Mixer VNA Measurements
Frequency Translated Devices Measured with a VectorStar® VNA
MS4640A Series Vector Network Analyzer

1.0 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 today’s VNAs, where the source and receiver are independently synthesized, such measurements are possible and require a much less complicated setup. With special calibration techniques, vector error corrected measurements are possible for added accuracy, and absolute phase, as well as group delay information.

This application note will discuss the following Mixer Measurements, giving helpful hints and recommendations. VectorStar VNA specific information will be included in an appendix section at the end.

Scalar Measurements (magnitude-only)
• Conversion Loss or Gain
  – Input to Output
  – Output to Input
• Port to Port Isolation
  – LO to Output
  – LO to Input
• Pout vs. Pin (@ CW Frequency)
• Inter-modulation Distortion (IMD)

Vector Error Corrected Measurements (without a characterized mixer)
• Port Match
  – Input
  – Output
  – LO (requires moving the mixer)
• Port to Port Isolation
  – Input to Output
  – Output to Input

Vector Error Corrected Measurements (using a characterized and de-embedded mixer)
• Conversion Loss or Gain (Magnitude and Phase)
• Group Delay
• Input Port Match
• Compression

Appendix
• Using Multiple Source Control Mode
• Calibrating the Input Power to the DUT (Test Port Power Cal)
• Calibrating the Receiver (Receiver Cal)
• Characterizing a Mixer for de-embedding purposes (NxN Routine)
• De-embedding a Characterized Mixer (Embedding/De-embedding Routine)
2.0 General Information (check Figure 1)

Though this application note applies to many types of Frequency Translated Devices, we will use a Mixer and its typical terminology for simplicity.

When measuring mixers some general precautions are advised:

- Make sure to measure the mixer in its linear range, unless a compression measurement is being made. Do not overdrive the device under test (DUT).
- Adding attenuation at the ports of the mixer is sometimes recommended to improve the generally poor match of the DUT. This padding should be calibrated out. Based on the dynamic range available, the extra loss could increase the noise level of the measured signal.
- Make sure to drive the LO port of the mixer with the recommended proper power, without starving or over-driving it. Though Anritsu Signal Generators have enough power to drive most mixer LO ports, adding external amplification will add isolation from unwanted signals going back into the Signal Generator.
- Mixers do generate mixing products at their output, other than the desired signal. If these spurious responses affect the measurement, a filter is recommended at the output. This app note will assume a low pass filter (LPF) is used. If a LPF is added at the output, its response needs to be calibrated out.

VNA and Signal Generator Connections:

- It is always recommended to tie the 10 MHz reference of both instruments together for tighter frequency tracking.
- The VNA controls external sources via GPIB over its Dedicated Bus. Properly connect the GPIB cable and set the external source GPIB address in the VNA. (System\Remote Interface\Ext. Sources\)
- Apply the above to all sources, in the case of multiple LOs.
- Check Appendix A for some information on how to configure and control the sources from within the VNA.

The measurement setup and steps will be mentioned in the body of the application note. How to perform a specific step, such as setting up Multiple Source Control Mode, or performing a Flat Test Port Power Calibration is explained in the appendix section, or in the instrument's Measurement Guide.

![Figure 1. General Recommendations](image)
3.0 Scalar Measurements

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 a phase measurement.

3.1 Conversion Loss or Gain:

3.1.1 Input to Output

– Use the setup in Figure 1.
– Calibrate the port 1 power at Reference Plane A, for the desired level over a frequency range that covers both Input and Output frequency ranges. This ensures a flat and known input level and an identical level at the Output frequencies to calibrate the receiver.
– Calibrate Receiver b2 (port 1 driving) at the same level as above, over the same frequency range, connecting Reference Planes A and B without the DUT.
– Set the response to b2/1 with port 1 driving.
– Normalize by leaving Reference Planes A and B connected, over the Input frequency range, with the desired number of points: Measure b2/1; Store the response to memory; Change the display to Data/Memory. A flat trace should be displayed at the 0 dB conversion level.
– Set the following Multiple Source Control definitions: (Be sure to select "Done Editing" when done.)
  Band Start & Stop Frequencies = Input Frequency Range
  Internal Source = Input Frequency Range
  External Source = LO Frequency Range
  Receiver & Receiver Source = Output Frequency Range
– Set Multiple Source Control Mode ON.
– Then insert the device, measuring Data/Memory for the mixer’s conversion loss or gain.

3.1.2 Output to Input

Notice that Multiple Source Control Mode is a per channel feature. If both Input to Output and Output to Input conversion need to be measured, without removing the DUT, each set-up could be created in two different channels, where the VNA can make both measurements serially.

– Use the setup in Figure 1.
– Calibrate the port 2 power at Reference Plane B, for the desired level over a frequency range that covers both Input and Output frequency ranges. This ensures a flat and known input level and an identical level at the Input frequencies to calibrate the receiver.
– Calibrate Receiver b1 (port 2 driving) at the same level as above, over the same frequency range, connecting Reference Planes A and B without the DUT.
– Set the response to b1/1 with port 2 driving.
– Normalize by leaving Reference Planes A and B connected, over the Output frequency range, with the desired number of points: Measure b1/1; Store the response to memory; Change the display to Data/Memory. A flat trace should be displayed at the 0 dB conversion level.
– Set the following Multiple Source Control definitions:
  Band Start & Stop Frequencies = Output Frequency Range
  Internal Source = Output Frequency Range
  External Source = LO Frequency Range
  Receiver & Receiver Source = Input Frequency Range
– Set Multiple Source Control Mode ON.
– Then insert the device, measuring Data/Memory for the mixer’s conversion.
3.2 Port to Port Isolation (LO to Input and LO to Output)

- Use the setup in Figure 1.
- Set the frequency range to the LO frequency range, with the desired number of points.
- Calibrate the port 1 power at Reference Plane A, for the proper LO drive level.
- Calibrate the port 2 power at Reference Plane B, for the proper LO drive level.
- Calibrate the Sig Gen’s power at Reference Plane C, for the proper LO drive level. Use its manual.
- Calibrate Receiver b1 (port 2 driving) at the same level as above, over the LO frequency range, connecting Reference Planes A and B without the DUT.
- Calibrate Receiver b2 (port 1 driving) at the same level as above, over the LO frequency range, connecting Reference Planes A and B without the DUT.
- Set the following Multiple Source Control definitions:
  - Band Start & Stop Frequencies = LO Frequency Range
  - Internal Source = CW at a frequency away from the Input, Output, and LO frequencies.
  - External Source = LO Frequency Range
  - Receiver & Receiver Source = LO Frequency Range
- Set Multiple Source Control Mode ON.
- Set up two traces to measure responses b1/1 (trace 1) and b2/1 (trace 2), both with port 1 driving.
- Normalize, connecting Reference Planes C and A without the DUT: Measure b1/1 on trace 1; Store the response to memory; Change to Data/Memory. A flat trace should be displayed at the 0 dB conversion level.
- Normalize, connecting Reference Planes C and B without the DUT: Measure b2/1 on trace 2; Store the response to memory; Change to Data/Memory. A flat trace should be displayed at the 0 dB conversion level.
- Then insert the device, measuring Data/Memory, b1/1 being the LO to Input Isolation (dB) and b2/1 being the LO to the Output Isolation (dB).

3.3 \( P_{out} \) vs. \( P_{in} \) (@ CW frequency)

- Use the setup in Figure 1.
- Calibrate the port 1 power at Reference Plane A, for the desired level over a frequency range that covers both Input and Output frequency ranges. This ensures a flat and known input level and an identical level at the Output frequencies to calibrate the receiver.
- Calibrate Receiver b2 (port 1 driving) at the same level as above, over the same frequency range, connecting Reference Planes A and B without the DUT.
- Select the CW Frequency Power Sweep mode: Sweep\Sweep Types\Power[CW]
- Set your power sweep range, starting in the linear range and ending-up past the input power needed to compress the DUT.
- Set your frequency to the desired Input CW frequency.
- Perform a power cal at Reference Plane A.
- Set the response to b2/1 with port 1 driving.
- Set the following Multiple Source Control definitions:
  - Band Start & Stop Frequencies = Input CW Frequency
  - Internal Source = Input CW Frequency
  - External Source = LO CW Frequency
  - Receiver & Receiver Source = Output CW Frequency
- Set Multiple Source Control Mode ON.
- Then insert the device, measuring \( P_{out} \) vs. \( P_{in} \), observing the compression as deviation from a linear trace.
3.4 IMD

IMD can be measured at CW or over swept frequencies. The VNA can do both. Notice that the resultant data is the dBc value of the intermod product to the carrier. Third-order Intercept (TOI) calculations will have to be done outside the VNA application. Tabular data could easily be moved into a spreadsheet. The CW case is a subset of the swept case, and will not be elaborated on here. Since a single slice in time is being measured in the CW case, the receiver could be set to measure both output tones and both output third-order products, by using Segmented Sweep to concentrate the points in the areas of interest. This will show a spectrum analyzer-like traditional 4 tones on the display. In the swept frequency case, the VNA will be set to measure one product at a time, but over the whole frequency range of interest.

Figure 2 shows the additional equipment for an IMD setup. For simplicity, the basic recommendations for the mixer setup are grayed-out. The second external source for the second tone should be setup as External Source #2. It should also share the 10 MHz reference and GPIB bus with the other source. Its GPIB address should be added to the VNA, etc. Isolators are recommended so the two sources do not interfere with each other.

Figure 3 shows the Frequency Ranges that the mixer experiences, Tones 1 and 2 on the Input side, including the Third-order IMD products, and Tones 1 and 2 on the Output side, including the Third-order IMD products.

*Preferably choose an Offset (OS) that is not a direct multiple of 10 MHz to reduce spurious effects. For example, choosing 99.9 MHz instead of 100 MHz will eliminate such artifacts.
IMD (swept)

– Calibrate the port 1 power at Reference Plane A, for the desired level over a frequency range that covers both Input and Output frequency ranges. Fig 5. shows the Input frequency range being Input1-OS to Input1+2OS, and the Output frequency range being Output1-OS to Output1+2OS. This ensures a flat and known input level. Make sure to either disconnect the tone 2 source from the combiner and terminate the combiner port, or turn the Output OFF on the source, during this step.

– Calibrate Receiver b2 (port 1 driving) at the same level as above, over the Output frequency range, connecting Reference Planes A and B without the DUT. Use the same number of points desired in the final measurement. Keep tone 2 off or disconnected.

– Calibrate the tone 2 source for flat power at Reference Plane A, for the same level as above, over the same frequency range as above. Make sure to either disconnect the tone 1 source from the combiner and terminate the combiner port, or make the VNA drive port 2, during this step.

– Reset the Frequency Range of the VNA to the Input1 frequency range, using the same number of points.

– Set the following Multiple Source Control definitions:
  
  Band Start & Stop Frequencies = Input 1 Frequency Range
  Internal Source = Input1 Frequency Range
  External Source 1 = LO Frequency Range
  External Source 2 = Input 1 + OS
  Receiver & Receiver Source = Output 1 Frequency Range

– Set Multiple Source Control Mode ON.

– Insert the device; measure b2/1. Notice that you are measuring Output Tone 1. Store the response to memory; change the display to Data/Memory. A flat trace should be displayed at the 0 dBc level to measure the IMD Output Tones relative to Output Tone 1.

– In Multiple Source Control, now change Receiver & Receiver Source to Output 1+2OS Range or Output 1-OS Range, depending on the IMD tone of interest.

– After Done Editing, the VNA will measure the selected IMD product as a dBc value relative to Output Tone 1.

4.0 Vector Error Corrected Measurements (without a characterized mixer)

All mixer parameters where the input and output frequencies are the same can be performed with standard VNA calibrations. Notice that in this case, Multiple Source Control is only activated to drive the LO source. The receiver is simply set at the same frequency as the internal source. Parameters that meet this criterion are match and isolation terms.

4.1 Port Match and Port to Port Isolation (Input to Output and Output to Input)

4.1.1 Input Port Match and Input to Output Isolation

– Use the setup in Figure 1.

– Set the frequency sweep range to the Input frequency range, with the desired number of points.

– Set the following Multiple Source Control definitions:

  Band Start & Stop Frequencies = Input Frequency Range
  Internal Source = Input Frequency Range
  External Source 1 = LO Frequency Range
  Receiver & Receiver Source = Input Frequency Range

– Set Multiple Source Control Mode ON.

– Perform a 2-port cal at Reference Planes A and B.

– Set up two traces to measure responses S_{11} and S_{21}.

– Store the setup to be able to recall it later.

– Insert the DUT, measuring the match of the Input port and Input to Output Isolation.
4.1.2 Output Port Match and Output to Input Isolation
– Use the setup in Figure 1.
– Set the frequency sweep range to the Output frequency range, with the desired number of points.
– Set the following Multiple Source Control definitions:
  Band Start & Stop Frequencies = Output Frequency Range
  Internal Source = Output Frequency Range
  External Source 1 = LO Frequency Range
  Receiver & Receiver Source = Output Frequency Range
– Set Multiple Source Control Mode ON.
– Perform a 2-port cal at Reference Planes A and B.
– Set up two traces to measure responses $S_{22}$ and $S_{12}$.
– Store the setup to be able to recall it later.
– Insert the DUT, measuring the match of the Output port and Output to Input Isolation.
Notice that with the mixer inserted, recalling the previous setup measures the Input port match, and recalling this setup measures the Output port match, without having to move the mixer around.

4.1.3 LO Port Match
– Use the setup in Figure 4.
– Set the frequency sweep range to the LO frequency range, with the desired number of points.
– Set the following Multiple Source Control definitions:
  Band Start & Stop Frequencies = Input Frequency Range
  Internal Source = LO Frequency Range
  External Source 1 = Input Frequency Range
  Receiver & Receiver Source = LO Frequency Range
– Set Multiple Source Control Mode ON.
– Perform a 1-port cal of port 1 at Reference Plane A, using the appropriate LO drive level.
– Set the response to $S_{11}$.
– Insert the DUT, measuring the match of the LO port.
Notice that this measurement requires physically moving the mixer compared to the previous two measurements.

Figure 4. LO Port Match Setup
5. Vector Error Corrected Measurements (using a characterized and de-embedded mixer)

Figure 5 shows a setup where two mixers are used back to back with a band pass filter in between them to eliminate unwanted spurious signals. In this setup, the VNA is operating over the Input Frequency Range of the DUT, where the source and receive are at the same frequency. This allows a reference for phase measurements, making vector-error-corrected conversion loss or gain possible, as well as Group Delay.

The process is rather simple, once you have a characterized mixer and a characterized band-pass filter. (Check 5.1 below for characterizing instructions.)

– Perform a 2-port calibration at Reference Planes A and B, over the Input Frequency Range with the desired number of points.
– De-embed two 2-port networks (appendix E):
  a. The characterized Mixer
  b. The characterized BPF with pads

(This step will ensure to de-embed the effects of these networks from the Reference Planes A and B measurements, leaving the DUT response.)

– Insert the DUT between points A and C and measure corrected $S_{21}$ and $S_{11}$ (Magnitude and Phase), and/or Group Delay.

– Measure compression, over Swept Frequency, as if a non-frequency translation device is being measured.

5.1 Characterizing the mixer and band-pass filter instructions:

Remember that this step results in two .s2p files, one for each of the two networks. Once these files are obtained, this step does not have to be repeated.

– Characterizing the filter network which includes the pads on each side is a basic VNA measurement. Just calibrate a VNA over the Output frequency range, using the same number of points as the final measurement, measure the network, and store the data of the network as a .s2p file.

– Characterizing the mixer is explained in Appendix D.
Appendix A: Using Multiple Source Control Mode

Multiple Source Control (Option 007)

A1. Overview

Multiple source control is an application to independently control the internal source and receiver as well as up to four external synthesizers. Since there are no constraints on frequency linkage (other than the ranges the hardware is capable of), a wide array of mixer, multiplier, converter and other specialized measurements can be performed. Some examples include:

- Mixers (up and down conversion, many conversion stages)
- Frequency multipliers
- Dividers
- Harmonic measurements (including the ability to look at fractional harmonics)
- IMD measurements
- Very high frequency measurements where the source and LO are generated externally

Since the interface is extremely flexible, this procedure also works for broadband/mm-wave measurements for applications where the broadband/mm-wave interface is too limiting.

A2. Introduction

This section discusses the interface and how to configure the instrument and the hardware for generic measurements. Multiple Source menu selections are available from the Main Applications menu.

A3. Multiple Source Control Set Up

Key concepts to setting up multiple source control are:

- All source frequencies (internal or external) and the receiver frequency must be linearly related. All are expressed as linear equations as a function of a runner variable \( f \). This variable \( f \) is always the one displayed on the x-axis although it need not represent an actual frequency (although for convenience it usually does).
- These linear relationships can change in different 'bands' that the user defines. The band edges are always in terms of the runner variable \( f \).

The main multiple source setup menu is shown in Figure A-2.
The top button on the menu toggles Multiple Source mode on or off, similar to the mode selection buttons on the application menu (turning Multiple Source mode off here will change the mode to Standard). When this menu is entered, the table will appear in the lower part of the screen (Figure A-3).

When the Multiple Source table first appears, the first band is in the table. The Add Band, Delete Band, and Clear Band buttons will have the obvious effects.

<table>
<thead>
<tr>
<th>Band #</th>
<th>Start Freq</th>
<th>Stop Freq</th>
<th>Src = (M/D) * (f + OS)</th>
<th>CW ON</th>
<th>Multiplier (M)</th>
<th>Divisor (D)</th>
<th>Offset Freq (OS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 kHz</td>
<td>10 GHz</td>
<td>Internal Source</td>
<td>0 Hz</td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 1 (Inactive)</td>
<td>0 Hz</td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 2 (Inactive)</td>
<td>0 Hz</td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 3 (Inactive)</td>
<td>0 Hz</td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 4 (Inactive)</td>
<td>0 Hz</td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Receiver</td>
<td>0 Hz</td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Receiver Source</td>
<td>0 Hz</td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
</tbody>
</table>

Figure A-3. Multiple Source Table

A red exclamation point (!) in the first column of the table indicates that an error is detected.

For each band, the following must be defined:
- A start and stop frequency for the band
- Equations for each source, the receiver, and receiver source (an index used to work with receiver calibrations). If a source is inactive, its equation may be left at anything. If active, the result of the equation must be a valid frequency for that source (or receiver).

Each equation is of the following form:

\[ Src_X = \frac{M}{D} \cdot (f + OS) \]

unless CW ON is selected, then

\[ Src_X = \frac{M}{D} \cdot OS \]

Using the multiplier (M) and divisor (D) a rational relationship can be created between the desired frequencies. The offset (OS) completes the remainder of the linear relationship and is the CW frequency when the source is set to CW ON. Any of these parameters may be negative as long as the result of the equation is a valid frequency for that source (or receiver). This can be used for a reverse sweep (in certain mixer measurements for example).
When a cell is highlighted in the table (with the mouse or touch screen), the text entry box becomes active. Text can be directly entered into the table by double-clicking on the cell. The entry must be typed with a space between the number and the frequency units.

When a second band is added, the table adds another block as shown in Figure A-4. Note that the bands must be contiguous although the sweep range need not be (by using segmented sweep for example).

<table>
<thead>
<tr>
<th>Band #</th>
<th>Start Freq</th>
<th>Stop Freq</th>
<th>Source</th>
<th>CW</th>
<th>Multiple</th>
<th>Divisor</th>
<th>Offset Freq (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70 MHz</td>
<td>10 GHz</td>
<td>Internal Source</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 1 (Inactive)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 2 (Inactive)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 3 (Inactive)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 4 (Inactive)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Receiver</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Receiver Source</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td>2</td>
<td>10,000,000,000 MHz</td>
<td>20 GHz</td>
<td>Internal Source</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 1 (Inactive)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 2 (Inactive)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 3 (Inactive)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>External Source 4 (Inactive)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Receiver</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Receiver Source</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0 Hz</td>
</tr>
</tbody>
</table>

**Figure A-4. Two Band Multiple Source Table**

As soon as values are changed in the table, the Done Editing button in Figure A-2 becomes active. Selecting the Done Editing button will start an error check of all entered parameters. An error dialog may appear if an error is found. During the error checking, the system applies the band limit frequencies to each equation and checks that the results are valid for a given source or the receiver. If an external source is inactive, the error checking will not be performed for that line.
Phase Inversion

Particularly in mixers, it is important to know the relationship between RF and LO frequencies. Consider a down converter:

- LO>RF: High side mixing. Here the IF will have the expected phase behavior for the system and phase inversion is not required.
- LO<RF: Low side mixing. Here the IF will be conjugated by the DUT and the phase behavior will be the inverse of that expected. Phase inversion should be used.

Since the system has no way of knowing which source is the RF and which is the LO, or if additional fixed conversions are occurring, the information must be input manually through the Phase Inversion button, as shown in Figure A-5.

![Figure A-5. Multiple Source Menu (phase inversion selection)](image)

To understand how this affects measurements, consider the phase of a delay line (after normalization with a thru line for example) when high side vs. low side mixing occurred (Figure A-6).

![Figure A-6. Phase Inversion Behavior](image)

The selection of the phase inversion button reverses the effect seen in low side mixing. The most severe impact can occur in calibrations where line and offset lengths are presumed to impact phase according to equations like (where \( L \) is the length and \( B \) is the propagation constant):

\[ \varphi = -n \cdot \beta \cdot L \]

If low side mixing is present, the sign of this equation is incorrect and the calibrations will proceed with the wrong phase values. Proper selection of the phase inversion button will avoid those problems.
A4. Setting Up External Synthesizers

External synthesizers can be used when in multiple source mode.

Note that:
- The synthesizers are synchronized to the 10 MHz reference of the MS464XX so frequency accuracy is
  maintained. External 10 MHz sources can also be used if they have at least the spectral purity of the VNA
  internal clock.
- The GPIB connections are used for controlling the synthesizers and usual GPIB cable length practices apply.
  Note that the dedicated connector on the VNA is used. The synthesizer GPIB addresses must match those on
  the VNA external source address menu located under Utility | System | Remote Interface (Figure A-7).

![Figure A-7. External Source Address Menu](image)

- The system will poll the GPIB bus for the external synthesizers periodically including when Multiple Source
  mode is activated and when the Multiple Source menus are accessed. To verify if a connection has been
  established, check the External Source Control menu (under Multiple Source Setup) to see if the State is Active.
  A connected source can be manually activated prior to entering data in the table to avoid having to re-enter the
  data, since data is only saved when Done Editing is selected. Flatness calibrations of external synthesizers may
  be available in certain versions of instrument firmware, in which case those buttons in will enabled.
• If one or both synthesizers are turned off or disconnected, GPIB errors or sluggish system response may be experienced. It may be necessary to return to standard mode, reconnect/restart the synthesizers and then re-enter multiple source mode to continue. In extreme circumstances, it may be necessary to exit the VNA application, restart the synthesizers, and restart the VNA to establish communication.

• Power of the external sources is controlled by the External Source Power button on the Main Power menu (Figure A-8). This leads to the power entry fields as shown in Figure A-9. Again, flatness calibrations may be available with certain firmware versions.

With the External Source Power Entry menu, select the source with the top button, then enter the source power with the second button.

To enable or disable fast trigger mode when using MG3702xA external synthesizers, click on the Ext. Src. Fast Trigger button which will bring up the dialog shown in Figure A-10. Select the desired mode (ensuring needed cables are connected) and click ok to effect the mode change.
Appendix B: Calibrating the Input Power to the DUT (Test Port Power Cal)

Menu: Power>Power Cal

The objective of the power cal is to improve the accuracy of the power delivered to the DUT beyond that provided by the factory ALC calibration (0.1 dB vs. on the order of 1 dB). This is particularly useful if a preamplifier or other network is needed between the test port and the DUT. The exact loss/gain of that network over frequency can be corrected with reasonable precision. A common setup for executing this calibration is shown in Figure B-2.

Figure B-1. Power Cal Menu

Figure B-2. Port 1 Power Calibration Example Setup
Since the power cal performs the calibration at every point, this calibration can be time consuming (particularly if a slower thermal power sensor is being used). One should exercise some restraint when selecting the number of power points if this time delay will be an issue. Details of power meter connection and setup are covered in the operation manual, but one should ensure that the power meter GPIB address matches that shown on the MS4640A series VNA GPIB menu system and that the dedicated GPIB connector on the VNA is used. The dialog that appears when executing this calibration is shown in Figure B-3.

![Power Calibration (Port 1) Dialog](image)

Figure B-3. Power Calibration (Port 1) Dialog
Appendix C: Receiver Calibrations

C1. Overview

The purpose of this section is to show how receiver calibrations can be set up, and how some of the additional receiver calibration utilities can be used.

C2. Introduction

Unlike conventional VNA RF calibrations (like SOLT, LRL/LRM, and others) that are used to calibrate the VNA for S-parameter measurements, the receiver calibration is more of an absolute power calibration to help with measurements such as:

- Harmonics
- IMD and IP3, and other multi-tone distortion measurements
- Mixer conversion loss (in the simpler scalar cases)
- Other times when the VNA is just used as a channelized receiver

The concept of the receiver cal is to take a known source power at some source reference plane and transfer that knowledge to the receiver at a desired receiver reference plane. If it is convenient to use the test port as the source reference place, the built-in factory ALC calibration can be used to establish the power knowledge. If this is not convenient (because of frequency translation or some other network is required, or greater accuracy is needed), then a power calibration can be performed with the help of a GPIB-controlled power meter to better establish that power knowledge. Power calibrations are covered in more detail in Appendix B.

In all of these discussions, power refers to signal amplitude at the fundamental frequency. Since the receivers are all tuned they are not measuring full integrated power as in a power meter. This can be important as will be discussed in the uncertainties section.

The receiver calibration menu system begins under the Power menu (since it is associated with power reference planes rather than S-parameter calibration). The Receiver Setup menu is shown in Figure C-1.

There are four different receiver calibrations possible (since there are four receivers in the MS464XX) and they can be activated at the top of this menu. A menu item will be active only if that calibration exists. The calibrations can be saved and recalled from this menu. Calibrations can also be saved and recalled as part of the global setup save using the commands located under the File menu.
C3. Setting Up Receiver Calibrations

To get started, it will help to take a closer look at the architecture of the MS464XX as suggested by Figure C-2.

As this is a 2-port VNA, there are four unique receivers that are performing the measurements: a reference receiver associated with each port (a1 and a2) and a test receiver associated with each port (b1 and b2). An absolute power calibration, which is the receiver calibration, can be associated with each of these receivers.

Note that although the receivers are shown here as associated with couplers, this need not always be the case. With option -051, -061 and -062, loops are in place between the coupler arms and the receivers allowing direct access to those receivers. This brings up the point of receiver reference planes. The receiver calibration will establish an absolute power reference but how the calibration is setup will establish where the reference is being established.
Consider the three cases shown in Figure C-3. The use of three different receiver reference planes is shown. Where the known source power reference plane is connected for the receiver calibration establishes where that power knowledge is transferred to.

In all of the cases, the source reference plane (where the power is accurately known) is at the end of the dashed cable. This will be connected in different places in the three cases thus establishing the receiver reference plane in three different places. In this case, the absolute power reference has been transferred to (all referring to the port 2 test, or b2 receiver cal in this example set):

- Case 1: to port 2
- Case 2: to the input of a network connected to port 2 (could be a pad, a cable assembly, a switch matrix)
- Case 3: to the direct access loop input to the b2 receiver

All of these may be valid receiver reference planes depending on where one wants to connect the DUT (and, more precisely, where one wants to measure power).

The source reference plane is any plane where one accurately knows the signal level. The factory ALC calibration establishes that knowledge at the test ports with moderate accuracy (on the scale of 1 dB). It may be that greater accuracy is needed or it may be that this plane is inconvenient:

- A cable is needed to reach the receiver reference plane and it is not desired that this cable loss be neglected
- A preamplifier is needed before the DUT and it is desired that this power level form the reference (if, for example, the receive-side network has very large loss and one wants a better signal-to-noise ratio for the receiver cal)
- other reasons
For these cases, a power calibration using a GPIB-controlled power meter can be performed at the desired source reference plane prior to performing the receiver calibration. Over reasonable periods of time, the power calibration accuracy can be on the order of 0.1 dB. Aspects of the power calibrations are discussed in the Sweep Types section of the Measurement Guide and in the Operations Manual.

A key point in establishing the source reference plane is that the receiver calibration needs to be informed of what that power level is. This is done through the power menu. The value entered there is used as the power reference. When using the factory ALC calibration at the port, this link is obvious. When using a power cal at some other reference plane, the power entry field on the power menu is also now linked to that reference plane. Thus in both cases, the correct power value is transferred to the receiver cal.

Now that the setup is physically ready, the execution of the receiver calibration is performed from the menu in Figure C-4.

![Figure C-4. Receiver Calibration Execution Menu](image)

The first two menu items describe which receiver is being calibrated and the third describes the driving port and, hence, the source reference plane. Once the source and receiver reference planes are connected, the Begin Cal button can be selected. The note indicates that a thru line should be connected between ports but what is really meant is that the source and receiver reference planes should be connected together.

During the calibration, different parameters will be displayed as the system collects the appropriate receiver data. Once complete, the calibration will be activated as shown in the Figure C-1 menu.
The receiver calibration is indexed to frequency at the receiver so two vectors of data are key (first two columns). The power level used in the calibration is also shown in the third column as a reference.

The frequency index vector brings up an important point when using receiver calibrations with multiple source mode and certain other frequency conversion modes. It is important that the frequency index match the frequencies present at the receiver reference plane so that the computations can be performed correctly. Consider the setup shown in Figure C-5 that uses multiple source control.

![Figure C-5. Example of a Frequency-translated Receiver Reference Plane](image)

The DUT in this case is up converting and a down converter is used to bring the DUT output back to within range of the MS464XX. To measure the DUT output power, the receiver reference plane must be in the mm-wave zone and the frequency list should be referenced here. The receiver source equation in multiple source mode can be used to help here.

The proper indexing can be established using the Receiver Source equation in the multiple source table (Figure C-6).

![Figure C-6. Receiver Source Equation From Multiple Source Mode](image)

The purpose of this equation is precisely to provide the proper frequency index for the receiver calibration. See the multiple source section for more details.

A final utility controls the interaction between the receiver calibration and ratioed S-parameters. Typically, the receiver calibration pertains to non-ratioed measurements so the correction is not applied to the non-ratioed variables prior to forming the S-parameter ratios. This is done to avoid the confusion of the receiver calibrations interacting with the regular S-parameter calibrations (SOLT, LRL/LRM). The application of the receiver cal is, by default, off for ratios. If desired, the application of the receiver cal to the S-parameter ratios can be turned on (to allow off-line ratio comparison for example) but performing a receiver calibration after an S-parameter calibration will invalidate the S-parameter calibration (as well as trace memory comparisons and other measurements).
Appendix D: Characterizing a Mixer for de-embedding purposes (NxN Routine)

D1. Chapter Overview

The NxN technique is an application for measuring non-separable devices. NxN is used when devices can only be measured in pairs and information about the individual devices is required. Examples of NxN include:

- Mixers (where one of each pair is an up converter and one is a down converter so that the VNA sees no frequency translation)
- Long cable runs (where two cables are needed to complete a round trip to the VNA)
- Fixture parts (where an individual part cannot be easily measured since one of its interfaces is noncoaxial/ non-waveguide).

D2. Introduction

This section provides a brief overview of the method and how the application within the MS464XX is used. The idea is that there are three devices that should or must be measured in pairs, and to measure every pair-wise combination of them. This collection of measurements provides enough information to extract the transmission characteristics of each of the devices. The information on any one of the first three devices can then be used to de-embed from measurements when this reference device is paired with any number of other parts. The measurements pairings to get started are shown in Figure D-1. Device 2 is required to be reciprocal, meaning its $S_{12} = S_{21}$.

![Figure D-1. NxN Technique Measurements](image1)

If the devices are poorly matched, it may be necessary to place a pad or other network between the devices. As long as this inner network is present for all measurements and its S-parameters are known, its effects can be removed. This technique was originally used in mixer measurements, hence it is termed an IF network. This measurement setup is shown in Figure D-2. The three measurements required to execute NxN are shown here when using an inner network N (which may be a pad or filter combination). Device 2 is required to be reciprocal.

![Figure D-2. NxN Measurement Setup (using an inner network N)](image2)
NxN is a popular mixer technique since the VNA sees the same input and output frequencies. Thus normal calibrations can be used, no frequency offsets are needed and there are no reference complications. The first device in each pair will be used as an up converter or down converter and the second device will be the opposite. Device 2 must be able to fulfill both roles so it must be a passive mixer. The same frequency plan must be used in all of the measurements.

Typically a common LO is used for all devices (with some splitter assembly) but multiple LOs can also be used as long as they share a common 10 MHz reference. These sources can often be controlled using multiple source control (see separate section in this Measurement Guide for more information). If one of the devices has multiple conversion stages, it may be desirable for the other devices to have the same conversion pattern for optimal trace noise. If this is not feasible, the only real requirement is that the input and output frequencies for all devices match.

The nature of the frequency plan between the devices must be known if the IF network (N in Figure D-2) is to be removed. If the first device is not performing an inversion (i.e., if the input signal ramps up in frequency, the output signal ramps up in frequency) then the lookup of the IF network behavior is not inverted. If the first device does perform an inversion, then the lookup of the IF network must be inverted.

**D3. Using the NxN Application**

The NxN application is started from the Application menu as shown in Figure D-3.
Selecting the NxN button will open the main NxN dialog as shown in Figure D-4. The measurements shown in Figure D-1 or Figure D-2 must first be performed and those measurement results saved as .s2p files. The match information in these files will be ignored, but the file format for a full 2-port measurement is used for convenience. These .s2p files are entered in this dialog using the browse buttons shown.

![Figure D-4. Main NXN Solution Using S2P Files Dialog](image)

If the scheme of Figure D-2 is used, then the inner or IF network must be specified. Select IF Path De-embed in this case and use the browse function to locate the .s2p file for the IF network. Note that all of these .s2p files must have the same number of points and the frequency range of the IF file must be appropriate for the IF sweep range between the devices. If the devices are non-converting, the frequency range of the IF file must match that of the other files.

If the devices are frequency converting, the sweep direction in the inner or IF zone must be specified. If the inner frequency sweeps up for a sweep up in the input frequency, then select LO-HI (non-inverting). Otherwise, select HI-LO.

The computation produces a phase ambiguity when it solves for the devices so some information about the electrical length of the devices should be entered. Boxes are provided for entering the approximate air-equivalent electrical length of each device. The calculator icon can be used if time delay estimates are known instead and a conversion calculator will appear. If the phase shift for the devices is not of interest, these lengths may be left at zero. If they are of interest, the estimate should be accurate to within a half wavelength at the lowest input frequency being used.

Once all of the information is entered, the Solve Device x buttons at the bottom of the dialog (x = 1, 2, or 3) will trigger the computation. Each invocation will bring up a file dialog to name the .s2p file describing the device in question. If only one device's information is needed, only that button need be selected.

If more devices are to be tested in the same configuration (e.g., one has a collection of mixers to measure of the same model), then these devices can be combined, one at a time, with a now known device (1, 2, or 3). Since the .s2p file for the now known device has been generated, it can be de-embedded using the standard embedding/de-embedding utility described elsewhere in this measurement guide.
Appendix E: De-embedding a Characterized Mixer
(Embedding/De-embedding Routine)

Chapter 10 in the MS4640A Measurement Guide has a complete Embedding/De-embedding explanation. Here we are simply de-embedding two networks, whose .s2p files have been obtained. Both networks are on port 2. The filter network is closest to the DUT and the mixer is next.

Select Measurements → Edit Embed/De-embed → Edit Network
Select Port 2 under VNA Port Config, since the networks are on port 2.
Select the De-embedding radio button.
Select the S2P radio button then Load S2P File which will allow you to navigate to the .s2p file of choice.

First select the filter .s2p file, since it is closest to the DUT and hit Add/Change Network.
Then load the second network, which is the mixer’s .s2p file and hit Add/Change Network.

Both files should be listed in the table, in the proper order from the DUT to the Port.

You are now done, so hit Apply then Done.
Save this De-embedding Setup for later use.

Notice that the Embed/De-embed selection is still Off. Turn it ON during the DUT measurement.

Figure E-1.