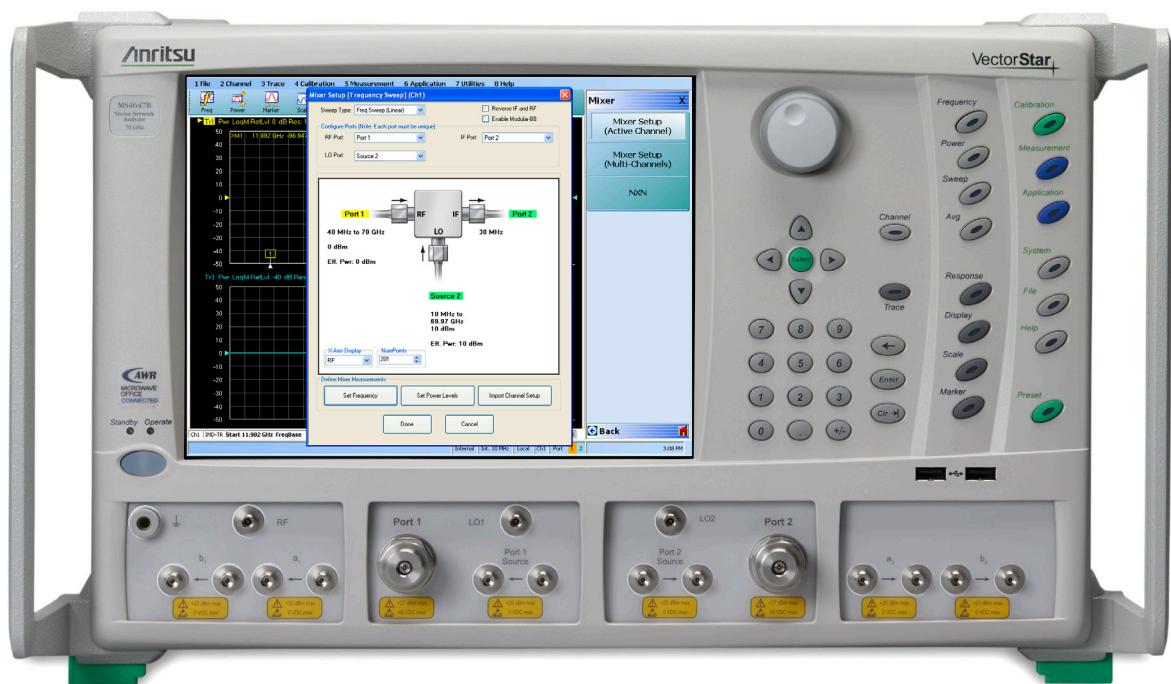


# Mixer Measurements utilizing the Mixer Setup Application and Dual Sources on VectorStar VNAs

## MS4640B Series Vector Network Analyzer



### 1. Introduction

Frequency translated devices are key components of any communication system, whether they are up-converters, down-converters or basic mixers. Since their input and output frequencies are different, they require special features and setups for Vector Network Analyzer (VNA) measurements. With the frequency offset capability of VectorStar VNAs, where the source and receiver are independently controlled, and the option to include a second source, such measurements are possible and can be easily configured.

This application note will discuss various Mixer Measurements, giving helpful hints and recommendations. Example measurements using the VectorStar VNA with the Mixer Setup application along with the dual sources (option 031) will be shown. The steps described cover the microwave bands but also apply to the mm-wave bands.

## 2. Mixer Theory

The main purpose of a mixer is the translation from one frequency at the input to another in an additive or subtractive fashion at the output. This paper will use the terms 'input' and 'output' so the names do not have to keep changing depending on the type of conversion.

The ideal mixer is a 3-port electronic circuit that "mixes" the two input signals such that the output signal frequency is either the sum or difference frequency of the inputs as shown in equation 1 below.

$$f_{out} = |f_{in1} \pm f_{in2}| \quad (eq. 1)$$

The 3 ports of a mixer are typically named the Intermediate Frequency (IF) port, the Radio Frequency (RF) port, and the Local Oscillator (LO) port. The LO port is usually used as an input port. Depending on the application, the IF and RF ports can be interchanged as either input or output ports. Extensive literature on mixer theory is available and many topics will not be covered here. The interested reader is referred to, (for example) [1] and references therein for a complete treatment.

### 2.1. Upconversion

When the desired output frequency is higher than the input frequency, the process is called upconversion. In this case, the IF is the input port and the RF is the output port. If we treat the mixer as ideal, then the output will be at the sum and difference frequencies as shown in equation 1. Figure 1 shows the spectra of an upconversion where both the sum and difference frequencies are available at the RF output port. Typically, only one of the products is wanted, therefore, the LO and the unwanted product will usually be filtered out. Notice that spectral inversion (the reversal of the orientation of the signal bandwidth with respect to the carrier frequency) occurs in the difference product. Depending on the application, this may or may not be of consequence, so care must be taken if that is the product chosen to be used.

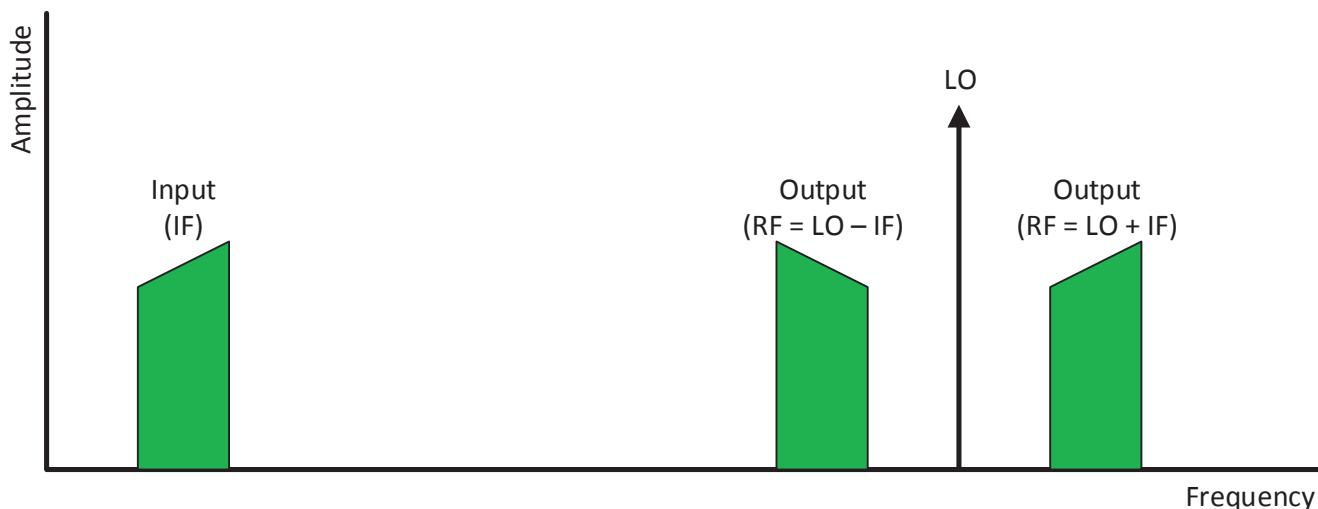


Figure 1: The spectra of signals in an upconversion case are shown here. The LO is normally greater than the input but this is not a requirement. Notice the spectral inversion on the difference product.

## 2.2. Down Conversion

When the desired output frequency is lower than the input frequency, the process is called downconversion. In this case, the RF is the input port and the IF is the output port. It is important to note that the relationship of the input frequency to the LO frequency makes a difference in the behavior of the output. If the input frequency is greater than the LO frequency, then there is no spectral inversion; whereas, if the LO is greater than the input, there is an inversion as shown in Figure 2.

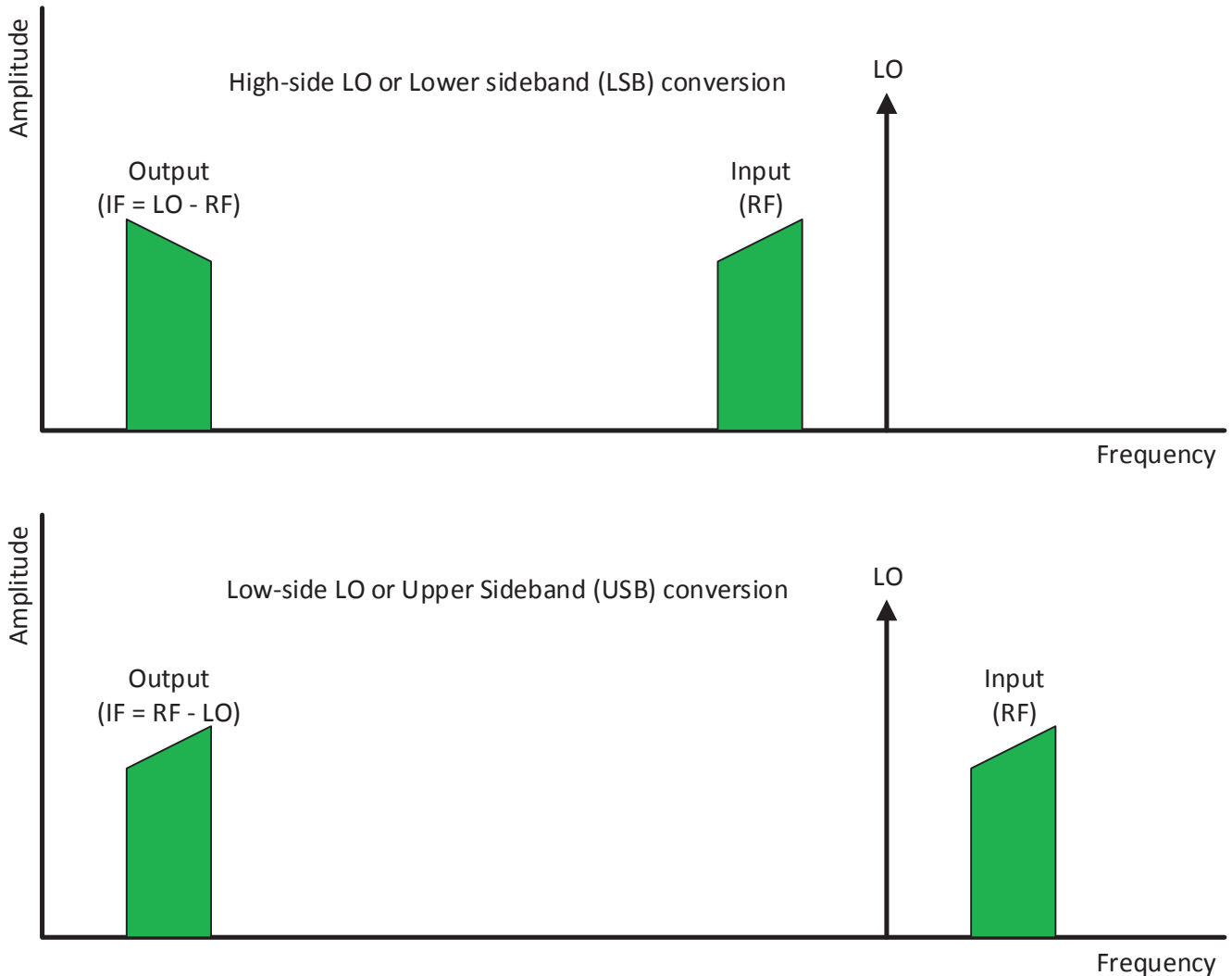


Figure 2: The spectra of signals in downconversion cases are shown here. The LO position relative to the input affects the behavior. The spectra picture on the top is of a High-side LO or Lower Sideband (LSB) case while the spectra picture on the bottom is of a Low-side LO or Upper Sideband (USB) case. Notice the spectral inversion for the LSB case.

Various terms are used to separate these two cases including 'high-side LO vs. low-side LO' and 'USB vs. LSB conversion' (for upper sideband vs. lower sideband). This document and the VectorStar instrument software will generally use the latter terminology.

Up to this point, we have been treating the conversion as ideal. In practice, the mixer (or converter) will have gain/loss and some phase shift (both typically frequency dependent), some mismatch, and potentially considerable non-linearity. There are also additional higher order terms. This means that any integer combination of input and LO frequencies can appear at the output (and many do). These other frequency components are often termed spurs with a nomenclature like an 'M by N spur' if the output frequency is of the form  $Mf_{in1} \pm Nf_{in2}$ . The measurement of these spurs is also possible with the VectorStar MS464xB, however, it will not be covered in this application note. For a discussion on spur measurements, see Chapter 19-5 of [4].

### 3. Mixer Measurement Definitions

While the terms used are common, the below may serve as a way of clarifying the nomenclature to be used in this note.

#### 3.1. Frequency/Power Plan

This is a description of the frequencies involved in the mixer measurement including the input sweep range (if swept), the LO sweep range (if any), and how the output frequency is related to the input frequency. It also includes the power levels required. In the case of a power sweep, the fixed frequencies are part of the plan along with which variable is sweeping in power (input or LO) and over what range.

#### 3.2. Input Match, Output Match, and LO Match

These are the usual return loss terms. The terms 'input' and 'output' are used in the dialog choices in lieu of IF and RF to avoid some confusion. The Mixer Setup Application default has an input of RF and an output of IF but these can be reversed. The arrow directions in the Mixer Setup diagrams always make clear what the input port is. A standard S-parameter calibration (1 port or more but with different frequency ranges on the different ports) is used.

#### 3.3. Isolation

This is transmission through the mixer (input  $\rightarrow$  output, output  $\rightarrow$  input, LO  $\rightarrow$  output or LO  $\rightarrow$  input) but without frequency conversion. The test frequency range is based on the stimulus port of the selection and the defined frequency plan. This is sometimes also called 'bleed through'. A normalization or a standard s-parameter calibration is normally used.

#### 3.4. Conversion Gain/Loss

This is a measure of energy transferred from the input frequency to the output frequency. There are a number of different calibrations available ranging from a simple scalar (but narrowband) normalized power measurement to enhanced match correction that vectorially takes into account the DUT's match (input and output) interacting with the VNA.

## 4. Mixer Measurements

There are different mixer measurements and many ways of making these measurements. These measurements also have different calibration requirements. This section will discuss some of the different measurements and calibrations.

### 4.1. Simple S-Parameter Measurements

Some of the mixer measurements such as match and some isolation measurements are essentially simple S-parameter measurements.

The match measurements (input, output, and LO) are generally 1 port, in the case of mixers, from a correction point of view since the other ports of the mixer are operating at different frequencies. Depending on the isolation of the mixer, there can be some load match dependencies and some confusion in the meaning of the practical match of the mixer (see Figure 3).

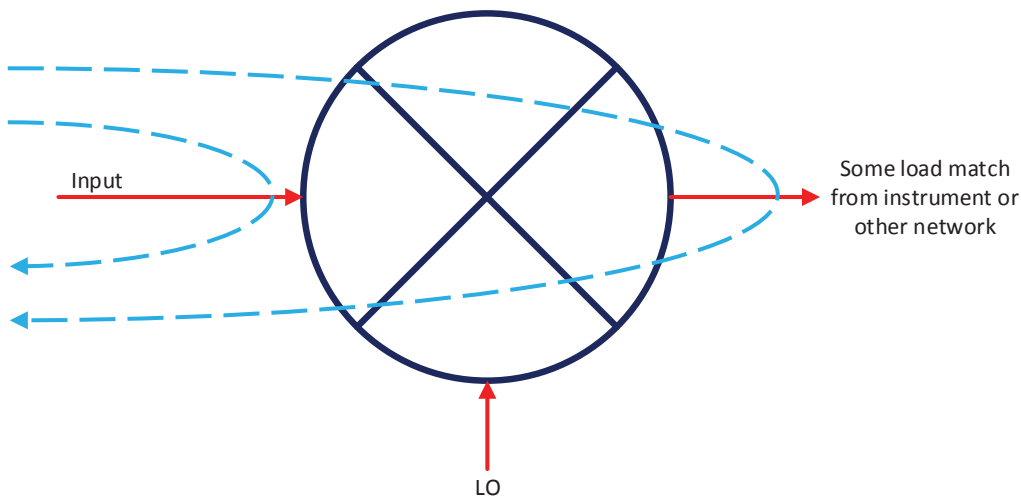


Figure 3: An illustration of the dynamics of the actual match of a mixer is shown here. If the isolation of the mixer is poor and the load match at the input frequencies is poor, multiple reflections can make the actual match of the mixer (in system) worse than one might expect. This can also have implication in conversion loss measurements as will be discussed.

Input-to-Output and Output-to-Input isolation measurements are performed with the same input and output frequencies and can be treated as a standard vector error corrected 2-port measurement. For these simple s-parameter measurements, the input and output frequencies are the same, so standard VNA calibrations can be performed.

## 4.2. Scalar Measurements (magnitude only)

The scalar measurement technique is the traditional way mixers are measured on a VNA, meaning that only magnitude information is gathered on the DUT. Since the source and receive frequencies are not the same, the VNA does not have a phase reference to make phase measurements. Some measurements that fall into this category include:

- Conversion Loss or Gain
  - Input to Output
  - Output to Input
- Pout vs. Pin (@ CW Frequency)
- Inter-modulation Distortion (IMD)

For these types of measurements, a full 12-term calibration is not possible as the input and output frequencies are at different frequencies. Depending on the measurement, one or several of these calibrations may need to be performed:

- port power calibration
- receiver calibration
- receiver normalization

## 5. Tips, Techniques, and Best Practices

This section contains some general hints on successful mixer measurements.

### 5.1. General Hints and Tips:

- For scalar-like measurements (normalization-based conversion loss measurements for example), mismatch can be critical. If the DUT is poorly matched, consider padding the test ports before calibration.
- Even for enhanced match calibration situations, the match seen by higher order products can matter if the DUT is non-linear enough.
- Know what the compression level of the DUT is. The default power levels of the VNA (+5 dBm for some models) can compress many simple mixers and particularly high gain converters.
- Understand the frequency plan of the DUT, particularly the relationship of the input frequency to the LO in downconversion cases.
- Knowing all of the required measurements in advance can help speed up the setup when using the Multi-Channel Mixer Setup Application.
- For complex conversion scenarios (harmonic or sub-harmonic conversion, multiple LOs and multiple stages, etc.), the multiple source control system gives very flexible control of the internal sources and up to 4 external synthesizers. For a detailed description of the multiple source control system, see chapter 17, “Multiple Source Control (Option 007)” of [4].
- Know the required LO power. Often one might assume a required power based on the mixer architecture (e.g., +7 dBm for a double balanced Si diode mixer), but with so many technologies and topologies available, these assumptions may be less valid than in the past. In certain high gain DUTs, LO leakage out the port can be large enough to induce compression in the instrument as well (filtering may help in this extreme case).
- As with S-parameter measurements, consider the calibration method to be used based on the available calibration kits/standards and their respective uncertainties.

### 5.2. Uncertainty Terms

On the subject of uncertainties, the conversion gain/loss measurement warrants some additional commentary. For a normalization-based calibration, there are several uncertainty terms:

- Port power accuracy (1 to 2 dB without a power calibration, 0.1 to 0.2 dB typically with a power calibration)
- Receiver calibration accuracy (typically <0.5 dB based on port mismatch)
- Linearity accuracy (<0.1 dB assuming away from compression)
- Mismatch interaction with DUT

## 6. Measurement Example

### 6.1. Conversion Loss/Gain Example

The conversion gain/loss measurement is a measurement of power transfer from input to output, but since the frequencies are different, a classical ratioed S-parameter is not possible as the port 1 source receiver (a1) is at the DUT input frequency and the port 2 test receiver (b2) is at the DUT output frequency. This example measurement will be performed using the Mixer Setup Application (Active Channel) and internal dual sources (option 031).

#### 6.1.1. Equipment Needed

- VectorStar B with the following options:
  - Option-007 - Receiver Offset (includes Mixer Setup Application)
  - Option 031 – Dual source
  - Option 051, 061, or 062 (for the direct access loops)
- Power Meter – Anritsu ML2430/80/90 Series
- Power Sensor – MA2440/70/80 Series
- Mixer – Mini-Circuits ZEM-4300 (30 MHz to 4.3 GHz)
- Diplexer – Anritsu PN: 64901

#### 6.1.2. Hardware Setup

Although this measurement requires three ports (two source ports and a receive port), a 2-port VectorStar VNA with the options listed above can be used to make the measurement. To do this, either one of the sources or the receive port must be configured via a direct access loop. Using the output from a source loop for the second source will provide additional drive power, whereas using a receiver loop will provide more dynamic range. The choice of which setup to use will depend on what is more important. Typically, drive power will be more desirable as most mixers will work better with higher LO drive power.

When using the direct access loops, one must take into account the architecture of the VectorStar. The dual band VectorStar VNA is composed of a mixer based low band (70 kHz to 2.5 GHz) VNA using a bridge reflectometer and a high band (>2.5 GHz) VNA using Non-Linear Transmission Line (NLTL) samplers and a broadband coupler reflectometer. The access loops on the rear panel of the unit are used for the low band and the loops in the front panel are used for high band. When making measurements that cross these two bands, one must combine the signals to/from the low and high band loops. A combiner or diplexer may be used to accomplish this. It is recommended that a diplexer be used because they typically have better insertion loss and isolation characteristics.

This measurement example will use the following port configuration (shown in Figure 4):

- IF – Port 1
- LO - Both low band and high band Source 2 Loops combined using a diplexer
- RF – Port 2

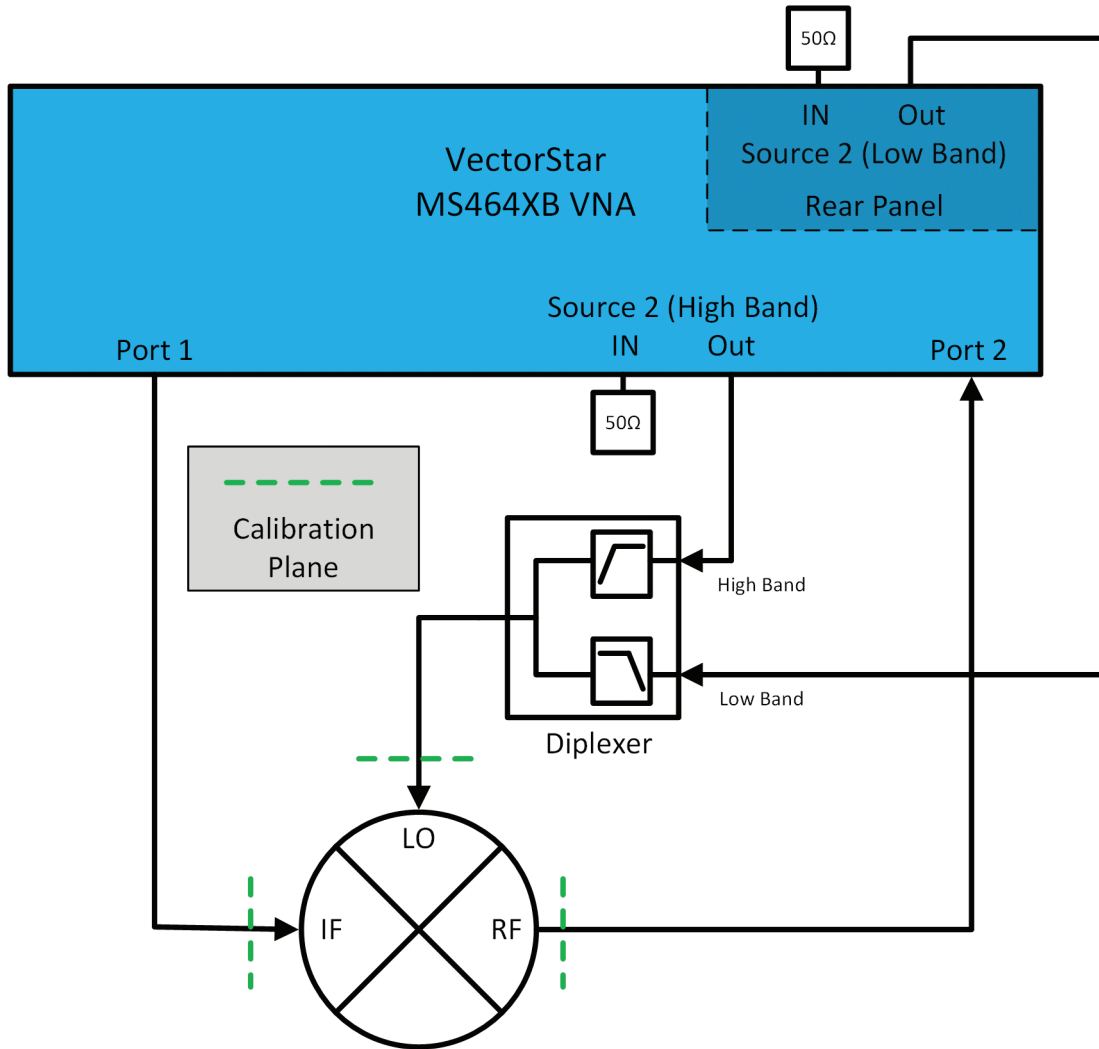


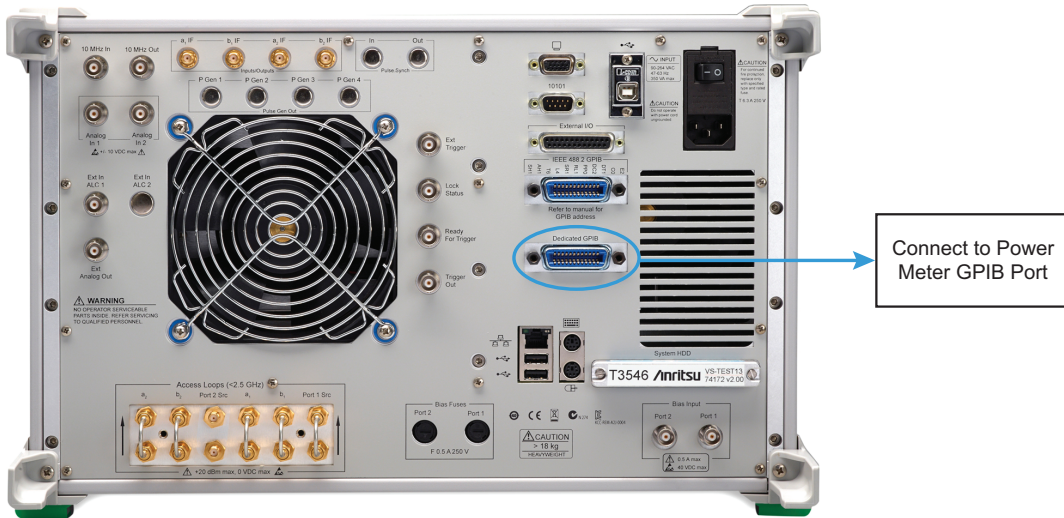
Figure 4: Hardware Configuration for example measurement



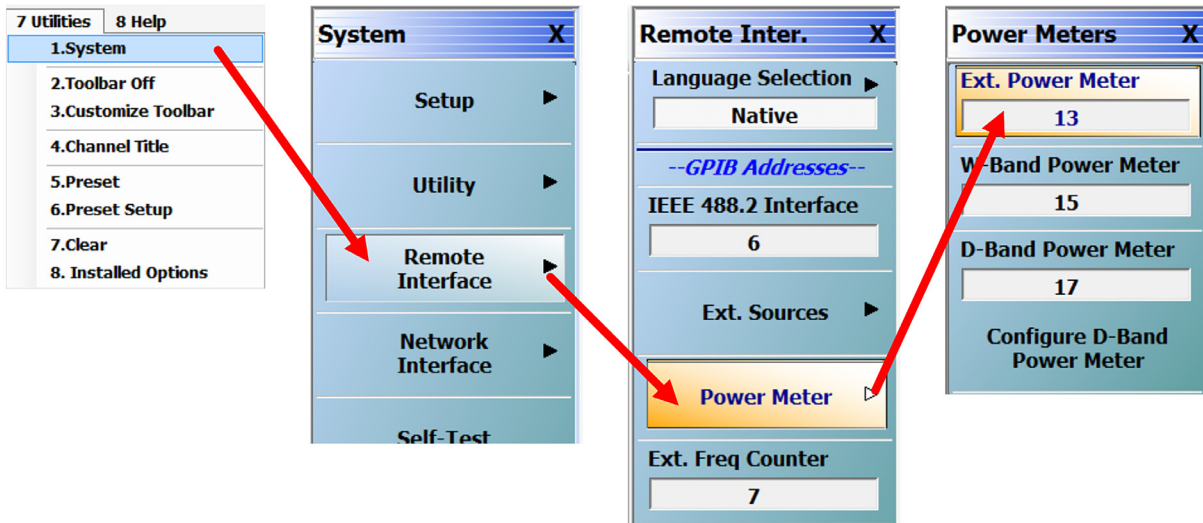
### 6.1.3. Measurement Procedure

#### Setup Power Meter and sensor

1. Connect the power meter's GPIB port to the Dedicated GPIB port of VectorStar



2. Verify VectorStar and the power meter GPIB addresses are set correctly:
  - a. Set GPIB Address of Power Meter to 13
  - b. On the VectorStar – Set GPIB Address of Ext. Power Meter to 13



3. Zero and Calibrate the Power Meter (per your power meter's instructions)

#### Setup Hardware for calibration

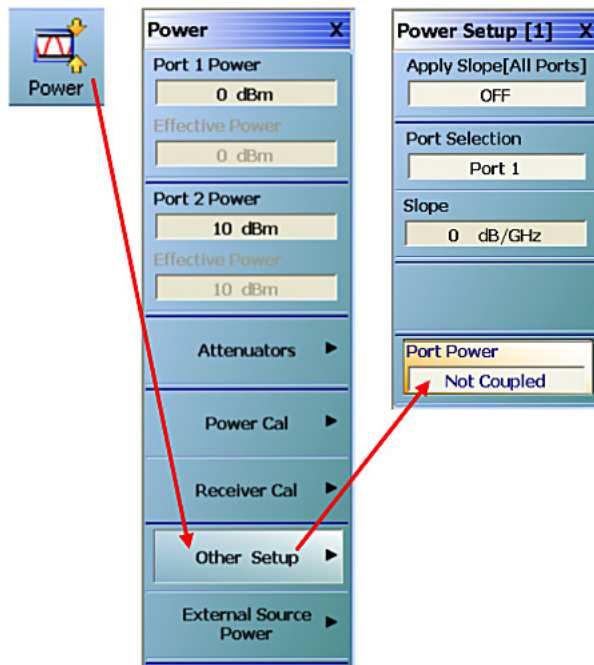
1. Remove Source 2 Loop from both front and rear panels
2. Terminate the inputs of the source loops with 50 Ohm terminators
3. Connect the outputs of the source loops to the Diplexer
  - a. Connect the low band source to the low band port of the diplexer
  - b. Connect the high band source to the high band port of the diplexer



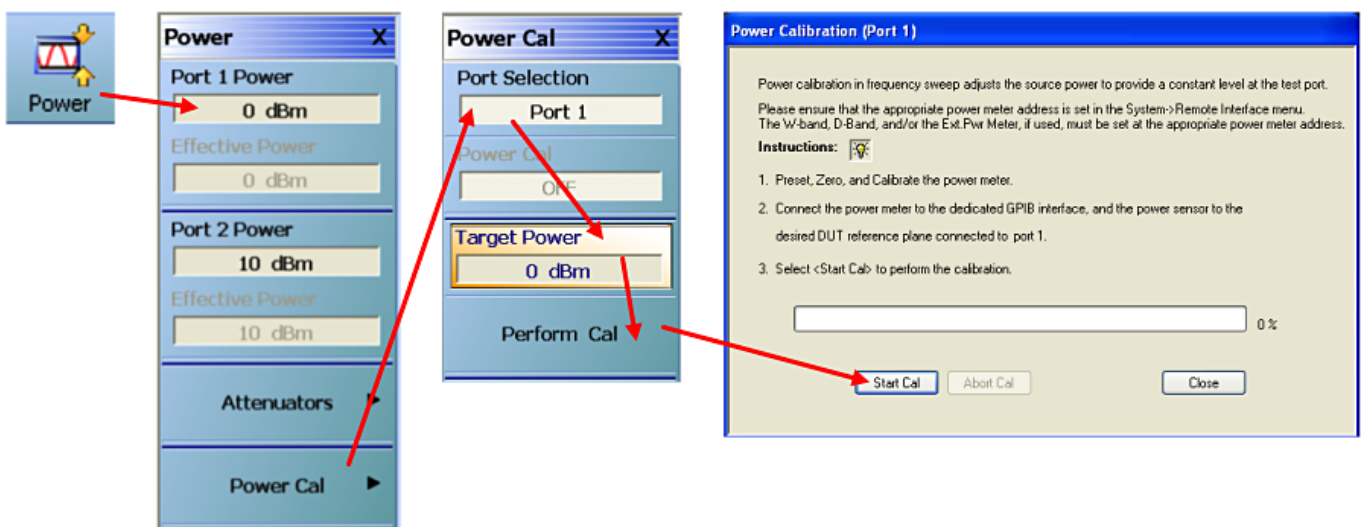
## Perform Power Flatness Calibrations

The calibrations required for this measurement are power flatness for the two sources and receiver normalization calibrations for the receiver. It is recommended that the power flatness calibration be done first.

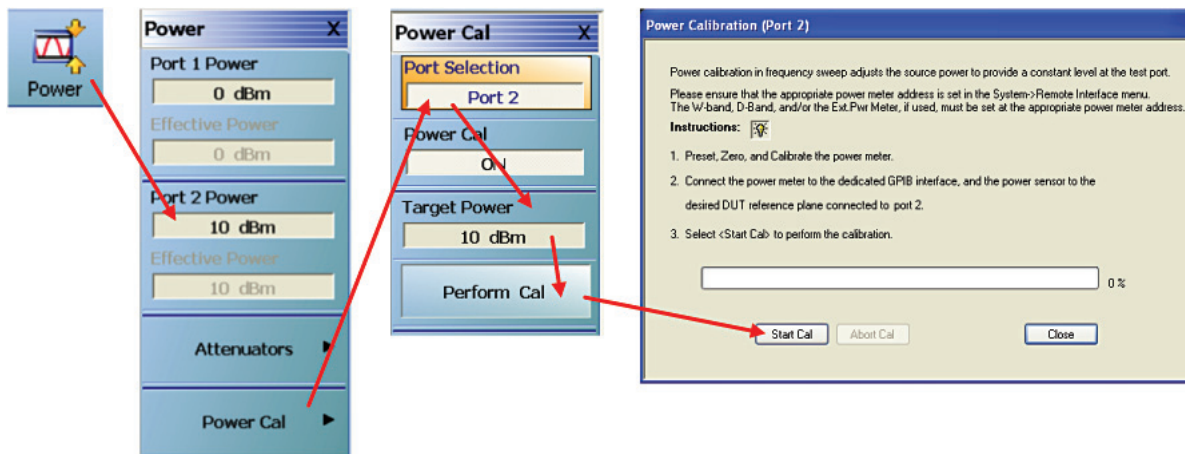
1. Press the Preset Button on the VectorStar VNA to get it to a known state.
2. Uncouple Port 1 and Port 2 power settings
  - a. Power → Other Setup → Port Power = Not Coupled



3. For Port 1, perform a flat test port power calibration to cover both IF and RF ranges (i.e., 300 MHz to 4.3 GHz) to a target level of 0 dBm,
  - a. Set VectorStar Frequency Start to 300 MHz and Frequency Stop to 4.3 GHz
  - b. Set Vector Star Number of Points to 201
  - c. Connect Port 1 to the Power meter and perform power calibration
    - i. Power → Port 1 Power = 0 dBm
    - ii. Power Cal → Port Selection = Port 1
    - iii. Target Power = 0 dBm
    - iv. Perform Cal → Start Cal



4. For Source 2, perform a flat test port power calibration to cover LO sweep range (i.e., 100 MHz to 4 GHz) to target level of +10 dBm.
  - a. Set VectorStar Frequency Start to 100 MHz and Frequency Stop to 4 GHz
  - b. Set Vector Star Number of Points to 201
  - c. Connect common port of diplexer to the Power meter and perform power calibration
    - i. Power → Port 2 Power = +10 dBm
    - ii. Power Cal → Port Selection = Port 2
    - iii. Target Power = +10 dBm
    - iv. Perform Cal → Start Cal



### Configure Mixer Setup Application

Configure the conversion gain/loss measurement using Mixer Setup (Active Channel).

1. Application → Mixer → Mixer Setup (Active Channel)
2. Configure measurement as shown in Figure 5.
  - a. Sweep Type = Freq Sweep (Linear)
  - b. Reverse IF and RF = Checked
  - c. Enable Modular - BB = Unchecked (may not be available depending on system configuration)
  - d. RF Port = Port 2
  - e. IF Port = Port 1
  - f. LO Port = Source 2
  - g. X-Axis Display = RF
  - h. NumPoints = 201

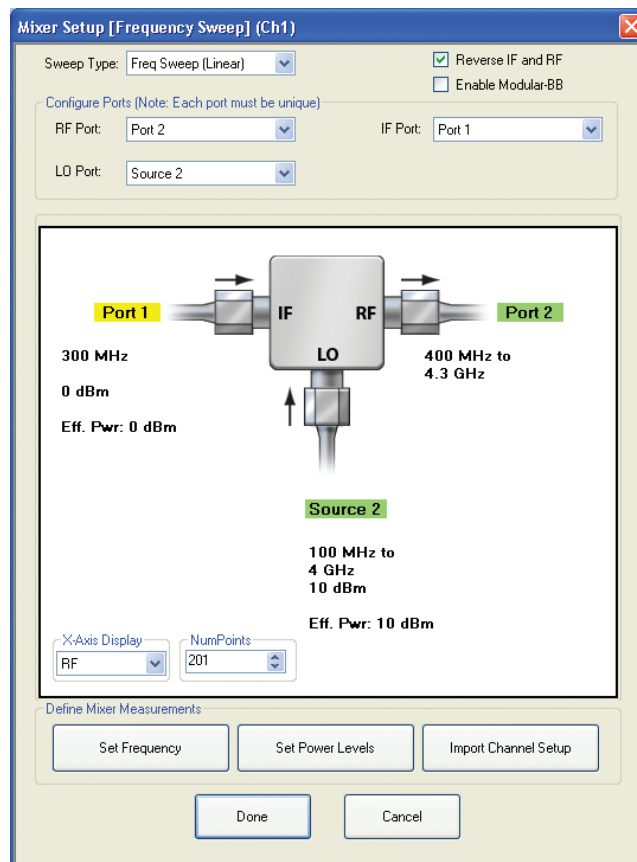


Figure 5: Mixer Setup (Active Channel) Configuration Window

- i. Select Set Frequency and setup frequency plan as shown in Figure 6
  - i. IF Frequency Mode = Fixed
    - 1. CW Frequency = 300 MHz
  - ii. LO Frequency Mode = Auto
  - iii. RF Frequency Mode = Swept
    - 1. Start Frequency = 400 MHz
    - 2. Stop Frequency = 4.3 GHz
  - iv. Conversion = RF = IF + LO(Up)
  - v. Select OK
- j. Select Set Power Levels and setup the power levels as shown in Figure 7
  - i. IF Power = 0 dBm
  - ii. LO Power = 10 dBm
  - iii. Select OK
- k. From the Mixer Setup (Active Channel) configuration window, select DONE.

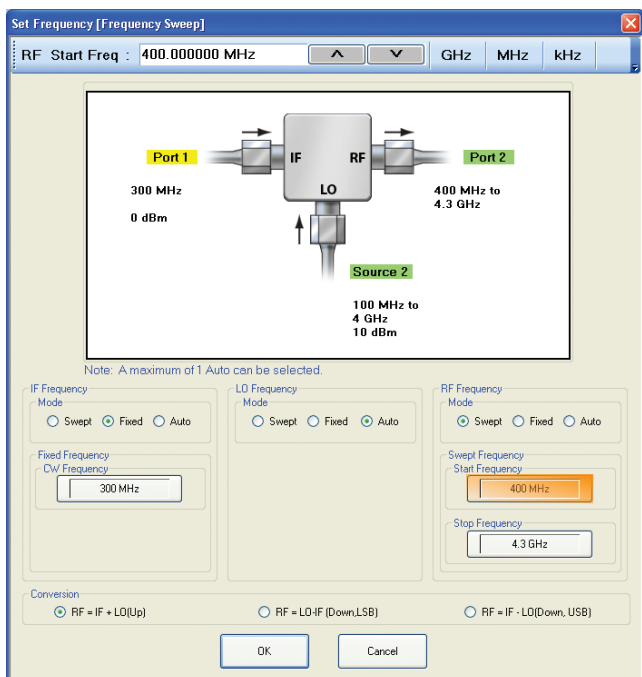


Figure 6: Mixer Setup Set Frequency Configuration Window

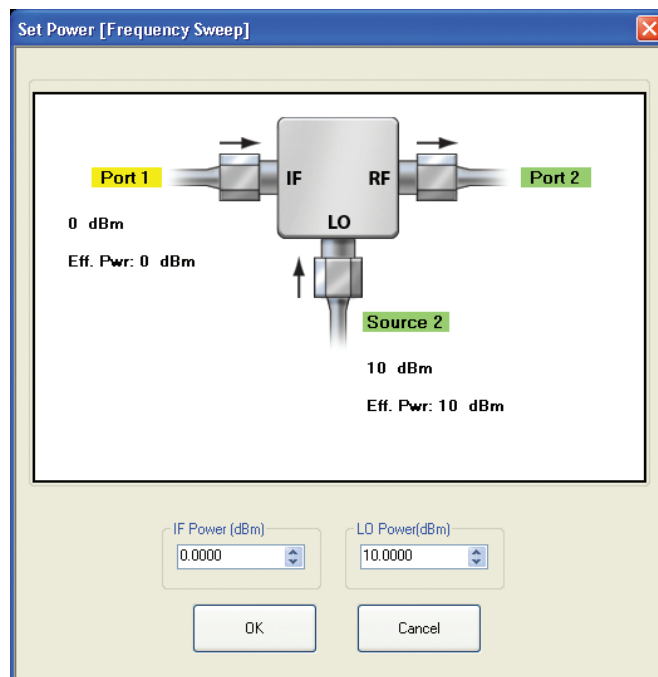
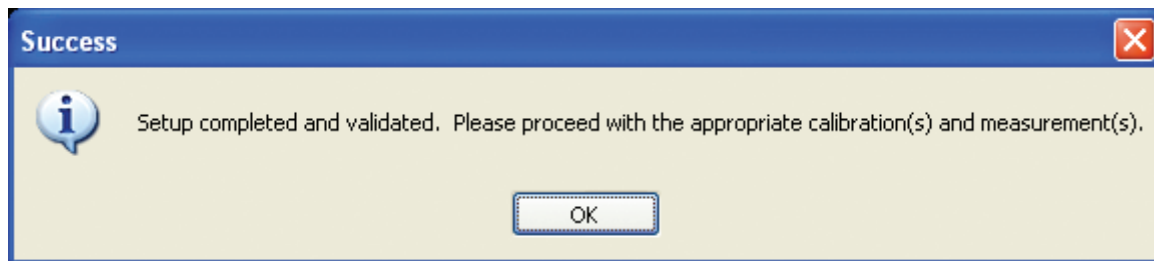


Figure 7: Mixer Setup Set Power Configuration Window

A message should now pop out stating that the setup is now complete and has been validated. The next step is to proceed with the receiver calibrations.

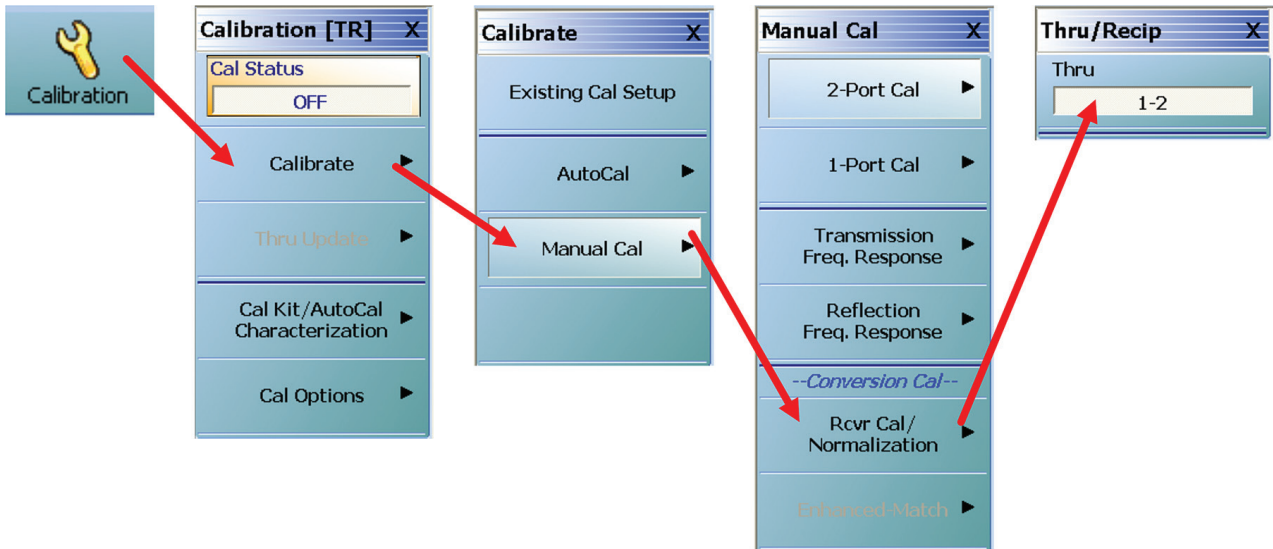


## Perform Receiver Calibration

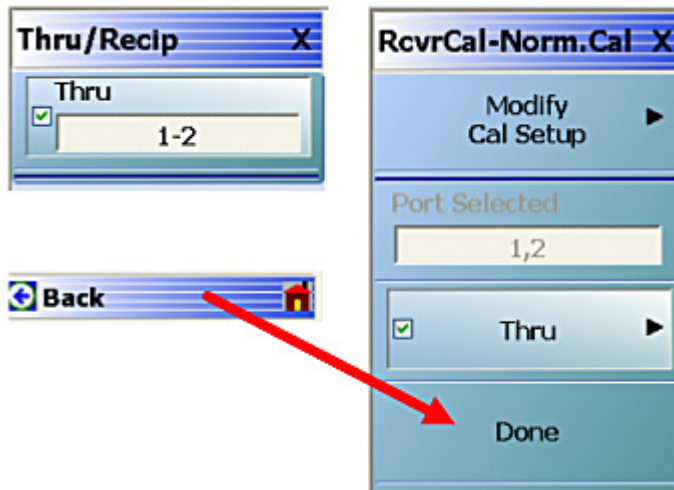
Next, we will perform a Receiver Calibration and Normalization. Normalization cal is a quick scalar calibration that normalizes the path between port 1 and port 2. Select this choice to perform the scalar calibration. Be sure to select proper DUT connector in Modify Cal Setup menu (under Edit Cal Parameters).

Note that the Enhanced-Match calibration is not available. This is because port 2's source is being used as the LO source, therefore the Enhanced-Match calibration cannot be performed.

1. Connect a thru adapter between ports 1 and 2.
2. Perform the Receiver Calibration and Normalization
  - a. Calibration → Calibrate → Manual Cal → Rcvr Cal/Normalization → Thru → 1-2



- b. When calibration is done a check mark should appear
  - i. Select Back
  - ii. Then Select Done



### Connect DUT and make measurement

At this point, we are ready to make the conversion loss measurement by simply connecting the DUT as shown in Figure 4 and setting up a trace to display the proper results.

1. Connect the mixer as shown in Figure 4
2. Maximize one of the traces.
3. Configure the trace
  - a. Response = b2/1 (conversion loss) measurement.
  - b. Display → Trace Format = Log Mag

Figure 8 shows the result of the conversion loss measurement of the mixer with the IF set at 300 MHz CW, and the LO swept from 100 MHz to 4 GHz.

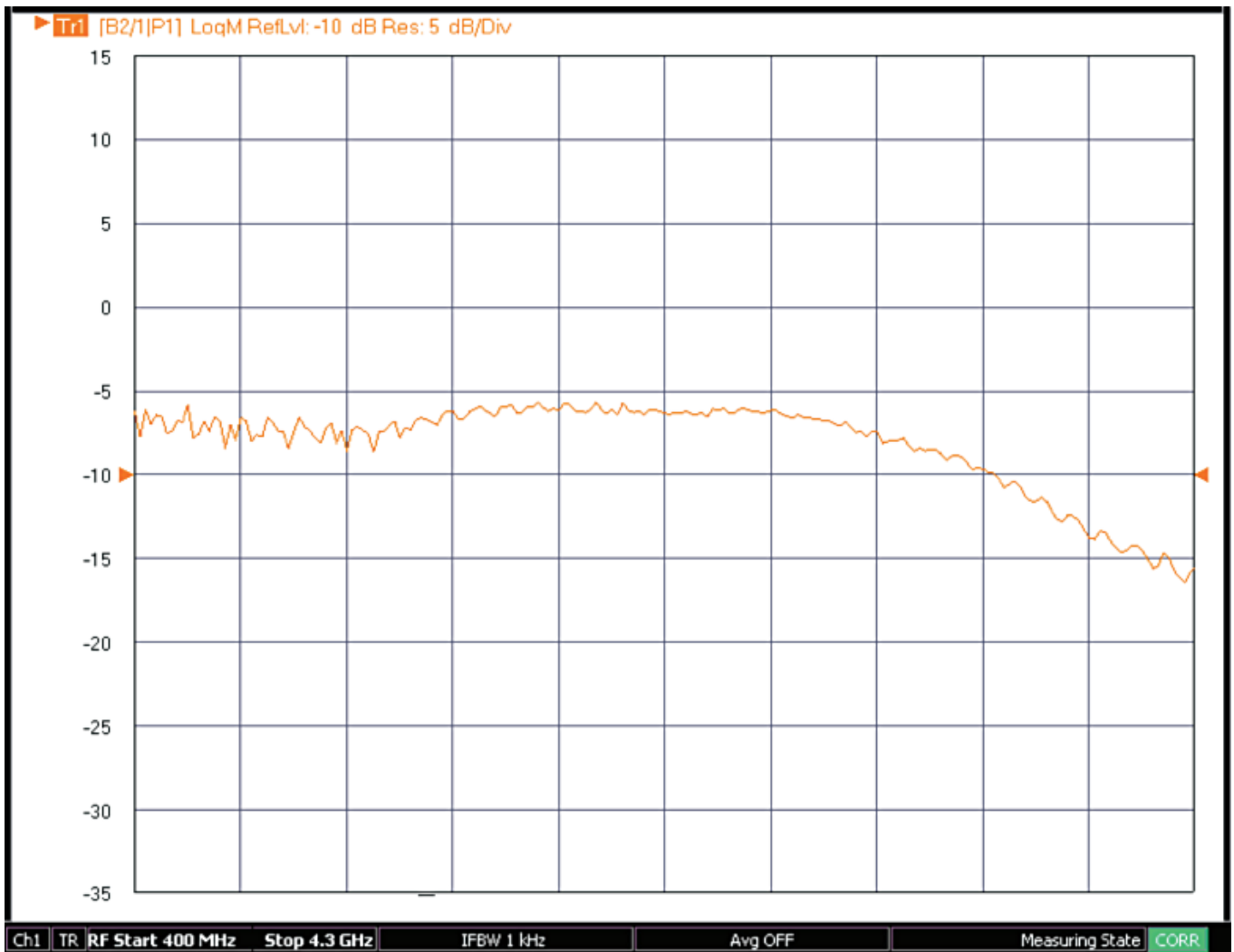


Figure 8: Conversion Loss Measurement

## 7. Mixer Setup – Multiple Channel Wizard

The multiple channel mixer wizard is, in some sense, a natural extension of the single channel setup method introduced previously. The difference here is that multiple measurements are orchestrated for the user in different channels with the corresponding sweeps already setup and the calibrations suggested. The main configuration dialog is shown in Figure 9. In addition to some of the controls discussed in the active channel case are a list of possible measurements separated into 3 groups: between input and output, between LO and output, and between LO and input. The three groups require different connections since the LO port needs access to receivers in the second two sets. All measurements can be set up at once, but the results from different groups will only be meaningful if the DUT is connected correctly.

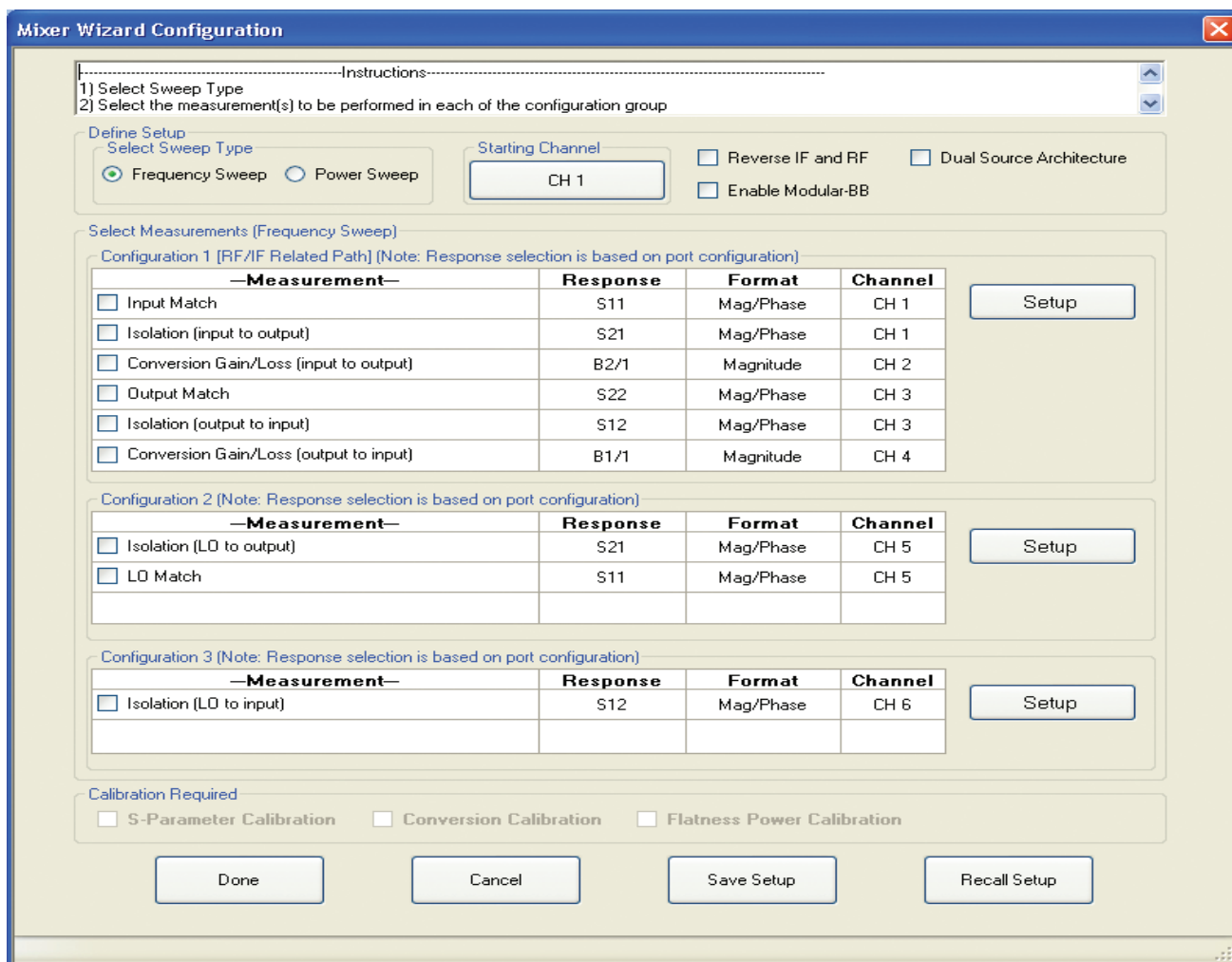


Figure 9: Multi-Channel Mixer Setup Wizard Frequency Sweep Configuration Window

All of the measurements that can be made using the active channel controls can also be made with the multiple channel wizard, but now they are automatically assigned to different channels that will control the different sweeps. To see this concept, suppose one requests forward conversion gain/loss (input to output), isolation (input to output) and isolation output to input. The first measurement requires the source to sweep over the input frequencies while the receiver sweeps over the output frequencies. The second measurement requires both the source and receiver to sweep over the input frequencies. The third measurement requires both the source and receiver to sweep over the output frequencies. By placing these three measurements in different channels, all the measurements can be completed in one 'super sweep' without user intervention and all of the results displayed at once.

There is a Starting Channel button on this dialog to indicate which channel should have the first measurement and the others will increment from there. While the default is to start with channel 1, the user may have setups in one or more channels that they would like to keep sweeping in addition to those measurement orchestrated by the mixer wizard.



The power and frequency setup dialogs are essentially the same as for the single channel setup system. For the power sweep case, the choices are more limited and are shown in Figure 10. Conversion gain as a function of input power (compression) may be of interest as can conversion gain versus LO power (looking for LO saturation while the input power is constant). Unlike the manual method in the single channel setup, here the swept power on the respective port will be requested.

For a more thorough discussion of the multi-channel wizard, see [4].

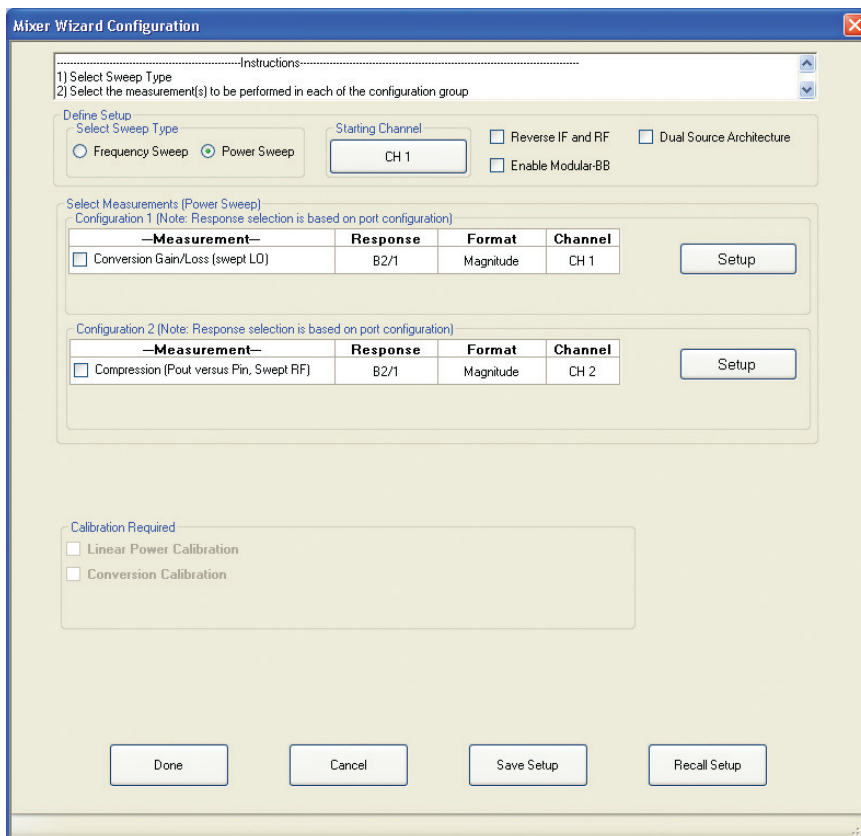


Figure 10: Multi-Channel Mixer Setup Wizard Power Sweep Configuration Window

## 8. Conclusion

There are many different measurements that are required to characterize a mixer. These measurements often require complicated hardware and software configurations. The VectorStar MS464xB series VNAs with the optional second source and the Mixer Setup Application helps users make these measurements quickly and easily. The Multiple Source control feature allows users to independently control the internal sources and receivers as well as up to 4 additional external sources to configure even the most complicated of measurements.

## 9. References

- [1] S. A. Maas, Microwave Mixers, Artech House, Norwood, MA 1993
- [2] L. Dunleavy, T. Weller, E. Grimes and J. Culver, "Mixer Measurements using Network and Spectrum Analysis," 48th ARFTG Conference Digest, Dec. 1996, pp. 16-27.
- [3] J. Dunsmore, "Novel Method for Vector Mixer Characterization and Mixer Test System Vector Error Correction", 2002 International Microwave Symposium Digest, June 2002.
- [4] "VectorStar MS464xB Calibration and Measurement Guide," Anritsu publication 10410-00318D, May 2014.
- [5] "Mixer VNA Measurements," Anritsu Application Note 11410-00519, July 2009.
- [6] "Lighting 37000 Series Vector Network Analyzers Application Note: Measuring Frequency Conversion Devices," Anritsu Application Note 11410-00197, April 1998.

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