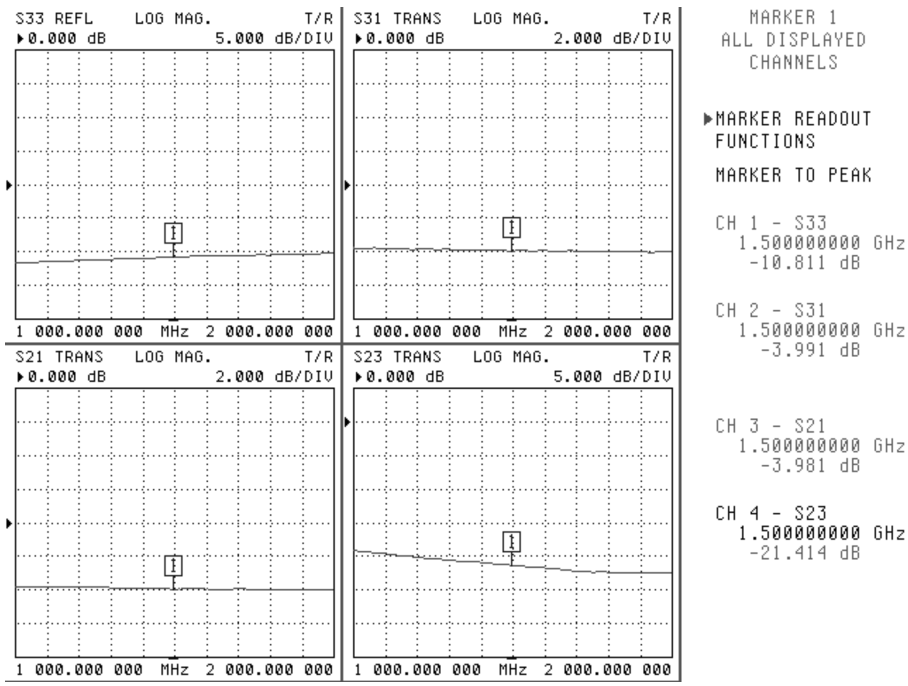


Figure 2-3. *Four of the most relevant S-parameters of a simple Wilkinson combiner.*

While not a particularly demanding measurement, this sequence shows the expected results for a simple combiner. The main thru-path insertion losses (S21 and S31) are consistent and easily meet their specifications. The isolation measurement (S23) also produces expected results with a difference between desired and undesired transmissions around 17 dB at midband.

Another important parameter, S11, was isolated as before for further examination. This parameter is shown in Figure 2-4 when both the above 3 port cal is applied and when only a two port cal is applied. The effect of not correcting for the port 3 load match is quite obvious in this highly trilateral device.

S11 of the combiner is shown here with both a 2-port and a 3-port cal applied. The 2-port cal ignores the contribution of the port 3 load match and the results can be severe since the device is quite trilateral.

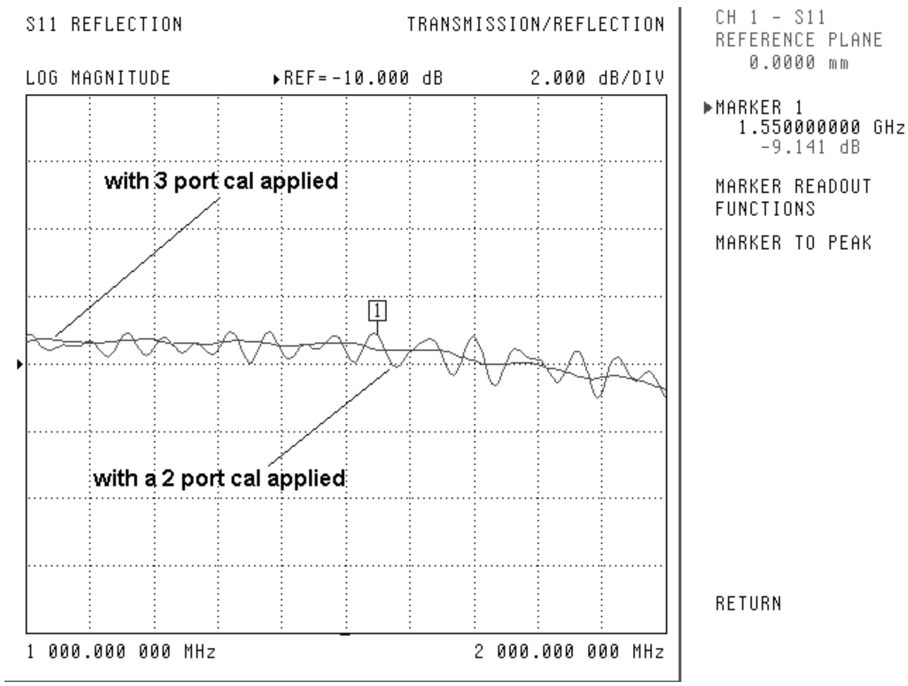


Figure 2-4. *S11 of the Combiner*

For the same level of uncertainty, extra care during calibration is normally required for LRL/LRM/TRX methods (ensuring connections are tight, cables not stressed, components are clean and undamaged, etc.) than for SOLT methods due to lower levels of data redundancy. It is, however, a method capable of high accuracy, is more compatible with on-wafer measurements, and requires fewer standards connections.

2-6 3-PORT CAL METHOD DETAILS

The basic error model for two port calibrations consists of 12 error coefficients that correct for non-idealities in the VNA test set. Both of the three port calibrations discussed expand this set of coefficients to 24, which can be grouped as follows:

Basic two port cal	12 terms
Port 3 directivity and matches	3 terms
Port 3 tracking	5 terms (to and from the other ports + reflection tracking)
Additional isolation terms	4 terms

The model is illustrated in Figure 2-5 shows the error boxes that embody the error terms. The isolation and transmission tracking terms (12 out of the 24) involve paths between ports and are not shown directly in the figure. The 12 other terms (source and load match, directivity, and reflection tracking) are associated with each individual error box. Both three port completion steps will start with a two port calibration (first 12 terms) and will use the same isolation measurement steps to get the last 4 terms. The two methods differ in how they find the middle 8 terms in the above list

As one might expect, the SOLT version first proceeds by performing a one port cal on port 3 by measuring an open, a short and a load. These measurements allow the computation of source match, directivity and reflection tracking terms. The remaining thru line measurement(s) allows the computation of load match and the required transmission tracking terms to complete the model.

The TRX method follows in the path of the LRL/LRM/TRM methods and exploits some of the data redundancy in the standard SOLT approach. The thru line measurement allows the direct computation of directivity, load match and some of the transmission tracking terms. The short measurement allows direct computation of the source match and the completion of calculation of the remaining tracking terms.

Since the 24-term model is shared between the two methods, the calibration will be applied in the same way for both via a matrix equation system.

Figure 2-5 illustrates the three port error model. An error box is associated with each port that contains the coefficients describing that port's non-idealities.

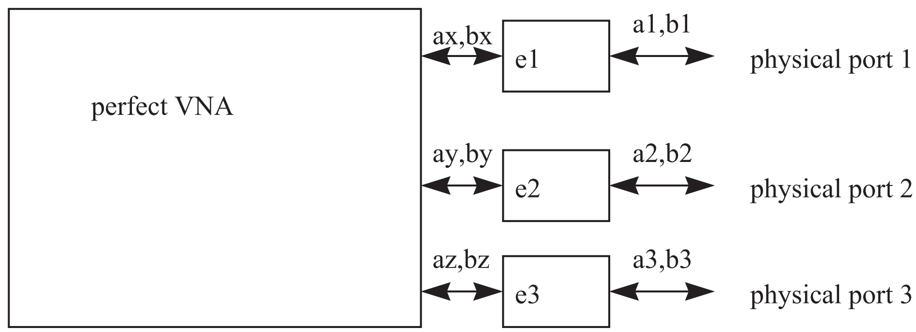


Figure 2-5. *Three Port Error Model*

Chapter 3
Noise Figure Measurement

3-1 INTRODUCTION

This chapter addresses one of the innovative measurement capabilities of the MS462xx Vector Network Measurement System; the ability to perform vector error-corrected noise figure measurements with a single measurement system. This chapter provides enough information to perform and to understand vector error-corrected noise figure measurements using the MS462xx Vector Network Measurement System.

3-2 NOISE FIGURE FUNDAMENTALS

It is essential to understand noise figure and the traditional scalar approach in order to appreciate the accuracy improvement of the vector error-corrected approach. Appropriately, the fundamentals begin with the similarities between the scalar and vector approach.

The most important parameter that quantifies a device's ability to process weak signals is noise figure. The following equation is the noise figure equation:

$$F\,(\mathrm{dB}) = 10 \bullet \log \left[\frac{\left(\frac{S_I}{N_I}\right)}{\left(\frac{S_O}{N_O}\right)} \right]$$

Noise figure, typically expressed in dB, is the log ratio of the input signal-to-noise ratio to the output signal-to-noise ratio.

This definition quantifies the amount of thermal and shot noise generated within a device. More noise generated within a device causes more degradation in the output signal-to-noise ratio. This degradation causes a higher noise figure.

The following diagram presents the scalar noise figure measurement configuration using the MS462xx. In this configuration, the noise source location is external.

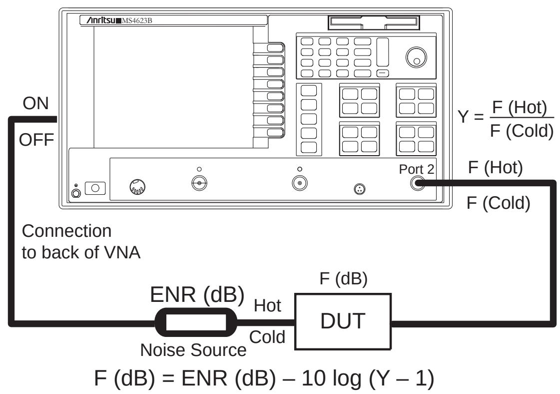


Figure 3-1. *Scalar Noise Figure Measurement Configuration*

Noise figure measurements employ the Y-Factor method for measuring noise figure. This method uses a calibrated (NIST traceable) broadband noise source to apply two different noise signals to the DUT. Within the noise source, the application and removal of bias to an avalanche diode causes the transition between these two noise signals. With bias, the first noise signal (hot) is large, but calibrated. Without bias, the second noise signal (cold) is small. Note that there could be impedance changes (caused by changing diode impedance with bias) between these hot and cold states. The ratio of measured power in these two cases (hot/cold) leads to the Y-Factor.

The simplified noise figure equation in terms of the Y-Factor (assuming Tc = To) is shown below.

$$F\ (dB) = ENR\ (dB) - 10 \log (Y - 1)$$

Frequency translation within the measurement instrument allows noise figure measurements at reasonable IF frequencies. There may be multiple frequency translations in some instruments. In this situation, the overall noise figure is the cascade of both the DUT noise figure and the instrument receiver noise figure.

The following diagram shows how the cascaded noise figure equation allows removal of the instrument receiver noise figure from the overall noise figure measurement. Note that F_2 is acquired during calibration.

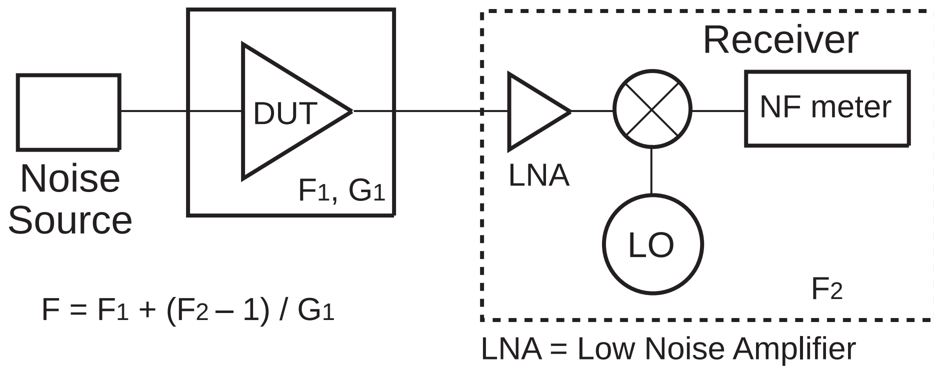


Figure 3-2. *Cascaded Noise Figure*

Solving this equation for F_1 allows the instrument to calculate the DUT noise figure from the overall cascaded noise figure measurement. The following equation shows the results after solving for F_1.

$$F_1 = F - \{(F_2 - 1) / G_1\}$$

Note that this equation indicates that the second-stage contribution becomes more significant as the DUT gain decreases.

Indeed, the foundation of both scalar and vector approaches is similar. Both approaches use the noise figure definition, the Y-Factor method for measurement, and the cascaded noise figure equation to remove the measurement receiver noise figure effect. A comparison of these approaches beyond this foundation continues with a discussion of the uncertainties that affect measurement accuracy.

3-3 UNCERTAINTIES OVERVIEW

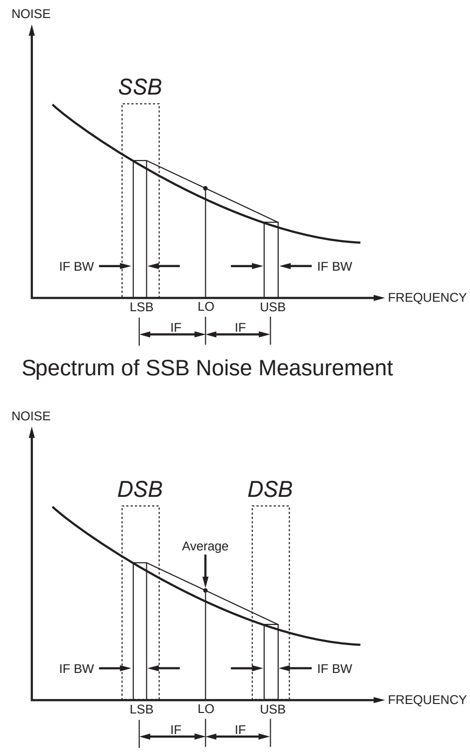
When measuring small noise figure values, measurement uncertainties become more significant regardless of the measurement approach. A discussion of factors that contribute to measurement uncertainty emphasizes the differences between the scalar and vector approaches. Many sources can contribute to measurement uncertainty considering each one of these sources during measurements can result in more accurate measurements.

Good Measurement Practice

Good measurement practice is the foundation of all accurate noise figure measurements. Be aware of interference and avoid measurements in occupied RF or IF frequencies of the test environment. Minimize interference by using shielded cables, threaded connectors, enclosures, and shielded rooms for the DUT. Cables and connectors should be clean and of high quality. Avoid any DUT discontinuities and spurious responses. These simple steps can eliminate significant uncertainties.

Receiver Architecture

The receiver architecture includes the frequency translations that allow measurements at reasonable IF frequencies within the measurement instrument. The receiver architecture is either a single or a double sideband architecture. A description of these receiver architectures is appropriate before discussing their contribution to measurement uncertainty. The following diagrams show the included frequencies for both receiver architectures.



Spectrum of DSB Noise Measurement

Figure 3-3. *Included Frequencies for Both Receiver Architectures*

In the traditional scalar approach, a single sideband (SSB) receiver architecture performs the frequency translation. By definition, *either* the upper (USB) *or* lower (LSB) sideband is translated to an intermediate frequency (IF). Under certain circumstances, the SSB receiver architecture can be less susceptible to abrupt DUT noise figure variations versus frequency (i.e., band limited devices).

In the vector approach, a double sideband (DSB) receiver architecture performs the frequency translation. By definition, *both* the upper (USB) *and* lower (LSB) sidebands are translated to an IF. An average of both the upper and lower sidebands represents the measurement. A significant advantage of this DSB receiver architecture is that one receiver can perform both a noise figure measurement and an S-parameter characterization. The combination of these two measurements is an accurate vector error-corrected noise figure measurement.

Uncertainties related to receiver architecture are an issue for measurements where noise figure varies substantially versus frequency. Band limited devices exhibit this type of noise figure performance. A DSB receiver architecture can be more susceptible to DUT noise figure variations than an SSB receiver architecture; however, a narrowband (as opposed to a wideband) DSB receiver architecture can accurately measure this kind of DUT performance.

Receiver Architecture Comparison

The best way to evaluate these receiver architectures is to understand noise figure variation and the effect on uncertainty. Clearly, significant uncertainty is introduced when there is a noise figure variation in the frequency range of the measurement. An example of this type of variation is exhibited in band limited devices. Obviously, more noise figure variation can be accommodated by limiting the amount of frequency included in the measurement. This observation implies that less measurement frequency range allows more noise figure variation. Considering the frequency range included in the measurement will be the basis for evaluating the two receiver architectures.

The following diagram shows the included frequencies for the traditional scalar SSB noise measurement architecture.

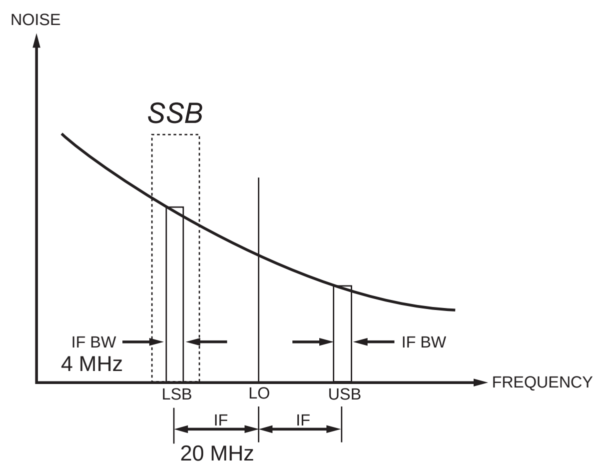


Figure 3-4. *Traditional Scalar SSB Noise Measurement Architecture*

In the traditional scalar receiver architecture, the IF is 20 MHz and the bandwidth is 4 MHz. The frequency measurement range is 4 MHz with this SSB receiver architecture. Note that this traditional scalar approach contains more uncertainty as the bandwidth of the DUT decreases from 4 MHz. This frequency range represents the standard for comparison with the following wideband and narrowband DSB receiver architectures.

Next, the following diagram shows the included frequencies for the wideband DSB noise measurement architecture.

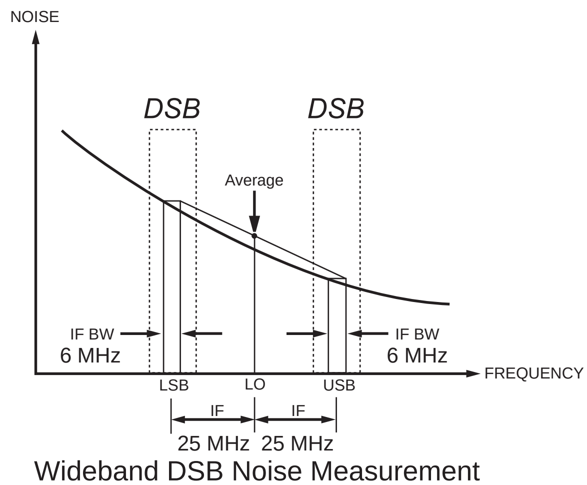


Figure 3-5. *Wideband DSB Noise Measurement Architecture*

In the wideband DSB receiver architecture, the IF is 25 MHz and the bandwidth is 6 MHz. The frequency measurement range is comprised of 12 MHz of frequency separated by 44 MHz, or 56 MHz (12 + 44 MHz). As expected, this architecture can be more susceptible to DUT noise figure variations than the SSB architecture, which only used 4 MHz. This comparison indicates more measurement uncertainty can be associated with the wideband DSB receiver architecture than the SSB receiver architecture. Finally, the following diagram shows the included frequencies for the narrowband DSB noise measurement architecture.

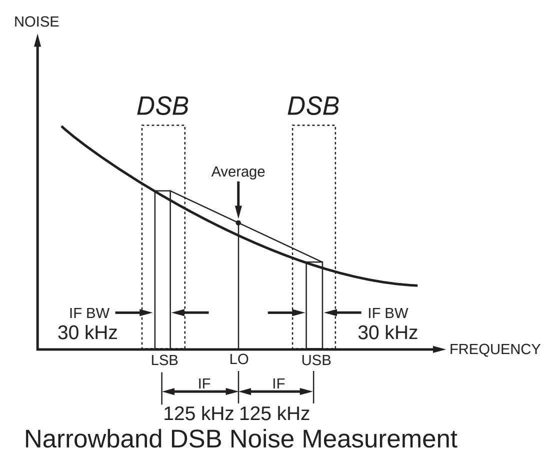


Figure 3-6. *Narrowband DSB Noise Measurement Architecture*

In the narrowband DSB receiver architecture, the IF is 125 kHz and the bandwidth is less than 30 kHz. Similarly, the frequency measurement range is comprised of 60 kHz of frequency separated by 220 kHz, or 280 kHz (60 + 220 kHz). This narrowband DSB architecture can be less susceptible to DUT noise figure variations than both the SSB and wideband DSB architectures. In addition, this narrowband DSB approach allows more accurate measurement of band limited devices than the traditional scalar approach (particularly as the DUT bandwidth decreases from 4 MHz). This comparison clearly shows that the least measurement uncertainty can be associated with the narrowband DSB receiver architecture.

Using the DSB receiver architecture of the Vector Network Measurement System allows more accurate vector error-corrected noise figure measurements. In addition, the narrowband DSB receiver architecture can be less susceptible to noise figure variations than the traditional scalar approach.

Insertion vs. Available Gain

The noise figure calculation is a function of the Y-Factor, the receiver noise figure, and the available gain. The uncertainty associated with removal of the receiver (or second-stage) noise figure depends on whether insertion or available gain is included in these calculations. For this reason, a more detailed description of insertion and available gain provides a better understanding of their effect on measurement uncertainty.

Second-stage uncertainty occurs because the receiver following the DUT has a noise figure. The evaluation of this second-stage effect is not straight forward. The cascaded noise figure equation for correction is $F_1 = F_{meas} - [(F_2 - 1) / G_1]$, where G_1 is the available gain of the DUT. The scalar approach substitutes insertion gain for available gain in this equation; whereas, the vector approach calculates available gain directly from the S-parameter characterization. By definition, the available gain provides the more correct measurement.

Insertion gain measurements are based on the existing matches in the test setup. The first measurement takes place with the noise source connected to the receiver. The second measurement takes place with the DUT connected between the Noise Source and the receiver. By definition, the ratio between these two measurements (second/first) is insertion gain. Note that the power measurement is always made at the input of the receiver; therefore, accommodations for mismatches are not possible. Indeed, mismatches can contribute significant uncertainty for the scalar approach.

Available gain is the ratio of power available from the DUT to power available from the source. Note that S-parameter characterization provides the DUT input and output reflection characterization for these measurements. Accordingly, available gain is more accurate because it takes into account the effect of mismatches during measurements.

Available gain calculations can minimize the uncertainties of mismatches and second-stage removal calculations by including S-parameter characterization during the measurement. Specifically, available gain addresses mismatches during measurements which allows more accurate removal of the second-stage noise figure and results in a more accurate vector error-corrected measurement.

Instrument Related

The Excess Noise Ratio (ENR) uncertainty, instrumentation uncertainty, and instrument noise figure contribute to overall uncertainty in the noise figure measurement. Explanation of these uncertainties is straightforward and applicable for both approaches.

Clearly, the ENR accuracy of the noise source contributes heavily to the accuracy of the noise figure measurement. Calibration of the noise source with devices from NIST provides the greatest accuracy. Maintain ENR accuracy by ensuring calibration of the noise source at regular intervals. Both scalar and vector approaches are susceptible to this uncertainty.

In application, the ENR values provided by the manufacturer assume perfect matches; consequently, any mismatches introduce significant ENR accuracy uncertainties. The error-corrected approach adjusts the ENR values to reflect the matching characteristics of the measurement including impedance changes between the “on” and “off” states of the noise source. In addition, the error-corrected approach supports ENR extension compensation for routing the noise through the Vector Network Measurement System to the test port. The traditional approach does not address these sources of uncertainty.

Instrumentation uncertainty affects the repeatability of measurements. Typically, higher performance receivers contribute less uncertainty. Know the instrument specifications and their contribution to this uncertainty.

One very important specification is the noise figure of the instrument. The higher the noise figure of the instrument, the more uncertainty associated with the second-stage removal calculations. The second-stage uncertainty becomes more significant as the DUT available gain decreases. In this case, the receiver noise figure is a more significant portion of the measurement and, consequently, more difficult to remove. Again, the error-corrected approach can help minimize this uncertainty.

3-4 NOISE FIGURE MEASUREMENTS

This section provides a procedure for performing a noise figure measurement using the MS462xx Vector Network Measurement System. This procedure requires a basic understanding of the preceding discussions. This section also briefly explains menu nomenclatures and calibration considerations. Upon completion of the section, noise figure measurements will be straightforward and intuitive to perform using the MS462xx.

Noise Figure Application

Selection of the applications key (Appl) is the first step in the procedure for performing a noise figure measurement. Selection of the Appl key provides the following Noise Figure Application Menu Structure:

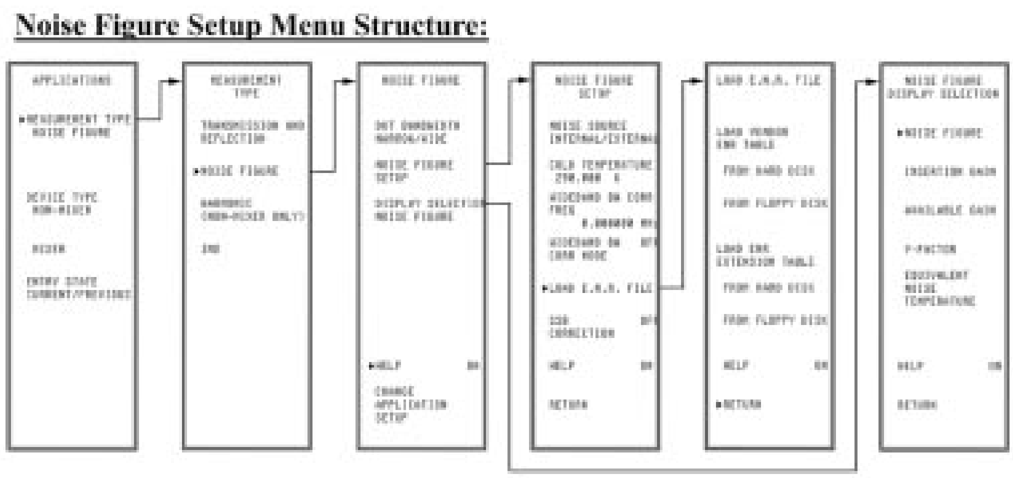


Figure 3-7. *Noise Figure Application Menu Structure*

This menu tree allows configuration of the noise figure measurement. A thorough understanding of this menu structure is required for the rest of this discussion; therefore, a brief explanation is appropriate.

The first menu on the left is displayed following the selection of the Appl key. The second menu is displayed following the selection of MEASUREMENT TYPE. Similarly, the third menu is displayed following the selection of NOISE FIGURE. At this point, the MS462xx is configured for a noise figure measurement.

From the NOISE FIGURE application, selection of NOISE FIGURE SETUP displays the NOISE FIGURE SETUP menu. Similarly, selection of DISPLAY SELECTION brings up the DISPLAY SELECTION menu.

Selection of LOAD E.N.R. FILE from the NOISE FIGURE SETUP menu displays the LOAD E.N.R. FILE menu.

Note that each menu has a title corresponding to the functions available in the menu.

The Calibration Menu Structure is also referenced during this discussion.

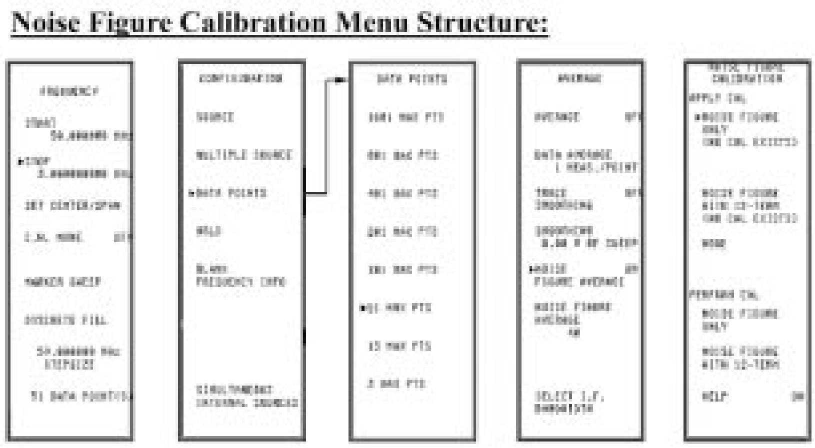


Figure 3-8. *Noise Figure Calibration Menu Structure*

It is important to note that the calibration menus are not sequential in their implementation. This means that frequency, data points, and averaging are accessible in any sequence as long as all these settings are in place before calibration. In addition, the Frequency, Configuration, Average, and Noise Figure Calibration menus are all accessible as front panel key selections. Specifically, the Frequency and Configuration keys are in the Stimulus area of the front panel and the Average and Noise Figure Calibration keys are in the Enhancement area of the front panel.

The Noise Figure Setup Menu structure and the Noise Figure Calibration Menu structure provide the primary interface for configuring the noise figure measurement.

Hardware Organization

The noise figure measurement application requires the location of the noise source to correctly configure the instrument for measurement. The two choices are external or internal. The following photos show the noise source location for both configurations.

Noise Figure Setup

Reference the Setup Menu Structure for the following noise figure setup discussion.

The MS462xx is configured for a noise figure measurement when NOISE FIGURE is selected as the Measurement Type. Next, the setup procedure further configures the system for the noise figure measurement by specifying the DUT Bandwidth, the Noise Source Location, and the loading of the appropriate ENR Files. The remaining setup parameters allow Cold Temperature, Bandwidth Correction, and SSB Correction selection.

The following table provides further explanation for these setup parameters.

Setup Parameter	Explanation
DUT Bandwidth	Wide indicates that the DUT noise figure performance is relatively broadband (BW≥ 6 MHz). Wide also provides the fastest measurement. Narrow allows measurements for band limited DUTs (BW< 6 MHz).
Noise Source	Internal indicates that the Noise Source is connected to the rear panel. External indicates that the Noise Source is not connected to the rear panel. Note that Eternal Error-corrected measurements are not possible.
Local ENR File	This controls the loading of the ENR values.
__Load Vendor ENR Table	This refers to the ENR values for the noise source. The table on the noise source(s) is stored in a tab-delimited ASCII format for retrieval.
__Load ENR Extension Table	This refers to the S-Parameter characterization file between the rear panel noise source connection and the Test Port 1 connection on the DUT. This file contains up to 101 points and combines S2P data with the noise source reflection coefficient data.
Cold Temperature	This represents the noise source temperature for the measurement.
Wideband BW Corr Freq	For DUT bandwidth = Wide, this allows bandwidth correction when Narrowband is not desired. This frequency should correspond to the “brick wall” bandwidth of the DUT.
Wideband BW Corr Mode	For DUT Bandwidth = Wide, this allows enabling and disabling of the BW Correction.
SSB Correction	This allows compensation for a DUT (usually a mixer) with single sideband (SSB) behavior.

Noise Figure Calibration

Refer to the Calibration Menu Structure for the following noise figure calibration discussion.

The calibration procedure combines the previous noise figure setup with the system settings for Frequency, Data Points, and Noise Figure Averaging for a noise figure calibration. This calibration can include 12-term correction when using the Internal selection for Noise Source.

The following table provides further explanation for these calibration parameters.

Calibration Parameter	Explanation
Frequency	Specify the Frequency range for the noise figure measurement. The Start and Stop frequencies correspond to the frequencies of the lower (LSB) sidebands. Typically, a range slightly larger than the passband is chosen. Alternately, the range of the 12-term calibration is chosen.
Data Points	Specify the Number of Points for the noise figure measurement. The noise figure measurement more time for more data points.
Noise Figure Average ON/OFF	This allows enabling and disabling of the Noise Figure Averaging function.
Noise Figure Average	This indicates the quantity of measurements to include in the averaging function. The default value is 40 and this averaging is adequate for both Wideband and Narrowband measurements.

The noise figure calibration requires a decision whether to include the 12-term calibration. When including the 12-term calibration, the noise figure calibration defaults to the exact system settings as the 12-term calibration. The relevant system settings include Start Frequency, Stop Frequency, and Data Points. For this reason, these system settings are important to consider before the noise figure measurement.

An example clarifies this concern. Consider an amplifier with a 3 dB noise figure between 800 and 900 MHz. The relevant system settings for a typical S-parameter calibration are 201 Data Points between 750 and 950 MHz. These same system settings for noise figure would lead to a noise figure measurement that typically only requires 15 Data Points. Considering the noise figure system settings before selecting the S-parameter system settings will help optimize both measurements for speed.

A noise figure calibration is straightforward with or without the 12-term calibration. The noise figure calibration only requires one through connection between the noise source and the MS462xx receiver. The S-parameter of this through connection are simultaneously measured when Noise Figure with 12-term is selected.

Noise Figure Measurement

Refer to the Setup Menu Structure for the following noise figure measurement discussion.

The noise figure measurement follows the calibration process. Choosing between the Display Selections allows convenient viewing of the noise figure measurement results. The Display Selections are accessible from the Noise Figure Application and include Noise Figure, Insertion Gain, Available Gain, Y-Factor, and Equivalent Noise Temperature.

The following table provides further explanation of these Display Selections.

Display Selection	Explanation
Noise Figure	With 12-term calibration applied, this represents vector error-corrected noise figure; otherwise, this represents scalar noise figure.
Insertion Gain	Available with or without 12-term correction, this represents the gain measurement making no correction for matching characteristics.
Available Gain	Only available with 12-term correction, this represents the gain as determined by the S-parameter measurements.
Y-Factor	The DUT output measurement ratio between the hot and cold states of the noise source.
Equivalent Noise Temperature	The temperature of a resistor whose noise power is equal to the input-referred noise-added power of the DUT.

An example clarifies the use of these Display Selections. Consider a scalar noise figure measurement output which consists of both insertion gain and noise figure. The following table outlines a procedure to configure the Vector Network Measurement System for the appropriate output.

Step	Action	Description
1	Press Ch 1 on the front panel.	Selects Channel 1 as the active channel.
2	Display/Graph Type/Log Magnitude.	Change Graph Type to Log Magnitude.
3	Appl/Display Selection/Noise Figure.	Change Display Selection to Noise Figure.
4	Display/Scale Resolution.	Adjust the Scale.
5	Press Ch 3 on the front panel.	Selects Channel 3 as the active channel.
6	Display/Graph Type/Log Magnitude.	Change Graph Type to Log Magnitude.
7	Appl/Display Selection/Insertion Gain.	Change Display Selection to Insertion Gain.
8	Display/Scale/Resolution.	Adjust the Scale.
9	Display/Display Mode/Overlay Dual Channels 1 & 3.	Change Display Mode to Overlay Dual Channels 1 & 3.

A similar procedure allows comparison between insertion gain and available gain. Simply replace the noise figure display above (Step 3) with available gain (and make sure the calibration includes the 12-term correction).

Another interesting output is the use of Trace Memory (Display/Trace Memory) on a Single Channel (Display/Display Mode/Single Channel) to make comparisons between vector error-corrected and scalar noise figure measurements. Clearly, this flexible output capability allows some creativity in displaying the measurement results.

Typical Noise Figure Data for an Amplifier

The previous sections provide the foundation for performing a noise figure measurement using the MS462xx. The following data demonstrates the application of this noise figure measurement for a typical amplifier. The emphasis is on application rather than the measurement setup, calibration, and display details. In this way, the flexibility of this noise figure measurement capability is clearly demonstrated.

The typical data includes S-parameter and noise figure measurement data. The S-parameter data consists of input and output matching characteristics (S11 & S22), isolation (S12), and gain (S21). This data is displayed in four-channel log magnitude format. The noise figure data consists of traditional scalar and vector error-corrected noise figure measurements using overlay dual channels.

The amplifier has the following typical specifications.

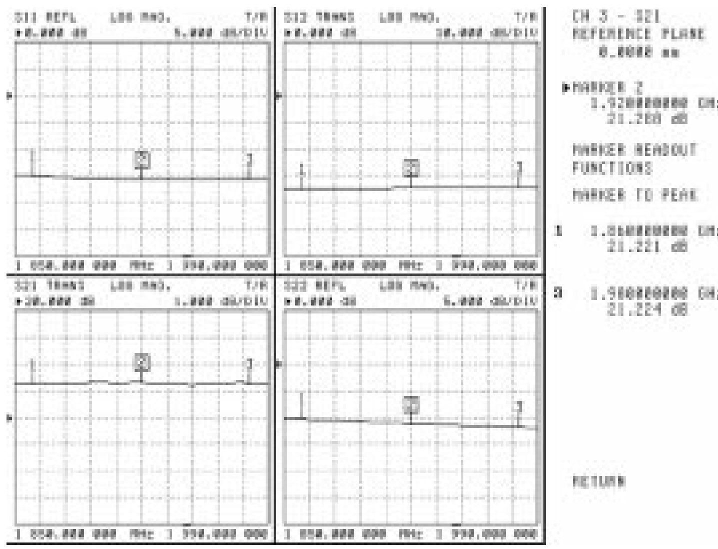
Parameter	Specification
Frequency Range	1850 to 1990 MHz
Gain	21 dB
Noise Figure	1.0 dB
1 dB Power Output Compression	+12 dBm

The MS462xx is configured with the following relevant settings for these measurements.

Instrument Parameter	Setting
Frequency	1850 to 1990 MHz
Source 1 Power	–15 dBm
Data Points	51 points
IF Bandwidth	1 kHz
Averaging	25
DUT Bandwidth	Wide
Noise Source (15 dB ENR)	Internal
NF Averaging	40

S-Parameter Measurements

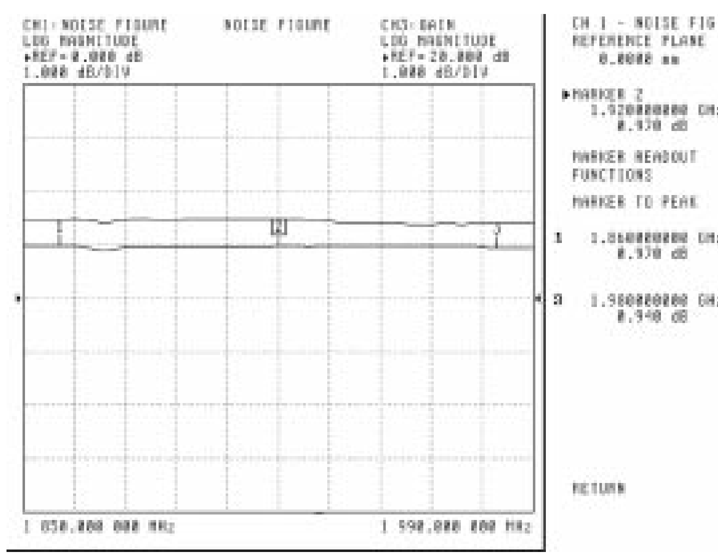
The following data shows the S-parameter measurements of the amplifier using the previous relevant system settings.



Note that the input matching is greater than 15 dB and the output matching is greater than 10 dB. The scalar and vector error-corrected noise figure measurements should produce similar results based on this matching performance.

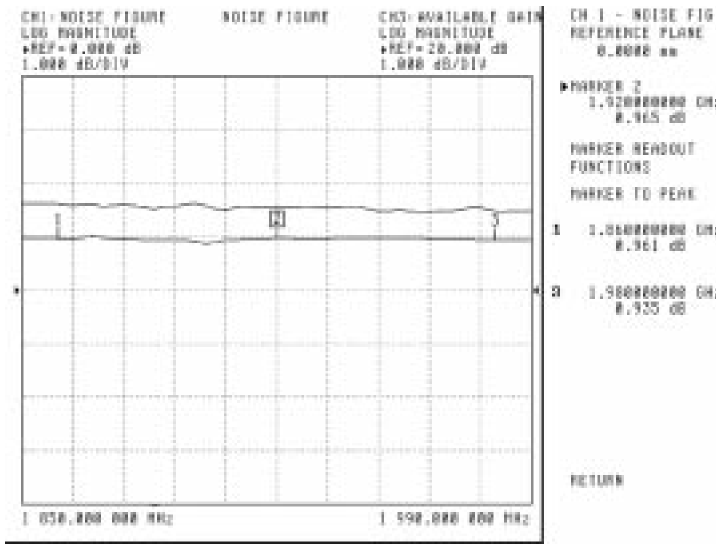
Scalar Noise Figure Measurement

The following data shows the scalar noise figure measurement of the amplifier using the previous relevant system settings. In this case, the noise figure calibration is performed without the 12-term correction. Note that the top trace is Gain (Insertion Gain).



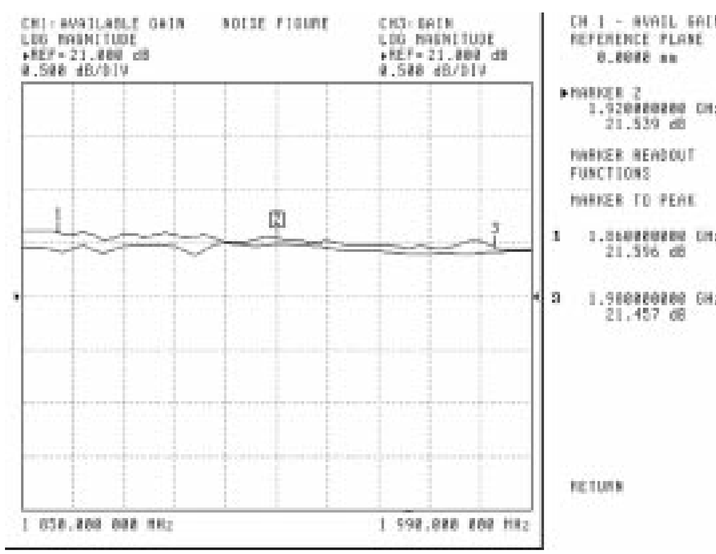
Vector Error-Corrected Noise Figure Measurement

The following data shows the vector error-corrected noise figure measurement of the amplifier using the previous relevant system settings. In this case, the noise figure calibration is performed with the 12-term correction. Note that the top trace is Available Gain.



Comparison of Available Gain to Insertion Gain

The following data shows the Available Gain versus Insertion Gain measurement of the amplifier using the previous relevant system settings. In this case, the noise figure calibration is performed with the 12-term correction, but only applied during the Available Gain measurement. Note that the markers are on the Available Gain trace.



Summary of Typical Data

The following table summarizes the results of the previous data.

Parameter	Scalar	Vector Error-Corrected	S21
Gain	Mkr 1: 21.455 dB Mkr 2: 21.474 dB Mkr 3: 21.395 dB	Mkr 1: 21.596 dB Mkr 2: 21.539 dB Mkr 3: 21.4557 dB	Mkr 1: 21.221 dB Mkr 2: 21.288 dB Mkr 3: 21.224 dB
Noise Figure	Mkr 1: 0.970 dB Mkr 2: 0.970 dB Mkr 3: 0.940 dB	Mkr 1: 0.961 dB Mkr 2: 0.965 dB Mkr 3: 0.935 dB	N/A

The previous prediction (based on the S-parameter data) that both approaches should produce similar results is clearly indicated by this data. Indeed, both the scalar and vector error-corrected measurements provided similar results.

Note that the Vector Error-Corrected and S21 values for gain are similar but, the interpretation of these values requires an understanding of the calculations. The differences are related to the way these parameters are measured. Remember that the Vector Error-Corrected measurement uses available gain. For this reason, the available gain calculations are based on conjugate matches to the amplifier; whereas, the S21 gain assumes 50 ohm matches. Only as the conjugate matches approach 50 ohms does the available gain approach the S21 gain.

This data represents typical amplifier measurements using the foundation provided in the previous sections. This data also demonstrates the flexible noise figure measurement capability of the MS462xx.

Recommended Evaluation Approach

Develop confidence and familiarity with the noise figure measurement capability of the MS462xx by performing the following five measurements.

1. Perform a 12-term (using 51 points) calibration and measurement of the DUT. Note both input and output return loss performance. Expect differences between vector error-corrected and scalar noise figure measurements for return loss performance of less than 10 dB.

2. Perform an External noise figure measurement (NOISE SOURCE = EXTERNAL) for comparison with traditional scalar measurement. Be sure to use DUT BANDWIDTH = Wide.

3. Next, perform an Internal noise figure measurement (NOISE SOURCE = INTERNAL) without 12-term correction for comparison with the previous measurement.

4. Finally, perform an Internal noise figure measurement (NOISE SOURCE = INTERNAL) with 12-term correction for the vector error-corrected noise figure measurement.

5. Additionally, compare noise figure measurements using DUT Bandwidth = Narrow versus DUT Bandwidth = Wide.

Chapter 4 Intermodulation Distortion

4-1 INTRODUCTION

In this chapter, methods to successfully measure two-tone intermodulation distortion products using the IMD option on the MS462xx Vector Network Measurement System are reviewed. The application is designed to properly configure the receiver to perform CW or swept measurements of all necessary signals, set up the sources, coordinate necessary calibrations, and present the results in a useful form. Since the IMD application is quite flexible and there are a number of setup options, a careful analysis of the measurement needs will lead to a better measurement system.

4-2 TWO-TONE IMD

There are many ways to characterize the distortion properties of a device but two-tone intermodulation distortion (IMD, related terms referring to third order intercept point TOI and the term IP3 are also used) is one of the most common. The two-tone IMD measurement describes a fairly common communications scenario: if strong tones in neighboring channels are present, can they introduce spurious signal energy in a troublesome amount into an adjacent channel? This is a very real and legal issue for equipment makers and renders this measurement of significant importance. While the two-tone measurement is not perfectly realistic in that it assumes that the signals are CW (or narrowband modulated at best), it is a relatively straightforward measurement conceptually, is well defined, and is quite repeatable.

The general assumption for this measurement is that two tones are applied to a device under test (DUT) at frequencies of f_1 and f_2 ($|f_1–f_2|$ small). The difference in frequency between the two tones, termed the offset, is often between a few hundred kHz and a few MHz, although other values are possible.

The non-linear characteristics of the DUT generates intermodulation products; among them are signals at $2f_1–f_2$ and $2f_2–f_1$, which will be very close to the original tones in frequency and represent potential adjacent channel spurious signals. The relationship of these various spectral components is illustrated in Figure 4-1.

Since these are third order products, their amplitude dependence on input power will be about three times that of the fundamental (prior to saturation). Hence, if one plots P_{out} (fundamental) and P_{out} (third order product) as a function of P_{in}, the slopes of the curves will be approximately 1:1 and 3:1, respectively, at sufficiently low power where the system is linear. With these disparate slopes, the lines will eventually intersect and the point of intersection is termed the third order intercept point (TOI).

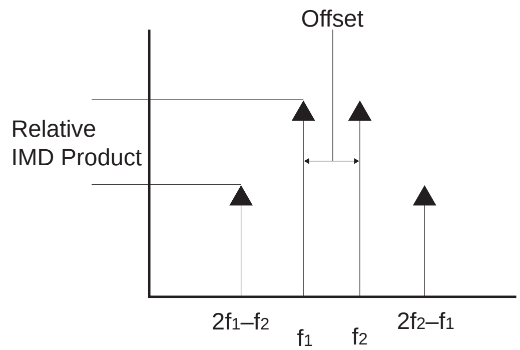


Figure 4-1. *The frequency relationships in a two-tone IMD measurement are illustrated in this diagram. Tones at f1 and f2 are applied to the DUT and third order products at* $2f_1–f_2$ *and* $2f_2–f_1$ *may be generated. The relative magnitude of these tones defines the intermodulation distortion.*

The amplitude of P_{out} (third order) relative to P_{out} (fundamental) at a given input power level is termed the IMD level. These concepts are illustrated in Figure 4-2.

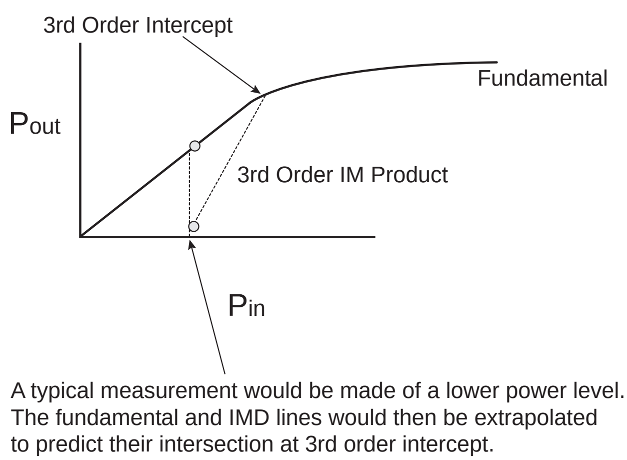


Figure 4-2. *An illustration of the power relationship between the fundamental tones and the third order products in a simple non-linear DUT is shown in this diagram. The Third Order Intercept is based on an extrapolation from measurements at low power and assumes ideal slopes for the output tone level dependencies.*

Generally, the IP3/TOI measurement is done at a single power level and straight lines constructed (since the slopes are assumed and the one data point will then establish the equation of a line). The intersection of these extrapolation lines determines the IP3/TOI value.

By performing the extrapolation, the output referred IP3/TOI can be calculated as:

$$\frac{3P_{TONE2} - P_{LOWER\ IMD}}{2} \text{ or } \frac{3P_{TONE1} - P_{UPPER\ IMD}}{2}$$

where the tone powers are in dBm.

The intercept point generated by this measurement has its limitations; foremost among which is that the intermodulation product does not always follow the 3:1 slope ratio. Thus the simple analysis will lead to an erroneous intercept point. Also, the details of the intermodulation power may be of interest in itself.

An initial thought may be to do a measurement set at a few different power levels and attempt to do a more accurate extrapolation of the intercept point based on this data. This would seem inadvisable for several reasons:

- From experiments and manufacturer data, a few added points will not help accuracy very much and, if properly positioned, could produce an even worse result than that obtained with the single point.
- Definition problems arise if the tones are of unequal amplitude. For the second power level, would the instrument raise both tones equally? Raise only one? In the single point scenario, the instrument has the luxury of assuming the default P_{in} scale definition: the tones are assumed to rise by the same amount at each succeeding step along the P_{in} axis

For these and other reasons, the two most common measurements are the raw IMD product (usually expressed relative to one of the main tones) and the IP3 extrapolation discussed above. The MS462xx Vector Network Measurement System is set up to measure these two quantities directly.

4-3 MEASUREMENT FLOW

The measurement process is illustrated in the flow chart of Figure 4-3. The first two steps, designing the setup and analyzing potential uncertainties are the most important since there are many potential choices.

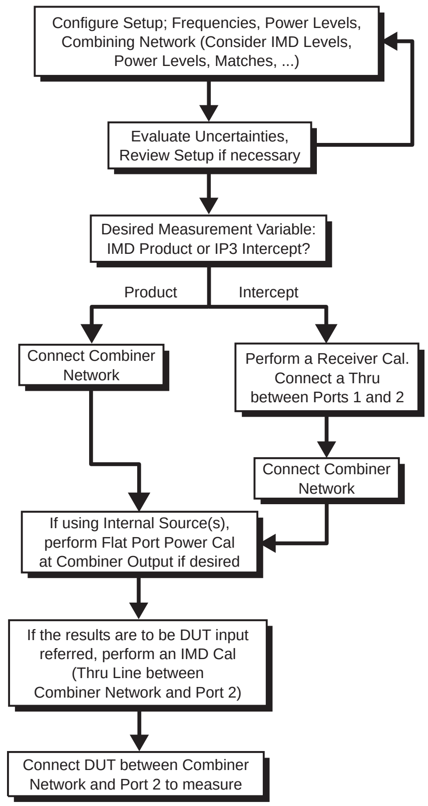


Figure 4-3. *IMD Measurement Process Flow Chart*

The flow chart describes the IMD measurement process in the MS4623X. Generally less effort is required for strict product measurements since absolute power knowledge is not required. Some of the choices to be considered are:

Which Sources to Use?

If the MS462xx was purchased with the optional second source, all that the user must provide is a combining network (see below). In cases where extremely low phase noise is important, or for a number of other reasons, external synthesizers can be used. In all cases, the sources will be controlled by the MS462xx for more convenient measurements. If external sources are used, evaluate their pulling sensitivity prior to designing the combiner network. Use the source submenu within IMD to set these up: Source 1 is always internal, Sources 3 and 4 are always external and source 2 will be internal (port 3 access) if the optional second source is installed.

CW or Swept Measurement?

Under the application menu, one can select the CW receiver mode for a display similar to that seen on a spectrum analyzer (tones fixed, all four tones visible as spectral entities). The markers can be positioned for direct IMD readings. This is a quick and familiar measurement but limited. The swept measurement allows the tones to be swept over any band and, at each frequency point, all four tones are measured to perform the required computations.

What Power Levels and Frequencies are to be Used?

These are generally set by the DUT and the test requirements. The power levels needed may affect the combiner network since the maximum internal source power may be as low as 5 dBm and the combiner network will usually contribute loss. Amplifiers may be required. The offset frequency (tone spacing) may not be set by the test requirements. When choosing an offset, select one as large as practical for the application (1 MHz is common) and avoid the image offset frequencies discussed in the appendix. Because of source phase noise, available dynamic range for the IMD measurement will start to decrease as the offset drops below about 200 kHz.

Is the DUT a Mixer?

If so, set up the DUT LO using the source menus and select the DUT type as mixer at application control. Be aware the mixer spurs and mixer match may be an issue and filters or pads may be helpful.

What Combining Network Should be Used?

This is a complicated question dependent on DUT, measurement, and source details. Figure 4-4 presents an example of a reasonably elaborate combining network. The added isolation (from the amplifiers) and signal filtering provided by this assembly may be needed for measuring extremely small intermodulation products.

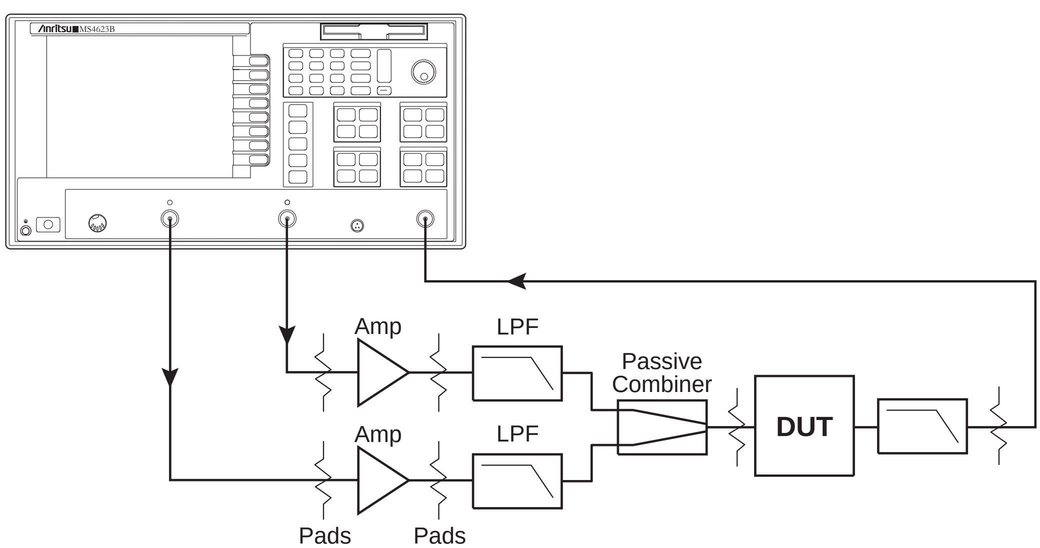


Figure 4-4. *Combining Network*

This level of complexity may be required if very low IMD levels are being measured (of order –70 or –80 dBc), if the sources can be easily pulled (external), if the source spur levels are very high, if the DUT is very sensitive to match, or for other reasons. In some cases, this structure can be simplified to that shown in Figure 5.

Figure 4-5 presents a simpler combining network. The lower levels of isolation provided by this network may be acceptable for measuring larger intermodulation products. Additional amplifiers may be needed if the DUT drive level must be higher than the system can provide (+5 to +10 dBm/tone prior to the network losses).

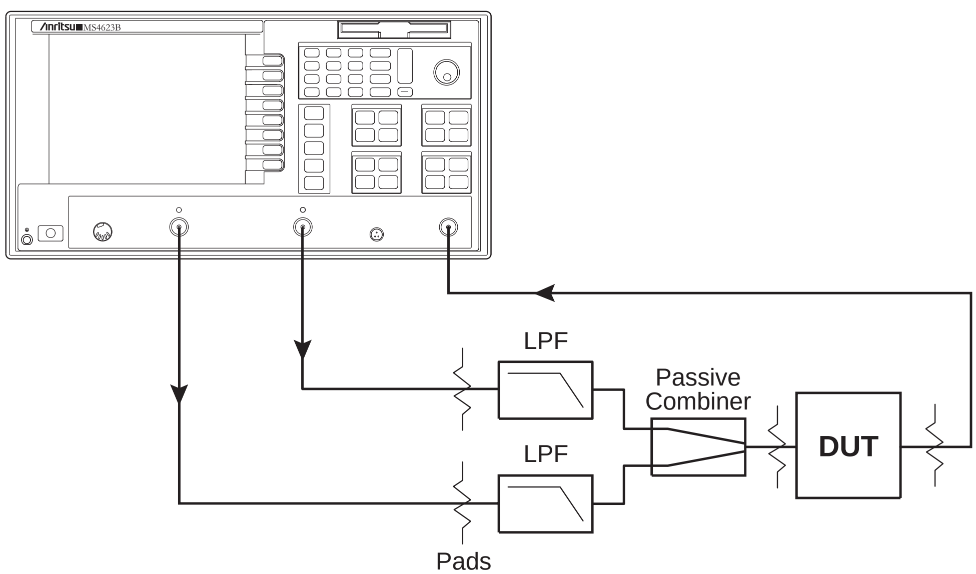


Figure 4-5. *A Simpler Combining Network*

It is recommended that filters always be used to reduce source harmonics to well below the expected IMD levels (can cause additional mix products in the DUT) and that a true combiner (resistive, Wilkinson, etc.) instead of a tee connection be used. The pads, which may be small, provide some additional isolation and impedance buffering. The pad before the receiver is still optional and is mainly there to ensure that receiver compression is not an issue. This approach is most likely to be valid if the expected IMD products are larger than –60 dBc.

In both the minimal and maximal combining scenarios, and anything in between, the frequency range selected may need to be revisited since the filters will reduce the available span to usually less than an octave (obviously not too important if in CW RCVR mode). If it is known that the given source impurities are particularly small or irrelevant, this condition can be relaxed somewhat.

Before accepting a setup, the user should consider a number of possible sources of uncertainty:

DUT Compression
If the DUT is already compressing, the extrapolated intercept point will be inaccurate (see Figure 4-2).

Receiver Compression and IMD
The receiver IP3 is typically about +35 dBm (excitation near 0 dBm) and can limit the measurement in some cases. Also the receiver enters compression above about +10 dBm port power. If the DUT output levels are high, use an output pad.

Dynamic Range and Noise Levels
While receiver IMD may limit the upper end of dynamic range, the source or receiver noise levels will usually limit the low end. If the internal sources are used, source phase noise will start to become important for offsets below a few hundred kHz (results will vary for external sources). A typical noise floor (0 dBm main tone levels) will be about –75 dBc or lower for higher offsets, degrading to about –70 dBc for a 200 kHz offset (internal sources). If an inadequate combining network is used, in isolation terms, these levels will rise due to pulling. Use a sufficiently small IF bandwidth to minimize noise effects.

Input Signal Effects
If the signal entering the DUT is already corrupt with harmonics, IMD products, or spurs, the results could be distorted. Filters are suggested for harmonic (and some spur) suppression. To keep self-IMD products low, ensure that there is sufficient combiner network isolation to prevent source pulling (frequency and amplitude pull) and that any amplifiers in the combing network are sufficiently linear.

Spurs from DUT
Particularly if the DUT is a mixer, spurs into the receiver may present a problem. Use adequate filtering.

Frequency Accuracy
If using external sources, ensure that the MS462xx is linked to the same 10 MHz reference. Even a few PPM difference in references can affect readings when using small IF bandwidths.

Images
Because of the receiver structure of the MS462xx, there are certain offset frequencies that will cause a main tone to land in the image response of the receiver while measuring the IMD product. The most troublesome offsets are 78.125, 125, 156.25 and 250 kHz. Avoiding these frequencies by even 5 kHz can usually remove any difficulty.

Impedances
Ensure that any filters used see their desired impedance levels and that the DUT is not presented with an impedance that may lead to altered behavior.

The remaining steps in the measurement flow center around performing calibrations and selecting measurement types. The available calibrations can be described as characterizing the receiver behavior, flattening the source behavior with frequency, or characterizing the path between the source and the receiver ports.

4-4 MEASUREMENT VARIABLES/ RECEIVER CALS

These selections are usually dictated by the test requirements but there are some important effects. If just the IMD product is required, this is a relative power measurement (product relative to main tone). As a result, the receiver calibration may be skipped.

This receiver calibration, required for intercept measurements, establishes an absolute power calibration at the receiver port and is available under the power menu and under the IMD cal menu. This very general calibration uses a simple thru line between port 1 and port 2 and uses the internal ALC accuracy to determine the frequency response of the receiver.

4-5 FLAT PORT POWER CALIBRATIONS

Because the input power to the DUT is often a critical test parameter and the combining network often has a frequency dependent insertion loss, it may be desired to flatten the power at the output of the combining network. This calibration, available if using internal sources, uses a routine under the power menus and a power meter to adjust the ALC systems as a function of frequency to produce a set level.

This calibration may be done for any number of frequency points and at any accessible power level, and must be performed separately for source 1 and source 2, although the power meter connection does not have to change. This step is less relevant if in CW RCVR mode.

4-6 INPUT REFERRALS

If the desired result (product or intercept) is to be referred to the DUT input, the tone level entering the DUT must be known so that the DUT gain can be computed. The IMD calibration performs this task and requires only a simple thru line connection between port 2 and the output of the combining network.

The main tone levels to be input to the DUT are stored as a function of frequency for later gain computation. Obviously if the power levels or frequencies are changed, this cal will have to be repeated. This step can be omitted if the measurements are to be output-referred or if CW RCVR mode is to be used.

4-7 MEASUREMENTS

At last, the DUT can be connected between the output of the combining network and port 2 and the desired variable measured. Aside from selecting the input/output referral and the intercept vs. product, the user must also select the distortion relative to Tone 1 or Tone 2. If the tone amplitudes are equal, these results will often not be too different but may be for certain DUTs.

When distortion relative to Tone 1 is selected, the upper IMD sideband is measured (and lower sideband for measurements relative to Tone 2). Some example measurements are shown below.

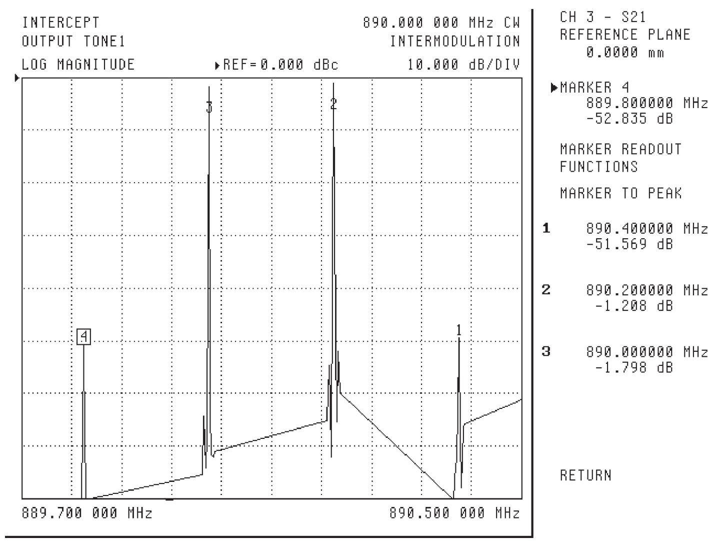


Figure 4-6. *CW RCVR Mode Example Measurement*

Figure 4-6 presents a CW RCVR mode example measurement for a model DUT. The tones in this case are fixed at 890 MHz and 890.2 MHz while the receiver sweeps a small swath of frequencies around the two IMD products and around the main tones.

The plot in Figure 4-6 is an example of the spectrum-analyzer-like display of CW RCVR mode. The amplifier DUT in this case was measured with a tone offset of 200 kHz and an output tone amplitude of about 0 dBm. The tones were placed at 890 and 890.2 MHz for this example and the markers show an IMD product on the order of –50 dBc. This product amplitude is high enough that a very simple combining network could be used.

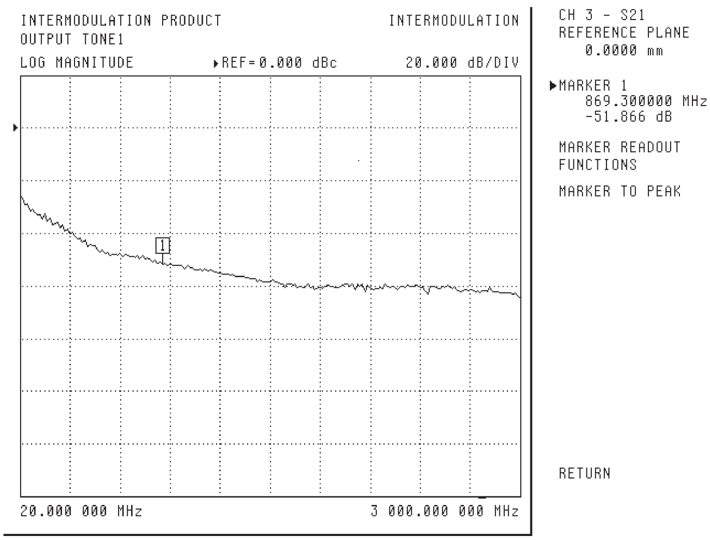


Figure 4-7. *Amplifier IMD Product as a Function of Frequency*

Figure 4-7 is an example illustrating an amplifier IMD product as a function of frequency. Tone 1 is swept from 20 MHz to 3 GHz with tone 2 always being 200 kHz higher (in this case). The system receiver measures both tone and the two IMD products at each sweep point (201 in this case). The product relative to tone 1 output amplitude reaches a minimum of about –65 dBc at higher frequencies.

The plot in Figure 4-7 is a swept version of the measurement of a DUT similar to that used in Figure 4-6. The offset is again 200 kHz but now the tones are swept from 20 MHz to 3 GHz. This measurement methodology is much faster than any spectrum analyzer equivalent when multiple frequencies must be measured.

In this plot, the amplitude of the IMD product relative to the tone 1 output amplitude is displayed. Note that in all Swept IMD measurements, the frequency displayed along the bottom axis of the graph is that of TONE 1.

Figure 4-8 presents a swept third-order-intercept plot illustrating the absolute power measurement required by many DUT manufacturers and customers. The common extrapolation algorithm is discussed in the text. As in Figure 4-7, the tones are swept and the receiver performs four measurements at each point.

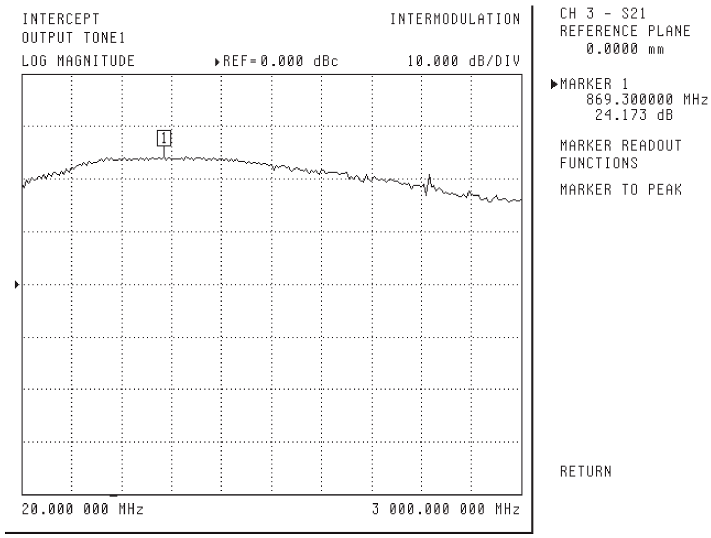


Figure 4-8. *Swept Third Order Intercept Plot*

The plot in Figure 4-8 is a swept third order intercept plot based on a DUT similar to that used in the other examples. As in Figure 4-7, the tones are swept, but this time the intercept is computed using the algorithm discussed earlier. Since a receiver cal was performed for this measurement, the vertical scale reference is actually in dBm. At the marker frequency, the output referred IP3 of this DUT is about +24 dBm.

4-8 OFFSET FREQUENCY SELECTION

The MS462xx is a Vector Network Measurement System designed to make a wide variety of measurements necessary of RF components and subsystem manufacturers. As such, its receiver architecture is a bit different from the spectrum analyzer that is typically used in IMD measurement.

The MS462xx is much more flexible and much faster (particularly in swept measurement) than a spectrum analyzer. It does have a few image responses that may affect an IMD measurement, but not other system measurements. Because multiple tones are obviously present during an IMD measurement, it is important that one of the main tones not land on an image response while the system is measuring a much smaller IMD product. For this reason, certain offset frequencies are to be avoided. The main offenders include 125 kHz, 78.125 kHz, 156.25 kHz, and 250 kHz. Certain mix products of these frequencies may occasionally present a problem if the IMD products to be observed are very small.

There is a simple test to determine if a desired offset frequency is a problem. Assemble the combining network and set the system up for the required IMD product measurement. Connect a thru line from the combining network to port 2 and observe the product.

If this level is sufficiently below the measurement needs, then the desired offset is acceptable.

If the organic IMD level is higher than acceptable, try changing the offset frequency by about 5 kHz. If the level drops substantially, then the original offset may present an image problem.

If the IMD level does not improve substantially, it is likely not an image problem and the deficiency may lie in the combining network or other setup details (refer back to the text).

Chapter 5
Harmonic Measurements

5-1 INTRODUCTION

Harmonic measurements have long been used to characterize a device under test's (DUT) non-linearity and have traditionally been measured with a synthesizer and a spectrum analyzer. A potentially faster, more integrated, and more flexible solution is to measure the DUT harmonics on a Vector Network Measurement System (VNMS). This application is intended to enable the measurement of a device's harmonics on an MS462xx Vector Network Measurement System over a possibly large dynamic range (up to 60 dB or more in some cases) with a number of measurement options.

There are two modes of operation to allow maximum flexibility: CW mode (for a display similar to that of a spectrum analyzer) and swept mode where both the source fundamental and the receiver (tuned to a harmonic) are swept.

There are also three calibration states. A scalar state in which the only possible calibration is for absolute power level, an enhanced calibrated state where source effects are vectorially removed, and a phase calibrated state where rudimentary harmonic phase measurements can be made.

5-2 CW RCVR VS. SWEPT MEASUREMENTS

The distinction between these two modes is straightforward. In CW RCVR mode, the source is kept at a fixed frequency while the receiver is swept over the various integral harmonics of that signal. Only scalar measurements are permitted in this mode meaning that only receiver calibrations (establishing a power reference) can be performed. This mode can be helpful for quickly assessing the overall relative harmonic performance of a DUT.

Swept measurements (termed SOURCE mode in the menus), on the other hand, involve sweeping the source fundamental over some range $[f_1,f_2]$ while the receiver sweeps over a harmonic of that frequency range $[nf_1,nf_2]$ (which must be in the range of the instrument; n=1,…,9). Only one harmonic can be examined per channel but different channels can be used to measure different harmonics. When in this mode, all calibration states are available and are discussed in the following sections.

5-3 UNCALIBRATED MEASUREMENTS

A significant percentage of measurements will fall into this category where the harmonic levels are relatively high (–30 to –40 dBc or higher). If absolute harmonic level measurements are desired (in dBm instead of dBc), a receiver cal, as discussed in the MS462xx Operation Manual, is available to establish the necessary reference.

Examples of measurements in this state are shown below for both CW RCVR and SOURCE swept modes.

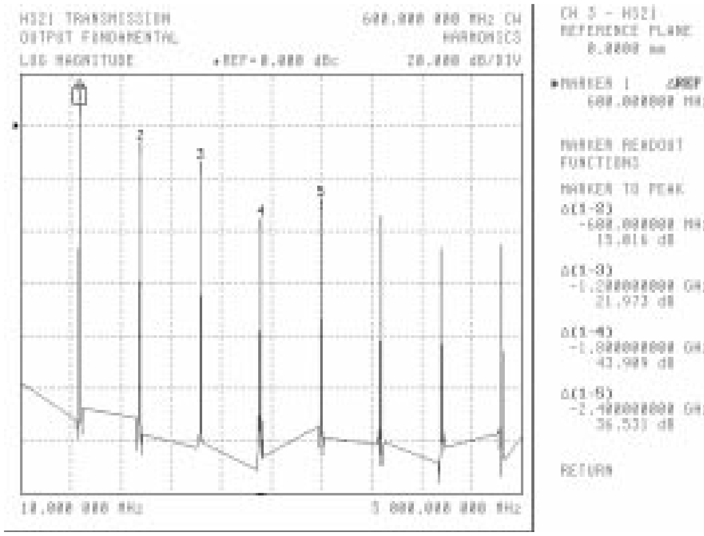


Figure 5-1. *CW RCVR Mode*

Figure 5-1 shows a plot in CW RCVR mode of the harmonics of a sample amplifier. The relative harmonic levels are displayed via marker reference. The source in this case is at 600 MHz and the first 8 harmonics are displayed.

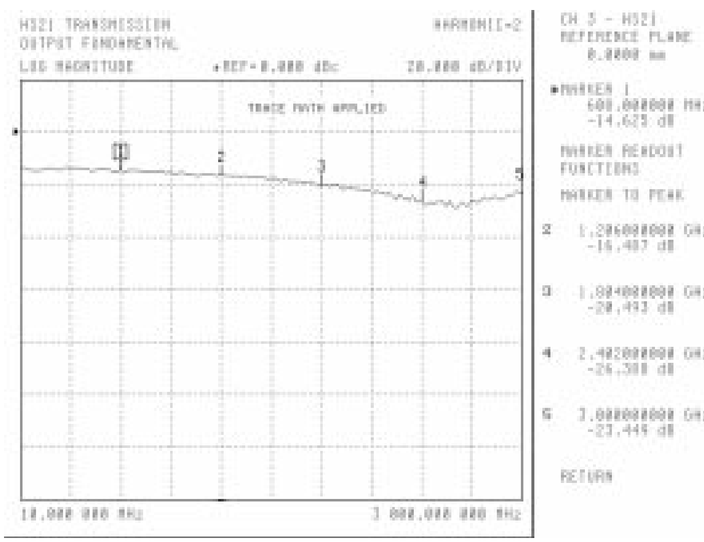


Figure 5-2. *Second Harmonic in Source Swept Mode*

Figure 5-2 shows the second harmonic of a sample amplifier in SOURCE swept mode. The trace data is divided by a normalization (obtained with harmonic =1) so the displayed values are relative to the fundamental. Note that the reference level will always be labeled ‘dBc’ with an absolute power reference, a reference to the fundamental carrier, or no reference at all. The user must interpret the displayed values as appropriate.

Several general points about the harmonic measurement application can be gleaned from these simple initial measurements:

- The CW receiver mode will sample several points around the fundamental and its harmonics (up through the ninth harmonic). Because of the way data is displayed, this leads to straight-line segments connecting the data groups. In the case of first or last point anomalies on the screen, it is possible that a spurious receiver response has been intercepted. This cosmetic defect can be removed by slightly changing the start and/or stop frequencies (since this will not affect the harmonics being displayed).
- In SOURCE swept mode, the horizontal axis is always in terms of the fundamental frequency.
- In swept mode, the system will not stop the user from examining invalid receiver frequencies. As an example, consider a MS4623 model (6 GHz machine) set to examine the third harmonic. While fundamental frequencies must remain below 2 GHz (3 x 2 GHz=6 GHz) to be valid, the user may set the frequency limit all the way up to 6 GHz. For invalid frequencies, meaningless data will be displayed.
- Presently only harmonics up through the ninth are available in either mode. The presence or absence of a receiver cal does not affect this availability.
- Harmonic mode only works between pairs of ports (either between 1 and 2, or between 1 and 3). Mixer measurements are not allowed within the application although they can be performed in Transmit/Receive mode using multiple source control. The four S-parameters associated with a given port pair are all available.
- The harmonics shown in the examples are of relatively high level. If the desired harmonic levels start to be on the order of source harmonics (2nd as high as –30 to –40 dBc, others lower) then errors can result. Uncalibrated harmonic measurement specifications are limited to the case when source power is less than –10 dBm since source harmonics tend to be smaller at lower power levels. If this is believed to be an issue, consider an enhancement calibration state discussed in the next section or use an external synthesizer (with lower harmonics presumably) as the signal source. If the latter approach is chosen, multiple source control can be used to simplify the measurement.

- Do not overload the receiver. In order to avoid receiver-generated harmonics, keep receive-port levels below +10 dBm.

Note that the labeled parameter is 'HS21' in the plots of Figures 5-1 and 5-2. All of the measurement parameters in this application have an H appended to the front to remind the user that definition may be different from that of the traditional S-parameter. When uncalibrated, the displayed variable is actually the unratioed test channel ($b_2/1$ instead of b_2/a_1 in this case) since no reference signal is used. When the Enhancement cal is applied, the parameter is ratioed (b_2/a_1 in this case). In both calibration states, the parameter is measured at the harmonic frequency.

The steps required to make measurements like the examples in Figures 5-1 and 5-2 are summarized below.

1. Enter the harmonics measurement application and select either SOURCE or CW RCVR sweep mode.

2. Select the 1, 2 port pair combination.

3. Set the source power appropriately (0 dBm for these examples).

4. If performing a SOURCE swept measurement, enter a harmonic number of 2 (for Figure 5-2) under Harmonic Setup. One may select Display output relative to OUTPUT FUNDAMENTAL although it has no effect during uncalibrated measurements.

5. Also, if performing a SOURCE swept measurement, select the desired start and stop frequencies for the fundamental sweep (10-3000 MHz here). If true relative harmonic measurements are desired, first store a trace with harmonic=1 (using trace memory) then select trace math (/) and switch back to harmonic=2.

6. If performing a CW RCVR measurement, enter the CW frequency on the frequency control menu (600 MHz for Figure 5-1). This establishes the source frequency. The start and stop frequencies determine the receiver sweep range and hence how many harmonics may be observed (10-5000 MHz for Figure 5-1).

7. Since trace math normalization was performed for the SOURCE measurements, markers will read directly in dBc (relative to the fundamental). In CW RCVR mode, one may use delta markers to accomplish the same task without performing a normalization.

5-4 ENHANCEMENT CALIBRATIONS

The enhancement calibration is designed to remove some of the effects of source harmonics in relatively linear measurements. Suppose that an amplifier is being measured in a sufficiently linear mode that most superposition rules still apply (primarily the assumption is that the source harmonics do not noticeably affect the DUT's operating point). Upon excitation by a source with some harmonic content, the output at the harmonic frequency is a vector sum of the DUT self-generated harmonic and the source harmonic passed through the DUT linearly. See the illustration in Figure 5-3.

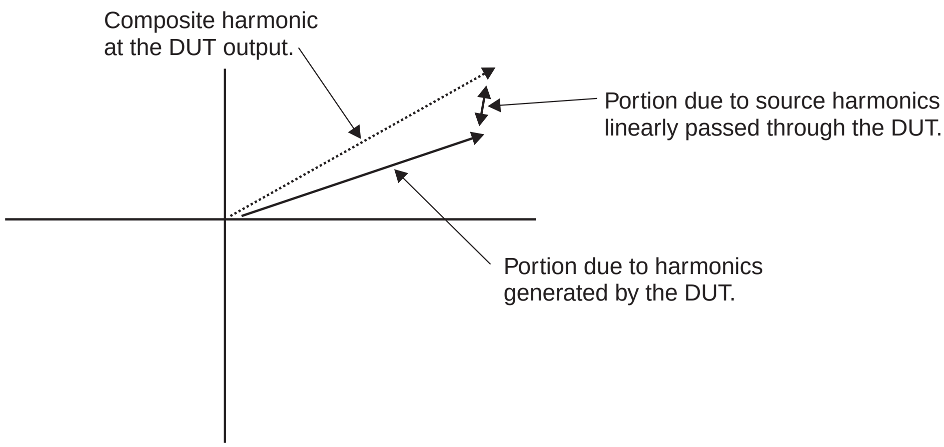


Figure 5-3. *Composition of the Harmonic Signal at the DUT Output*

Figure 5-3 presents an illustration of the composition of the harmonic signal at the DUT output assuming the source harmonics are not so large as to affect the DUT's operating state.

The vector sum is what is measured directly (uncalibrated mode) while the DUT harmonic term is usually the value that is of interest. Assuming the system has vector knowledge of the source harmonics and the DUT's linear performance, the vector addition can be undone thus revealing a better picture of the DUT actual harmonic generation. While this operation radically reduces the effect of source harmonics, it does not correct for other system non-ideal characteristics such as port match.

To see this effect, consider the harmonics measured with just a through line in place for the DUT. The result with an enhancement cal in place is shown in Figure 5-4. In the uncalibrated mode, the measurement floor would be in the –30 to –40 dBc range for the second harmonic and somewhat lower for the third harmonic. This calibration and measurement were performed with 0 dBm source power and a 100 Hz IF BW. Note that the reference is with respect to the output fundamental as will be the case for the remaining example plots.

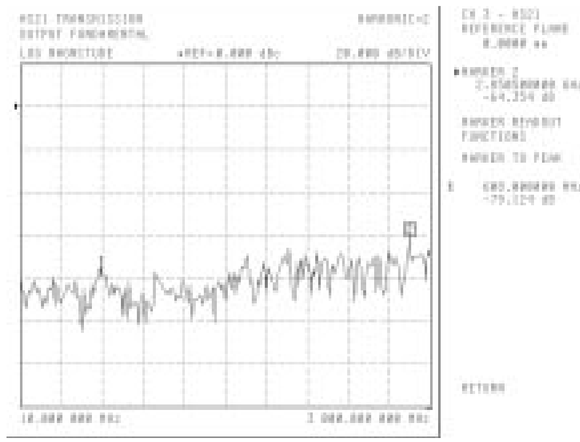


Figure 5-4. *Example Dynamic Range Plots*

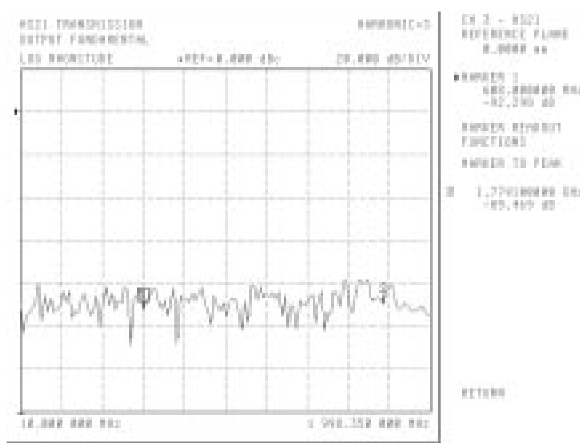


Figure 5-5. *Example Dynamic Range Plots*

Figures 5-4 and 5-5 present example dynamic range plots under ENHANCEMENT cal for both second and third harmonics. The calibration and measurement power is +0 dBm. The measurement is performed with the same thru line in place as was used during the cal.

A few remarks about the Enhancement calibration process can be made:

- The enhancement calibration is available only for the second and third harmonics. This limitation is due to a requirement for sufficient reference power to ensure that the vector calculations suffer from relatively low jitter. The calibration utilizes source harmonics to reference the computations and these must be sufficiently high to avoid excessive high level noise.

- The cal is strongly dependent on source power (since the source harmonics that are being removed are a strong function of source power). While no warning may be given, an enhancement cal should not be applied when the source power has changed. Note that it is acceptable to increase or decrease the step attenuator or add external pads since these steps do not affect source harmonics.

- As with TR measurements, the noise floor will be dependent on IF BW. Since reference powers are lower when measuring harmonics (as compared to linear S-parameters), higher noise levels will be seen for the same IF BW than in the T/R application.

- Pay attention to the measurement reference whether it is relative to source harmonic, source fundamental, or output fundamental. Output fundamental is the most common selection since that is how amplifiers and other DUTs are normally specified. A source fundamental selection will cause the results to be input-referred.

- The cal simultaneously covers both second and third harmonics and all four S-parameters associated with the selected port pair.

An example amplifier measurement is shown in Figure 5-6. The cal and measurement were performed at 0 dBm source power. The particular amplifier has about 12 dB of small signal gain and an output-referred 1 dB compression point of about 13 dBm. The amplifier output was padded with 6 dB to avoid receiver non-linearity effects.

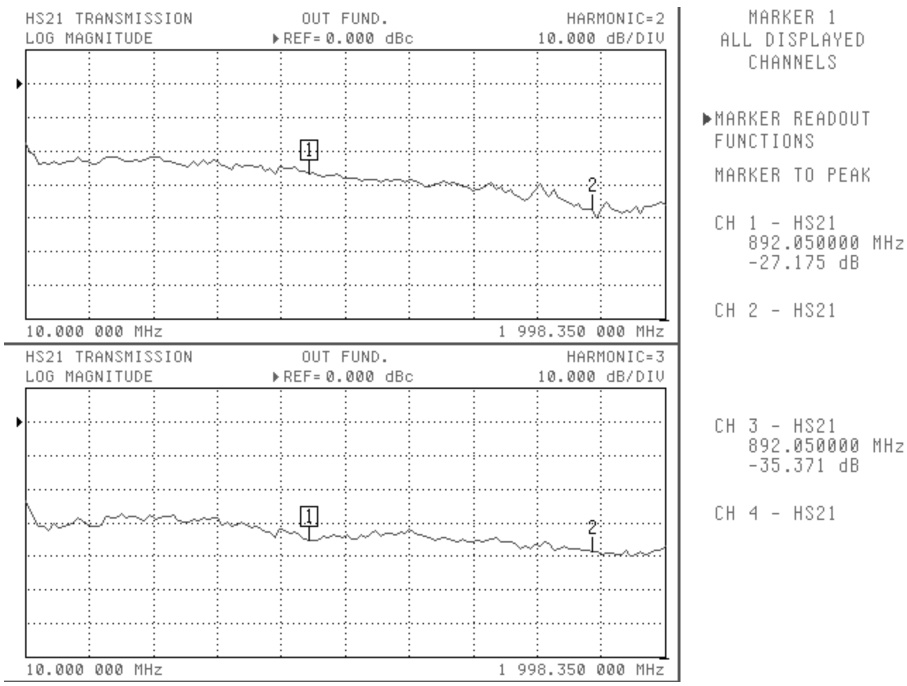


Figure 5-6. *Two Channel Plot Showing the Second and Third Relative Harmonic Levels*

Figure 5-6 presents a two channel plot showing the second and third relative harmonic levels of an amplifier using the ENHANCEMENT calibration state. The cal and measurement were performed with a source power of +0 dBm and the amplifier output was padded to avoid receiver compression.

The steps to make this enhanced measurement can be summarized as follows:

1. Set the frequency and power range as necessary (10-3000 MHz, 0 dBm). In the harmonic measurement application, select SOURCE swept mode, port 1-2 pairing, and display output relative to output fundamental.

2. Perform the Enhancement cal. This will involve connecting a thru line between ports 1 and 2 and later shorts on both ports. It may be desirable to reduce the IFBW during the cal in some cases.

3. Connect the DUT and apply bias. For this display of Figure 5-6, dual channel mode was used with channel 1 set to harmonic=2 and channel 3 to harmonic=3. The frequency range was reduced to about 2 GHz since the data above that frequency is meaningless for harmonic=3.

5-5 PHASE CALIBRATION

In some applications, most notably with ultralinear power amplifiers and device modeling, knowledge of harmonic phase would be useful either for improved efficiencies or a better understanding of device physics. Since this cannot be easily done with an ordinary spectrum analyzer, this type of measurement is usually not performed. An additional cal is available in the MS462xx Vector Network Measurement System that builds upon the vector information obtained in the enhancement cal to obtain potentially useful phase data.

The measurement results from the enhancement cal include phase data relative to the source harmonic. While perhaps interesting, this is not particularly useful since the system cannot know a priori the phase relationship of the source harmonic to the source fundamental or output fundamental. If this relationship could be established, then at least rudimentary harmonic phase information could be extracted.

To determine this relationship, a known waveform must be supplied to the receiver such that the harmonic phase differential can be computed on a frequency-by-frequency basis. While many options are possible, a self-biased shunt Schottky diode has been selected as a harmonic phase standard. When sufficient RF power is applied, the output waveform is basically a clipped sinusoid where the harmonic phase relationships are quite well-defined. When this waveform is sent to the receiver, the absolute source harmonic phases can then be computed to lead to a more interesting relative phase parameter.

An example measurement (HS21, third harmonic) of an amplifier is shown in Figure 5-6. The calibration and measurement was done at a source power of +5 dBm in this case. Such a measurement may be used to investigate/validate the non-linear model for the amplifier.

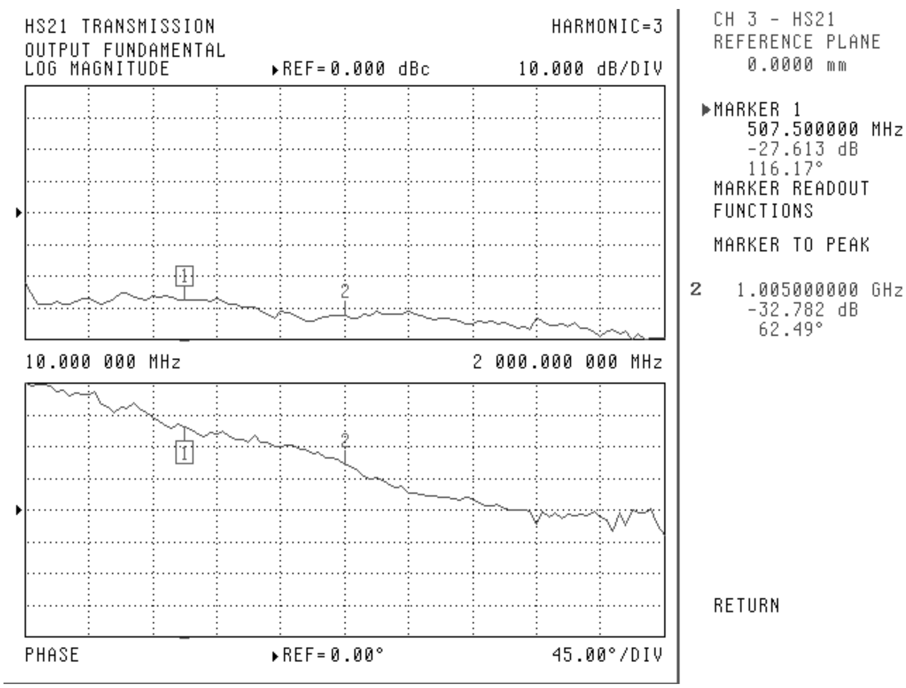


Figure 5-7. *Third Harmonic (magnitude and phase) of an Example Amplifier*

Figure 5-7 shows the third harmonic (magnitude and phase) of an example amplifier under fully calibrated conditions. This amplifier was driven with +5 dBm and had a 10 dB pad on the output to minimize non-linear receiver effects. A 10 Hz IFBW was used during measurement and calibration.

Some important notes:

- Sufficient power must be applied to the harmonic phase standard to minimize jitter. While any source power will work to some degree, it is recommended that the calibrations be performed at 0 dBm or higher. Pads and/or step attenuator steps can be added during the measurement.
- The phase cal establishes an absolute phase reference plane at the location of the phase standard.
- The phase cal requires an enhancement cal and also applies only to second and third harmonics.
- The phase displayed, like the magnitude, is relative to the indicated variable (usually the output fundamental). If the 'absolute' phase of the fundamental (relative to the phase standard) is required, it can be determined in T/R mode through the use of trace math.

The steps to obtain the data in Figure 5-7 are summarized below. Since the power level has changed from the previous figure, a new enhancement cal will be performed. If a valid enhancement cal already exists for the setup, that step could be omitted (just select PHASE CAL from the calibration menu).

1. Select the appropriate frequency range and power level (10-2000 MHz, +5 dBm). In the harmonic measurement application, keep the settings from before and keep harmonic=3. Select a magnitude and phase graph type, and a single channel display set for channel 3 (for this example).

2. Perform an ENHANCEMENT AND PHASE cal. For the enhancement portion, a thru line and shorts will again be used. For the phase cal portion, the harmonic phase standard must be placed (with a thru line) between ports 1 and 2. The position of the phase standard during this measurement establishes the reference plane.

3. Connect the DUT in the location of the phase standard. Apply bias and measure on the desired channel.

5-6 ACCURACY & UNCERTAINTY ISSUES

For the uncalibrated measurements, the uncertainty is that of relative power measurements of the receiver which is determined primarily by receiver linearity. This uncertainty will be comparable to that seen with a spectrum analyzer. The uncertainty will vary from between 0.5 and 1 dB for higher power levels to between 1 and 1.5 dB for lower levels (assuming an appropriate IF BW is selected for the level being measured). If an absolute power reference is established, that uncertainty will be determined by the power reference used.

An ordinary ALC cal has a specified accuracy of 1 dB, while it is typically better than 0.5 dB. If a flat power cal precedes the receiver cal, this added uncertainty will drop to below 0.1 dB typically. These values all assume the criteria of sufficiently high harmonic levels that source harmonics are not an issue.

The uncertainty during an Enhancement cal is available over a larger dynamic range because of source correction and over a larger range of source powers. The typical uncertainty is around 1 dB for harmonic levels sufficiently out of the noise floor (this is the specification for levels above –40 dBm).

SUMMARY

This chapter has attempted to present the various modes and calibration states of the harmonic measurement application along with examples and tips on their operation. The harmonic measurement application is quite flexible and can be used to quickly measure large scale harmonics at one source frequency or measure (possibly vectorially) swept harmonics over an extended dynamic range depending on need.

To summarize the various states and modes within the application:

- CW RCVR MODE: Fixed source frequency, receiver swept over one or more harmonics. Use only uncalibrated (or with a receiver cal for an absolute power reference).
- SWEPT MODE: Source sweeping and receiver sweeping at one harmonic (per channel). Use with any calibration state.
- UNCALIBRATED STATE (or with receiver cal): For quick harmonic measurements at higher levels (–30 to –40 dBc or higher generally). Limited source power range to ensure accuracy.
- ENHANCEMENT CALIBRATION: Vectorially removes source harmonic effects to extend dynamic range to as high as 60 or 70 dB. Assumes the DUT does not change its operating point because of source harmonics.
- PHASE CALIBRATION: Builds on the enhancement cal to offer fundamental-referenced harmonic phase data. Requires the use of the harmonic phase standard to establish internal phase relationships.

Chapter 6
Mixer Measurements

6-1 INTRODUCTION

Mixers are integral components of most measurement systems and their characterization is an important part of many test systems. This section describes how to make three classes of mixer measurements on the MS462xx: conversion loss, noise figure, and intermodulation distortion. These descriptions are not all-inclusive but should provide enough information to make fixed IF or fixed LO measurements on a wide class of frequency conversion devices.

6-2 MANUAL CONVERSION LOSS

This section describes the steps for measuring mixer conversion loss manually using the T/R Mixer device type mode. The steps focus on measuring a fairly generic mixer with additional application information provided as appropriate. The procedure consists of three main sections:

- calibrations to establish the power levels,
- setup of the sources and receiver for the mixer measurement,
- the measurement itself.

In this type of manual measurement, the calibrations can account for two sources of error: (a) power level accuracy via an optional flat test port power cal and (b) receiver frequency response via a receiver cal. Trace memory is used to store the RF power level to provide a normalization. Thus when the DUT IF is sent to the receiver, the displayed value will be the correct ratio of IF to RF signal level.

The setup of the sources is obviously quite important in a mixer measurement. The Mixer device type simplifies this task somewhat by allowing the quick selection of which source is to be the DUT LO, allowing simple selection of a fixed LO or fixed IF measurement scenario (and specifying that LO or IF frequency), and informing the receiver of what kind of DUT conversion to expect (up conversion |RF+LO|, down conversion |RF-LO|, or no conversion as might be used for a quick leakage measurement). Activating the Mixer device type also performs the important function of turning on both internal sources for front panel access (usually using ports 1 and 3 driving, port 2 being the receive port). Two ports are not allowed to drive simultaneously during normal S-parameter measurements.

The measurement itself is quite straightforward as it is just a simple T/R non-ratioed analysis. It is important to remember that since the RF and IF frequencies are unequal in up or down conversion, there is no reference signal available. As a result, the only display parameters that are normally used in a conversion loss measurement are the test channel values $b_i/1$.

Example Measurement

The device to be tested has a fixed LO of 1 GHz and a RF range of 1300-1900 MHz. The conversion loss on going to the IF range of 300-900 MHz will be measured. Internal source 1 will provide the RF signal and internal source 2 will provide the DUT LO. The procedure applies to any fixed LO measurement with all frequencies within the range of the instrument. Suggestions for other measurement scenarios are at the end of the section.

1. Set the system to T/R mode, STANDARD device type.
2. (optional) Perform a flat test port power cal if desired. This step is important for maximum accuracy (better than 0.5 dB or so). It is usually simplest if this cal is performed at the desired RF power level, and the frequency range should include both RF and IF ranges if possible. For this example, the cal will be performed over the whole range of the instrument.
3. Select single channel display (log magnitude graph type), S21, Meas/User Defined, $b_2/1$.
4. Connect a thru line between ports 1 and 2
5. (optional) Perform a RECEIVER CAL (port 1 transmitting, port 2 receiving). Perform the cal over the entire frequency range of the instrument. This step is optional since conversion loss is a relative measurement; it does however provide a correction for receiver slope between RF and IF frequencies.
6. Set source 1 to the first desired RF power level (–10 dBm for this example). If the receiver cal is enabled, you should see a straight line on the $b_2/1$ display.
7. Sweep over the RF frequency range of the DUT (1300-1900 MHz in this case) and save to trace memory.
8. Set the system to display divide-by-memory. This has established the RF power level so that the display in later steps will be of direct conversion loss.
9. Set the system to mixer device type and proceed to LO/RECEIVER setup under the application menu.
10. Select the LO as source 2, CW, 1 GHz, Receiver conversion down (DUT IF=|RF-LO|). Note that this setup screen is a way to avoid using multiple source control by simplifying some of the choices.

The types of conversions are limited to fixed IF and fixed LO. If a more complicated frequency plan for the DUT is needed, the user must go to multiple source control. For this example, we are using a fixed LO. The frequency display on screen will be the RF frequency of the DUT.

11. Set the LO power level (source 2) to +7 dBm as is required for this DUT.

12. Connect the mixer DUT with the IF at port 2, the RF at port 1, and the LO at port 3, as shown in Figure 6-1.

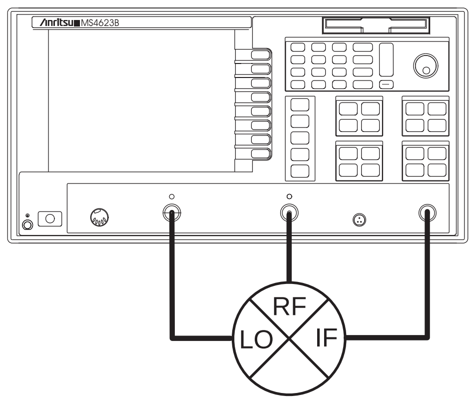


Figure 6-1. *Mixer DUT Connection*

The result shown on the $b_2/1$ display are portrayed in Figure 6-2. The nominal conversion loss is between 7 and 8 dB for this example mixer. The frequency axis is that of the RF. RF power = –10 dBm while LO power = +7 dBm. These results are within expectations for this DUT (max of 9.5 dB).

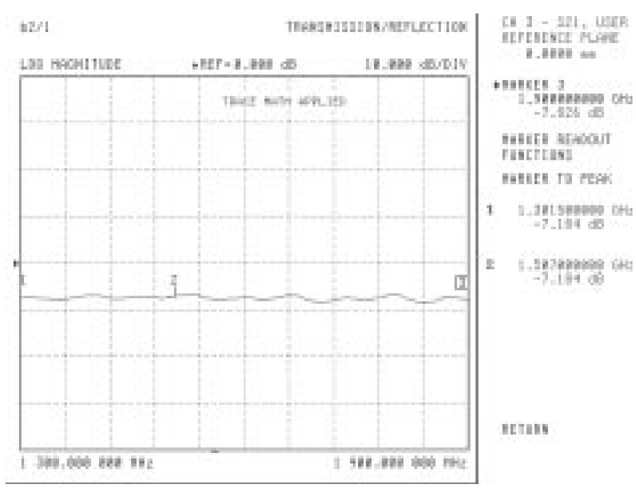


Figure 6-2. *Conversion loss of a simple doubly balanced mixer using a fixed LO of 1 GHz*

Let us now try the mixer at a higher power level to observe compression effects.

13. Remove the mixer and reconnect the thru between ports 1 and 2.

14. Return to Non-mixer mode and change the source 1 power to the second value (+5 dBm, was at –10 dBm).

15. Repeat the store to trace memory. (Alternatively, remain in mixer mode and select RCVR CONVERSION NONE; this is a way of setting the system for non-converting measurements while staying in the mode).

16. Return to mixer mode and reconnect the mixer (note that the frequency ranges did not have to change).

The results are shown in Figure 6-3. Note that the mixer is in heavy compression and the conversion loss has degraded markedly to nearly 11 dB.

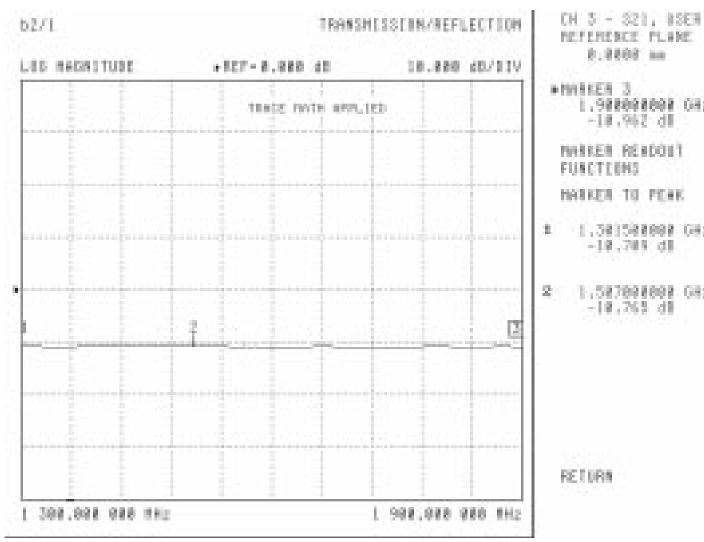


Figure 6-3. *Conversion loss of the same mixer as in Figure 6-1 but with a RF power level of +5 dBm.*

Finally, it may be interesting to observe direct RF-IF leakage while in this compressed state. While this measurement could be performed in non-mixer mode, it can be done in the mixer mode directly.

17. Keeping the trace memory normalization from the previous step, switch to RCVR CONV NONE (forcing the receiver to be tuned to the RF frequency). The resulting trace is shown in Figure 6-4. The level of leakage is still well within specifications.

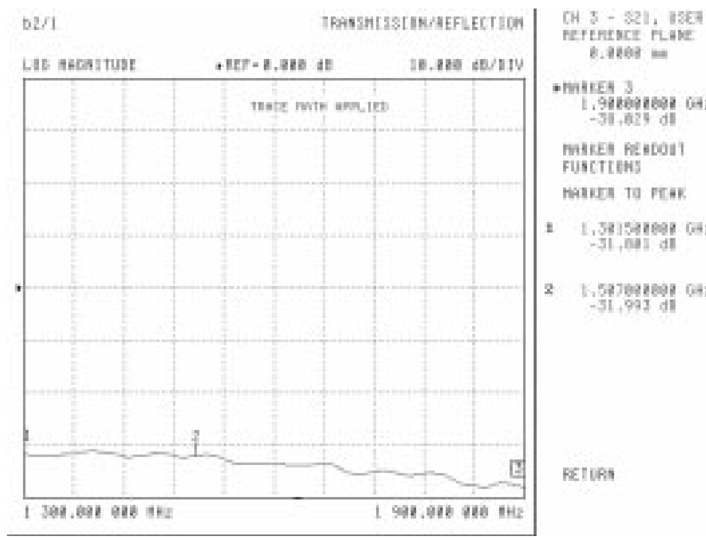


Figure 6-4. *Direct RF-IF leakage while under the compressed conditions of Figure 6-2.*

6-3 OTHER MEASUREMENTS

The conversion loss measurement algorithm just described was limited to the case of a fixed DUT LO at a conventionally low frequency. Several other common scenarios may also occur: a fixed DUT IF, the use of a very high DUT LO or RF frequency, or the requirement for a fairly complicated frequency plan. This section provides some suggestions for these measurement situations.

FIXED IF

In this case, the DUT LO is set for a fixed offset from the RF and it is assumed that all frequencies are within the range of the instrument. The trace memory storage step is the same since it is again the reference RF power that must be known for computing the conversion loss. An example is shown in Figure 6-5 where another doubly balanced mixer was used, but with a fixed IF of 70 MHz. In the LO/Receiver setup menu, the LO was set as source 2 with an offset from the RF of 70 MHz and down conversion was selected.

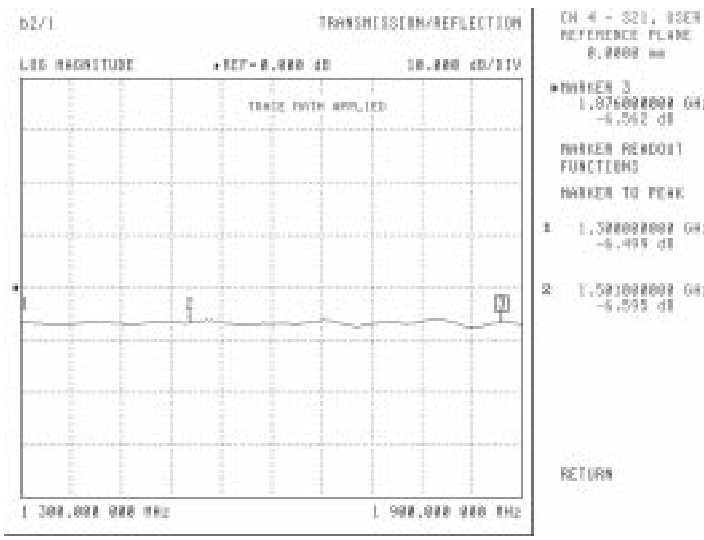


Figure 6-5. *Doubly Balanced Mixer With a Fixed IF of 70 MHz*

High RF or LO

If an external synthesizer is used with a DUT RF or LO frequency outside of the range of the instrument, the measurement may change substantially. A LO outside the range is less of an issue since no normalizations are done with respect to that signal. The RF can be normalized as before. If the RF is out of range, normalization is not possible and only absolute IF power can be measured (assuming the receiver cal was performed).

Swept IF and LO

In this case, the simple LO/Receiver control within the mixer device type cannot be used. The user must go to multiple source control to configure the sources and receiver appropriately. The same general measurement flow (including the normalizations) can be used.

6-4 NOISE FIGURE MEASUREMENTS

This section examines the methodology of making mixer noise figure measurements using the MS462XB Vector Network Measurement System. It is not meant to be an exhaustive description of the possible measurement sequences or of the possible measurement uncertainties, but should provide a general technique applicable to the measurement of many common frequency conversion devices.

It will be assumed that the DUT has some frequency conversion present in it and that the DUT IF (the port that will be connected to the MS462xx receiver at port 2) will have a frequency range within the present system limits of 50-3000 MHz.

The DUT LO may be provided by the optional source (see notes below, source 1 cannot be used during mixer noise figure measurements) or by an external synthesizer and may be of any frequency range consistent with the IF limits described above and the noise source frequency limits (generally not higher than 26.5 GHz). This is one exception to the general rule that DUT performance above 6 GHz cannot be examined with the MS462xx. As with ordinary noise figure measurements, there are three steps to performing the task:

Setup

Setup includes setting the frequency range of interest as well as answering the usual noise figure setup questions. Once the mixer device type is selected, the LO/Receiver menu can be used to set the DUT LO behavior and the device conversion that the receiver should expect.

These steps are the same as for mixer conversion loss measurements described earlier. The important points to remember are that the DUT LO must be in range of whatever source is being used (3 or 6 GHz if internal source 2 is used), and the DUT IF must be within range of the MS462xx receiver (50-3000 MHz).

Consider LO cleanliness and performance when selecting which source will be used. As with many VNA sources, the optional source is not perfectly clean and its spurs may result in measurement difficulties in some cases. This issue becomes more important as the DUT IF becomes smaller.

Calibration

Since frequency conversion is involved in the DUT, a linkage to a 12 term cal is not allowed; this leaves an ordinary noise figure cal as the only choice. This cal must be performed with mixer device type selected and with the frequencies set appropriately. This will allow the cal to proceed over the DUT IF frequencies as required and to employ the correct ENR values.

Internal or external noise routing is permitted, as is wideband or narrowband noise figure measurement.

Measurement

Finally the DUT may be connected. It is critical to properly filter the mixer output if there is not appropriate filtering within the DUT. This is important since no mixer has perfect LO-IF isolation and LO leakage into the noise receiver could adversely affect the measurement.

An example measurement setup is shown in Figure 6-6. In this example setup, the external noise source routing was used and the filter was considered part of the DUT (as in a receiver module being tested). The internal source 2 is being used as the DUT LO in this example, which may not be appropriate for all measurements.

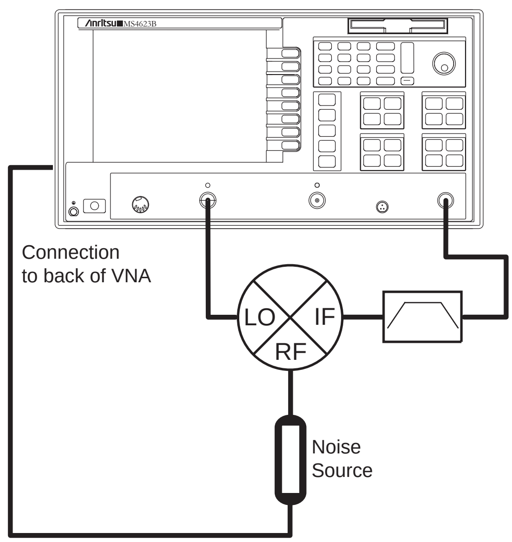


Figure 6-6. *Example Measurement Setup for Mixer Noise Figure*

An additional choice to be made during the measurement phase involves the Single Sideband (SSB) correction. Since the MS462xx receiver cannot differentiate between the upper and lower sidebands of the DUT response, it automatically measures both unless the DUT has image rejection or certain filtering.

As an example, if the DUT LO is 1 GHz and the DUT RF is selected to be 1200 MHz for a DUT IF of 200 MHz, the response for a RF of 800 MHz will also be measured. If the DUT will be used in a SSB application (as in most heterodyne receivers), this will cause the insertion gain to read 3 dB high assuming a flat frequency response. Enabling the SSB correction takes this behavior into account. If the DUT has an image reject mixer, has image filtering (including a highly variant frequency response to the image), or will be used in a DSB application (in radiometry, for example) then this correction should not be enabled.

Example Measurement

To illustrate these concepts, a simple mixer measurement is described in detail here. The DUT is a simple doubly balanced mixer where the RF is 1200-1300 MHz. In the first measurement scenario, a fixed DUT LO of 1 GHz and +7 dBm is used (provided by the internal source 2, since the IF is relatively high internal spurs are less of an issue). A 500 MHz low pass filter on the mixer IF is considered part of the DUT.

1. Set the system to noise figure mode with a mixer device type. Select Wideband NF (no BW correction), external noise source, SSB correction off (for now), the default 290K cold temperature and the proper vendor ENR table loaded. The default 40 noise averages will be adequate.

2. Proceed to the LO/Receiver menu and select source 2 as the LO with a CW frequency of 1 GHz, conversion down. Under the source 2 power menu, select a level of +7 dBm that is appropriate for this DUT.

3. Set the main frequency range (the DUT RF) for 1200-1300 MHz with 51 data points.

4. Connect the noise source to port 2 (since this is an external routing) and perform a noise figure only cal.

5. Connect the mixer-filter assembly as shown in Figure 6-6. The display should be set to channel 3, log magnitude graph type, plot variable of Noise Figure. With SSB correction off, the result shown in Figure 6-7 was observed.

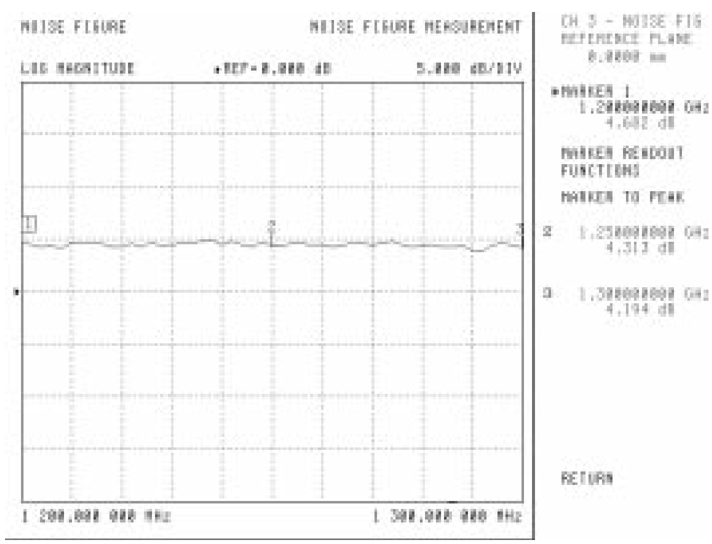


Figure 6-7. *Example Mixer Noise Figure Measurement*

The DUT LO was fixed at 1 GHz (+7 dBm) with the RF range shown on screen. SSB correction is off.

Since this DUT will likely be used in a SSB mode, a more useful value of the noise figure may be that with the SSB correction applied. While this is a fairly trivial correction (3 dB decrease in calculated insertion gain), it may be helpful in some situations.

The result is shown in Figure 6-8. The difference in NF may not be exactly 3 dB since it is the insertion gain that is being directly corrected. Since, as far as the noise system is concerned, this is the measurement of a pad, uncertainties will be elevated.

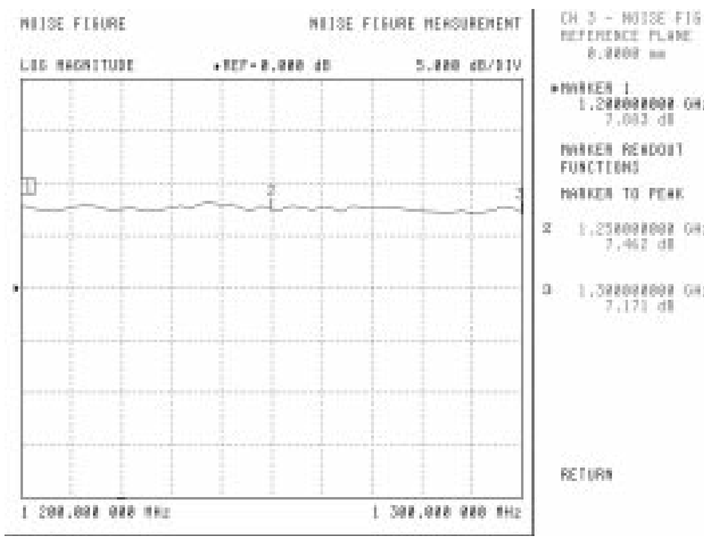


Figure 6-8. *Example Mixer Noise Figure Measurement with SSB Correction Turned On*

Finally consider a slightly different frequency plan. A fixed DUT IF of 250 MHz is used with the same RF frequency range.

1. Turn the existing cal off, disconnect the mixer assembly, and reconnect the noise source to port 2.

2. Return to the LO/Receiver menu and turn LO CW off and select a LO offset of –250 MHz (high side mixing). LO power will remain the same.

3. Perform the cal as before. Since the IF is fixed, the cal is actually only being done at one frequency although the unit will appear to be sweeping (the DUT LO will actually be sweeping but it is not used during the calibration).

4. Reconnect the mixer assembly and turn on the SSB correction. The results are shown in Figure 6-9.

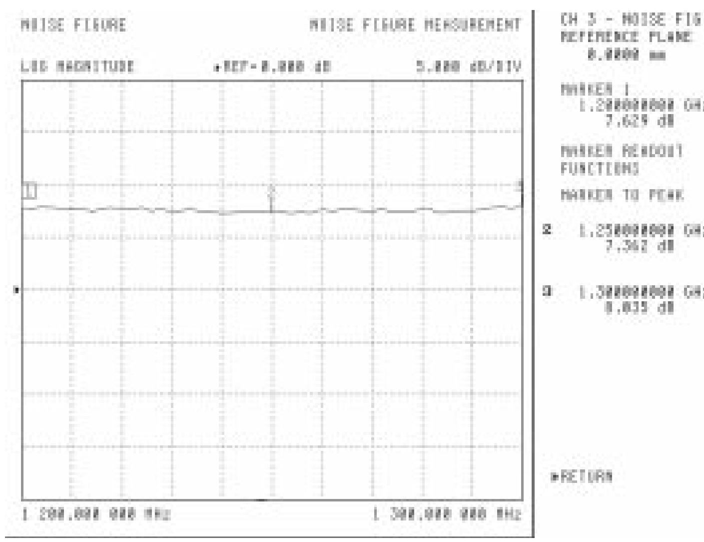


Figure 6-9. *Fixed DUT IF of 250 MHz with SSB Correction On*

The mixer NF for the measurement using a fixed DUT IF of 250 MHz is shown in this plot. SSB correction is on.

As might be expected, the results are similar to that shown in Figure 6-8. The differences result from a slightly different assembly being used and the different frequencies involved.

As a closing note, it may be helpful to consider some of the potential sources of error in a mixer noise figure measurement. In addition to the usual problems with noise figure, consider the following

- Inadequate LO filtering
- Effects of LO phase noise or spurs (particularly for small DUT IFs)
- Overlapping frequency ranges (so that filtering is difficult or not possible)
- Complicated conversion schemes (a multiple conversion DUT will have a more complex SSB correction than is available in the MS462xx)
- Spurs, generated by self-LO mixing, landing in the DUT IF frequency range
- Environmental sources converted into the IF frequency range
- Since there is conversion loss for many mixers, the fundamental noise figure uncertainties will be elevated.

6-5 MIXER IMD MEASUREMENTS

This section explains the methodology of making intermodulation measurements on mixers using the MS462xx. It is assumed that the user is familiar with IMD and TOI measurements on non-frequency conversion devices. This section will not exhaustively cover all possible measurement sequences, but is intended to help with setup issues and general measurement flow.

Since this is a two-tone measurement and the DUT presumably requires an LO, three sources will be required for the measurement (one obviously must be external). We will assume all three sources are under instrument control, but it is possible for the DUT LO to be fixed (even one of the tones may be fixed assuming CW RCVR mode) and this case will be discussed briefly at the end.

As with any IMD/TOI measurement, there are three steps to the measurement:

Setup

This is the most complicated step in a mixer IMD measurement largely because of the three source requirement. The main two tones must be configured as before (offset, power level), the mode must be configured (intermodulation product or intercept, input or output referred, swept or CW RCVR) and the tone frequency range selected. In addition, the DUT LO must be selected, its frequency plan and power levels defined, and the type of DUT conversion must be provided (up, down or none).

As with ordinary IMD measurements, the combining network can be of considerable performance and should be designed with some care. A fairly complete and higher performance setup is shown in Figure 6-10.

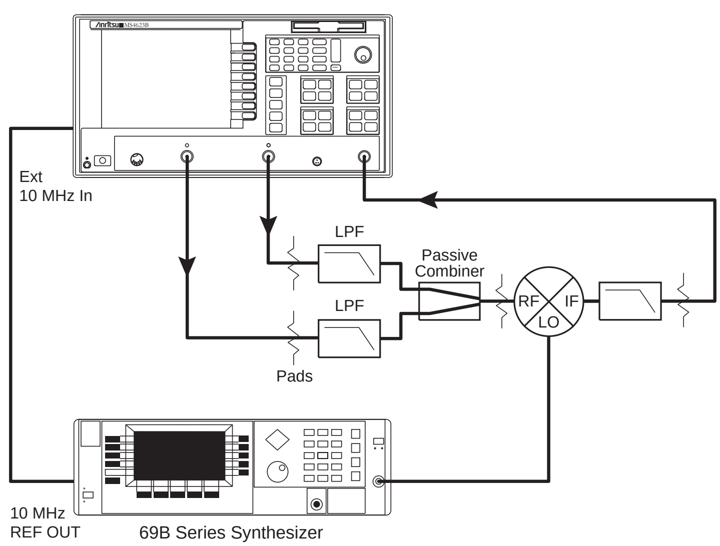


Figure 6-10. *An Example Mixer IMD Setup*

Calibrations

As with ordinary IMD, the cal choices are limited. A receiver cal is required to establish an absolute power reference if intercept measurements are to be made. The frequency range of the cal must include the entire planned DUT IF range (since that is the frequency range that the receiver sees). The receiver cal is normally performed with mixer mode NOT enabled since that is a linear measurement. An IMD cal may be performed if input-referred measurements are to be made. Again this cal is performed with mixer mode not enabled.

Measurement

The DUT may then be connected and mixer mode enabled. Filtering may be employed before and after the DUT if spurs are an issue.

An additional issue when using the external synthesizer is that the time bases of the instruments must be synchronized. The 10 MHz out from the synthesizer must be connected to the 10 MHz input port on the MS462xx and the reference selection must be switched to EXTERNAL (under Utility/Rear Panel). If this is not done, the tones and intermodulation products may not be exactly where the receiver expects them (particularly at smaller IF bandwidths) and poor results will be obtained.

If the external 10 MHz is not connected but the reference selection is still external, the MS462xx may not sweep or an error message 'PHASE LOCK FAIL DFCEBAKJ' (or similar alphabet soup) may be displayed.

While this section will not cover it in detail, there are a number of standard GPIB procedures that should be followed with regard to the external synthesizer. Ideally, the synthesizer will be connected to the dedicated GPIB port and turned on prior to turning on the MS462xx and the synthesizer will not be turned off while the MS462xx is running. If it is necessary to activate the synthesizer after turning on the MS462xx, the following procedure may be used:

1. Enter the multiple source menu (but go no further down that tree) AFTER the synthesizer has booted (this allows the system to recognize the existence of the synthesizer). Assuming the synthesizer is set to address 9 (default address for source 3), check Config/Sources/Source3 to see that the source is ACTIVE. If the addresses are out of synch, review the setups and repeat.

2. Verify that the sources have been selected under the IMD application menu/SOURCE SELECTION. The default sources 1 and 2 will be tones 1 and 2, while source 3 will be the LO. Ensure that the mode is APPLY.

3. Activate Mixer mode and the synthesizer will enter remote mode and will be programmed appropriately

4. If not done already, connect the 10 MHz lines as discussed above and switch the MS462xx to external reference.

If the synthesizer must be turned off or disconnected prior to shutting down the MS462xx (or the user will be later rebooting the MS462xx without a synthesizer connected), the following steps will help

5. Switch the MS462xx to INTERNAL reference and disconnect the 10 MHz line.

6. Under Config/Sources, set the external source to INACTIVE.

The external synthesizer can now be disconnected or turned off. Note that if a setup is to be saved, whether the external synthesizer is connected (and recognized) is critical. The setup can only be recalled with the same physical connections present.

Example

To illustrate these concepts, a few simple mixer measurements are described in detail. The DUT is a simple doubly balanced mixer initially using a fixed DUT IF of 100 MHz. Only output-referred intermodulation products are of interest so no calibrations will be performed. Sources 1 and 2 will be tones 1 and 2 and a relatively simple combining network will be employed (a Wilkinson combiner with a 6 dB pad on each input).

An Anritsu 68000 Series synthesizer will be the DUT LO and it will be programmed as source 3 at the default address of 9. The MS462xx had already been turned on with the synthesizer connected and is in Standard (non-mixer) mode.

1. Enter the IMD application and select CW RCVR mode (to start), with product display relative to tone 2 (for later). The initial offset will be 300 kHz. The CW frequency will be 1800 MHz. No filtering was used on the DUT. Set the IF BW to 10 Hz

2. Connect the 10 MHz out of the synthesizer to the 10 MHz in of the MS462xx and select EXTERNAL REFERENCE. Ensure that the VNMS is still sweeping.

3. Check under Config/Sources/Source3 to ensure that the source is ACTIVE.

4. Under Application/Source Selection, ensure that tone 1 is source 1, tone 2 is source 2, LO is source 3 and the mode is Apply.

5. Activate Mixer mode and go to Application/LO-Receiver setup. Note that the LO source # cannot be changed from this menu while in IMD (must use the source selection menu).

6. Select an LO offset from RF of 100 MHz and a RCVR CONVERSION of DOWN (so that source 3 will be programmed to 1900 MHz for this example and the receiver will be programmed for 100 MHz).

7. Set the source powers to 10 dBm for source 3 and 0 dBm for the two tones.

8. Setup markers as desired and observe the data as in Figure 6-11.

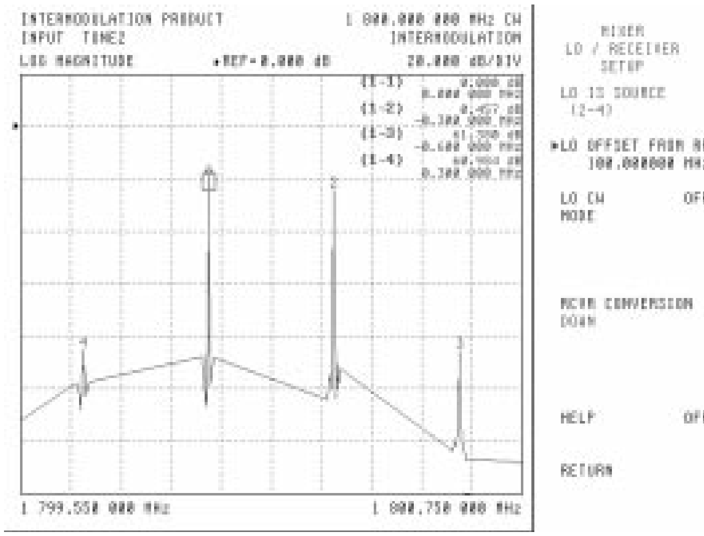


Figure 6-11. *Example Plot of Mixer IMD in CW RCVR Mode*

The markers are set to reveal the relative product amplitudes of around –60 dBc. No attempt was made to precisely equalize the tone powers (different cable lengths).

The data shows product levels on the order of –60 dBc, which is not unreasonable for the excitations employed. The display is slightly asymmetric due to the simple combining network and the small, integral offset.

Let us now try a swept measurement:

1. Set the application mode from CW RCVR to SOURCE, turn off CW mode on the Freq menu and select a start/stop pair of 800 MHz and 1050 MHz. Leave the power levels and LO/receiver settings as they were.

2. Set the offset to about 500 kHz.

3. Place markers as desired and observe the data as in Figure 6-12. The intermodulation products are in the mid –50 dBc range.

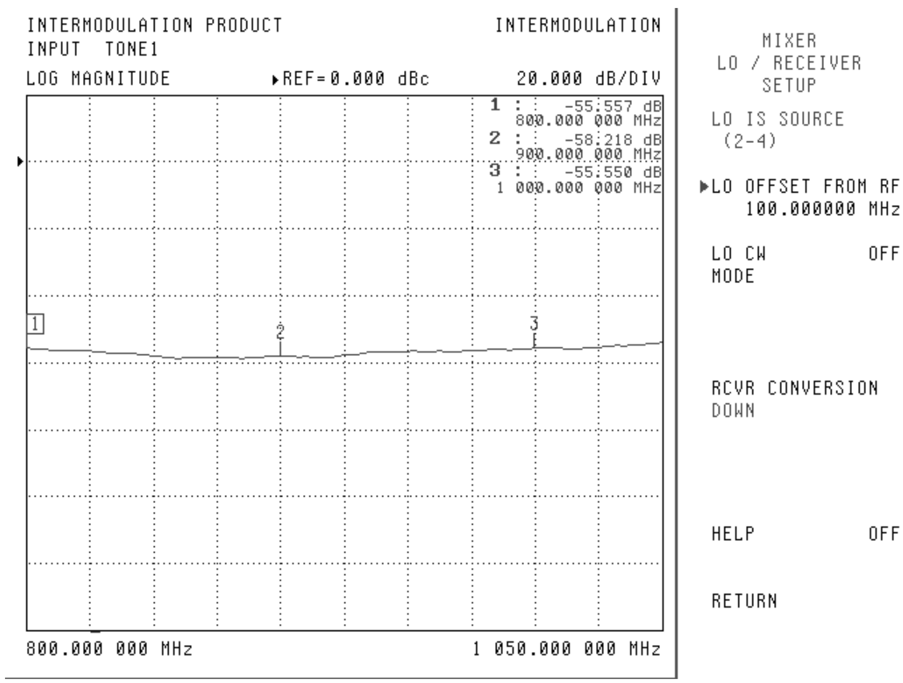


Figure 6-12. *Swept Mode Example Data for a Fixed DUT IF*

4. Next, change to a fixed LO frequency (LO CW MODE ON) of 1100 MHz so that the DUT IF will range over 50-300 MHz. Leave all other settings as before.

5. Place markers as desired and observe the data as in Figure 6-13.

For high DUT IFs (closer to 800 MHz RF), the intermodulation products climb slightly as the mixer performance begins to degrade.

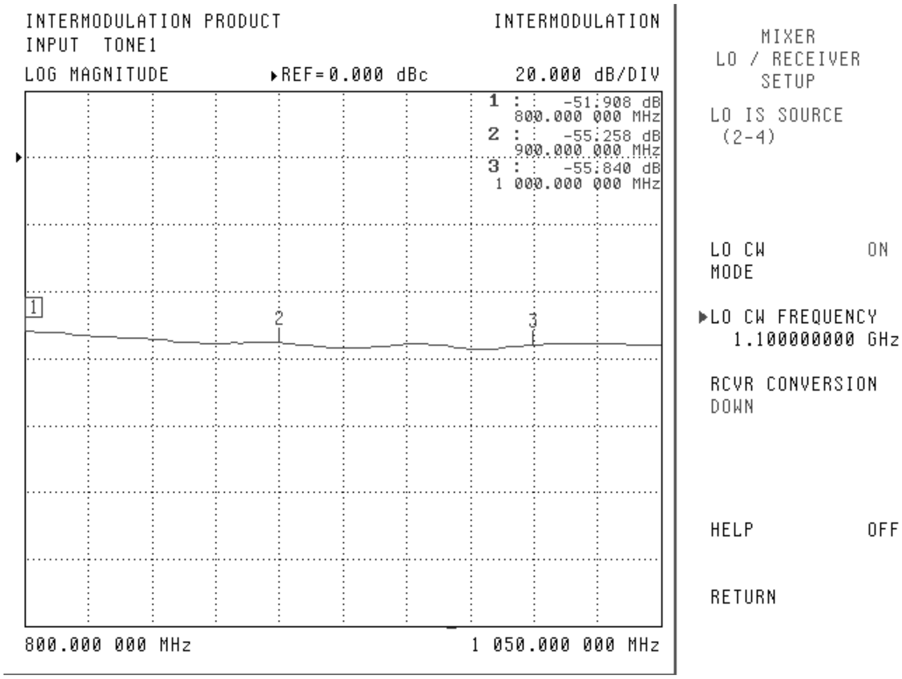


Figure 6-13. *Swept Mode Example Data for a Fixed DUT LO*

The data in these two examples are quite similar except for the small rise in IMD products as the DUT IF becomes larger. Since the mixer was primarily designed for lower IFs, it is not surprising that the intermodulation performance begins to degrade along with other device parameters.

In the situation where the system has no control over the DUT LO, the measurement may become a bit more complicated. Assuming the LO is fixed, its frequency can simply be entered in the LO/receiver setup menu even if no LO is being controlled (this tells the receiver where to tune). The 10 MHz references must still be synchronized if possible. If the external LO has no 10 MHz reference, then the measurement should be performed in a wide IF bandwidth (initially in CW RCVR mode).

The LO frequency entered into the system may need to be dithered (usually in increments of a ½ IF BW or so) until the response is maximized. This dithering process is used to move the receiver until it is aligned with the actual tones and products. It may not be possible to run in a narrow IFBW or go to swept source mode if the DUT LO is unstable since the tones will not be sufficiently aligned to make reliable measurements.

Index

A

available gain . . . 3-13

C

calibration . . . 3-10, 6-7
circulators . . . 1-1
combiner . . . 2-7
combining network . . . 4-5
compression . . . 6-4
couplers. . . . 1-1

D

data points . . . 3-12
default address . . . 6-14
DSB . . . 3-4, 6-8
duplexers . . . 1-1
dynamic range . . . 4-7

E

ENR . . . 3-8

F

filters . . . 4-6

G

General Information . . . 1-1
GPIB . . . 6-14

H

harmonic . . . 1-1, 5-1

I

IMD . . . 1-1, 4-1, 6-13
impedance . . . 4-8
insertion gain . . . 3-13
intermodulation distortion . . . 4-1
IP3 . . . 4-1

L

leakage . . . 6-5
LRL . . . 2-2
LRM . . . 2-2
LRM/TRX . . . 2-7
LSB . . . 3-4

M

manuals . . . 1-2
mixers . . . 1-1, 6-1

N

noise figure . . . 3-1, 6-7

O

offset . . . 4-1

P

power dividers . . . 1-1

R

related manuals . . . 1-2

S

shot noise. . . . 3-1
SMA . . . 2-4
SOLT . . . 2-1, 2-2, 2-9
S-parameters . . . 1-1, 2-1, 6-1
SSB . . . 3-4, 3-11, 6-8

T

thermal noise . . . 3-1
three port calibration . . . 2-1
TOI . . . 1-1, 4-1, 6-13
trace memory . . . 3-14, 6-1
TRM . . . 2-2
TRM/TRX . . . 2-2
TRX. . . . 2-3

U

uncertainty. 3-3, 5-11
USB. 3-4

V

VNA 1-2

Y

Y-Factor 3-2, 3-13

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