Calibration and Measurement Guide

VectorStar™ MS4640A Series Microwave Vector Network Analyzers

MS4642A, 10 MHz to 20 GHz, K Connectors
MS4644A, 10 MHz to 40 GHz, K Connectors
MS4645A, 10 MHz to 50 GHz, V Connectors
MS4647A, 10 MHz to 70 GHz, V Connectors

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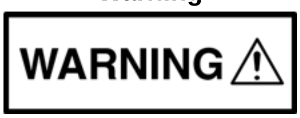
To prevent the risk of personal injury or loss related to equipment malfunction, Anritsu Company uses the following symbols to indicate safety-related information. For your own safety, please read the information carefully *before* operating the equipment.

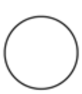
Symbols Used in Manuals

Danger 	This indicates a very dangerous procedure that could result in serious injury or death, and possible loss related to equipment malfunction, if not performed properly.
Warning 	This indicates a hazardous procedure that could result in light-to-severe injury or loss related to equipment malfunction, if proper precautions are not taken.
Caution 	This indicates a hazardous procedure that could result in loss related to equipment malfunction if proper precautions are not taken.

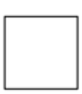
Safety Symbols Used on Equipment and in Manuals

The following safety symbols are used inside or on the equipment near operation locations to provide information about safety items and operation precautions. Ensure that you clearly understand the meanings of the symbols and take the necessary precautions *before* operating the equipment. Some or all of the following five symbols may or may not be used on all Anritsu equipment. In addition, there may be other labels attached to products that are not shown in the diagrams in this manual.


This indicates a prohibited operation. The prohibited operation is indicated symbolically in or near the barred circle.


This indicates a compulsory safety precaution. The required operation is indicated symbolically in or near the circle.


This indicates a warning or caution. The contents are indicated symbolically in or near the triangle.


This indicates a note. The contents are described in the box.


These indicate that the marked part should be recycled.

For Safety

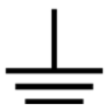
Warning

Always refer to the operation manual when working near locations at which the alert mark, shown on the left, is attached. If the operation, etc., is performed without heeding the advice in the operation manual, there is a risk of personal injury. In addition, the equipment performance may be reduced.

Moreover, this alert mark is sometimes used with other marks and descriptions indicating other dangers.

Warning

or



When supplying power to this equipment, connect the accessory 3-pin power cord to a 3-pin grounded power outlet. If power is supplied without grounding the equipment, there is a risk of receiving a severe or fatal electric shock.

Warning

This equipment can not be repaired by the operator. Do not attempt to remove the equipment covers or to disassemble internal components. Only qualified service technicians with a knowledge of electrical fire and shock hazards should service this equipment. There are high-voltage parts in this equipment presenting a risk of severe injury or fatal electric shock to untrained personnel. In addition, there is a risk of damage to precision components.

Warning

Use two or more people to lift and move this equipment, or use an equipment cart. There is a risk of back injury if this equipment is lifted by one person.

Caution

Electrostatic Discharge (ESD) can damage the highly sensitive circuits in the instrument. ESD is most likely to occur as test devices are being connected to, or disconnected from, the instrument front and rear panel ports and connectors. You can protect the instrument and test devices by wearing a static-discharge wristband. Alternatively, you can ground yourself to discharge any static charge by touching the outer chassis of the grounded instrument before touching the instrument front and rear panel ports and connectors. Avoid touching the test port center conductors unless you are properly grounded and have eliminated the possibility of static discharge.

Repair of damage that is found to be caused by electrostatic discharge is not covered under warranty.

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Chapter 1 — Calibration Overview

1-1 Manual Scope

The purpose of this Measurement Guide is to introduce the basic calibration and operation of the VectorStar MS4640A Vector Network Analyzer (VNA) System and reduce the time required to become proficient at performing basic measurements. The procedures in this manual assume a working knowledge of, and a familiarity with, vector network analyzers.

1-2 Chapter Summary

This chapter discusses general calibration requirements and the benefits of different calibration types, algorithms, and routines. General calibration setup and measurement procedures are described. Technical references to Anritsu and other calibration-related articles are also presented where appropriate. Some sections provide cross-references to more detailed explanations and procedures in subsequent chapters.

1-3 Related Documentation

Refer to the other documentation supplied with or available for the VectorStar MS4640A Series VNA for more detailed explanations and procedures. Available documents for the MS4640A Series VNA, ME7838A Modular Broadband/Millimeter-Wave VNA System, the ME7828A Broadband/Millimeter-Wave VNA System, and the MN4690B Series Multiport VNA System are listed below.

VectorStar MS4640A Series Vector Network Analyzers

- MS4640A Series VNA Technical Data Sheet (TDS) – 11410-00432
- MS4640A Series VNA Operation Manual (OM) – 10410-00266
- MS4640A Series VNA Measurement Guide (MG) – 10410-00269
- MS4640A Series VNA Programming Manual (PM) – 10410-00267
- MS4640A Series VNA Maintenance Manual (MM) – 10410-00268

VectorStar ME7838 Series 2-Port BB/mmW VNA Measurement System

- ME7838A Modular BB/mm-Wave Technical Data Sheet (TDS) – 11410-00593
- ME7838D Modular BB/mm-Wave Technical Data Sheet (TDS) –11410-00778
- ME7838A Modular BB/mm-Wave Quick Start Guide (QSG) –10410-00292
- ME7838D Modular BB/mm-Wave Quick Start Guide (QSG) –10410-00732
- ME7838 Series Modular BB/mm-Wave Installation Guide (IG) –10410-00293
- VectorStar Broadband/Banded Millimeter-Wave Modules (RM) –10410-00311
- ME7838 Series Modular BB/mm-Wave Maintenance Manual (MM) –10410-00306

VectorStar ME7828A Standard BB/mm Wave VNA Measurement System

- VectorStar ME7828A Series Standard Broadband/Millimeter-Wave Technical Data Sheet – 11410-00452
- VectorStar ME7828A Series Standard Broadband/Millimeter-Wave Quick Start Guide – 10410-00289
- VectorStar ME7828A Series Standard Broadband/Millimeter-Wave Installation Guide – 10410-00287
- VectorStar ME7828A Series Standard Broadband/Millimeter-Wave Maintenance Manual – 10410-00304

VectorStar MN4690B Series Multiport VNA Measurement System

- MN4690B Series Multiport VNA Measurement System Technical Data Sheet – 11410-00513
- MN4690B Series Multiport Test Set Installation Guide – 10410-00288
- MN4690B Series Multiport Test Set Quick Start Guide – 10410-00290
- MN4690B Series Multiport Test Set Maintenance Manual – 10410-00305

Calibration, Verification, and System Performance Verification

- 36585K and 36585V Precision Auto Calibrator (AutoCal) Module Reference Manual – 10410-00279
- 3650A, 3652A, 3653A, and 3654D Mechanical Calibration Kit Reference Manual – 10410-00278
- 366X-1 Verification Kits (3666-1 3.5mm Connectors, 3663-1 Type N Connectors, 3668-1 K Connectors, 3669B-1 V Connectors) and 3-2300-527 Performance Verification Software (PVS) User Guide – 10410-00270
- 366X-1 Verification Kit and 3-2300-527 PVS Quick Start Guide – 10410-00285
- 3656B W1 (1 mm) Calibration/Verification Kit and 2300-496 System Performance Verification Software User Guide for the VectorStar ME/7838A/ME7828A and Lightning ME7808A/B/C BB/mm-Wave VNA Systems – 10410-00286
- 3659 - 0.8 mm Cal-Verif- Kit-UG and 2300-558 System Performance Verification Software for BB-mmW ME7838D with 0.8 mm Connectors – 10410-00327

Updates to Manuals

- For updates to any of the VectorStar Series VNA documentation, visit Anritsu's Web site at: http://www.anritsu.com/VectorStar

1-4 Contacting Anritsu

To contact Anritsu, please visit:

http://www.anritsu.com/contact.asp

From here, you can select the latest sales, service and support contact information in your country or region, provide online feedback, complete a "Talk to Anritsu" form to get your questions answered, or obtain other services offered by Anritsu.

Updated product information can be found on your product page:

http://www.anritsu.com/en-us/products-solutions/products/ms4640b-series.aspx

On this web page, you can select various tabs for more information about your instrument. Included is a "Library" tab which contains links to all the latest technical documentation related to this instrument.

1-5 VectorStar MS4640A Series VNA Models

The VectorStar VNA is available in four basic models as shown in Table 1-1 below.

Table 1-1. VectorStar MS4640A Series VNA Models

VNA Model Number	Name	Specifications	Connectors
VectorStar MS4640A Series Microwave Vector Network Analyzers (VNA)			
MS4642A	Microwave Vector Network Analyzer	10 MHz to 20 GHz	K (m) Connector Test Ports
MS4644A	Microwave Vector Network Analyzer	10 MHz to 40 GHz	K (m) Connector Test Ports
MS4645A	Microwave Vector Network Analyzer	10 MHz to 50 GHz	V (m) Connector Test Ports
MS4647A	Microwave Vector Network Analyzer	10 MHz to 70 GHz	V (m) Connector Test Ports

For additional technical specifications and configuration data, see:

- **VectorStar MS4640A Series VNA Technical Data Sheet and Configuration Guide – 11410-00432**

1-6 Calibration Kits, Verification Kits, and Components

Anritsu and other vendors provide calibration kits for a variety of algorithms and circumstances. In all cases, certain information must be provided to the VNA in order to complete the calibration, but the nature of that information varies by kit and application.

Calibration kits contain the precision components and tools required to calibrate the VectorStar MS4640A Series VNA for up to a complete 12-term error-corrected measurement. The calibration kits are available as automatic calibrator units or as manual calibration kits. A set of verification kits is also available to verify the accuracy of the calibration kits and the instrument settings.

Calibration/Verification Equipment Part Numbers and General Specifications

This table summarizes the equipment related to calibration procedures.

Table 1-2. Calibration Equipment Listing (1 of 2)

Part Number	Name	Specifications	Connectors
Precision AutoCal Modules			
36585K-2M	Precision AutoCal Module, K	70 kHz to 40 GHz	K (m) to K (m)
36585K-2F			K (f) to K (f)
36585K-2MF			K (m) to K (f)
36585V-2M	Precision AutoCal Module, V	70 kHz to 70 GHz	V (m) to V (m)
36585V-2F			V (f) to V (f)
36585V-2MF			V (m) to V (f)
Standard AutoCal Module			
36581KKF	Standard AutoCal Module, K	40 MHz to 20 GHz	K (m) to K (f)
Matched Adapters for 36581KKF AutoCal Modules			
36583S	Matched Adapters Set, K	K (f) to K (f) (2 each) K (f) to K (m) (2 each)	
36583L	Matched Adapters Set, 3.5 mm	K (f) to 3.5 mm (f) (2 each) K (f) to 3.5 mm (f) (2 each)	
36583SMA	Matched Adapters Set, SMA	K (f) to SMA (m) (2 each) K (f) to SMA (f) (2 each)	
SMA Connector Manual Calibration Kits			
3650A	SMA/3.5 mm Calibration Kit	Without sliding loads	SMA/3.5 mm
3650A-1	SMA/3.5 mm Calibration Kit	With sliding loads	SMA/3.5 mm
K Connector Manual Calibration Kits			
3652A	K (2.92 mm) Calibration Kit	Without sliding loads	K
3652A-1	K (2.92 mm) Calibration Kit	With sliding loads	K
Type N Connector Manual Calibration Kit			
3653A	Type N Calibration Kit	With fixed loads	Type N
V Connector Manual Calibration Kits			
3654D	V (1.85 mm) Calibration Kit	Without sliding loads	V
3654D-1	V (1.85 mm) Calibration Kit	With sliding loads	V

Table 1-2. Calibration Equipment Listing (2 of 2)

Part Number	Name	Specifications	Connectors
V Connector MultiLine Calibration Kits			
3657	V (1.85 mm) Multi-Line Calibration Kit	Without shorts	V
3657-1	V (1.85 mm) Multi-Line Calibration Kit	With shorts	V
W1 Connector Calibration/Verification Kit			
3656B	W1 (1 mm) Calibration Kit	With fixed loads	W1 (1 mm)
0.8 mm Connector Calibration/Verification Kit			
3659	0.8 mm Calibration Kit	With fixed loads	0.8 mm
Verification Kits			
3661-1	3.5 mm Connector Verification Kit	NIST traceable standards with two attenuators, an airline, and a stepped impedance airline Beatty Standard. Includes the 3-2300-527 Performance Verification Software application and related documentation.	
3663-1	Type N Connector Verification Kit		
3668-1	K Connector Verification Kit	Used with Short-Open-Load-Through (SOLT) with Sliding Load (Fixed Loads for Type N) using separately purchased 365x-1 Cal Kit and 36585X-2MF Series Precision AutoCal Module.	
3669B-1	V Connector Verification Kit		
Test Port Cables			
3670K50-1	Ruggedized, Semi-Rigid, DC to 40 GHz, 1 each	30.5 cm (12 in)	K (f) to K (m)
3670K50-2		61.0 cm (24 in)	K (f) to K (m)
3670V50-1	Ruggedized, Semi-Rigid, DC to 70 GHz, 1 each	30.5 cm (12 in)	V (f) to V (m)
3670V50-2		61.0 cm (24 in)	V (f) to V (m)
3671S50-1	Flexible, Phase Stable, DC to 20 GHz, 2 each	63.5 cm (25 in)	K* (f) to 3.5 mm (m)
3671K50-1	Flexible, Phase Stable, DC to 40 GHz, 2 each	63.5 cm (25 in)	K* (f) to K (m)
3671K50-2	Flexible, Phase Stable, DC to 40 GHz, 1 each	96.5 cm (38 in)	K* (f) to K (m)
3671K50-3	Flexible, Phase Stable, DC to 40 GHz, 1 each (f)-(m) and 1 each (f)-(f)	63.5 cm (25 in)	K* (f) to K (m) K* (f) to K (f)
3671V50B-1	Flexible, Phase Stable, DC to 67 GHz, 2 each	63.5 cm (25 in)	V* (f) to V (m)
3671V50B-2	Flexible, Phase Stable, DC to 67 GHz, 1 each	96.5 cm (38 in)	V* (f) to V (m)
* Ruggedized style for VNA test ports. Does not fit standard K (m) or V (m) connectors.			
Universal Test Fixtures (UTF) and Right Angle Launchers			
3680-20	UTF, DC to 20 GHz	0.5 cm (min) to 10 cm (max)	3.5 mm (f) to (f)
3680K	UTF, DC to 40 GHz	0.5 cm (min) to 5 cm (max)	K (f) to K (f)
3680V	UTF, DC to 60 GHz	0.5 cm (min) to 5 cm (max)	V (f) to V (f)
36801K	Right Angle Launcher, DC to 40 GHz	1 cm (min) to 4 cm max	
36801V	Right Angle Launcher, DC to 60 GHz	0 cm (min) to 2 cm (max)	

1-7 AutoCal® Automatic Calibration Modules

The auto calibration process represents both a calibration kit and an algorithm that can be used to speed up the calibration process with extremely high accuracy and a minimal number of manual steps.

The 36585X AutoCal module calibrates the VNA by a process known as “transfer calibration.” There are a number of impedance and transmission states in the module designed to be extremely stable in time and these states are carefully “characterized,” generally by the Anritsu factory but also in a customer laboratory in certain cases. When the same states are re-measured during an actual calibration, and the results compared to the characterization data, an accurate picture can be generated of the behaviors and error terms of the VNA and setup being calibrated.

A very high calibration accuracy is maintained through the use of certain principles:

- The use of many impedance and transmission states.
- The creation of very stable states that are further enhanced with a constant-temperature thermal platform inside the module.
- The use of very reliable and repeatable solid-state switching constructed to provide a great variety of state impedances (for better calibration stability) and clean transmission paths.
- The use of a very careful characterization process that can generate excellent starting data.

The resulting accuracy can exceed that obtained with a typical mechanical calibration performed in a laboratory. The AutoCal results may not be better than that of an exotic manual calibration (such as is performed during factory characterization) but will be far better than that done typically. Since it is a very high performance calibration, connector care is of the utmost importance and is discussed in detail later in this chapter.

The AutoCal consists of the calibration module itself, a separate external power supply, a control cable that runs to the VNA, and the characterization data provided on a USB memory device.

Calibrations Available

Of the various calibration types described for the instrument, most are available with the AutoCal unit. Frequency response calibrations are omitted since the AutoCal unit would provide no benefit in these cases (since only a through or high reflect standard is needed for these calibrations). Available calibrations include:

- Full 2-Port calibration
- Reflection only (full 1-Port calibration); either port or both can be specified
- 1-Path 2-Port (1p2p); either direction can be specified (i.e., calibrate S11 and S21 or calibrate S22 and S12)

1-8 SOLT Kits (3650x and 3654x)

These kits, all based on short-open-load-through, require data describing all of the reflection standards (provided by the factory) be loaded into the instrument on a serial number basis. If this media (a USB key) is not available, average default coefficients are available within the VNA that may suffice for some measurements.

Typically these calibration kits are loaded using the CAL KIT/AUTOCAL utility menu (Figure 1-1) but user-defined kits can also be created using the parameters described above. If calibration kits from another manufacturer are used or to create a calibration kit, the following parameters are typically entered into one of the user-defined kits:

- Open definition (M and F typically)
- Short definition (M and F typically)
- Load definition (M and F typically)

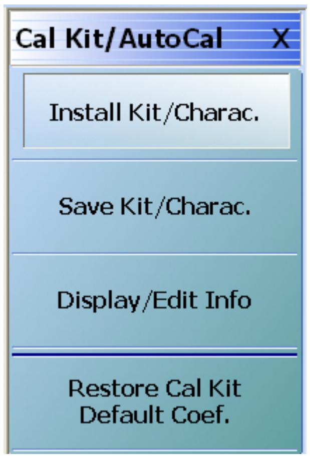


Figure 1-1. CAL KIT/AUTOCAL Utility Menu

The CAL KIT/AUTOCAL utility menu is shown here. This menu allows calibration kit details to be loaded from external files (as provided with Anritsu calibration kits), saved to a file (for user-defined cal kits), defaulted (for standard connector types), or simply displayed.

1-9 LRL Kits (3657/3657-1)

These airline-based kits use the LRL algorithm so much less definition of components is required. Reflects may be part of the kit but the only piece of information here is an offset length that is used to help with root selection (and is hence somewhat non-critical). The line lengths are the other parameters and they mainly serve for reference plane placement. All of these parameters must be entered manually since there are a large number of lines in the kit and usually only 2 or 3 will be used per calibration. Details on line selection and the trade-offs involved are discussed in the LRL/LRM section to follow.

Items as part of the definition:

- Line lengths (at least 2)
- Reflect offset length

1-10 Offset Short Waveguide Kits (3655X)

Waveguide calibration kits based on offset short calibrations are also provided for different waveguide bands. Here two different offset-length shorts (accomplished with flush shorts and two different insert lengths), loads, and a through must be specified. Some of the standard kits are pre-defined and user-defined kits are possible as usual. Additional pieces of information here due to line type are the cutoff frequency and dielectric constant. Items as part of the definition:

- Load definition
- Short 1 definition
- Short 2 definition
- Waveguide cutoff frequency

1-11 Microstrip/Coplanar Waveguide Kits for the UTF (36804-XXX)

For certain microstrip and coplanar waveguide measurements, the Universal Test Fixture (UT) can accommodate a range of substrate sizes and thicknesses (see 3680 brochure for more information). The 36804 series of calibration kits provide opens, shorts, loads and a variety of transmission line lengths on alumina that can be used for different calibration algorithms. User-defined kits must be generated based on the information provided with the kits.

1-12 On-Wafer Calibration Kits

A variety of calibration standard substrates or impedance standard substrates are available from other vendors that contain opens, shorts, loads, and transmission lines for on-wafer calibrations. A variety of calibration algorithms may be used depending on the application. For the defined-standards calibrations, a user-defined kit will have to be generated.

1-13 Calibration Algorithms

The VectorStar MS4640A Series VNAs provide for the following calibration methods:

- Short-Open-Load-Through (SOLT) with Fixed or Sliding Load
- Offset-Short
- Triple-Offset-Short
- Short-Open-Load-Reciprocal (SOLR)
- Reciprocal or Unknown Through Method
- Line-Reflect-Line (LRL) / Line-Reflect-Match (LRM)
- Advanced-LRM (A-LRM™) for improved on-wafer calibrations
- AutoCal

1-14 About Calibration

The most important central concept to making good VNA S-parameter measurements is the calibration of the instrument. The background on calibration mathematics and theory will only be lightly covered in this section; more information is available in Anritsu Application Notes and in the reference literature. While the VNA is a highly linear receiver and has sufficient spectral purity in its sources to make good measurements, there are a number of imperfections that limit measurements done without calibrations:

Match

Because the VNA is such a broadband instrument, the raw match can be good but not excellent. Even a 20 dB match, which is physically very good, can lead to errors of greater than 1 dB. By correcting for this raw match, the potential error can be greatly reduced.

Directivity

A key component of a VNA is a directional coupler that allows separation of the signal incident on the DUT from the reflected back from the DUT. While the couplers used in the VNA are of very high quality, there is an amount of coupled signal even when a perfect termination is connected. This is related to directivity and can impact measurements of very small reflection coefficients.

Frequency Response

While the internal frequency response of the VNA could be calibrated at the factory, any cables connected externally will have some frequency response that must be calibrated out for high quality measurements.

The calibration is a method of correcting for these and other defects. There are an enormous number of possible calibration algorithms and many of them are implemented within the MS4640A Series VNAs. The choice between them is largely determined by the media used, the calibration standards available, and the desired accuracy/effort trade-off. Some of the choices to be made are:

- **Calibration Type**

  Which ports are being corrected and to what level are they being corrected?

- **Calibration Algorithm**

  How is the correction being accomplished?

Calibration Types

Table 1-3. MS4640A Series VNA Calibration Types

VNA Mode	Type	Parameters Calibrated	Uses
2-Port VNA Mode	Full 2 Port	S_{11}, S_{12}, S_{21}, and S_{22}	Most complete calibration
	Full 1 Port	S_{11} or S_{22} or S_{11} and S_{22}	Reflection calibration only
	1 Path 2 Port	S_{11} and S_{21} or S_{22} and S_{12}	1 port reflection plus simple transmission (faster, lower transmission accuracy unless DUT very lossy)
	Frequency Response	Any one parameter (or pairs of symmetric parameters such as S12 and S21)	Normalization only. Fast, lower accuracy
4-Port VNA Mode	When in 4-Port mode, additional calibration types of 4-Port and 3-Port become available in the CALIBRATION menus with an associated expansion of S-Parameters, User-Defined, and Mixed-Mode options in the RESPONSE menus.		See Chapter 22, “Multiport Measurements”

Calibration Algorithms

The use of acronyms for the various calibration algorithms is often inconsistent. The following table presents calibration algorithm acronyms as used in Anritsu documentation.

Table 1-4. Calibration Algorithms

Calibration Algorithm	Description	Advantages	Disadvantages
SOLT (Short-Open-Load-Through)	Common coaxially	Simple, redundant standards; not band-limited	Requires very well-defined standards, poor on-wafer, lower accuracy at high frequencies
SSLT (Short-Short-Load-Through, also called Offset Short), shorts with different offset lengths	Common in waveguide	Same as SOLT	Same as SOLT and band-limited
SSST (Short-Short-Short-Through, also called Triple Offset Short), all shorts with different offset lengths	Common in waveguide or high frequency coax	Same as SOLT but better accuracy at high frequencies	Requires very well-defined stds, poor on-wafer, band-limited
SOLR/SSLR/SSSR, like above but with “Reciprocal” instead of “Through”	Like the above but when a good through is not available	Does not require well-defined through	Some accuracy degradation but slightly less definition, other disadvantages of parent cal
LRL (Line-Reflect-Line, also called TRL)	High performance coax, waveguide or on-wafer	Highest accuracy, minimal standard definition	Requires very good transmission lines, less redundancy so more care is required, band-limited
ALRM, advanced line-reflect-match, simplifies to LRM (Line-Reflect-Match) or TRM (Through-Reflect-Match)	Relatively high performance	High accuracy, only one line length so easier to fixture/on-wafer, not band-limited usually	Requires load definition. Reflect standard setup may require care depending on load model used

The following table relates the Calibration Types to the Calibration Algorithms.

Table 1-5. Calibration Types and Calibration Algorithms

<table>
<tr><th>VNA Mode</th><th>Type</th><th>SOLT</th><th>SSLT</th><th>SSST</th><th>SOLR/SSLR/SSSR</th><th>LRL</th><th>ALRM</th></tr>
<tr><td rowspan="4">2-Port Mode</td><td>Full 2 Port</td><td>YES</td><td>YES</td><td>YES</td><td>YES</td><td>YES</td><td>YES</td></tr>
<tr><td>Full 1 Port</td><td>YES</td><td>YES</td><td>YES</td><td rowspan="3">Can be selected for these types, but the reciprocal nature is not used and will function like the base calibration</td><td>–</td><td>–</td></tr>
<tr><td>1 Path 2 Port</td><td>YES</td><td>YES</td><td>YES</td><td>–</td><td>–</td></tr>
<tr><td>Frequency Response</td><td>YES</td><td>YES</td><td>YES</td><td>–</td><td>–</td></tr>
<tr><td>4-Port Mode</td><td colspan="7">The calibration types and modes change when the VNA is in multiport (4-Port) mode. See Chapter 22, “Multiport Measurements” for a discussion of multiport calibration methods and types.</td></tr>
</table>

1-15 Calibration Setup

Before proceeding to the calibrations and some of the alternatives available, there are certain instrument setup issues that must be discussed first since they will affect the performance of all calibrations. In almost all cases, the current VNA settings will be used during the calibration so setting up the VNA as desired beforehand will help.

Frequency Start, Stop, and Number of Points

The Start Frequency, Stop Frequency, and number of points should be decided and set in the VNA before performing a calibration. Segmented sweeps should also be set up in advance if a more custom frequency list is desired.

IF Bandwidth, Averaging and Power

These parameters control the digital filtering and post-processing that determine the effective noise floor, the amount of trace noise and, in some special cases, the immunity to interfering signals. The trade-off for improved noise performance is slower sweep speed.

- **IF Bandwidth (IFBW)**

  Settings of 1 Hz to 1 MHz are allowed with the RMS trace noise ranging from <1 mdB at the low end to a few hundred mdB at the high end (for high level signals, more for lower level signals). Sweep time will be roughly proportional with the reciprocal of IFBW once below 100 kHz IFBW.

- **Point-by-Point vs. Sweep-by-Sweep Averaging**
  - Point-by-Point averaging incurs additional measurements at each given frequency point and will increase sweep time roughly proportionally. Because the additional measurements are taken at once, the effect is similar to proportional change in IFBW.
  - Sweep-by-sweep averaging acquires additional measurements on subsequent sweeps and is better at removing lower frequency variations than point-by-point averaging or IFBW reduction. Sweep-by-sweep averaging is a rolling average so the time to fully stabilize from a sudden DUT change is roughly proportional to the average count.

- **Power**

  Port power is somewhat less critical because of the excellent linearity of the MS4640A Series VNA receivers, but any step attenuator settings must be selected before the calibration. Because changing the step attenuator settings alters the RF match in the measurement paths as well as insertion loss, changing them will invalidate the calibration

1-16 Types of Calibrations

The types of calibrations are defined by what ports are involved and what level of correction is accomplished (see Table 1-3, "MS4640A Series VNA Calibration Types" on page 1-11).

Full 2 Port

This is the most commonly used and most complete calibration involving two ports. All four S-parameters (S_{11}, S_{12}, S_{21}, and S_{22}) are fully corrected.

Full 1 Port

A single reflection parameter is fully corrected in this case (S_{11} or S_{22}). Both ports can be covered but only reflection measurements will be corrected. This calibration type is useful for reflection-only measurements including the possibility of doing two reflection-only measurements at the same time.

1 Path 2 Port (Forward or Reverse)

In this case, reflection measurements on one port are corrected and one transmission path is partially corrected (load match is not). Here forward means S_{11} and S_{21} are covered while reverse means S_{12} and S_{22} are covered. This technique may be used when speed is at a premium, only two S-parameters are needed and either the accuracy requirements on the transmission parameter are low or the DUT is very lossy ($\cong$ >10-20 dB insertion loss).

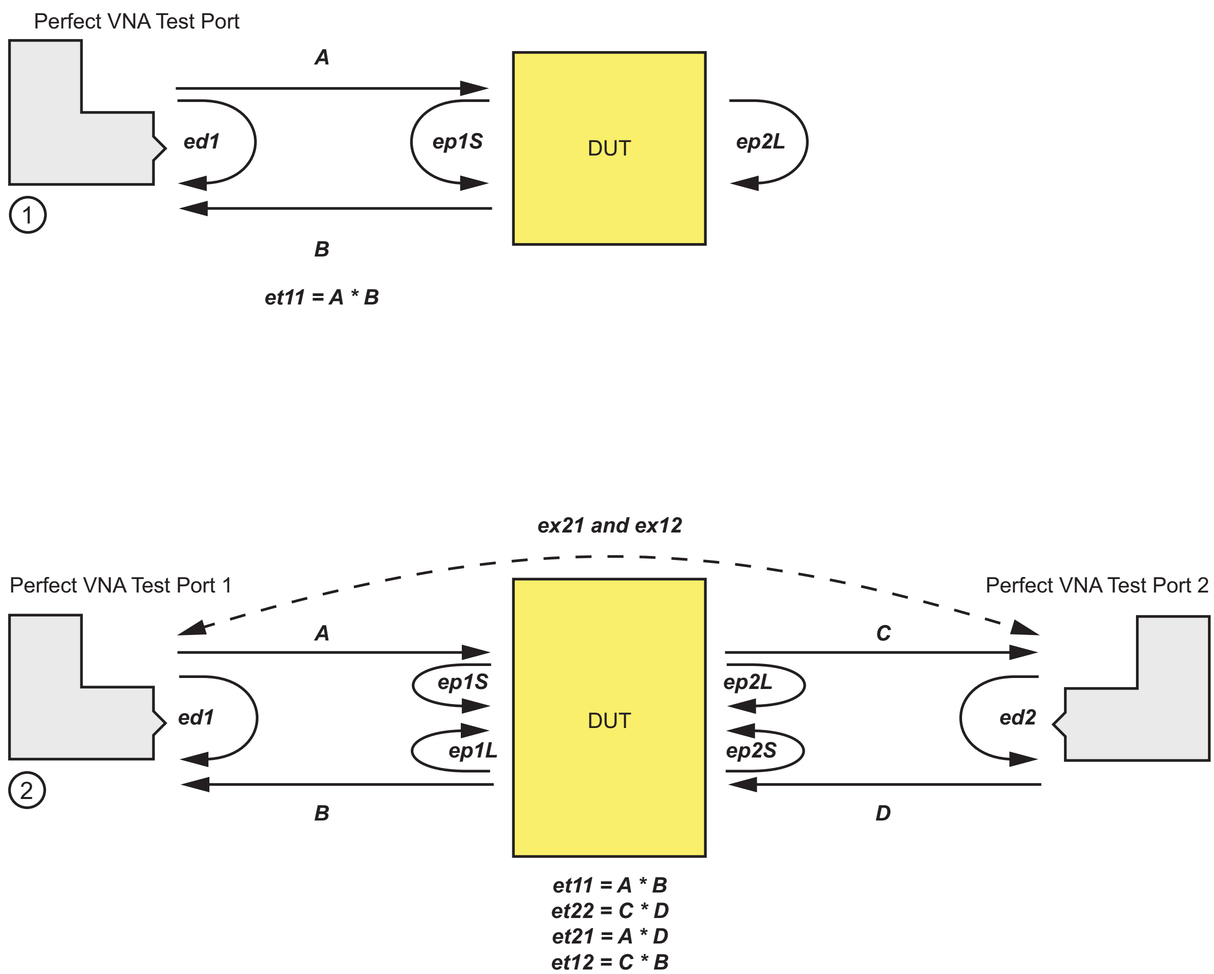
Frequency Response (Reflection Response and Transmission Frequency Response)

This calibration is essentially a normalization and partially corrects one parameter (although two can be covered within the cal menus). Only the frequency response, or tracking slope, of the parameter is corrected so directivity and match behaviors are not taken into account. This technique is valuable when accuracy requirements are not at a premium and a quick measurement is all that is needed.

Each of these calibrations has an associated error model that describes what is being corrected. The error coefficients used fall into several categories that roughly describe the physical effect that they are responsible for correcting.

Note	The calibration types and modes change when the VNA is in multiport (4-Port) mode. See Chapter 22, "Multiport Measurements" for a discussion of multiport calibration methods and types.

To establish a context for these error terms, consider the usual model where all of the VNA/setup errors are lumped into error boxes (that act like S-parameters) between a perfect VNA and the DUT reference planes (see Figure 1-2).



1. At top, a classic One-Port Error Model.	2. At bottom, a classic Two-Port Error Model

Figure 1-2. Classic One- and Two-Port Error Models

Two slightly different error models are used: one where each port is considered to be driving separately (so one can clearly delineate source match from load match) and one where both ports are present and no driving distinction is made (requiring some preprocessing to take care of source match-load match differences).

- **Directivity**

  Directivity (ed1 and ed2) describes the finite directivity of the bridges or directional couplers in the system. Partially includes some internal mismatch mechanisms that contribute to effective directivity.

- **Source Match**

  Source match (ep1S and ep2S) describes the return loss of a driving port.

- **Load Match**

  Load match (ep1L and ep2L) describes the return loss of a terminating port. In the 8-term error models used as a basis for the LRL/LRM and other calibration families, this is treated as the same as source match but the incoming data is precorrected to take into account the (measured) difference in match between driving and terminating states.

- **Reflection Tracking**

  Reflection tracking (et11 and et22) describes the frequency response of a reflect measurement including loss behaviors due to the couplers, transmission lines, converters, and other components.

- **Transmission Tracking**

  Transmission tracking (et12 and et21) is the same as above but for the transmission paths. The tracking terms are not entirely independent and this fact is used in some of the calibration algorithms.

- **Isolation**

  Isolation (ex12 and ex21) takes into account certain types of internal (non-DUT dependent) leakages that may be present in hardware. It is largely present for legacy reasons and is rarely used in practice since this type of leakage is typically very small in modern VNAs.

1-17 Line Types (Transmission Media)

Part of the calibration definition is the selection of line type. The main purpose of this is to assign a dispersion characteristic that will be needed later. Dispersion is the dependence of the phase velocity on the line with frequency. Media such as coax and coplanar waveguides are largely dispersion-free; that is, we can define phase velocity by a single number:

$$v_{ph} = \frac{c}{\sqrt{\varepsilon_r}} = \textit{Phase velocity for coaxial and non-dispersive media}$$

(Eq. 1-1)

Where:

- c is the speed of light in a vacuum (~2.9978108 m/s) and
- E_r is the relative permittivity of the medium involved.

Coaxial cable has its own selection since it is intrinsic to the instrument while other non-dispersive media can be selected separately.

One type of dispersive media is regular waveguide. The phase velocity here is defined by:

$$v_{ph} = \frac{c}{\sqrt{\varepsilon_r} \times \sqrt{1 - \left(\frac{f_c}{f}\right)}} = \frac{c}{\sqrt{\varepsilon_r - \left(\frac{f_{c0}}{f}\right)^2}} = \textit{phase velocity for waveguide}$$

(Eq. 1-2)

Where:

- E_r is the dielectric constant
- f_c is the cutoff frequency of the waveguide (with dielectric) and
- f_{c0} is the cutoff frequency of the waveguide in a vacuum (which is what is entered).

The system will compute the required values. This information is needed for computing distances when in time domain and when adjusting reference planes.

Microstrip lines are another example of dispersive media that can be selected. Here the dimensions of the line together with the dielectric material determine the phase velocity behavior. An intermediate quantity, called the effective dielectric constant ($S_{r,eff}$), is used and a suggested value computed by the VNA but this value can be overridden. At low frequencies, the structure can be considered non-dispersive (like coax) with a phase velocity given by:

$$v_{ph} = \frac{c}{\sqrt{\varepsilon_{r,eff}}}$$
$$= \textit{low frequency limit}$$

(Eq. 1-3)

At higher frequencies when additional mode behavior becomes important, dispersion must be handled. The dielectric constants (media-based and effective) together with a transition frequency f_t are used to compute this effect which is heavily dependent on the dielectric thickness:

$$v_{ph} = \frac{c}{\sqrt{\dfrac{\varepsilon_{r,eff} + \varepsilon_r \cdot \left(\dfrac{f}{f_t}\right)^2}{1 + \left(\dfrac{f}{f_t}\right)^2}}} \qquad \textit{where} \qquad f_t = \frac{Z_c \varepsilon_0 \sqrt{\varepsilon_r c^2}}{2t\sqrt{\varepsilon_{r,eff}}}$$

(Eq. 1-4)

Where:

- Z_c is the characteristic impedance of the microstrip line
- t is the dielectric thickness

1-18 Preparing a Sliding Load (Termination) Calibration Kit

Sliding terminations (loads) are the traditional Z_0 calibration-reference devices for vector network analyzer calibration. When correctly used and perfectly aligned, they can be more accurate than precision fixed loads. However, sliding terminations have a low frequency limit dependant on connector type and must be used with a fixed load for full frequency-range coverage. The connector frequency limits are:

- 2 GHz for 3.5 mm Connector sliding loads
- 2 GHz for K Connector sliding loads
- 4 GHz for V Connector sliding loads

Sliding terminations consist of a connector, a long section of precision transmission line, and a microwave load that is movable within the transmission line. Pin depth is the relationship between the interface positions of the outer and center conductors and is the most critical parameter that you can control in a sliding termination. An example of its criticality is that an incorrect pin depth of 0.001 inch can cause a reflection return loss of 44 dB. Since you are usually calibrating to accurately measure a greater than 40 dB return loss, correct pin depth is essential.

Since setting an accurate pin depth is so important, this discussion centers on describing how to set the pin depth for male and female sliding terminations. Calibration with the sliding termination is essentially the same as described below for the broadband load.

The procedure below uses the Model 3652 Calibration Kit and its 17KF50 and 17K50 Sliding Terminations. Calibration is similar for the Model 3650 SMA/3.5mm, and Model 3654 V connector kits.

Procedure

1. Remove the **Pin Depth Gauge** from the kit, place it on the bench top.

Note	The gauge is convertible between male and female. The following procedure describes the zeroing process for the female fitting. The procedure for the male fitting begins with Step 16 below.

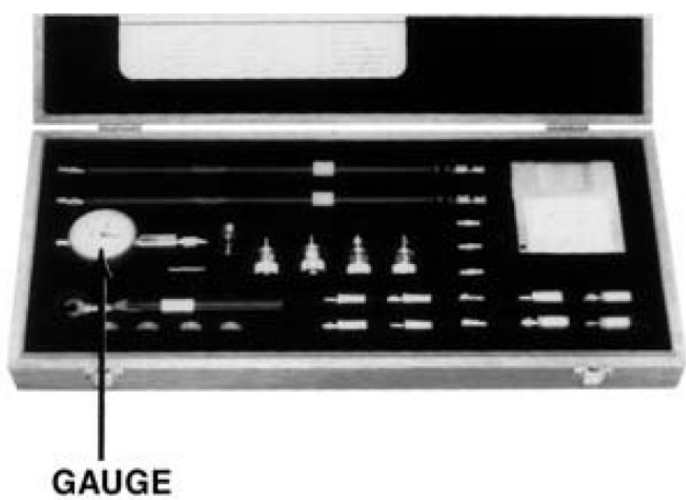


Figure 1-3. Calibration Kit

2. Push the outer locking ring towards the gauge to expose the center pin.

Figure 1-4. Exposing the Center Pin

3. Take the **01-210 Reference Flat (Ref Flat)** from the kit.

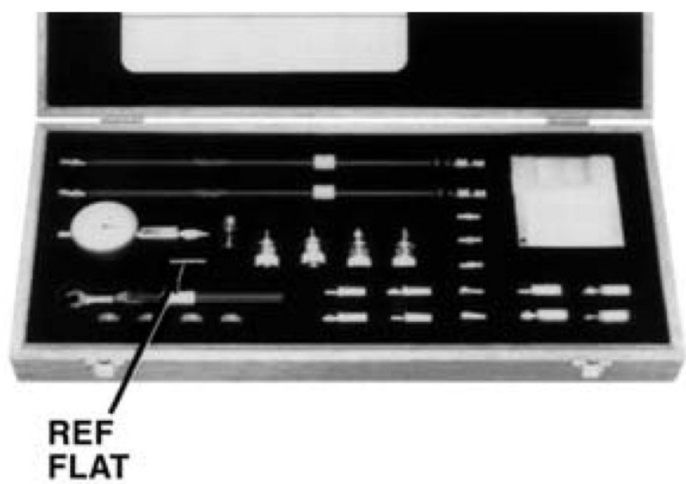


Figure 1-5. Reference Flat in Case

4. While holding the gauge as shown, press the **Ref Flat** firmly against the end of the exposed center pin.

Figure 1-6. Setting Pointer to “0”

5. While pressing the **Ref Flat** against the center pin, check that the pointer aligns with the “**0**” mark. If it does not, loosen the bezel lock screw and rotate the bezel to align the pointer with the “**0**” mark. Tighten the **bezel lock screw**.

Note	Gently rock the Ref Flat against the center pin to ensure that it is fully depressed and you have accurately set the gauge for zero.

Figure 1-7. Dial Bezel and Pointer at “0”

6. Remove the **Sliding Termination** with the female-connector (17KF50, for this example) from the kit, and slide the load all the way toward the end closest to the connector.

Figure 1-8. F-F Sliding Terminator, Towards End Closest to Connector

Caution	The center pin of the sliding load is floating. The load should be sighted from the connector end and rotated to allow gravity to pull the center pin such that it is concentric with the outer housing. Note the orientation of the sliding load assembly and ensure this orientation is preserved when making connections to the sliding load to avoid damaging the center pin.

7. With either hand, pick up the sliding termination near its connector end.

Figure 1-9. Holding F-F Sliding Terminator

8. Cup the **Sliding Termination** in your palm, and support the barrel between your body and crooked elbow.

Figure 1-10. Holding F-F Sliding Terminator, Ready to Measure

9. Remove the **Flush Short** by holding its body and unscrewing its connector.

Figure 1-11. F-F Sliding Terminator, Removing Flush Short

10. Ensure that the orientation of the sliding load is such that the center pin is concentric with the outer housing and install the gauge onto the end of the sliding termination.

Figure 1-12. F-F Sliding Terminator, Installing Gauge

11. If the factory-set **COARSE SET** adjustment has not moved, the inner dial on the gauge will read "**0**." If it does not, perform the **Coarse Set Adjustment** in Step 15 below.

Figure 1-13. Gauge Reading, Outer Dial Reading, Inner Dial Reading

12. Place the sliding termination, with the gauge attached, on the bench top.

Figure 1-14. F-F Sliding Terminator with Attached Dial Gauge

13. Loosen the **FINE LOCK** ring and turn the **FINE ADJ** ring to position the gauge pointer 0-3 small divisions on the "**–**" side of zero. The Sliding Load Pin Depth specification is from 0.000 inches to –0.0003 inches (0.000 in to –0.0003 in).

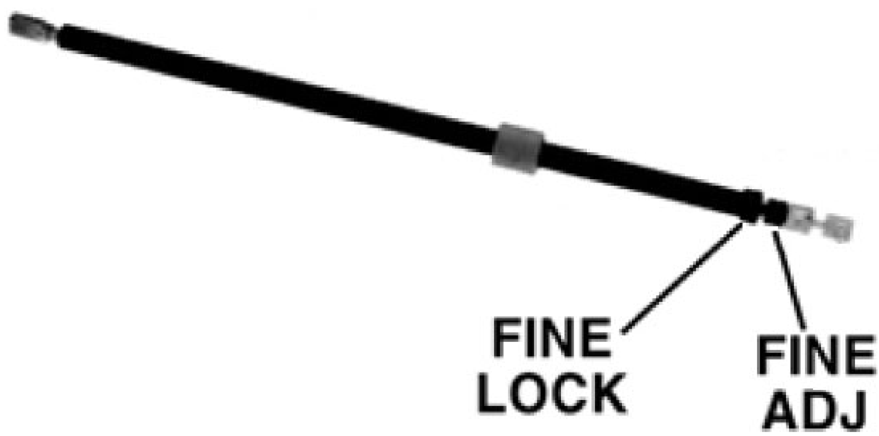


Figure 1-15. Using the Fine Lock Ring and Fine Lock Adjustment

14. Turn the **FINE LOCK** ring clockwise to both tighten the adjustment and place the pointer exactly to "0." The Sliding Termination is now ready to use.

Note	Insure that the inner dial reads "0." The following step is not normally necessary and it needs to be performed only if the adjustment has changed since it was set at the factory.

Figure 1-16. Fine Lock Adjustment with Gauge Inner Dial Reading “0”

15. With the **01-211 Flush Short** installed, loosen the **COARSE LOCK** and gently push the **COARSE SET** adjustment rod in as far as it will go. This coarsely sets the center conductor to be flush against the attached short. Return to Step 2 above.

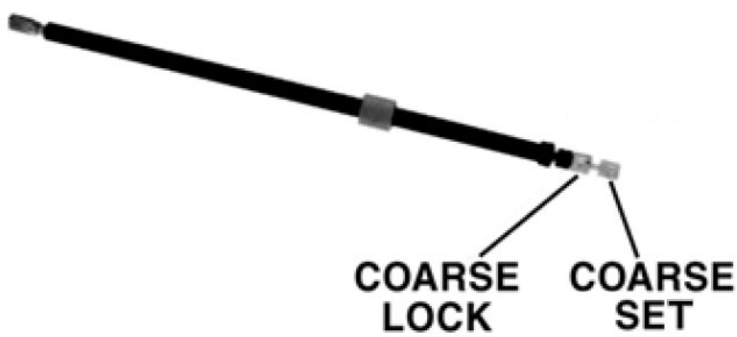


Figure 1-17. M-M Sliding Terminator

16. The procedure for adjusting the male-connector sliding termination is essentially the same as that described above. The only difference is that you must install the female adapter on the end of the gauge shaft, over the center conductor. To install this adapter, proceed as follows:

- **a.** Zero-set the gauge as described in Step 2 through Step 5 above.
- **b.** Push the outer locking ring back toward the gauge and turn it clockwise onto the exposed threads.

c. Loosen the lock ring one turn in a counterclockwise direction.

Figure 1-18. Preparing the Gauge for the Female Adapter

17. Remove the **01-223 Female Adapter** (“F ADAPTER FOR PIN GAUGE”) from the kit.

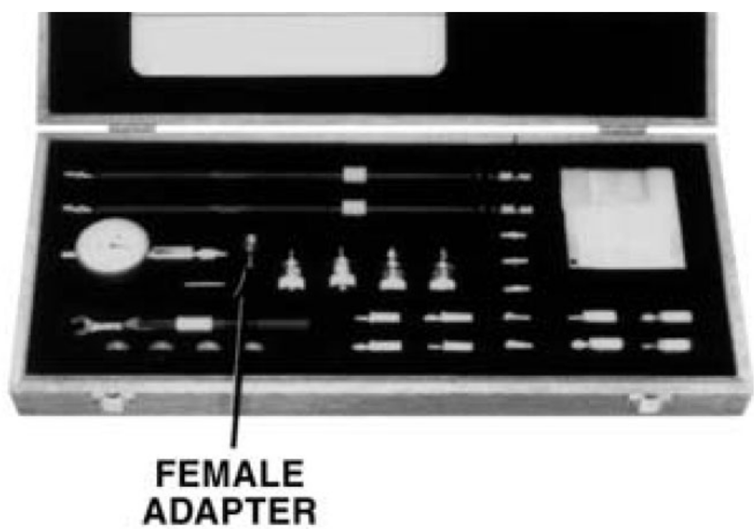


Figure 1-19. Female Adapter Location in Case

18. Install the female adapter over the center pin and screw it into the locking ring, and tighten the outer ring until it is snug against the housing.

Figure 1-20. Installing the Female Adapter on the Gauge

19. Inspect the end of the adapter, you should see no more than two exposed threads. If so, repeat Step 7 through Step 10 above.

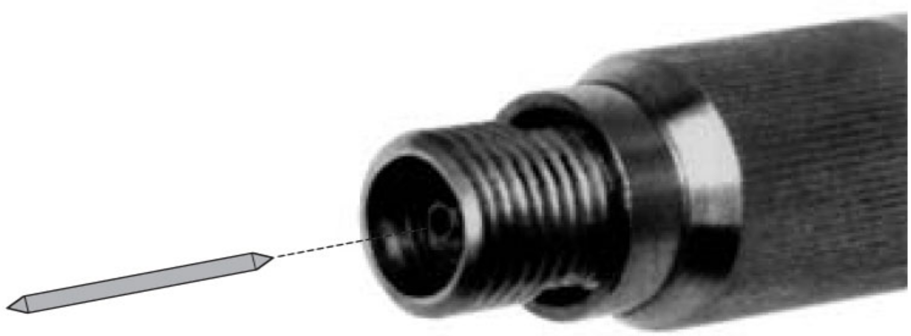


Figure 1-21. Inspecting the End of the Female Adapter

20. Insert the **Female Alignment Pin – 7862** as shown in Figure 1-21 to aid in center-pin alignment with the pin-depth gauge.

21. Connect the gauge to the sliding termination and zero set the center pin using the **FINE ADJ** as previously described in Step 2 through Step 5 above.

1-19 Connector Precautions

The following are precautionary notes are related to the use and care of connectors.

Pin Depth

Before mating, measure the pin depth (Figure 1-22) of the device that will mate with the RF component, using a **Anritsu Pin Depth Gauge** or equivalent (Figure 1-23). Based on RF components returned for repair, destructive pin depth of mating connectors is the major cause of failure in the field. When an RF component is mated with a connector having a destructive pin depth, damage will likely occur to the RF component connector. (A destructive pin depth has a center pin that is too long in respect to the reference plane of the connector.)

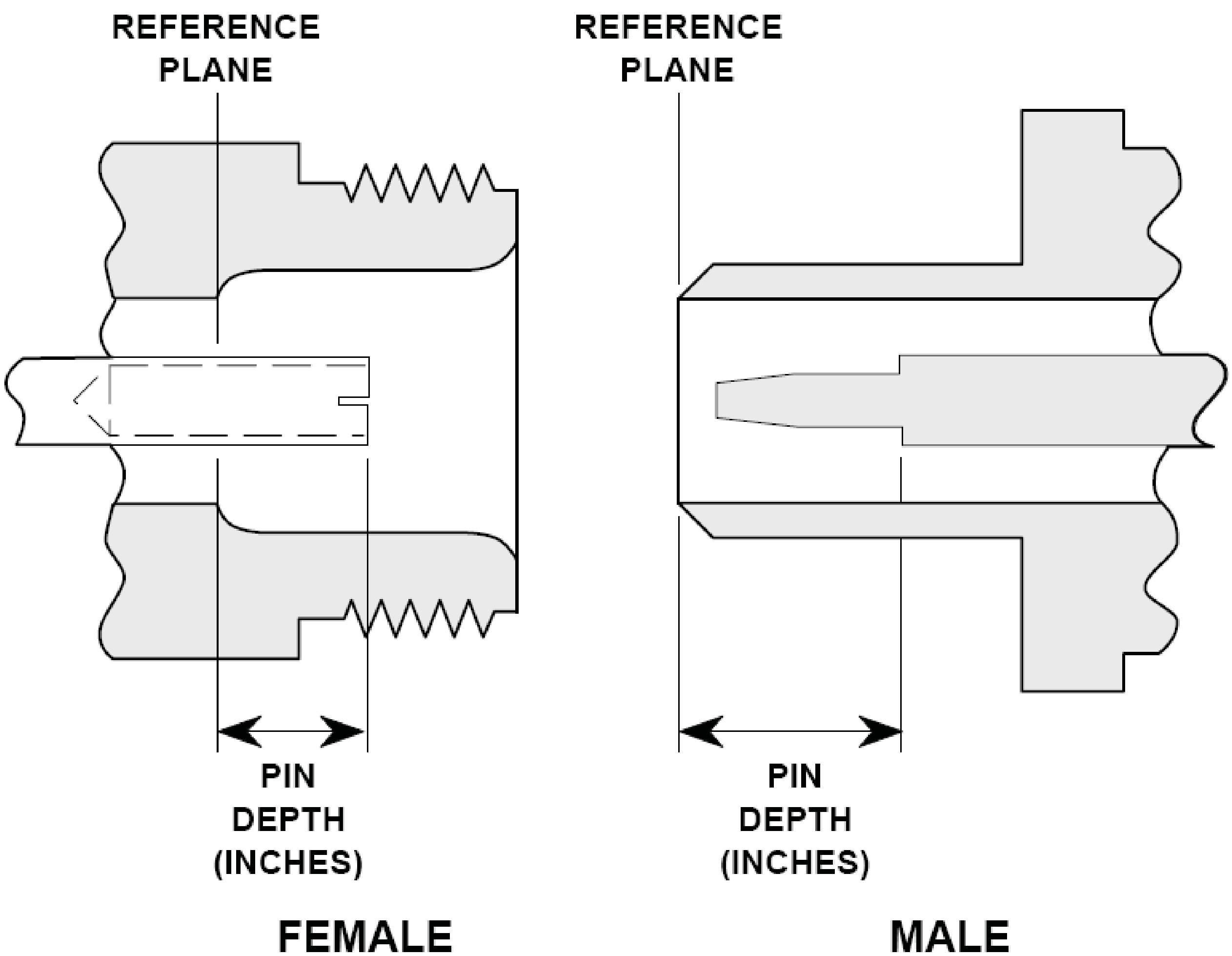


Figure 1-22. N Connector Pin Depth

Pin Depth Tolerance

The center pin of RF component connectors has a precision tolerance measured in mils (1/1000 inch). Connectors on test devices that mate with RF components may not be precision types and may not have the proper depth. They must be measured before mating to ensure suitability. When gauging pin depth, if the test device connector measures out of tolerance as listed in Table 1-6, "Pin Depth Tolerances" on page 1-30 in the "+" region of the gauge (Figure 1-23), the center pin is too long. Mating under this condition will likely damage the termination connector.

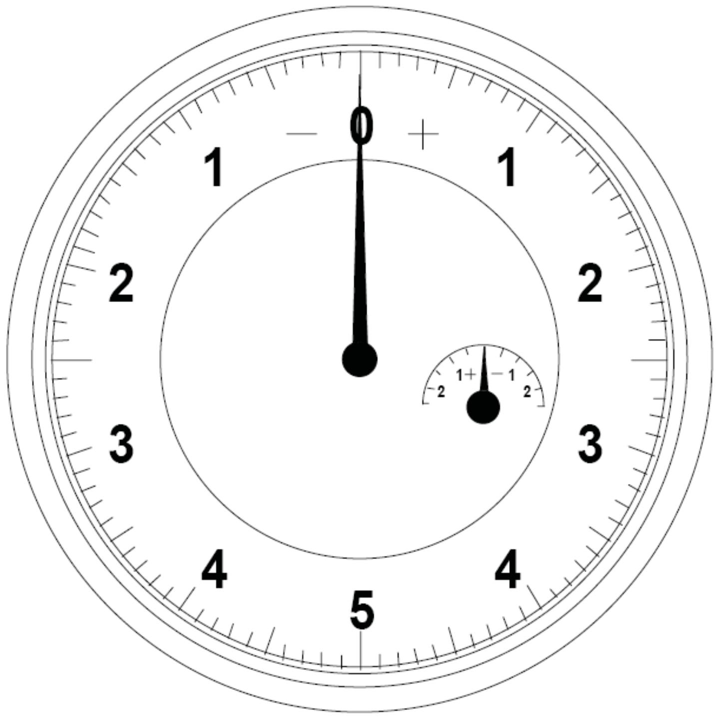


Figure 1-23. Pin Depth Gauge

On the other hand, if the test device connector measures out of tolerance in the "**–**" region, the center pin is too short. While this will not cause any damage, it will result in a poor connection and a consequent degradation in performance.

Over-Torquing Connectors

Over torquing connectors is destructive; it may damage the connector center pin. Finger-tight is usually sufficient, especially on Type N connectors.

Caution	**Never** use pliers to tighten connectors.

Teflon Tuning Washers

The center conductor on most RF components contains a small teflon tuning washer located near the point of mating (interface). This washer compensates for minor impedance discontinuities at the interface. The location of the washer is critical to the performance of the RF components.

Caution	**Do not disturb** the teflon tuning washer in connectors.

Mechanical Shock

RF components are designed to withstand years of normal bench handling. However, do not drop or otherwise treat them roughly. They are laboratory-quality devices, and like other such devices, they require careful handling.

Table 1-6. Pin Depth Tolerances

Port/Connector Type	Pin Depth (mils) (0.000 in)	Anritsu Gauge Setting
N Male	0.207 in –0.000 in +0.001 in	0.207 +0.000 –0.001
N Female	0.207 in +0.000 in –0.001 in	Same as pin depth
3.5 mm Male 3.5 mm Female	–0.0002 in –0.0007 in	Same as pin depth
K Male K Female	–0.0002 in –0.0007 in	Same as pin depth
V Male V Female	–0.0002 in –0.0010 in	Same as pin depth
2.4 mm Male 2.4 mm Female	–0.0002 in –0.0010 in	Same as pin depth

1-20 Connector Cleaning Instructions

Connector interfaces, especially the outer conductors on the SMA connectors, should be kept clean and free of dirt and other debris.

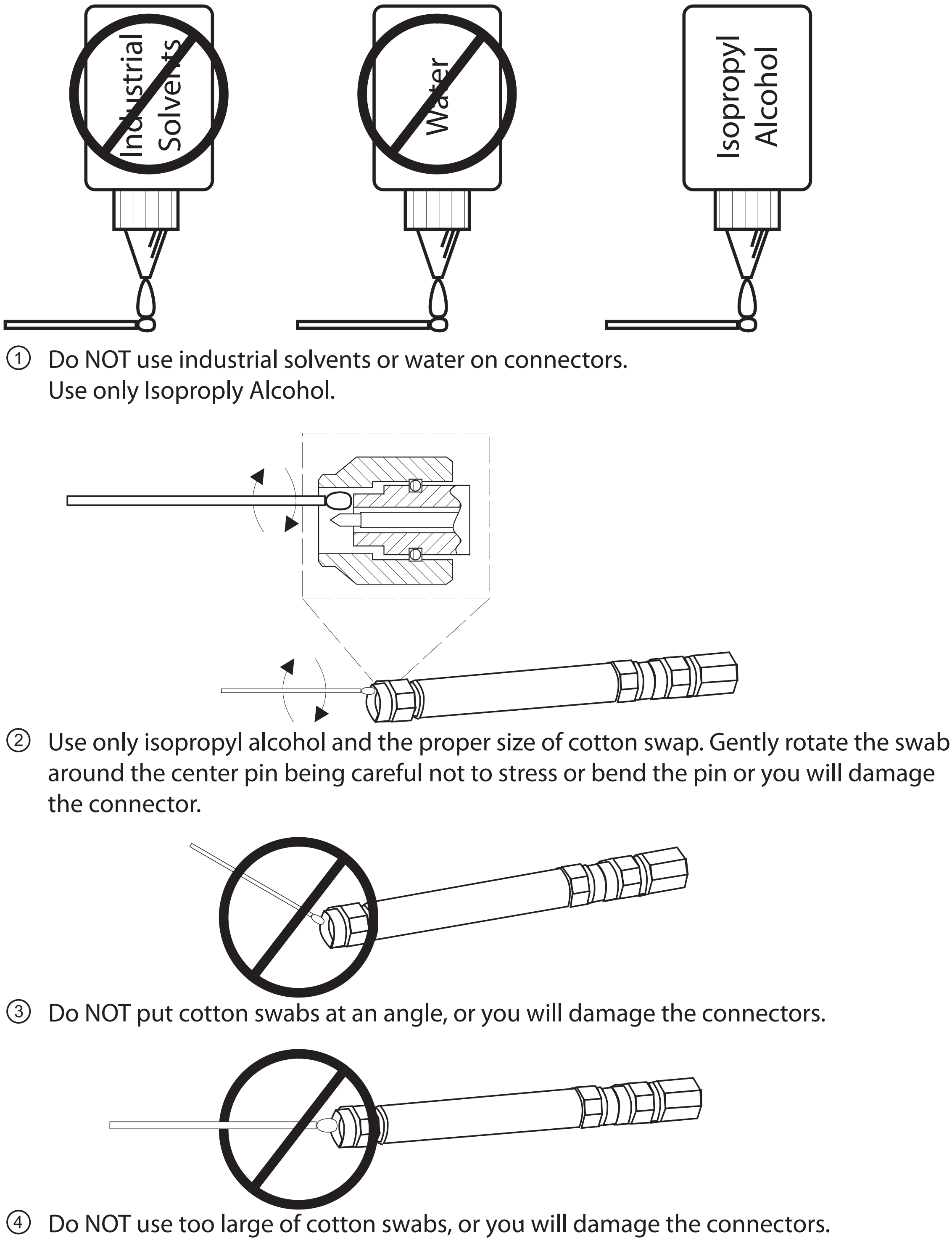
Isopropyl alcohol applied with a cotton swab applicator is recommended for cleaning connector interfaces.

Note	Most cotton swabs are too large to fit in the smaller connector types. It is necessary to remove most of the cotton and then twist the remaining cotton tight. Be sure that the remaining cotton does not get stuck in the connector.

The following are some important tips on cleaning connectors:

- Use only isopropyl alcohol as a solvent.
- Always use an appropriate size of cotton swab.
- Gently move the cotton swab around the center conductor.
- Never put lateral pressure on the center pin of the connector.
- Verify that no cotton or other foreign material remains in the connector after cleaning.
- Only dampen the cotton swab. Do NOT saturate it.
- Compressed air can be used to remove foreign particles and to dry the connector.
- Verify that the center pin has not been bent or damaged.

The following illustrates how to properly clean connectors.



1 – Do NOT use industrial solvents or water on connectors. Use only Isopropyl Alcohol.	3 – Do NOT put cotton swabs at an angle, or you will damage the connectors.
2 – Use only isopropyl alcohol and the proper size of cotton swab. Gently rotate the swab around the center pin being careful not to stress or bend the pin or you will damage the connectors.	4 – Do NOT use too large of cotton swabs, or you will damage the connectors.

Figure 1-24. Cleaning Calibration Kit Connectors

Chapter 2 — AutoCal Procedures

2-1 Chapter Overview

This chapter describes common procedures for both Internal Through and True-Through calibration using Anritsu AutoCal® modules including the **36585-Series Precision AutoCal Modules** and the **36581KKF Standard AutoCal Module**. This chapter provides two examples of using a precision adapter with an AutoCal unit to create difference-gender reference planes as is adapter removal with an AutoCal unit. The chapter concludes with user-based AutoCal module characterization and working with older Anritsu AutoCal units.

Figure 2-1. MS4647A VNA with 36585V-Series Precision AutoCal Module

2-2 Automatic Calibrator (AutoCal) Terms

This section defines various terms used with AutoCal modules and the calibration procedures used with the VectorStar.

Insertable and Non-Insertable Devices

Insertable devices have an insertable connector pair such as a male input connector and a female output connector. These devices can be measured after a through calibration. A non-insertable device has a non-insertable pair of connectors such as female connectors on both ports or different connector types such as a DUT with both a K and V connector. Non-insertables cannot be connected directly into the measurement path without an adapter.

- **Through ("Thru")**

  A *thru* (properly called a "through") is a connection of the two test ports. Two kinds of through connections, internal through and true through, are defined for the AutoCal calibration.

- **Internal Through**

  An Internal Through is an internal path through the calibrator requiring no operator involvement in the AutoCal setup.

- **True Through ("True Thru")**

  A True Through is a direct cable connection between the test ports, with no intervening connectors. An internal through is not as accurate as a true through but requires more operator involvement and takes more time to accomplish. The true through can be more accurate than the internal through (if very well-matched and of very low loss) but the length and loss must be entered. The return loss of the adapters must be very good to avoid added error.

Auto-Sense

A selectable function of the AutoCal module where, if enabled, the AutoCal module decides the left/right test cable assignment. If not enabled, the operator defines the port number to left/right assignment.

Characterization File

Each calibrator module has a file containing data which characterizes each standard in the calibrator. This file also contains information (identification number, start and stop frequencies) concerning the capabilities of the calibrator. Each characterization file has the extension "`.acd`." When modules are changed, the appropriate new characterization file must be installed. The files are typically stored on a Characterization Memory Device (USB memory device). Insert the **Characterization Memory Device** into a **VectorStar USB** port. This file can be installed by navigating to the INSTALL (AUTOCAL CHARACTERIZATION/CAL KIT) dialog box:

- MAIN MENU | Calibration | CALIBRATION | Cal. Kit/AutoCal Characterization | CAL KIT/AUTOCAL | Install Kit/Charac. | INSTALL (AUTOCAL CHARACTERIZATION/CAL KIT) dialog box

From the dialog box, navigate to the location of the Characterization Memory Device. Select the file, and copy it to a location within the `C:\AnritsuVNA` folder. In addition, each AutoCal module can be re-characterized using the VNA, although specifications are only valid if Anritsu has performed the characterization (recommended re-characterization interval is 12 months). A valid 12-term calibration must be active, which is used to characterize the standards within the module.

2-3 AutoCal Introduction

Note	In some menus and screens, S11 is used to represent the S_{11} calibration parameter, S12 for S_{12}, S21 for S_{21}, and S22 for S_{22}, and so on.

The auto calibration (AutoCal) process represents both a calibration kit and an algorithm that is used to speed up the calibration process with extremely high accuracy, minimizing the number of manual steps and test operator involvement.

Transfer Calibration

The **36585x-Series Precision AutoCal** and the **36581KKF Standard AutoCal** module calibrates the VNA by a process known as "transfer calibration." There are a number of impedance and transmission states in the module designed to be extremely stable in time and these states are carefully "characterized", generally by the Anritsu factory but also in a customer laboratory in certain cases. When the same states are re-measured during an actual calibration, and the results compared to the characterization data, an accurate picture can be generated of the behaviors and error terms of the VNA and setup being calibrated.

Calibration Accuracy

A very high calibration accuracy is maintained through the use of certain principles

- The use of many impedance and transmission states
- The creation of very stable states that are further enhanced with a constant-temperature thermal platform inside the module.
- The use of very reliable and repeatable solid-state switching constructed to provide a great variety of state impedances (for better calibration stability) and clean transmission paths.
- The use of a very careful characterization process that can generate excellent starting data.

The resulting accuracy can exceed that obtained with typical mechanical calibration typically performed in a metrology laboratory. The AutoCal results may not be better than that of an exotic manual calibration (such as calibration performed during factory characterization), but is far better than that typically done.

AutoCal Components

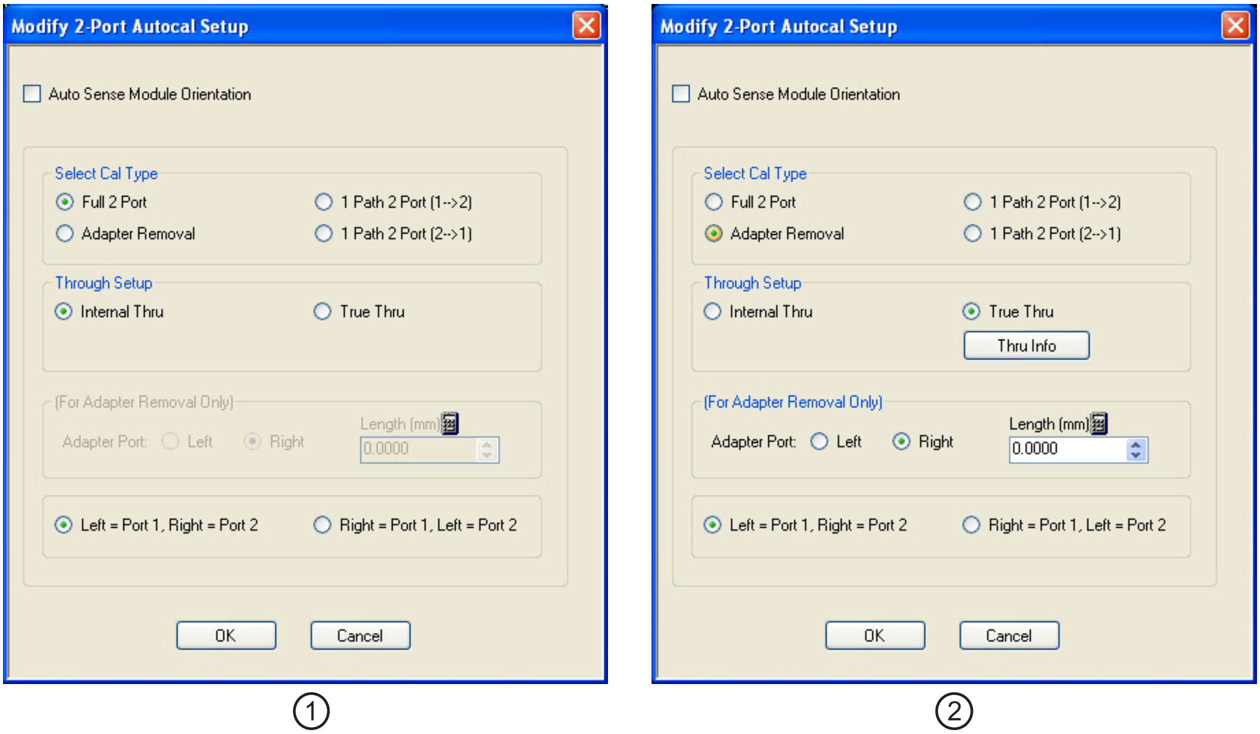
The AutoCal unit consists of the calibration module itself, a separate external power supply, a control cable that runs to the VNA, and the characterization data that is initially provided on a USB memory device. The AutoCal unit should be powered up and allowed to warm up prior to use (typically a few minutes, the blue **Operate LED** will illuminate when the unit is at temperature). Allow 90 minutes warm-up time for calibrations. The control cable should be connected to the serial port on the back of the VNA.

Connector Care

Since an AutoCal calibration is a very high performance calibration, connector care is of the utmost importance.

AutoCal Calibration Parameters and Types

AutoCal requires four general parameters be defined, as shown in the AutoCal dialog box:



1. Settings (at left) for Full Two Port Calibration with Internal Thru.	2. Settings (at right) for Adapter Removal and True Thru.

Figure 2-2. MODIFY 2-PORT AUTOCAL SETUP Dialog Box

The parameters are:

- the calibration type required
- the through type to be used
- whether to automatically or manually define the left/right test port assignments
- whether an adapter will be used with the AutoCal module.

Most standard calibration types are available with the AutoCal units. Frequency response calibrations are the only ones omitted since the AutoCal unit would provide no benefit in these cases since only a through or high reflect standard is needed for these calibrations. The AutoCal modules support:

- Full Two Port (also called Full 2-Port) calibration
- Full Port 1 (S_{11}) reflection only calibration
- Full Port 2 (S_{22}) reflection only calibration
- 1 Path 2 Port Forward (S_{11}, S_{21}) calibration
- 1 Path 2 Port Reverse (S_{22}, S_{12}) calibration

Adapter Removal

The DUT may require a different connector configuration than is on the current AutoCal unit (e.g., F-F DUT and the auto cal is M-F). AutoCal adapter removal is one way of handling this situation by performing two auto calibrations with an adapter connected to the AutoCal. The instrument will guide the user through the required connections.

Through Options

For each calibration type above, there are two through AutoCal calibration options:

- **Internal Thru**

  The AutoCal module provides the internal through connections without the user having to move or reconnect the test cables. The benefit is speed of calibration balanced against potentially less accuracy and accommodates inexperienced operators such as in an assembly line testing station.

- **True Thru**

  All AutoCal modules can also be configured to allow True Thru where the user is prompted when and how to connect the test cables to complete the calibration. The benefit is a higher accuracy calibrations balanced against a longer calibration time and more operator involvement.

Test Port Left/Right Naming Assignments

The AutoCal module setup allows the user to specify the left/right identification of the test port cables as either:

- **Auto Sense Module Orientation = ON**

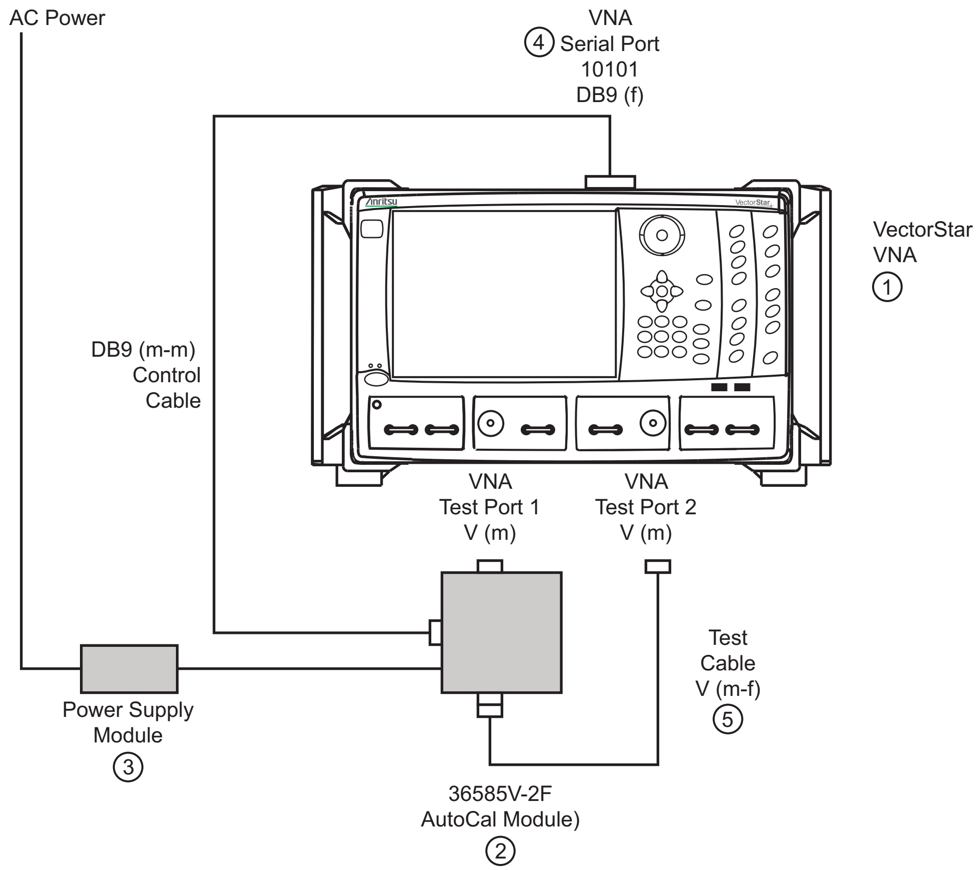
  Where the module determines the left/right identification of the test port cables

- **Auto Sense Module Orientation = OFF**

  Where the user defines either Left = Port 1 and Right = Port 2, or Left = Port 2 and Right = Port 1. This setting is useful where the VNA orientation is different for the operator.

Typical AutoCal Module Connections

The typical **F-F AutoCal** module connections are shown below in Figure 2-3.

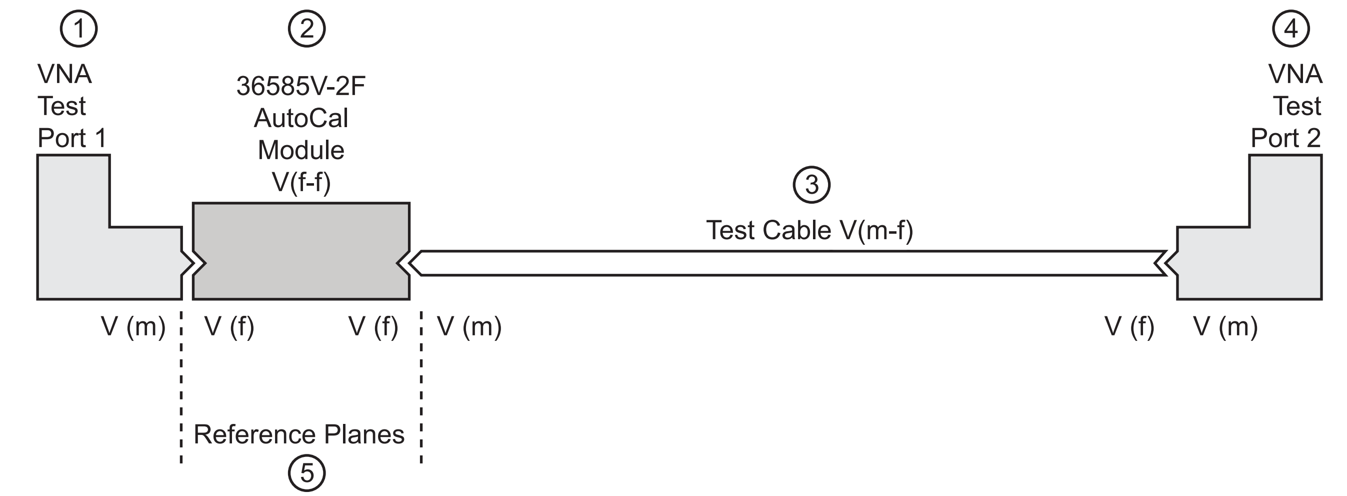


1. MS4645A or MS4647A VNA with V connectors. 2. 36585V-2F AutoCal Module 3. AutoCal Power Supply Module with extension able to local AC Mains power.	4. AutoCal DB9 (m-m) Control Cable connected between AutoCal Module and VNA rear panel Serial 10101 Port. 5. Test Cable V (m-f)

Figure 2-3. AutoCal Module Connections for Internal Through

1. Prepare the **VectorStar MS4645A or MS4647A VNA** and power it up. The instrument has two V (m) test ports.
2. Connect the **366565V-2F Precision AutoCal Module V (f)** connected directly to **VNA Test Port 1 V (m).**
3. The AutoCal module is then connected to its **AC Power Supply Module** and it to AC power
4. Connect the **DB-9 (m-m) Serial Control Cable** to the AutoCal module and the VNA rear panel **Serial Port (10101)**.
5. The second **AutoCal V (f)** connector is connected to the **V (m)** end of the **Test Cable**. The test cable can be changed depending on measurement requirements. Cables on both VNA ports may be used, different types of cables may be used, or other configurations established. Then connect the **V (f)** end of the **Test Cable** to the **VNA Test Port 2 V (m).**

Schematically, this setup is shown in Figure 2-4.



1. VNA Test Port 1 V (m)	4. VNA Test Port 2 V (m)
2. 36585V-2F AutoCal Module	5. Resultant reference planes
3. V (m-f) Test Cable	

Figure 2-4. Schematic of AutoCal 36585V-2F Module Connections for Internal Thru

For optimal results, use the shortest cable lengths that do not require excessive bending when performing calibration or measurements. Results will be improved using the most practical phase- and amplitude-stable cables.

The power supply and control cables may be bundled for ease of routing or may be separated for convenience in some cases.

Using the AutoCal Module

The calibration procedure can be broken up into several simple steps:

1. Power up the VNA and connect the control cable to the AutoCal unit.
2. Install the characterization file if not already done. Copy the AutoCal Characterization File from the Characterization Memory Device (a USB memory device) onto the VectorStar hard disk drive.

Note	The AutoCal Characterization File (ACD file) is provided on a USB memory device and can be installed directly from that device. These files can also be copied from the USB memory device to the VectorStar hard drive and installed from there. The preferred method is to copy all ACD files onto the hard drive, and then install the file for the specific AutoCal being used.

3. Connect the AutoCal module to the VNA:
   - AutoCal Module directly to one **VNA Test Port**
   - A test cable between the AutoCal and **VNA Test Port**
   - The Serial Control Cable between the AutoCal module the VectorStar back panel **Serial 10101** port
4. Connect the AutoCal Module to its power supply and AC power. The green **Power LED** illuminates immediately. When the module is at operating temperature, the blue **Operate LED** will illuminate.
5. Setup the VNA instrument for the desired calibration:
   - The required minimum settings are Frequency Start, Frequency Stop, and Number of Points.
   - If required, optional settings for Segmented Sweep, IF Bandwidth, and/or Averaging are applied.

6. Select the AutoCal parameters of interest and connect the test port cables to the AutoCal unit. Make the required selections for Cal Type, Thru Select, Adapter Removal, and Auto Sense Module.
7. Perform the calibration by clicking Begin Cal to start the auto calibration.
8. A status dialog box with a progress bar appears after an AutoCal sequence has started. The status messages define has far the program has progressed and if any user actions are required.
9. At any time, the AutoCal sequence can be cancelled by clicking the dialog box Abort button.
10. If any manual steps are requested such as specifying a true-through, a dialog box will prompt for the action.
11. When the auto calibration is complete, a status message appears with a statement about assurance passing or failing. On the Calibration menu, the Cal Status field button shows ON.

Each procedure is described in greater detail in the following sections.

2-4 Available AutoCal Modules and Adapters

The Precision and Standard AutoCal modules are show in the figure below.

1. 36581KKF Standard AutoCal Module (at left).	2. 36585-Series Precision AutoCal Module (at right).

Figure 2-5. AutoCal Automatic Calibrator Calibration Modules

AutoCal Modules and Adapters

Anritsu has both Precision AutoCal modules as well as a Standard AutoCal module. The table below shows the available modules.

Table 2-1. Precision and Standard AutoCal Kits and Adapters

Part Number	Name	Frequency Range and Connectors
Precision AutoCal Kits		
36585V-Series Precision AutoCal Modules can be used with MS4642A or MS4644A VNAs with adapters. The calibration range is limited to that of the VNA. Only the 36585V-2MF and 36585K-2MF Precision AutoCal Modules can be used with the 366xX-1 Verification Kits. The 36585K-Series Precision AutoCal Kits can be used with MS4645A or MS4647A VNAs with adapters. The calibration range is limited to 40 GHz.		
36585K-2M	Precision AutoCal Kit, K (m-m), 2-Port	70 kHz to 40 GHz, K (m) to K (m)
36585K-2F	Precision AutoCal Kit, K (f-f), 2-Port	70 kHz to 40 GHz, K (f) to K (f)
36585K-2MF	Precision AutoCal Kit, K (m-f), 2-Port	70 kHz to 40 GHz, K (m) to K (f)
36585V-2M	Precision AutoCal Kit V (m-m), 2-Port	70 kHz to 70 GHz, V (m) to V (m)
36585V-2F	Precision AutoCal Kit V (f-f), 2-Port	70 kHz to 70 GHz, V (f) to V (f)
36585V-2Mf	Precision AutoCal Kit V (m-f), 2-Port	70 kHz to 70 GHz, V (m) to V (f)
Standard AutoCal Kit		
The 36581KKF Standard AutoCal Module can be used with any MS4640A VNA with adapters as required on the Test Ports and/or Module. The calibration range is limited to 20 GHz.		
36581KKF	Standard AutoCal Kit	40 MHz to 20 GHz, K (m) to K (f)
Standard AutoCal Kit Matched Adapters		
Matched adapters are recommended only for use with the 36581KKF Standard AutoCal Module. The standard AutoCal module can be ordered with connector adapters which assume the use of K (m) test port cables. These adapters can be also used on the Precision AutoCal modules, but with some degradation of precision. See Chapter 1, "Calibration Overview" for available calibration modules, tools, and accessories.		
36583K	Matched K Adapters Set, 2 adapters	40 MHz to 20 GHz, K (f) to K (m) adapters
36583L	Matched 3.5 mm Adapters Set, 4 adapters	40 MHz to 20 GHz, K(f) to 3.5 mm (m) adapters, 2 each K (f) to 3.5 mm (f) adapters, 2 each
36583S	Matched SMA Adapters Set, 3 adapters	40 MHz to 20 GHz, K (f) to SMA (m) adapter, 1 each K (f) to SMA (f) adapters, 2 each

2-5 Copying the AutoCal Module Characterization File to the VectorStar

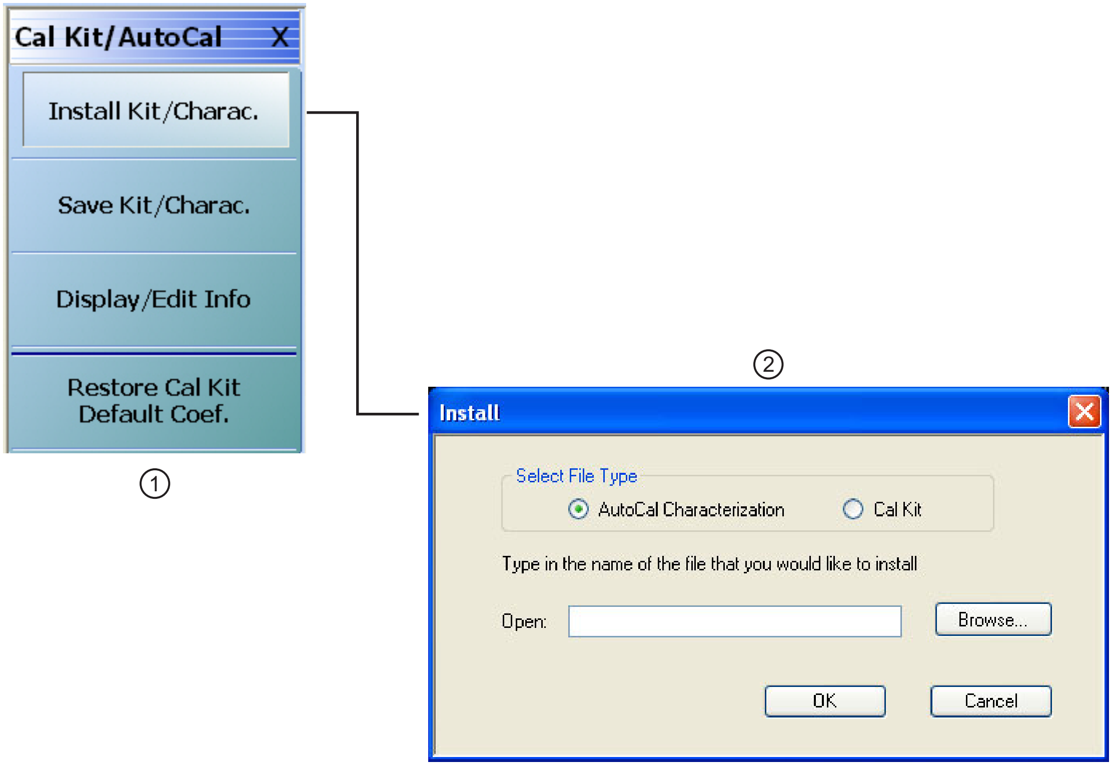
The AutoCal Characterization File (.acd file) is provided on a USB memory device and can be installed directly from that device. The files can also be copied from the USB memory device to the VectorStar hard drive and installed from there. The preferred method is to copy all ACD files to the hard drive, and then select the file for the specific AutoCal being used.

Procedure

1. Inspect the AutoCal kit and make a note of its serial number. Typical AutoCal Kit serial numbers are six-digit integers such as "123456."
2. Insert the AutoCal Characterization Memory Device (USB memory device) into one of the VectorStar USB Ports.

Note	Alternatively, Windows Explorer can also be used to move files from the USB memory device to the VectorStar hard drive.

3. Navigate to the CAL KIT/AUTOCAL menu:
    - MAIN | Calibration | Cal Kit/AutoCal Characterization | CAL KIT/AUTOCAL



1. At left, the CAL KIT/AUTOCAL Characterization Coefficients Utility Menu

2. The Install Kit/Charac. (Characterization) button links to the INSTALL AUTOCAL CHARACTERIZATION/CAL KIT Dialog Box shown here with the AutoCal Characterization button selected.

Figure 2-6. CAL KIT/AUTOCAL Utility Menu – INSTALL CHARACTERIZATION FILE Dialog Box

4. On the CAL KIT/AUTOCAL menu, select Install Kit/Charac. The Install (AutoCal Characterization/CalKit) dialog box appears.
5. Select the AutoCal Characterization radio button and then click Browse. The Open (AutoCal ACD File) dialog box appears.
6. Navigate to the USB port location holding the USB memory device and select the file "`V123456.ACD`," where "`123456`" is the serial number of the AutoCal kit.
7. Click the dialog box Open button. The Open dialog box closes; the Install dialog box re-appears.
8. Click OK in the Install dialog box. Another install dialog box appears (this one showing the AutoCal controller serial number, which is not the module serial number). Click Install in this box close it.
9. On the Cal Kit/AutoCal menu, select Save Kit/Charac. The Save (AutoCal Characterization) dialog box appears. Click OK.
10. Navigate to the required storage directory for the characterization file. The recommended directory destination on the VectorStar is `C:\Anritsu\VNA\AutoCal`
11. Click Save. The Save dialog box closes, the CAL KIT/AUTOCAL menu reappears.
12. Repeat the steps above to copy each new AutoCal Characterization File to the VectorStar.

2-6 Loading a Previously Stored AutoCal Characterization File

Use this procedure if the AutoCal Characterization File has already been copied onto the VectorStar hard drive.

Procedure

1. Navigate to CAL KIT/AUTOCAL menu.
    - MAIN | Calibration | CALIBRATION | Cal Kit/AutoCal Characterization | CAL KIT/AUTOCAL
2. On the CAL KIT/AUTOCAL menu, select Install Kit/Charac.
3. Select the AutoCal Characterization radio button and then click Browse.
4. Navigate to the hard drive (or USB memory device) location of the AutoCal Characterization file for the AutoCal module in use. The recommended directory destination on the VectorStar is `C:\Anritsu\VNA\AutoCal`
5. Select the AutoCal Characterization file, such as "`V123456.ACD`," where "`123456`" is the serial number of the AutoCal kit. Click Open.
6. Click OK in the Install dialog box. Another install dialog box appears (this one showing the AutoCal controller serial number, which is not the module serial number). Click Install in this box close it.
    - The Install dialog box closes and the Cal Kit/AutoCal menu is again available.

2-7 Pre-Calibration Instrument Setup

Use this procedure to setup the minimum required instrument configuration parameters:

- Frequency Start
- Frequency Stop
- Number of Points

Any other required measurement parameters must be defined and applied before the AutoCal procedure. This section provides a highlight of typical additional measurement parameters.

Segmented Sweep

If required, segmented sweep must be setup in advance if the calibration needs a custom frequency list. See "Frequency-Based Segmented Sweep" on page 14-11.

IF Bandwidth (IFBW) and Averaging

IF Bandwidth and Averaging control the digital filtering and post-processing that determine the effective noise floor, the amount of trace noise, and, in some cases, the immunity to interfering signals. The trade-off for improved noise performance is slower sweep speed.

Port Power

Port power is less critical than IFBW or Averaging due to the excellent linearity of the VectorStar MS4640A Series VNA receivers. The AutoCal unit has an absolute maximum power limit of +10 dBm. The preferred calibration power is –10 dBm for improved accuracy at frequencies <100 MHz.

If power adjustments are required, any step attenuator settings must be selected before the calibration. Changes in the step attenuator settings alters both the RF match and the insertion loss in the measurements paths. Power can be changed after a calibration, but an attenuator change after a calibration invalidates the prior calibration.

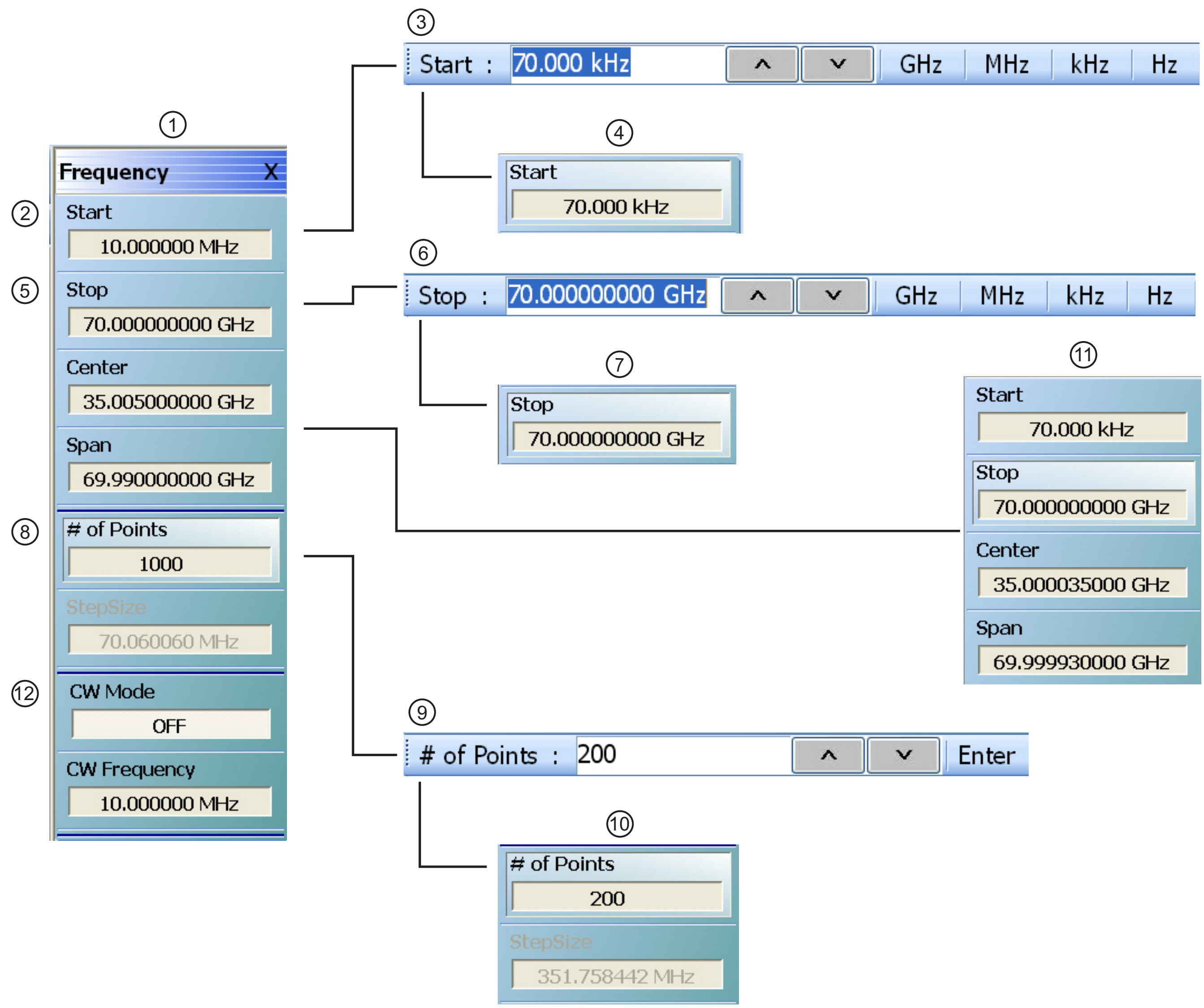
Example Procedure

This example procedure assumes the VectorStar MS4640A Series VNA is equipped with the Option 070 – 70 kHz Low Frequency Extension and that only Frequency Start, Frequency Stop, Number of Points, and CW Mode settings are required.

1. Determine the values for the minimum setup parameters:
    - Frequency Start: 70 kHz
    - Frequency Stop: 70 GHz
    - Number of Points: 200
    - CW Mode: OFF
    - Segmented Sweep: Not required
    - IFBW: Defaults to 1 kHz
    - Averaging: Defaults to no averaging
2. Power up the VectorStar and allow it to stabilize its internal temperature.

3. Navigate to the FREQUENCY menu:

- MAIN | Frequency | FREQUENCY



1 – FREQUENCY Menu	7 – Stop Button after set to 70 GHz
2 – Start (Frequency) Button before.	8 – # (Number) of Points (Frequency) Button before
3 – Start Field Toolbar with 70.000 kHz set	9 – # of Points Field Toolbar with 200 points set
4 – Start Button after set to 70.000 kHz	10 – # of Points Button after set to 200 points. Below, Step Size automatically calculated to 351.758442 MHz.
5 – Stop (Frequency) Button before	11 – Center (Frequency) Button automatically calculated to 35.00003500 GHz. Below, Span Button automatically calculated to 69.999930000 GHz.
6 – Stop Field Toolbar with 70 GHz set	

Figure 2-7. FREQUENCY Menu - Setting Initial AutoCal Parameters

4. On the FREQUENCY menu, click the Start frequency button (Figure 2-7 – #2).

- The frequency Start toolbar appears just below the icon toolbar (Figure 2-7 – #3).

5. Enter the required start frequency number value.

- For this example, set the start frequency value at 70.

6. Enter the required start frequency units.
    - For this example, set the units to kilohertz by clicking kHz.
    - The Start frequency field button now shows 70.000 kHz (Figure 2-7 – #4).

Note	If the MS4640A Series VNA is not equipped with Option 070 – 70 kHz Low Frequency Extension, the lowest available starting frequency is 10 MHz.

7. On the FREQUENCY menu, click the Stop frequency field button (Figure 2-7 – #5).
    - The frequency Stop toolbar appears (Figure 2-7 – #6).
8. On the Stop frequency toolbar, enter the required frequency number value and units.
    - For this example, set the stop value at 70 and click the GHz units button.
    - The Stop frequency button now shows 70.000000000 GHz (Figure 2-7 – #7).
9. The Center and Span display buttons show calculated values based on settings made above (See Figure 2-7 – #7 above).
    - The Center frequency field button shows a value of 35.000035000 GHz.
    - The Span frequency field button shows a value of 69.9999930000 GHz.
10. On the Frequency menu, click the # of Points (Number of Points) button (Figure 2-7 – #8).
    - The # of Points toolbar appears (Figure 2-7 – #9).
11. On the # of Points toolbar, enter the required number of points.
    - In this example, set the # of Points to 200 and then click Enter on the toolbar.
    - The # of Points field button shows 200 (Figure 2-7 – #10).
    - The Step Size display button automatically calculates the step size of 351.758442 MHz.
12. Click the CW Mode toggle button so it is set to OFF.
13. The FREQUENCY menu appears with the new settings as shown below.

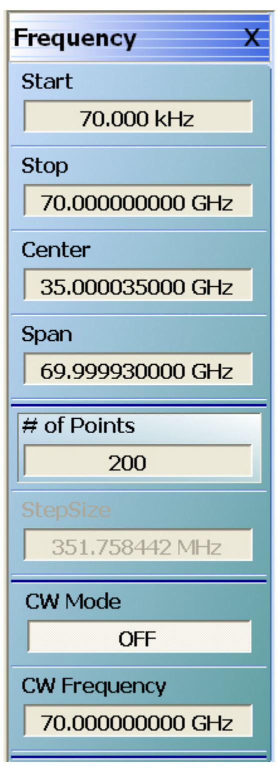


Figure 2-8. FREQUENCY Menu – After Settings

14. If optional parameters are required, do any of the following optional procedures described elsewhere in this manual:
    - "Frequency-Based Segmented Sweep" on page 14-11.
    - "IFBW" on page 12-28.
    - Averaging
    - Power and Attenuation
15. If no optional parameters are required, the AutoCal is ready to proceed.
    - "AutoCal - Full Two Port - Internal Through" on page 2-16.

2-8 AutoCal - Full Two Port - Internal Through

This procedure performs an AutoCal calibration using a full two port calibration with an internal through, which is sufficiently accurate for most DUTs. The AutoCal Characterization file has already been loaded onto the VectorStar.

Required Equipment

- VectorStar MS4645A or MS4647A VNA with V (m) test port connectors, with Option 070 – 70 kHz Low End Frequency Extension.
- 36585V-2F Precision AutoCal Module, with V (f) connectors and required power and control cables. The AutoCal Characterization File has been loaded onto the VectorStar VNA.
- Test port cable, V (f) to V (m)

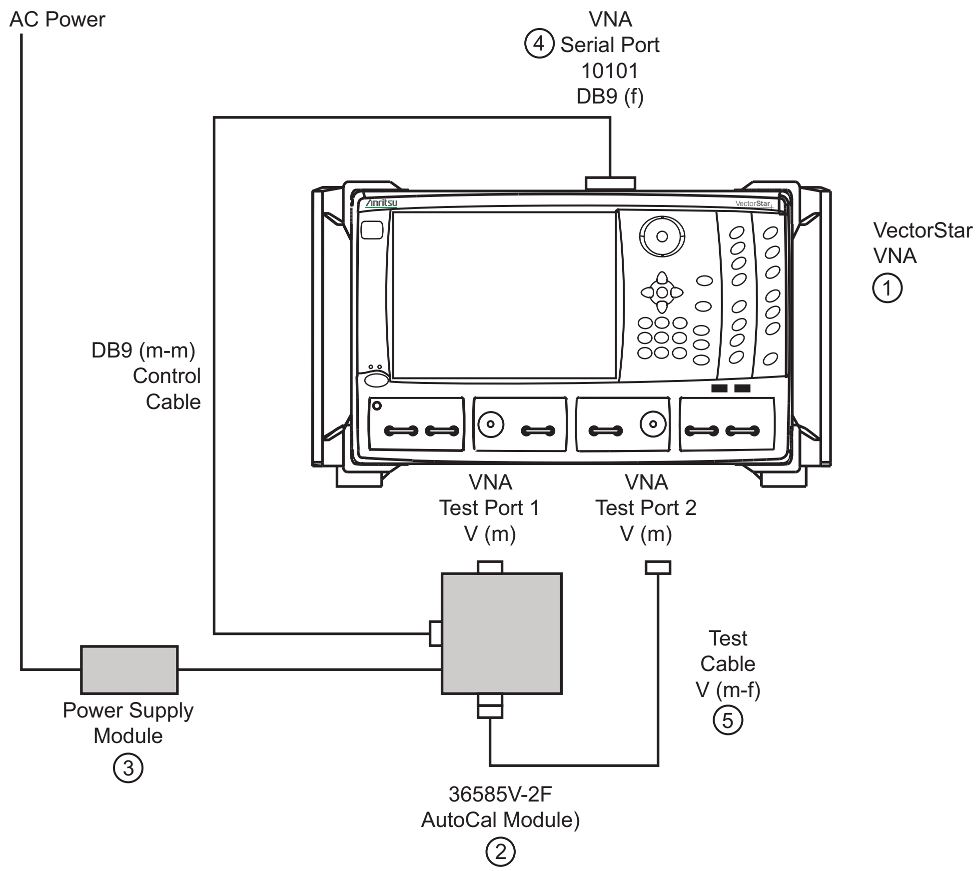
Procedure

1. Power up the VectorStar VNA.
2. Set the required Frequency Start, Frequency Stop, and Number of Points parameters.
    - See "Pre-Calibration Instrument Setup" on page 2-12.
3. If required, set up other parameters as required such as Segmented Sweep, IFBW, Averaging, and Power and Attenuation.

AutoCal Module Connections

4. Make the necessary cable connections between the **AutoCal Module**, its **Power Module**, and the **VectorStar** rear panel.
5. Connect the **AutoCal V (f)** connector directly to the VectorStar left side **V (m) Test Port 1**.
6. Connect the **Serial Control Cable** between the DB-9 connector on the top of the AutoCal Module and the **Serial (10101) Port** on the VectorStar rear panel.
7. Connect the coaxial power plug from the **Power Supply Module** to the **AutoCal Module**. Connect the other end to AC power.
8. Once connected to power, the **AutoCal Module Power LED** is illuminated green. When the module has warmed up to operating temperature, the **LED** illuminates as blue.

9. Connect the **test cable** between the **V (m) Test Port 2** and the remaining **AutoCal V(f)** port.



1. MS4645A or MS4647A VNA with V Test Port Connectors 2. 36585V-2F AutoCal Module 3. AutoCal Power Supply Module	4. AutoCal DB9 (m-m) Control Cable connected between AutoCal Module and VNA rear panel Serial 10101 Port. 5. Test Cable V (m-f)

Figure 2-9. Precision AutoCal 36585V-2F Cable Connections for Internal Through

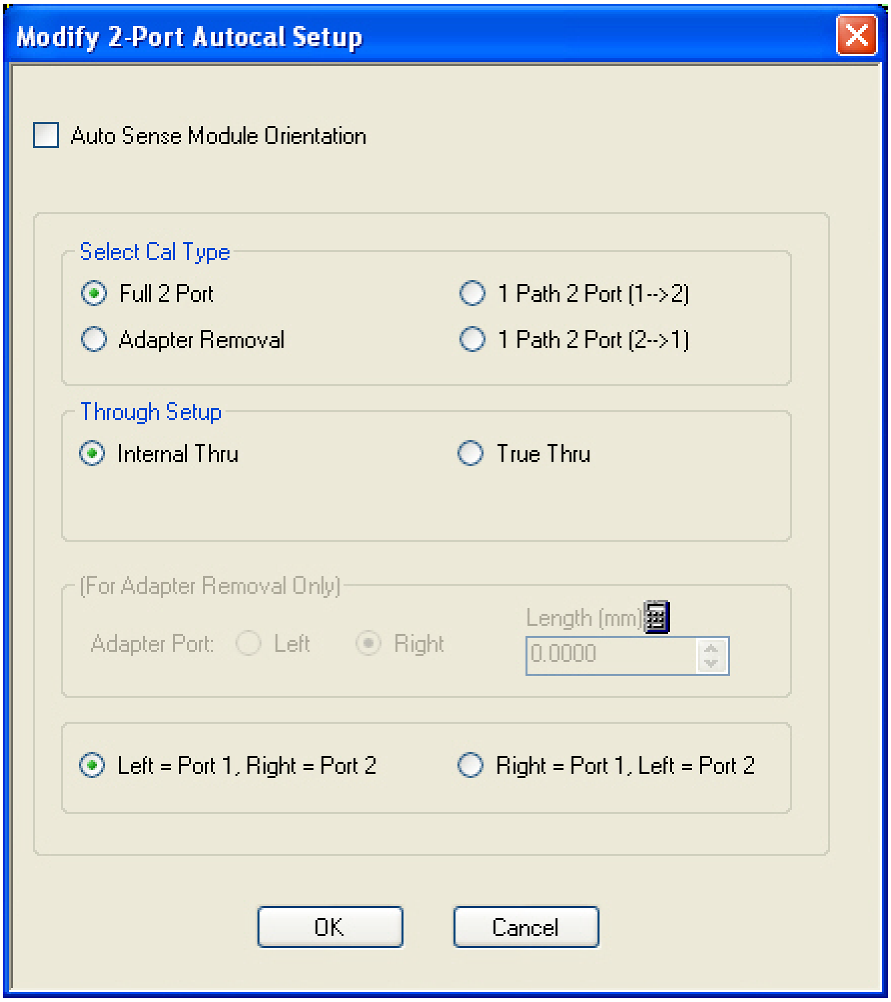
10. Navigate to the AUTOCAL SETUP (2-Port) menu:

- MAIN | Calibration | CALIBRATION | Calibrate | CALIBRATE | AutoCal | AUTOCAL PORTS | 2-Port Cal | AUTOCAL SETUP (2-Port)

11. On the AUTOCAL SETUP (2-Port) menu, if the Port Selection, Cal Type, Thru Type, and Module Orientation display buttons do not show the correct values, click the Modify Cal Setup button.

- The MODIFY AUTOCAL SETUP dialog box appears. The exact name depends on the VNA mode and the user selections for the number of ports. The dialog box can be named:
  - MODIFY 1-PORT AUTOCAL SETUP dialog box
  - MODIFY 2-PORT AUTOCAL SETUP dialog box
  - MODIFY 4-PORT AUTOCAL SETUP dialog box

12. In this example, the required settings are for a Full 2 Port Calibration, with Auto Sense Module Orientation ON, and Internal Through while running on a VNA in 2-Port Mode. The resultant configuration dialog box is names MODIFY 2-PORT AUTOCAL SETUP.



Settings for 2-Port AutoCal Calibration	• Internal Thru (Through)
• Auto Sense Off	• Left = Port 1, Right = Port 2
• Full 2-Port	

Figure 2-10. MODIFY 2-PORT AUTOCAL SETUP Dialog Box

13. On the MODIFY 2-PORT AUTOCAL SETUP dialog box, select the settings:

- **a.** Cal Type Select area: Select the Full Two Port radio button.
- **b.** Thru Select area: Select the Internal Thru radio button.
- **c.** Auto Sense Module Orientation check box selected: Allows the AutoCal module determine left/right cable identification.
- **d.** When the settings are complete, select OK to close the dialog box.

14. The AUTOCAL SETUP (2-Port) menu reappears with new values for Cal Type, Thru Type, and Module Orientation.

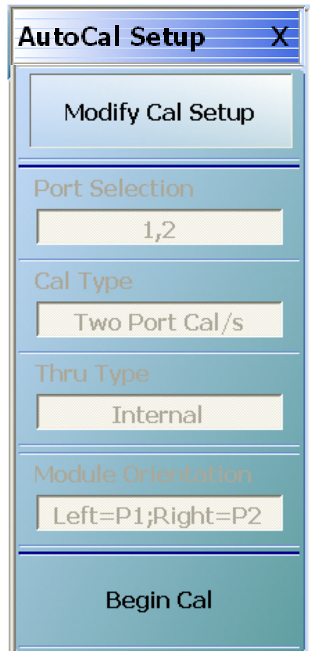
15. The window area at the bottom of the instrument display area appears with general instructions:

- **a.** Ensure correct cable connections to AutoCal module.
- **b.** Ensure that the **Power** and **Operate LEDs** are both illuminated.

c. Ensure characterization file is loaded before starting Cal. To load characterization file, go to the INSTALL (AUTOCAL CHARACTERIZATION) dialog box.

- MAIN | Calibration | CALIBRATION | Cal Kit/AutoCal Characterization | CAL KIT/AUTOCAL | Install Kit/Charc. | INSTALL (AUTOCAL CHARACTERIZATION)

d. Existing system setups such as averaging, power level, etc. will be applied during the cal.

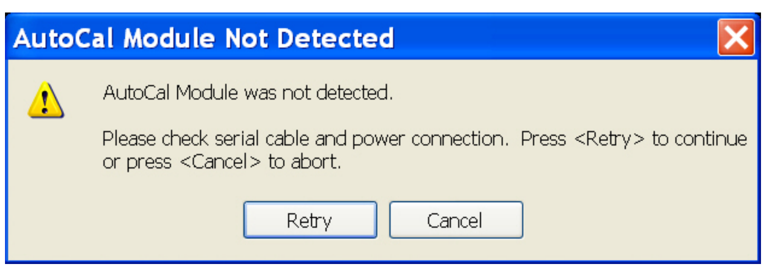


Settings for Port 1 and 2 - Full Two Port - Internal Through - Auto Sense On

Figure 2-11. Configured AUTOCAL 2-Port Menu

16. When ready, click the Begin Cal button.

17. If the AutoCal module is connected incorrectly, the AUTOCAL MODULE NOT DETECTED warning message appears.



- Correct the connections as required and click Retry.

Note	A different dialog box may appear if the RF cables are connected incorrectly (with Autosense on) that states that Autosense was unable to determine the orientation of the module. If this dialog appears, and a large amount of loss is not present between the port and the AutoCal module, check the connections. If a known large amount of loss is present (from the test fixtures or the use of very long cables), the orientation should be manually entered.

18. When the calibration is complete, the Status Message dialog box will close and the display will return to the CALIBRATION menu with the Cal Status button set to ON. The assurance dialog will remain up with the pass/fail message, and must be manually closed.

2-9 AutoCal - Two Port Cal - True Through

This procedure performs an AutoCal procedure using a full two port calibration where a True Through (or external through) is required.

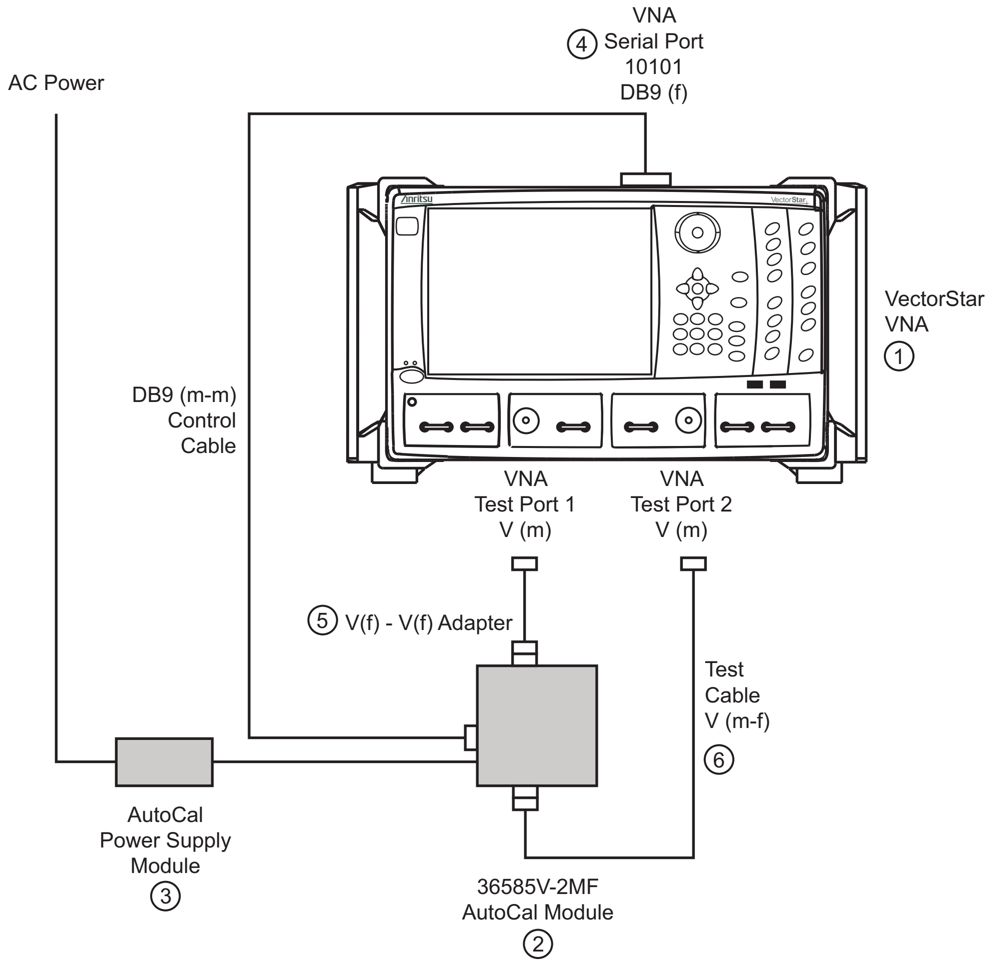
Required Equipment

- VectorStar MS4645A or MS4647A VNAs with V (m) test port connectors, with Option 070 70 kHz Low Frequency Extension.
- 36585V-2MF Precision AutoCal Module, with V (f) and V (m) connectors and required power and control cables. The AutoCal Characterization file has been loaded onto the VectorStar.
- Test port cable with V (f) to V (m) connectors
- Test port cable with V (f) to V (f) connectors, or a V (f)-V (f) adapter.

Procedure

1. Power up the VectorStar.
2. Set the required Frequency Start, Frequency Stop, and Number of Points parameters.
    - "Pre-Calibration Instrument Setup" on page 2-12.
3. If required, set up other parameters as required such as Segmented Sweep, IFBW, Averaging, and Power and Attenuation.
4. Make the necessary cable connections between the **AutoCal Module** and the **VectorStar**:
    a. Connect the **Test Cable V (f) - V (m)** between Test Port 2 V (m) and the AutoCal V (f) port.
    b. Connect the **Test Cable V (f) - V (f)** between Test Port 1 V (m) and the AutoCal V (f) port.
    c. Connect the **Serial Control Cable** between the DB-9 connector on the AutoCal Module and the Serial (10101) Port on the VectorStar back panel.
    d. Connect the **coaxial power plug** on the Power Supply Module to the AutoCal Module and the other end to AC power.

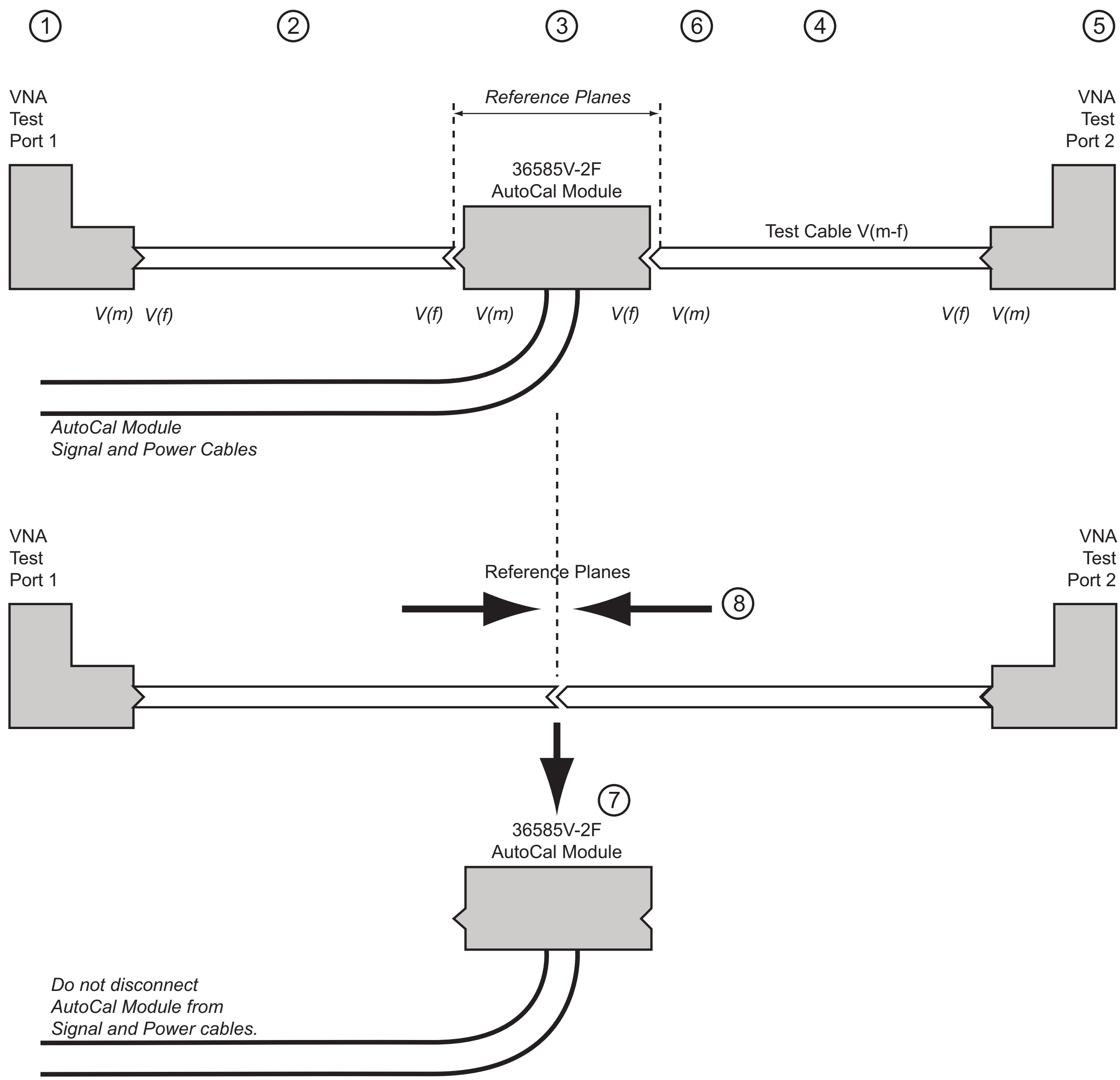
5. Once connected to power, the **Power LED** illuminates as green. When the AutoCal module has warmed up, the **LED** illuminates as blue.



1. VectorStar MS4645A or MS4647A VNA with V Test Port Connectors	4. AutoCal DB9 (m-m) Signal Cable connected to VNA Rear Panel Serial 10101 Port
2. 36585V-2F Precision AutoCal Module	5. V (f-f) Adapter connected to VNA Test Port 1
3. AutoCal Power Supply Module connected to AC Power	6. V (m-f) Test Cable connected to VNA Test Port

Figure 2-12. Precision AutoCal 36585V-2MF Cable Connections for True Through

Schematically, the connections shown in Figure 2-12 above are shown in Figure 2-13.



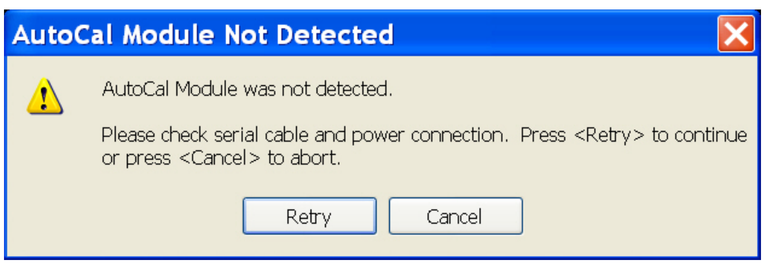
Part 1 – AutoCal True Thru Procedure	**Part 2 – AutoCal True Thru Procedure**
1. VNA Test Port 1 V (m) 2. V(f-f) Test Cable 3. 36585V-2MF AutoCal Module 4. V (m-f) Test Cable 5. VNA Test Port 2 V (m) 6. Resultant reference planes during first AutoCal procedure.	7. After initial calibrations, user is directed to remove AutoCal module and connect test cables. At all times during the calibration procedure, the AutoCal module must be connected to the VNA and to AC power. 8. Connect the two Test Cables together to complete the through calibration.

Figure 2-13. AutoCal True-Through Connections

6. Navigate to the AUTOCAL SETUP menu:
   - MAIN | Calibration | CALIBRATION | Calibrate | CALIBRATE | AutoCal | AUTOCAL PORTS | 2-Port Cal | AUTOCAL SETUP
7. On the AUTOCAL SETUP menu, if the Cal Type, Thru Type, and Module Orientation display buttons do not show the correct values, select the Modify Cal Setup button.
   a. The MODIFY 2-PORT AUTOCAL SETUP dialog box appears.
   b. Change the settings as required.
   c. In the Cal Type Select area: Select the Full Two Port radio button.
   d. In the Thru Select area, select the True Thru radio button and the THRU INFO dialog box appears.
   e. Enter information about the through line. Enter 0 length and 0 dB/mm loss (and a reference frequency of 0, which forces it to use that loss at all frequencies) and 50 ohm impedance. Select OK to close the dialog box.
   - Select the Auto Sense Module Orientation check box which allows the AutoCal module determine the left/right cable identification.
   - Click OK to close the dialog box.

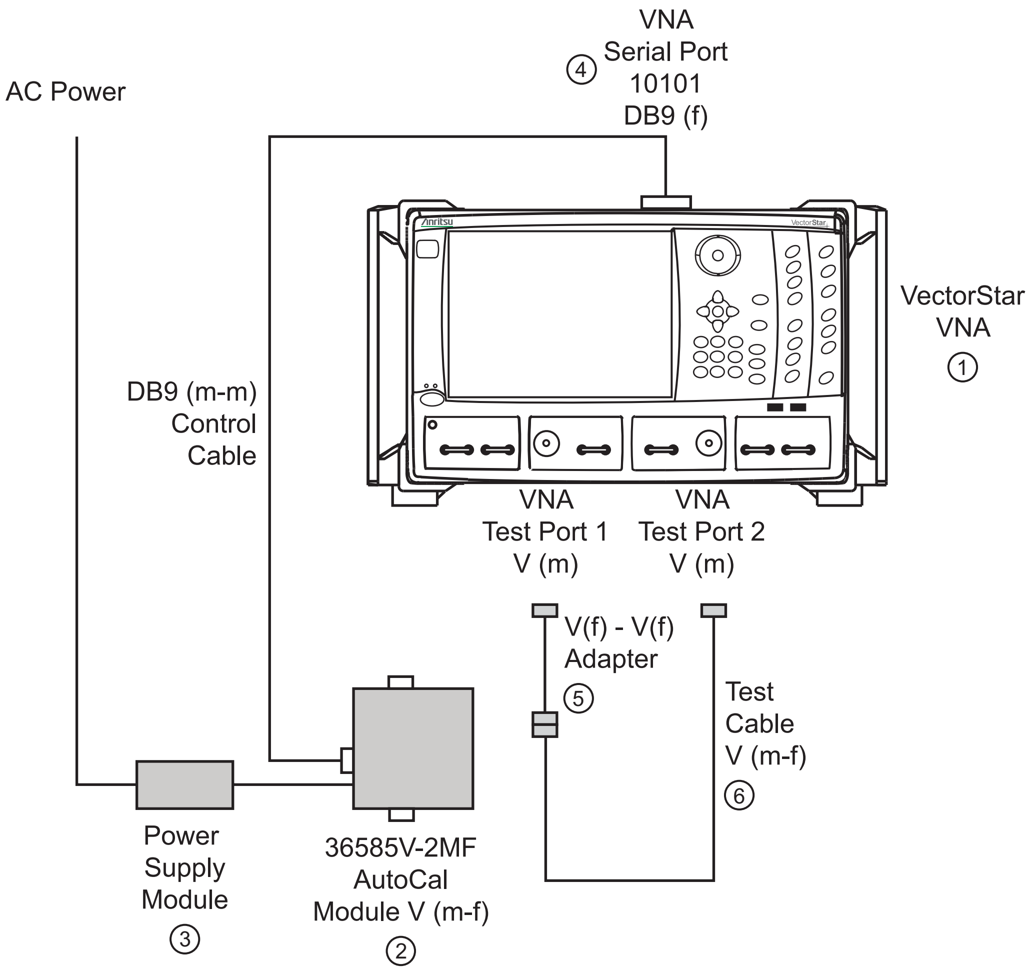
Note	All existing system setups such as IF Bandwidth, Averaging, and Power Level will be applied during the calibration procedure.

8. When ready, click the Begin Cal button.
9. If the AutoCal module is connected incorrectly, the AUTOCAL MODULE NOT DETECTED warning message appears.



   - Correct connections as required and click Retry.
10. A status dialog box with a progress bar appears after an AutoCal sequence has started. The status messages define has far the program has progressed and if any user actions are required.
11. At any time, the AutoCal sequence can be cancelled by clicking the dialog box Abort button.
12. A dialog box will appear when the true through is to be connected.

13. Connect the **Test Port 1 test cable** to the **Test Port 2 test cable**.



1. MS4645A or MS4647A VNA with V Test Port Connectors	4. AutoCal DB9 (m-m) Signal Cable connected to VNA Rear Panel Serial 10101 Port
2. 36585V-2MF AutoCal Module	5. V (f) to V (f) Adapter connected to Test Port 1 V (m)
3. AutoCal Module Power Supply connected to AC Power. AutoCal module and connect test cables. At all times during the calibration procedure, the AutoCal module must be connected to the VNA and to AC power.	6. V (m-f) Test Cable connected to V (f-f) adapter and Test Port 2 V (m)

Figure 2-14. AutoCal True-Through Connections - Module Removed

14. After connecting the through, select Continue.

15. When the auto calibration is complete, a status message appears with a statement about assurance passing or failing. On the CALIBRATION menu, the Cal Status field button shows ON.

16. Closing the dialog box returns to the CALIBRATION menu.

2-10 AutoCal Module Characterization

Characterization

Typically, characterization is performed by Anritsu since the process can be very carefully controlled for maximum accuracy. In certain cases, the customer may wish to perform the characterization themselves but it is important to note that all specifications for the calibration are void and the customer takes responsibility for performing a characterization of adequate quality. With that caveat, the process for performing a characterization is as follows:

1. Setup the instrument for the frequency range, point count, power level, and IFBW desired. It is particularly important to use as many points as reasonable in order to reduce interpolation needs.
2. Perform as high a quality manual calibration as possible at the reference planes that will be connected to the AutoCal module. LRL/LRM is recommended if possible.
3. Connect the AutoCal module to the reference planes, apply power, and connect the control cable to both the AutoCal module and to the MS4640A Series VNA. Allow the AutoCal module to reach operating temperature so the blue **Operate LED** illuminates.
4. Select the AUTOCAL CHARAC. menu (shown below) to start characterization. The VNA will automatically switch the unit through its various states and characterize them. Alternatively, the connected test port order may be specified and may be necessary if there is substantial loss in the test setup (note that this may indicate an accuracy hazard).
   - MAIN | System | SYSTEM | Utility | UTILITY | AutoCal Characterization | AUTOCAL CHARAC.
5. Save the characterization file as appropriate. Note that the characterization file will be tied by serial number to the particular AutoCal module that was characterized.

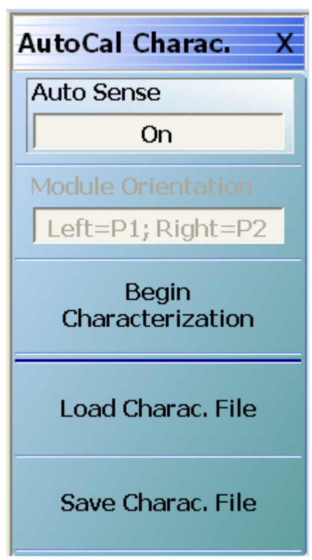


Figure 2-15. AUTOCAL CHARAC. (AUTOCAL CHARACTERIZATION) Menu

2-11 Working with Older AutoCal Modules

Auto Calibration Units 36581x and 36582x

Older Anritsu auto calibration units are supported by the MS4640A Series VNAs but with somewhat lower performance and different functionality. Fewer reflection states are available in these older models so an over-determined algorithm is not employed and a different characterization process is typically employed; both of which result in lower accuracy (see data sheets for quantities). These differences are practically less significant at 20 GHz and below where one may use the 36581X; they may be more significant at higher frequencies. The 36582X is an electromechanical switch-based unit unlike the other modules so it may suffer from additional degradation due to switch repeatability.

The characterization load process is similar. It may be required to transfer the characterization file from a floppy to a USB stick for transfer to the VNA (or transfer by network or GPIB).

A maximum of 1601 characterization points are possible on the older platforms so interpolation errors may be higher. These AutoCal units may be re-characterized with the MS4640A Series VNA to increase point count with the caveats discussed in "AutoCal Module Characterization" on page 2-25.

Autosensing of the AutoCal orientation is not possible. The current orientation must be entered correctly or large errors will result.

Adjustable switch averaging is no longer supported. A factory recommended level will automatically be invoked for electromechanical units.

2-12 Adapter Removal - M-M or F-F Reference Plane with a M-F AutoCal

Adapter Removal Overview

Adapter removal for AutoCal modules primarily refers to the case of connector gender incompatibility when it is not desired to use test port converters such as when the user has a M-F AutoCal module and M-M reference planes are required. A separate menu item is provided for AutoCal adapter removal to speed up the process since fewer manual steps are needed. In this calibration sequence, one uses an adapter (that can mate the desired reference plane connectors) as port of the calibration. Two possible scenarios are covered; both use a pair of calibration sequences to remove the effects of the adapter. In both of the cases below, it is assumed all connectors are from the same family. If not (e.g., one is using a special inter-series AutoCal unit), then this AutoCal-specific adapter removal technique may not be applied; see the standard adapter removal section.

This procedure performs an AutoCal procedure when an adapter is required to accommodate either the AutoCal unit or the DUT connector genders and a M-M reference plane is required.

Required Equipment

- **VNA**

  MS4642A or MS4644AA VNA MS4632A, MS4633A, MS46434A, MS4642A, or MS4644A VNAs with K Test Port Connectors
- **AutoCal Module**

  Precision AutoCal Module, 36585K-2MF, with K (f-m) connectors. Includes the necessary Power Supply Module with cords to AutoCal Module and to AC power
- **Test Cable**

  A test port cable with K (m-f) connectors
- **K (f-f) Adapter**

  A Matched K Adapter, 36583K with K (f-f) connectors.

Prerequisites

The following prerequisite procedures have already been accomplished:

- AutoCal Characterization file previously loaded.
- VectorStar powered up.
- Required settings for Frequency Start, Frequency Stop, Number of Points, and CW Mode configured.
- Optional settings as required for Segmented Sweep, IF Bandwidth, Averaging, and Port Power configured.

Procedure

1. Make the necessary cable connections between the AutoCal Module, its Power Module, AC power, and the VectorStar back panel.
   - When the blue **Operate LED** is illuminated, the module has warmed up and is ready for calibration operations.
2. Connect the **36583K (f-f) Adapter** to the **AutoCal K (m) connector**.
   - Consider the Adapter and AutoCal module as an “assembly” for the duration the AutoCal procedure.

Note	Once assembled, do not break the connection between the adapter and the AutoCal module, do not disconnect the assembly from the **VNA Serial 10101 Port**, and do not disconnect the assembly from AC power. If the connection between the adapter is broken before the AutoCal procedure is completed, the entire calibration is invalidated and must be repeated.

3. Connect the remaining **36583K (f) connector** to the VectorStar **Test Port 1 K (m) connector**.

4. Connect the **Test Cable K (f) connector** to the VectorStar **Test Port 2 K (m) connector**.

5. Connect the **Test Cable K (m) connector** to the **AutoCal Module K (f) connector**.

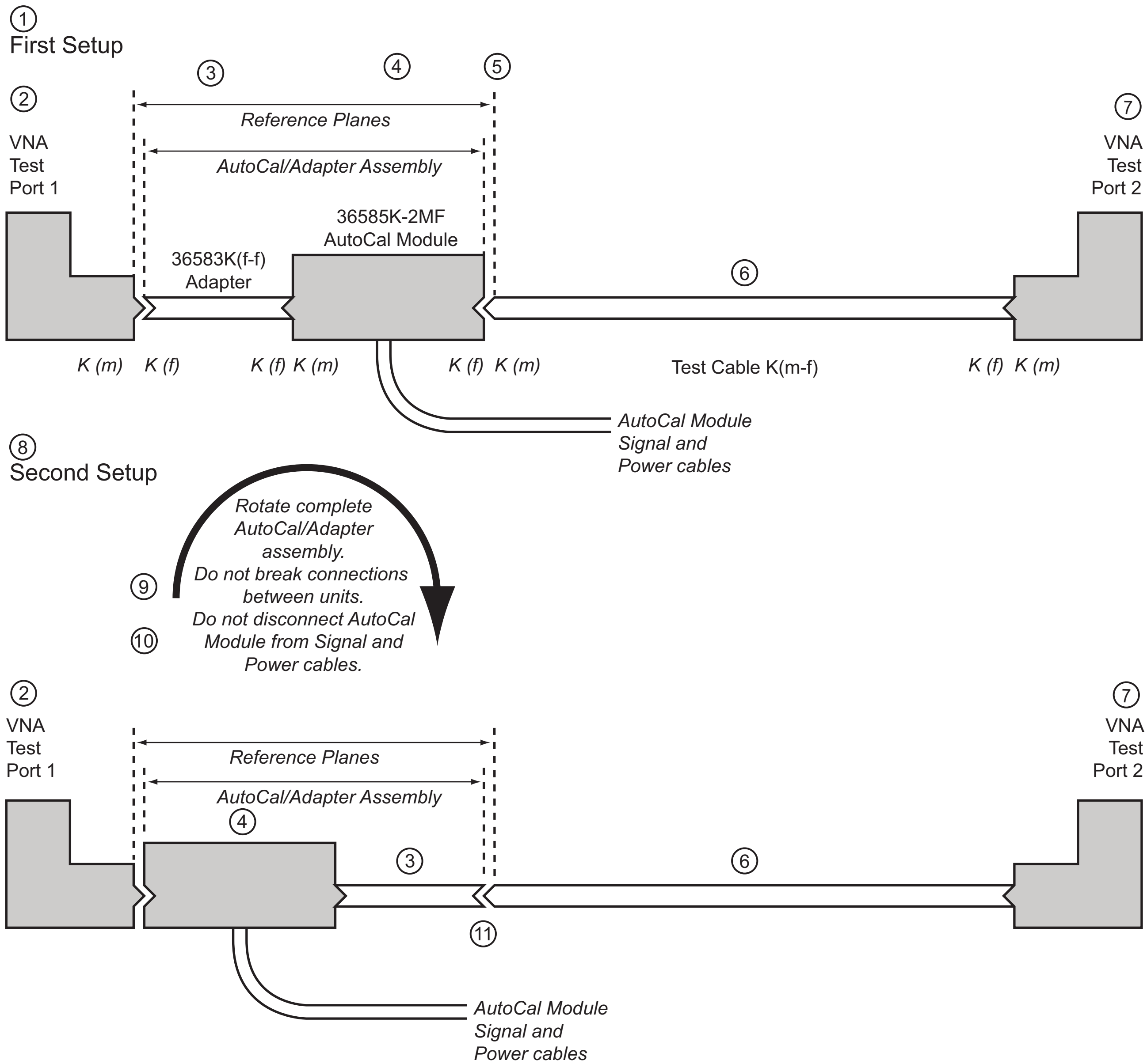


Figure 2-16. Precision MF AutoCal 36585K-2MF, Adapter Removal, Internal Thru (1 of 2)

Part 1 – AutoCal Adapter Removal Procedure	Part 2 – AutoCal Adapter Removal Procedure
1. First setup for the Adapter Removal procedure. 2. VNA Test Port 1 3. 36583K (f-f) Adapter 4. 36585K-2MF AutoCal Module – For the duration of the calibration, the K (f-f) Adapter and the AutoCal Module must be connected as an assembly. Do not disassemble or disconnect from its Power and Signal cables. 5. Resultant calibration reference planes. 6. K (m-f) Test Cable 7. VNA Test Port 2	8. Second setup for the Adapter Removal procedure. 9. After the first calibration, rotate the complete assembly so that the AutoCal K (f) connector is connected to VNA Test Port 1. Do not disconnect the Adapter from the AutoCal module. 10. Do not disconnect the AutoCal Module from its Power or Signal cables. 11. Connect the 36583 K (f-f) adapter to the Test Cable K (m-f). The reference planes remain in place. The user is guided through the remaining steps of the procedure.

Figure 2-16. Precision MF AutoCal 36585K-2MF, Adapter Removal, Internal Thru (2 of 2)

6. Navigate to the AUTOCAL SETUP menu.
   - MAIN | Calibration | CALIBRATION | Calibrate | CALIBRATE | AutoCal | AUTOCAL PORTS | 2-Port Cal | AUTOCAL SETUP
7. If the Cal Type, Thru Type, and Module Orientation display buttons do not show the correct values, select the Modify Cal Setup button.
   - The Modify AutoCal Setup dialog box appears.
8. Make the following changes to the Modify AutoCal Setup dialog box settings:
   a. Select the Auto Sense Module Orientation check box which allows the AutoCal module determine the left/right cable identification.
   b. In the Select Cal Type area, select the Adapter Removal radio button. The For Adapter Removal Only area becomes available.
   c. In the Through Setup area, select the Internal Thru radio button and Adapter Removal.
   d. In the For Adapter Removal Only area, enter the estimate of electrical length (in mm) and select which AutoCal port the adapter is attached to.
   e. Select OK to close the dialog box. The AUTOCAL SETUP menu reappears with new values for Cal Type, Thru Type, and Module Orientation.

Note	All existing system setups such as IF Bandwidth, Averaging, and Power Level will be applied during the calibration procedure.

9. When ready, click the Begin Cal button.
10. If the AutoCal module is connected incorrectly, the AutoCal Module Not Detected warning message appears. Correct connections as required and click Retry.
11. A status dialog box with a progress bar appears after an AutoCal sequence has started. The status messages define has far the program has progressed and if any user actions are required.
12. At any time, the AutoCal sequence can be cancelled by clicking the dialog box Abort button.
    - When the first AutoCal process is complete, the user is prompted to reverse the Adapter/AutoCal assembly.

Note	Once assembled, do not break the connection between the adapter and the AutoCal module. If the connection between the adapter is broken before the AutoCal procedure is completed, the entire calibration is invalidated and must be repeated.

13. The instrument will prompt the user to reverse the module-adapter assembly.
14. As shown above in Figure 2-16, "Precision MF AutoCal 36585K-2MF, Adapter Removal, Internal Thru" on page 2-28 above, disconnect the **Adapter** from **Test Port 1** and the **AutoCal Module** from the **Test Cable** on Test Port 2.
15. Reverse the **Adapter/AutoCal Module assembly** so that the Adapter end is pointing towards Test Port 2.
16. On the AutoCal module, connect the free **AutoCal Module K (f) connector** to Test Port 1 K (m).
17. On the Adapter, connect the free **Adapter K (f) connector** to the Test Cable connected to Test Port 2.
18. When the auto calibration is complete, a status message appears with a statement about assurance passing or failing. Closing the dialog will return to the regular menu system. On the CALIBRATION menu, the Cal Status field button shows ON.

Chapter 3 — SOLT/SOLR Calibration

3-1 SOLT/SOLR Introduction

This chapter describes calibration procedures using the SOLT/SOLR calibration algorithms. One of the more common calibration algorithms is based on Short-Open-Load-Thru. This is a defined-standards calibration meaning the behavior of all of the components is specified in advance via data or models. Since the behaviors of all standards are known, by measuring them with the VNA we can define all of the error terms. The load behavior largely sets the directivity terms, the short and open together largely determine source match and reflection tracking and the thru largely determines transmission tracking and load match.

3-2 Definitions

Shorts

Shorts can be defined by a model consisting of a transmission line length and a frequency dependent inductance.

Opens

Opens can be defined by a model consisting of a transmission line length and a frequency dependent capacitance.

Loads

Loads can be defined by a model consisting of a transmission line length, a shunt capacitance, a resistance and a series inductance.

Note that a sliding load can be used in lieu of a fixed load. The sliding load is based on a sliding termination embedded in an airline and the transmission line properties of that airline are used to deduce a more nearly perfect synthetic load. Because of the transmission line dependence, a fixed load is also needed at low frequencies (below 4 GHz for V connectors (shorter sliding load) and below 2 GHz for others).

Thru

Modeled as a transmission line length with some frequency dependent loss. A root-f frequency dependence of that loss is assumed.

Reciprocal

The thru can sometimes be replaced by a unknown but reciprocal network (like an adapter or a fixture) when an actual thru connection is not practical. The accuracy will be somewhat less than if an actual thru could have been used but will be better than assuming a poor thru is a good one.

3-3 Setup

The coaxial setup dialog for SOLT (and SOLR), full 2-Port calibration is shown in below.

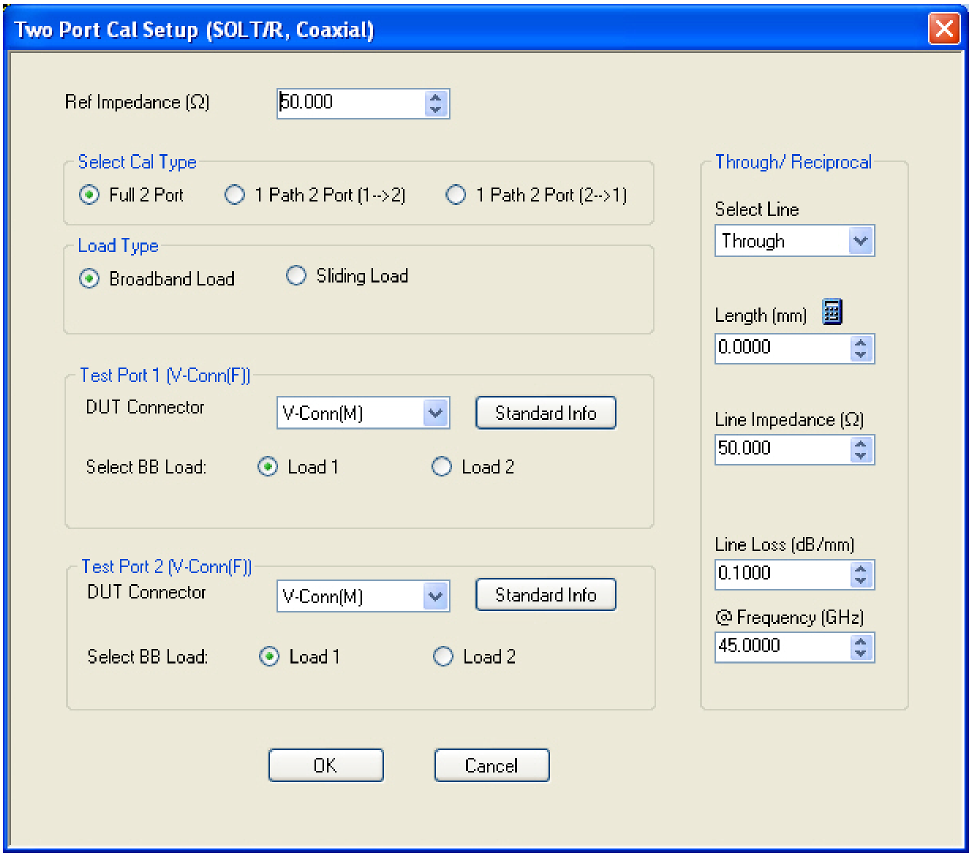


Figure 3-1. TWO PORT CAL SETUP (SOLT/R, COAXIAL) Dialog Box

In the coaxial setup dialog, the connector types for both ports are selected as well as the through details and the type of load to be used. For one port calibrations, only one of the port definitions (unless reflection-only calibrations are being performed for both ports 1 and 2) will be present. For a 1 path-2 port cal, one of the Test Port definition sections will not be shown.

The setup dialog above is for coaxial and non-dispersive line types. For waveguide and microstrip, a few things change:

- Fewer cal kits are factory-defined and more are user-defined
- The media must be part of the definition (cutoff frequency and dielectric constant for waveguide; line width, substrate height, and substrate dielectric constant for microstrip)
- SOLT is not recommended for waveguide due to the difficulty in modeling and open standard

A waveguide SOLT setup is shown in Figure 3-2 and a setup for microstrip is shown in Figure 3-3.

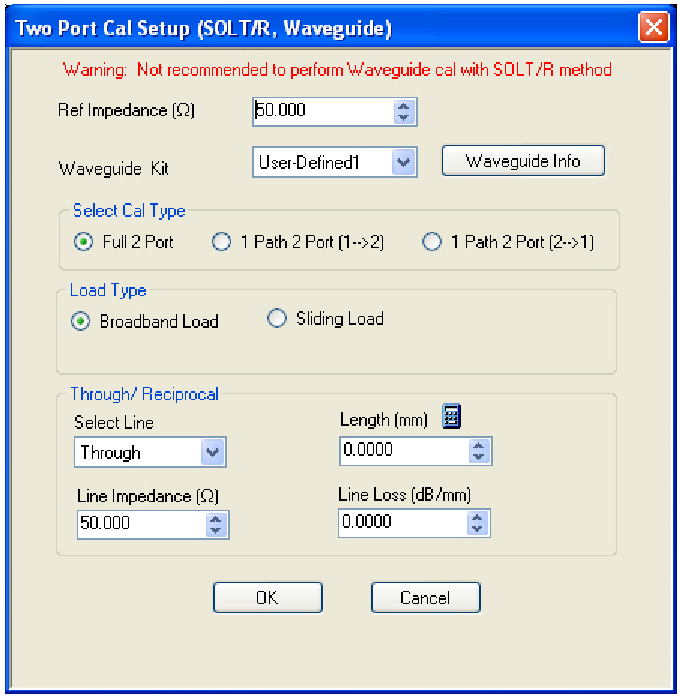


Figure 3-2. TWO PORT CAL SETUP (SOLT/R, WAVEGUIDE) Dialog Box

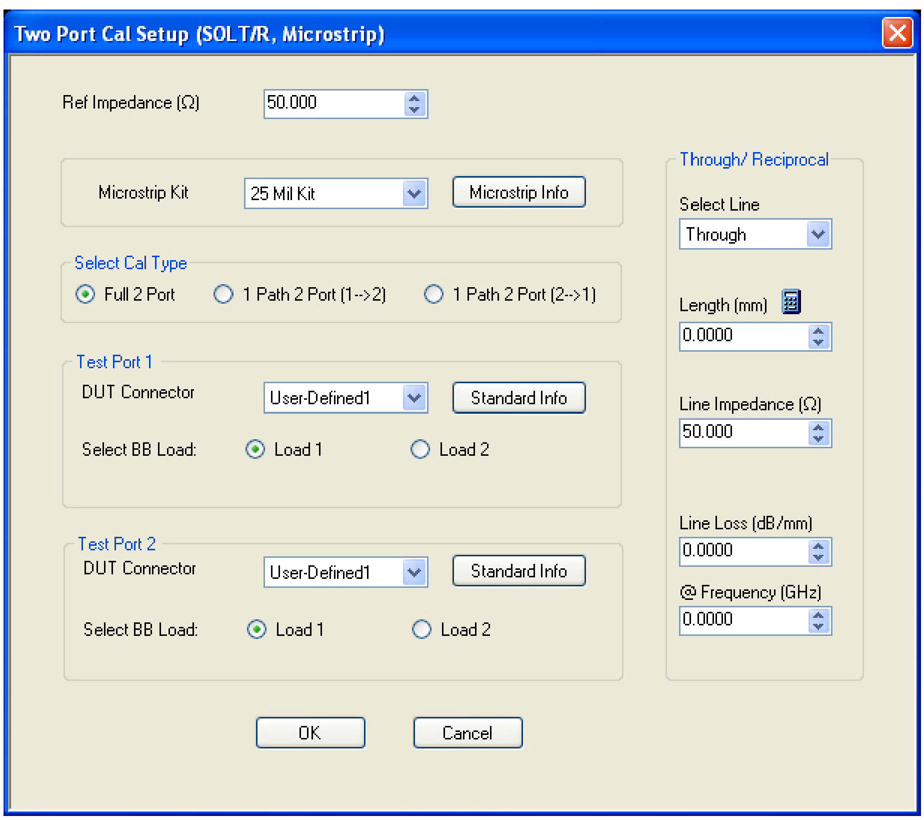


Figure 3-3. TWO PORT CAL SETUP (SOLT/R, MICROSTRIP) Dialog Box

The standards information dialog for SOLT (and SOLR) is shown in Figure 3-4, using a V-connector as an example.

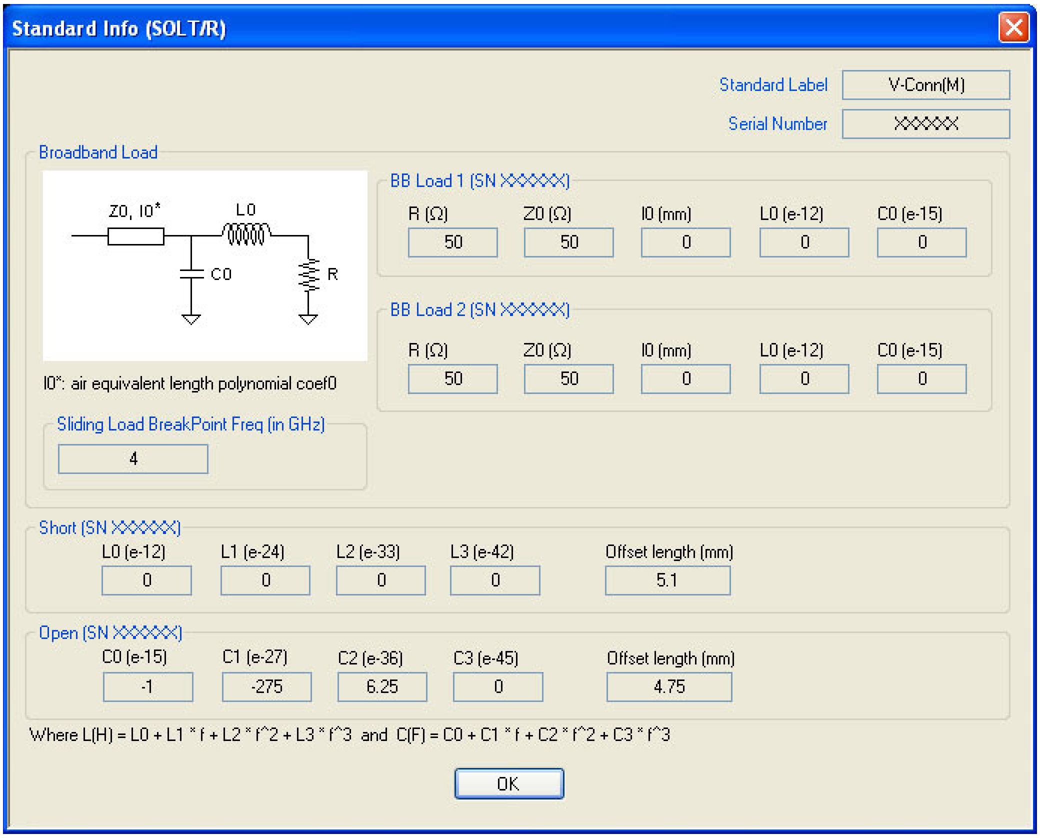


Figure 3-4. STANDARD INFO (SOLT/R) - V-Connectors (M)

For cal kits loaded from Anritsu cal kit files, the model terms are not editable. When using user-defined cal kits, the model terms can be edited.

The standards information for microstrip does not change but the microstrip media information must be either user-defined (Figure 3-5) or selected from an Anritsu microstrip cal kit (Figure 3-6, typically used with Anritsu Universal Test Fixtures).

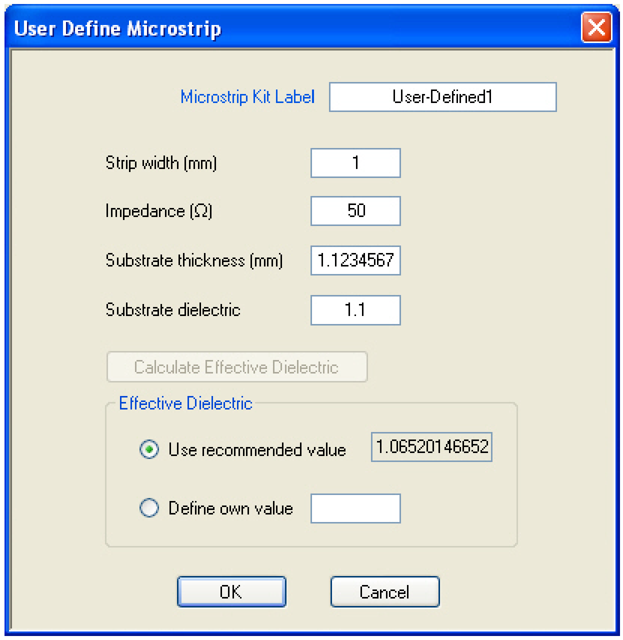
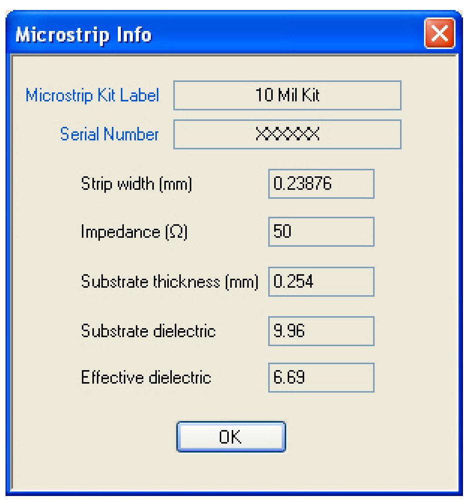


Figure 3-5. USER-DEFINED MICROSTRIP Data Input Dialog Box

Effective dielectric constants can be entered, or the recommended value can be selected.



Typical values for an Anritsu-defined 10 Mil Microstrip Kit

Figure 3-6. MICROSTRIP INFO 10 Mil Kit Dialog Box

For waveguide, the model parameters and the media parameters are combined in one dialog (Figure 3-7).

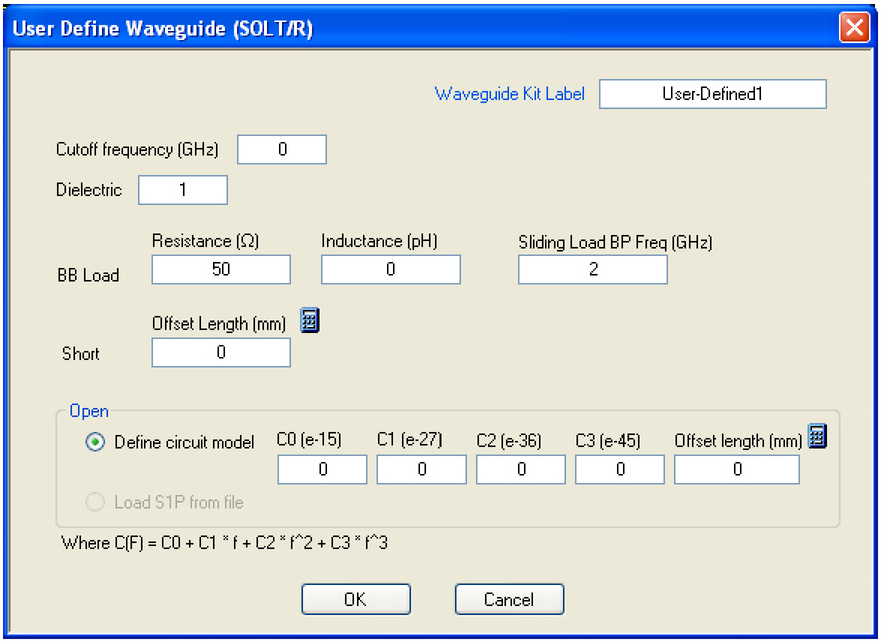


Figure 3-7. USER-DEFINED WAVEGUIDE (SOLT/R) Information Dialog Box

Note	Reciprocal measurements (SOLR vs. SOLT) are covered in more detail in Chapter 15, "Reciprocal Measurements".

3-4 SOLT/SOLR Calibration

The following example presumes an MS4647A (70 GHz unit) with V connectors. A different connector can be selected in step 4 if a different model/configuration is being used. It is assumed that a M-F cable is connected to port 2 so that a M (port 1) and F (port 2) reference plane pair is available. In this example, a full 2 port SOLT calibration will be performed although a number of other options are discussed along the way. The implications of these options are discussed in the calibration overview section.

1. Setup the desired frequency range (Frequency menu), power (Power menu) and IFBW/averaging (Averaging menu). As a default, the IFBW will be 1 kHz and the averaging will be off which is adequate for many applications. The default power level will vary depending on instrument model and options but will often be adequate for all passive and many active device measurements.
2. Navigate to the TWO PORT CAL menu.
   - MAIN | Calibration | CALIBRATION | Calibrate | CALIBRATE | Manual Cal | MANUAL CAL | 2-Port Cal | TWO PORT CAL

Note	If a previous calibration exists, the Thru Update button will be active. See “Through (Thru) Update” on page 9-1 for more information.

3. Select Modify Cal Setup. The CAL SETUP menu appears. On this level, select a cal method of SOLT/SOLR and a line type of Coaxial.
4. Select Edit Cal Params; the TWO PORT CAL SETUP (SOLT/R, COAXIAL) dialog box appears which describes the calibration components:
   a. Reference impedance defaults to 50 ohms and can be left there commonly. This value is used for referencing the standards reflection coefficients and for reference plane shift and Smith chart calculations. The latter two items can be handled later using a per-trace definition of reference impedance. The standards definition process is not affected by that later per-trace reference impedance change.
   b. In the Load Type area, select broadband load. A sliding load can be used for better performance if one is available in the calibration kit. If low frequencies are included in the frequency range (< 4 GHz for V, < 2 GHz for K or GPC3.5), then a broadband load will be used in addition to the sliding load.
   c. In the Through/Reciprocal area, a zero-length (or mating) thru will be used. Set the Select Line field to Through, 0 mm for the length and 0 dB/mm loss. Zero can also be entered for the reference frequency. When 0 is entered for this value, no loss scaling is employed and the entered loss value is used for all frequencies. If a reciprocal network was being used instead of a through, use Reciprocal for the Select Line field and the length entered would serve as an estimate for root choice purposes.
   d. For **Port 1**, select a DUT connector of V (f). Note the dialog will then indicate that port connector is V (m).
   e. For Port 2, select a DUT connector of V (f). The dialog will indicate a port connector of V (f).
   f. For both ports, select a BB load of Load 1. This selection is for certain firmware/cal kit versions where modeled loads are available and the distinction between loads is important.
   g. Select OK to close the dialog. Select Back at the bottom of the menu to return to the previous level and the TWO PORT CAL menu where two Reflective Devices buttons appear with six reflection standards on the two submenus.

Note	The menu calibration steps can be performed in any order. For these example, a top to bottom menu approach is assumed

5. Select Port 1 Reflective Devices and the REFL. DEVICES PORT 1 menu. On the menu, measure the three reflection standards of Open, Short, and Load. Connect each standard in turn, and THEN, click the corresponding button. When all are done, click the Back button to return to the TWO PORT CAL menu.
6. Then select Port 2 Reflective Devices and the REFL. DEVICES PORT 2 menu where next three reflection standards are listed. When all six are done (and six check marks appear), click Done to return to the previous level and the TWO PORT CAL menu.
7. After measuring all six reflection standards, connect the cable to **Port 1** to complete the zero length through. Now click on the Thru/Recip button where a check mark should appear after the sweep pair. Note that the displayed graphs may change during this step as the instrument must measure all four S-parameters of the thru line.
8. An optional isolation step using the Isolation (Optional) button and the linked ISOLATION menu is available but is generally not recommended. If desired, terminate **Port 1** and the end of the cable attached to **Port 2** before clicking on the Isolation (Optional) button if needed.
9. Click on Done. The calibration is now completed and turned on where the Cal Status button on the CALIBRATION menu is set to ON.

Chapter 4 — Offset Short (SSLT) Calibration

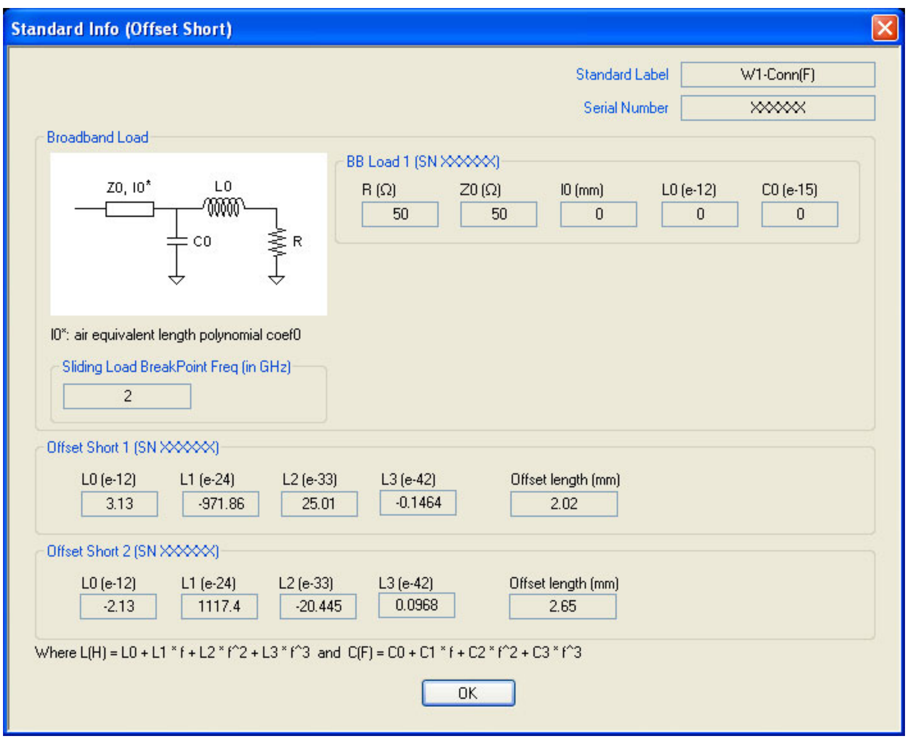
4-1 SSLT Introduction

This chapter describes calibration methods and procedures using the SSLT calibration algorithm.

The SSLT calibration differs from an SOLT calibration by the differing offset lengths between two shorts which are used to help define reflection behavior instead of an open and short. Because of this, the frequency range is limited since, at DC and at higher frequencies, these reflect standards will look the same. This method is most commonly used for waveguide problems where creating a stable, high reflection open standard is difficult, but there are certain coax and board-level or wafer-level situations where it is useful. The modeling constructs are about the same as for an SOLT calibration. From an error term perspective, the only difference is that the two shorts together now largely determine source match and reflection tracking behavior.

The electrical length difference between the shorts should be between 20 and 160 degrees over the frequency range of interest.

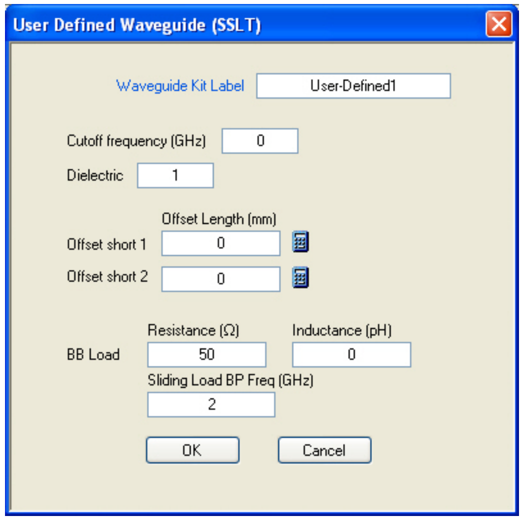
The top calibration kit definition dialog box for SSLT calibration is identical to the SOLT dialog (Figure 3-1, “TWO PORT CAL SETUP (SOLT/R, COAXIAL) Dialog Box” on page 3-2). The standards information dialog box is different and is shown below.



Typical parameters for Offset Short Calibrations

Figure 4-1. STANDARD INFO (OFFSET SHORT) Information Dialog Box

Variations for other line types (waveguide or microstrip) are similar to those for SOLT. For waveguide, the media and standards information are combined as shown in Figure 4-2. Defined, un-editable values would be present for Anritsu-defined cal kits.



Typical parameters for an Offset Short Calibration

Figure 4-2. Waveguide Media and Standards Information

A simplified short model is used for waveguide, with only an offset length and no inductance terms since usually those terms are small.

4-2 SSLT Calibration Example

The following example presumes a MS4640A Series VNA is being used with waveguide adapters (since SSLT is commonly used with waveguide). WR-10 is the waveguide size used in the example which presumes the use of mm-Wave extensions, but other waveguide kits can be used. In this example, a full 2-Port SSLT calibration is performed although a number of other options are available. The implications of these options are discussed in the calibration overview section.

Set the desired frequency range (Frequency menu), power (Power menu) and IFBW/Averaging (Averaging menu). The default power level varies depending on the instrument model and options, but will often be adequate for all passive and many active device measurements. The default IFBW is 1 kHz with averaging off, which is adequate for many applications.

1. Navigate to the TWO PORT CAL menu.
   - MAIN | Calibration | CALIBRATION | Calibrate | CALIBRATE | Manual Cal | MANUAL CAL | 2-Port Cal | TWO PORT CAL

Note	If a previous calibration exists, the Thru Update button will be active. See "Through (Thru) Update" on page 9-1 for more information.

2. Select Modify Cal Setup, then on the CAL SETUP menu, select a Cal Method of SSLT and a Line Type of Waveguide.

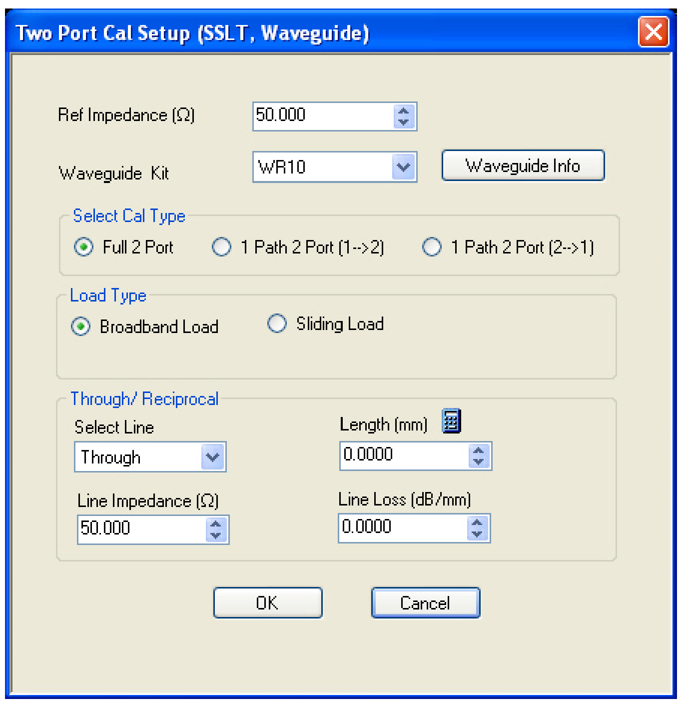


Figure 4-3. TWO PORT CAL SETUP (SSLT, WAVEGUIDE) Dialog Box

3. Select Edit Cal Params which will displays the TWO PORT CAL SETUP (SSLT, WAVEGUIDE) dialog box describing the calibration components (shown above).
   a. Reference impedance defaults to 50 ohms. Although this does not represent the waveguide impedance, it is commonly used for conventional Smith chart referencing. Reference impedance can be changed here for certain waveguide applications or it can be changed later on a per trace basis from the DISPLAY menu.
   b. Select Broadband Load. A sliding load can be used for better performance if one is available in the calibration kit. If low frequencies are included in the frequency range (< 2 GHz), then a broadband load will be used in addition to the sliding load.

c. A zero-length (or mating) thru will be used so enter Through for the line, 0 mm for the length and 0 dB/mm loss. Zero can be entered for the reference frequency when no loss scaling is employed and the entered loss value is used for all frequencies. If a reciprocal network was being used instead of a through, the line selection would be Reciprocal and the length entered would serve as an estimate for root choice purposes.

d. For a waveguide kit, select WR10 (for this example). A user-defined kit can be selected from the pull-down menu, but the cutoff frequency, the dielectric, the short offset lengths, and the load impedance (relative to the reference impedance) will have to be specified.

e. Select OK to close the dialog, then select BACK at the bottom of the menu to return to the previous level and the TWO PORT CAL menu.

4. The Port 1 Reflective Devices and the Port 2 Reflective Devices buttons display the REFL. DEVICES PORT 1 and PORT 2 menus. The six reflection standards to be measured (Short 1, Short 2, Load on each menu) will be displayed here along with the read-only fields showing the port connector choices. Connect each standard in turn, and THEN, click the corresponding button. When all six are done (and six check marks appear), click Done to return to the previous level and the TWO PORT CAL menu.

5. After measuring all six reflection standards, connect the test cable to **Port 1** to complete the zero length through. Click on the Thru/Recip button to display the THRU/RECIP menu where a check mark should appear after the sweep pair. Note that the displayed graphs change during this step as the instrument must measure all four S-parameters of the through line.

6. An optional isolation step is available but is not recommended. If desired, terminate **Port 1** and the end of the cable attached to **Port 2** before clicking on the Isolation (Optional) button and displaying the ISOLATIONS menu.

7. When all steps are successfully completed, the Done button is available where select returns to the CALIBRATION menu where the Cal Status button is set to ON.

8. The calibration is now completed and turned on.

Note	Much like SOLT/SOLR, there is another version of SSLT using a reciprocal in place of a thru called SSLR. Reciprocal measurements (SOLR vs. SOLT) are covered in more detail in Chapter 15, “Reciprocal Measurements”.

Chapter 5 — Triple Offset Short (SSST) Calibration

5-1 SSST Introduction

This chapter describes calibration using the triple offset short (SSST) algorithm. The next step in this progression is to remove the load so that the entire reflection space is defined by three shorts of varying offset lengths. The individual short definitions are the same as for an SOLT calibration.

5-2 SSST and Reflectivity Error Terms

With an SSST calibration the three shorts together determine all of the reflectivities error terms (directivity, source match and reflection tracking). This calibration is more band-limited than the double offset short method. If short1 is defined as having the smallest offset length, and short3 to the longest offset length, then two variables can be defined:

$$\begin{aligned} A &= L_{offset\_short2} - L_{offset\_short1} \\ B &= L_{offset\_short3} - L_{offset\_short2} \end{aligned}$$

(Eq. 5-1)

The electrical length equivalents of A and B should generally be between 20 and 85 degrees over the frequency range of interest. This is not sufficient in itself since one will also require that A+B (which represents the difference between short1 and short3) also be constrained:

$$20 < \frac{720 \cdot f \cdot A}{v_{ph}} < 90$$

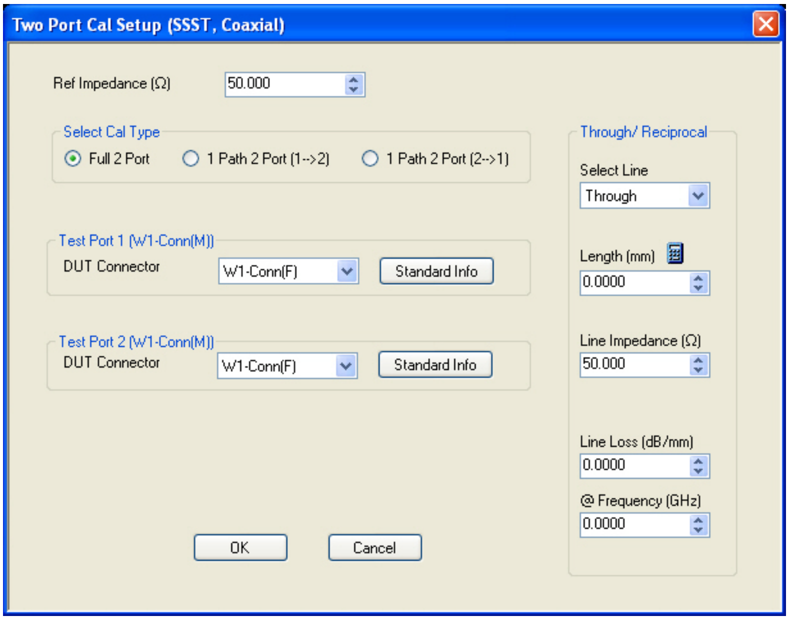
$$20 < \frac{720 \cdot f \cdot A}{v_{ph}} < 90$$

$$20 < \frac{720 \cdot f \cdot (A + B)}{v_{ph}} < 160$$

(Eq. 5-2)

Since the only standards needed are shorts, this method is attractive for mm-Wave applications and for certain board-level and wafer-level calibrations where other types of standards are difficult to manufacture.

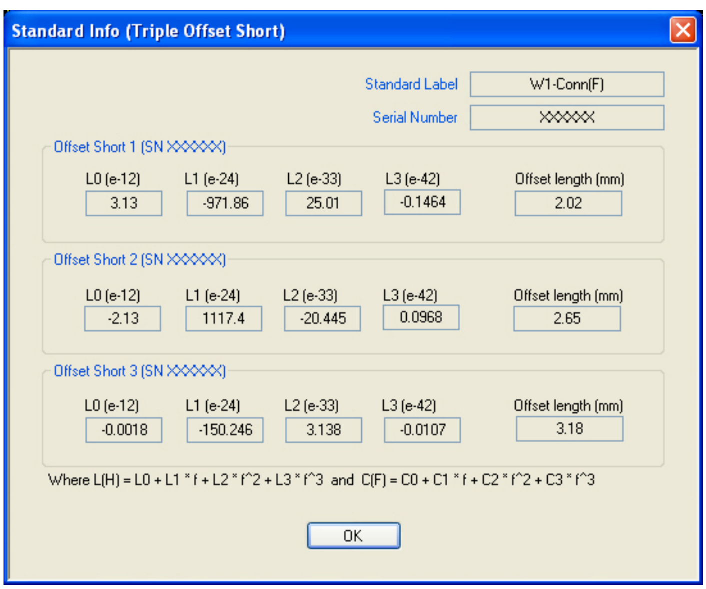
The setup and standards information dialogs for SSST are shown in Figure 5-1 and Figure 5-2 for a 2-Port calibration.



Typical parameters for Triple Offset Short calibration - SSST - Coaxial

Figure 5-1. TWO PORT CAL SETUP (SSST, COAXIAL)

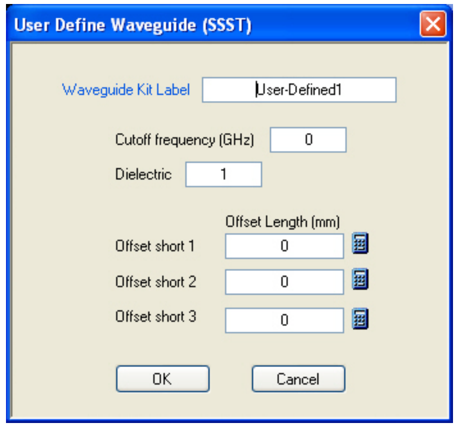
For one port calibrations, only one of the port definitions (unless reflection-only calibrations are being performed for both ports 1 and 2) will be present and the through line section will not be present. For a 1 path-2 port calibration, one of the port definition sections will not be present.



Typical parameters for SSST calibration - W1 (F) Connectors

Figure 5-2. STANDARD INFO (TRIPLE OFFSET SHORT) Information Dialog Box

Variations for other line types are similar to those for SOLT. For waveguide, the media and standards information are again combined into one dialog (Figure 5-3).



Typical parameters for SSST calibration - Waveguide - User-Defined1 - Triple-Offset Short Calibrations

Figure 5-3. USER DEFINED WAVEGUIDE (SSST) Information Dialog Box

Note	Reciprocal measurements (SSSR) are covered in more detail in Chapter 15, “Reciprocal Measurements”.

5-3 SSST/SSSR Calibration Example

The following example presumes an MS4640A Series VNA in a millimeter-wave or broadband setup so that W1 connectors can be used (since they represent a common triple offset short example). A different connector can be selected in Step 4 below if a different model/configuration is being used. It is assumed that a M-F cable is connected to Port 2 so that a M (port 1) and F (port 2) reference plane pair is available.

In this example, a full 2-Port SSST calibration will be performed although a number of other options are discussed along the way. These options are discussed in the Calibration Overview section.

1. Set the desired frequency range (FREQUENCY menu), power (POWER menu) and IFBW/Averaging (AVERAGING menu). The default power level varies depending on the instrument model and options, but will often be adequate for all passive and many active device measurements. The default IFBW is 1 kHz with averaging off, which is adequate for many applications.
2. Navigate to the TWO PORT CAL menu.
    - MAIN | Calibration | CALIBRATION | Calibrate | CALIBRATE | Manual Cal | MANUAL CAL | 2 -Port Cal | TWO PORT CAL

Note	If a previous calibration exists, the Thru Update button will be active. See the Calibration Overview section for more information.

3. Select Modify Cal Setup, and on the CAL SETUP menu, select a Cal Method of SSST/SSSR and a Line Type of Coaxial.

4. Select Edit Cal Params, the TWO PORT CAL SETUP (SSST, COAXIAL) dialog box appears (shown below).

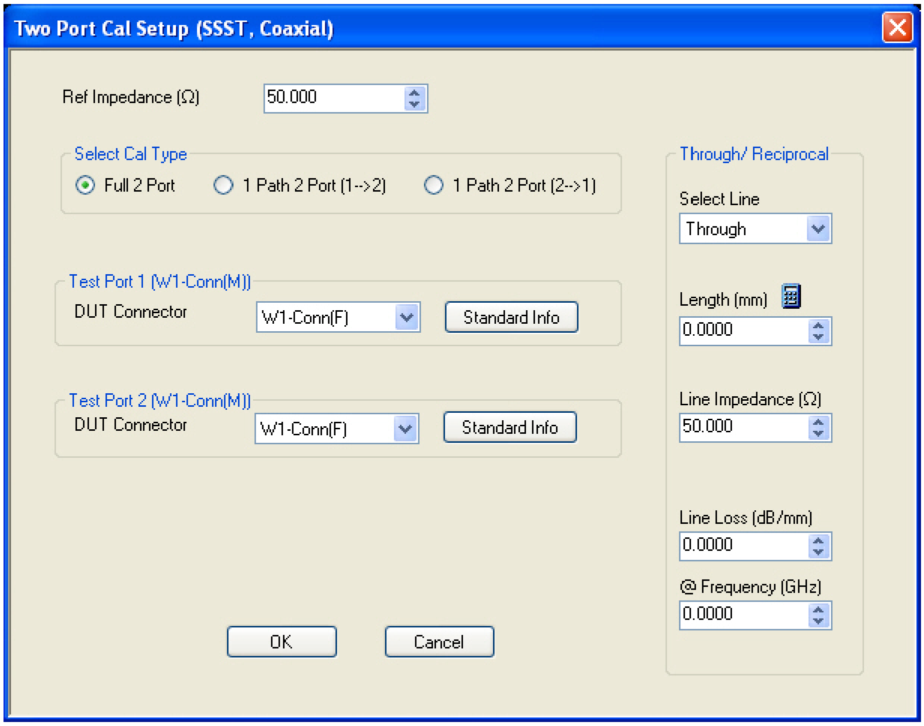


Figure 5-4. TWO PORT CAL SETUP (SSST, COAXIAL) Dialog Box

5. In the TWO PORT CAL SETUP (SSST, COAXIAL) dialog box, set the following calibration components:
   - **a.** Reference impedance defaults to 50 ohms. This establishes the reference impedance for reference plane changes and Smith chart plotting but can be changed later on a per-trace basis.
   - **b.** In the Select Cal Type area, select the Full 2 Port radio button.
   - **c.** A zero-length (or mating) thru will be used so enter Through for the line, 0 mm for the length and 0 dB/mm loss. Zero can be entered for the reference frequency when no loss scaling is employed and the entered loss value is used for all frequencies. If a reciprocal network was being used instead of a through, the line selection would be Reciprocal and the length entered would serve as an estimate for root choice purposes.
   - **d.** For **Test Port 1**, select a DUT connector of W1-Conn (F). The dialog box then displays a port connector as W1-Conn (M).
   - **e.** For **Test Port 2**, select a DUT connector of W1-Conn (M). The dialog box then displays a port connector as W1-Conn (F).
   - **f.** Click OK to close the dialog. Select Back at the bottom of the menu to return to the previous level and the TWO PORT CAL menu.
6. The Port 1 Reflective Devices and the Port 2 Reflective Devices buttons display the REFL. DEVICES PORT 1 and PORT 2 menus. The six reflection standards to be measured (Short 1, Short 2, Short 3 on each menu) will be displayed here along with the read-only fields showing the port connector choices. Connect each standard in turn, and then click the corresponding button. When all six are done (and six check marks appear), click Done to return to the previous level and the TWO PORT CAL menu.
7. After measuring all six reflection standards, connect the test cable to **Port 1** to complete the zero length through. Click on the Thru/Recip button to display the THRU/RECIP menu where a check mark should appear after the sweep pair. Note that the displayed graphs change during this step as the instrument must measure all four S-parameters of the through line.

8. An optional isolation step is available but is not recommended. If desired, terminate **Port 1** and the end of the cable attached to **Port 2** before clicking on the Isolation (Optional) button and displaying the ISOLATIONS menu.
9. When all steps are successfully completed, the Done button is available where select returns to the CALIBRATION menu where the Cal Status button is set to ON.
10. Click Done. The calibration is now completed and turned on.

Chapter 6 — LRL/LRM Calibration

6-1 LRL/LRM Introduction

This chapter describes LRL/LRM calibration algorithms and procedures. The LRL/LRM/ALRM family of calibrations relies more on the fundamental behavior of certain components (primarily transmission lines) than it does on characterized/modeled behaviors of components. It makes less use of redundancy, so fewer measurements are needed to complete a calibration, but it is also less tolerant of poor or non-repeatable measurements.

6-2 LRL/LRM Comparison

LRL - Line-Reflect-Line

LRL (Line-Reflect-Line) uses two (or more) transmission lines and a reflect standard (for each port). The line lengths are important as it is required that the two lines look electrically distinct at all times (meaning it will not work at DC nor at a frequency where the difference in length is an integral number of half wavelengths). The reflect standard is assumed to be symmetric and without a high return loss. The lines are assumed perfect (no mismatch), and are usually airlines for coaxial calibrations, although other structures can be used. On-wafer transmission lines can be very good and this calibration approach will work well if the required probe movement can be managed.

LMR - Line-Reflect-Match

LRM (Line-Reflect-Match) and ALRM (Advanced Line-Reflect-Match) calibrations have one of the lines above replaced with a match (or load). The load is modeled/characterized (or assumed perfect). Since only one line is involved, this calibration can work down to DC and up to very high frequencies (practically limited by the match knowledge/characterization). Variations allow one of the match measurements to be traded for a pair of additional reflect measurements (a second reflect standard is needed). Because of the requirement that the reflect standards be distinct, the calibration may become band limited.

In the limiting case of a match that is assumed perfect, or at least assumed symmetric, this calibration reduces to the classical LRM. The added flexibility is in the ability to define asymmetric load models and to use multiple reflect standards as discussed above. The double reflect methodology allows one to feed into a load modeling utility where the load model can be further optimized.

Some parameters to keep in mind:

Line Lengths

In addition to the LRL frequency limits, the line length is used for some reference plane tasks. The fundamental reference plane of an LRL/ALRM calibration is in the middle of the first line. If the reference plane is required at the ends of this line, the line length (and loss which can also be entered) is used to rotate the reference planes to the desired location. The line length delta is also used for some root choice tasks, although the accuracy required on this entry is less.

Line Length Delta

As mentioned above, the usable frequency range for LRL is set by the line length delta. Strictly speaking, the electrical length should be between 0 and 180 degrees for all frequencies of interest although some margin is usually desired to account for line parasitics, spurious mode launches and other problems. In general, the delta should be kept between 10 and 170 degrees or 20 and 160 degrees. Practically speaking, one can usually be more aggressive on the lower number and will want to be less aggressive on the upper number:

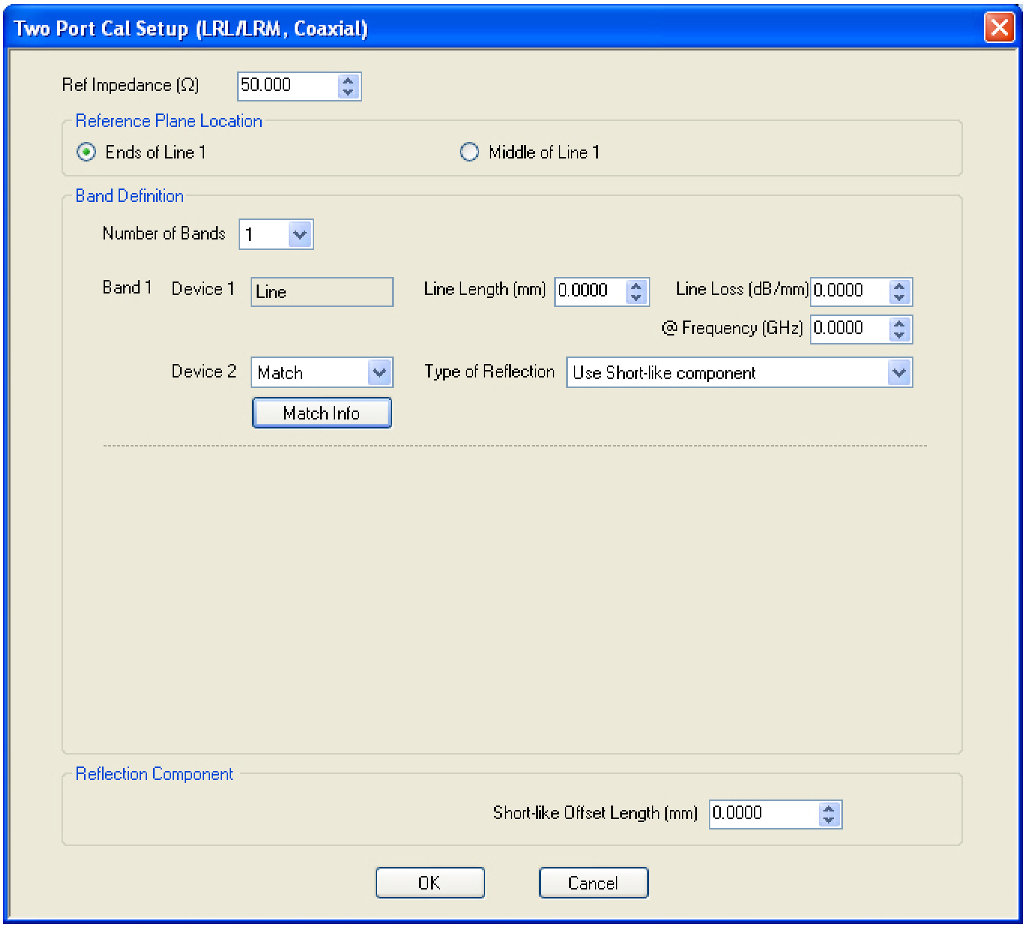
$$10 < \frac{360 \cdot f \cdot \Delta L}{v_{ph}} < 160$$

(Eq. 6-1)

Where $\Delta\mathbf{L}$ is in meters, v_{ph} is the phase velocity of the line (= 2.9978 10^8m/s = c for air dielectric) and f can be any frequency in the range of interest, expressed in Hz.

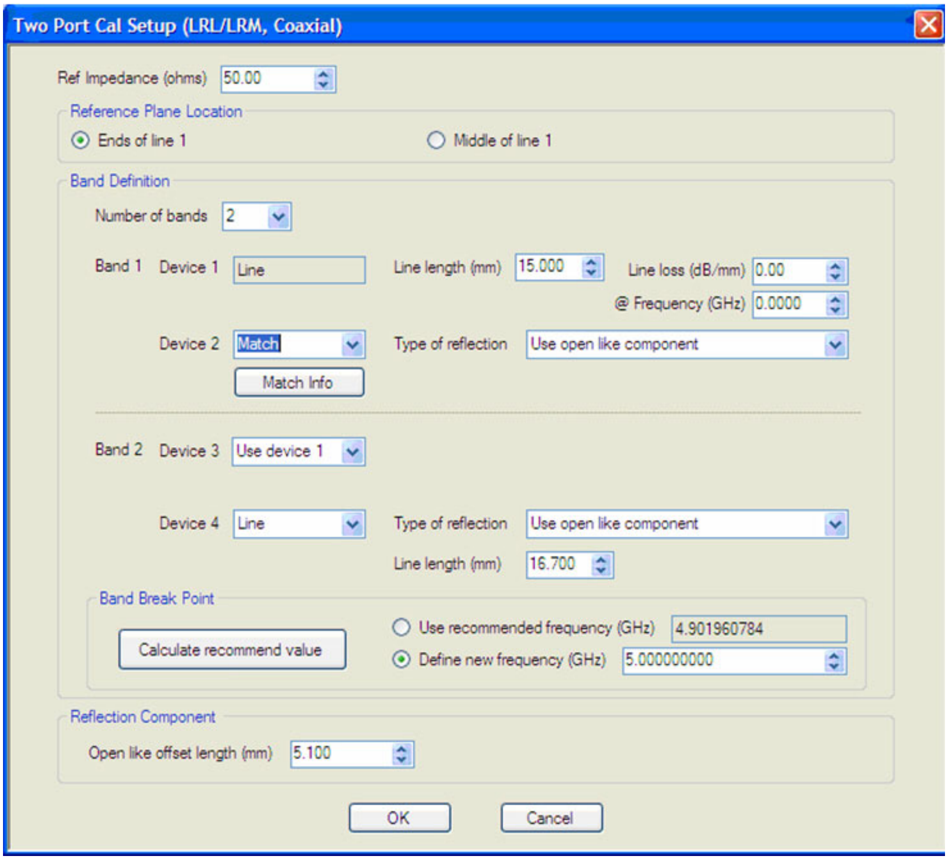
If this range is too small for the application, multiple lines and multiple bands can be used. Each band uses a line pair covering some range of interest. LRL can be combined with LRM/ALRM (LRM/ALRM usually covering the low frequency end) within the calibration system. When two bands are used, a frequency break point must be specified to indicate when to switch from one calibration to the other. A suggestion can be calculated and this will be done based on the line lengths entered.

The setup dialog for LRL/LRM/ALRM is quite flexible with decisions made based on what standards are selected. Several examples are shown in the figures below.



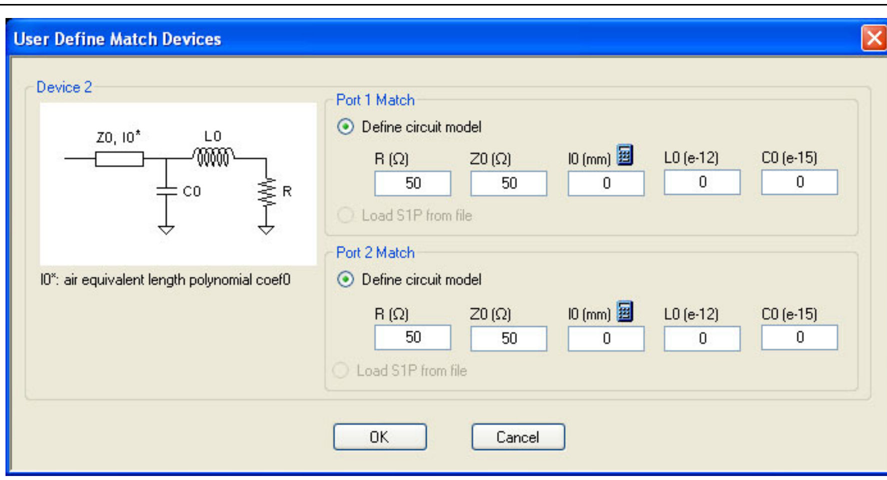
Typical parameters - One-Band LRL calibration

Figure 6-1. TWO PORT CAL SETUP (LRL/LRM, COAXIAL) Dialog Box



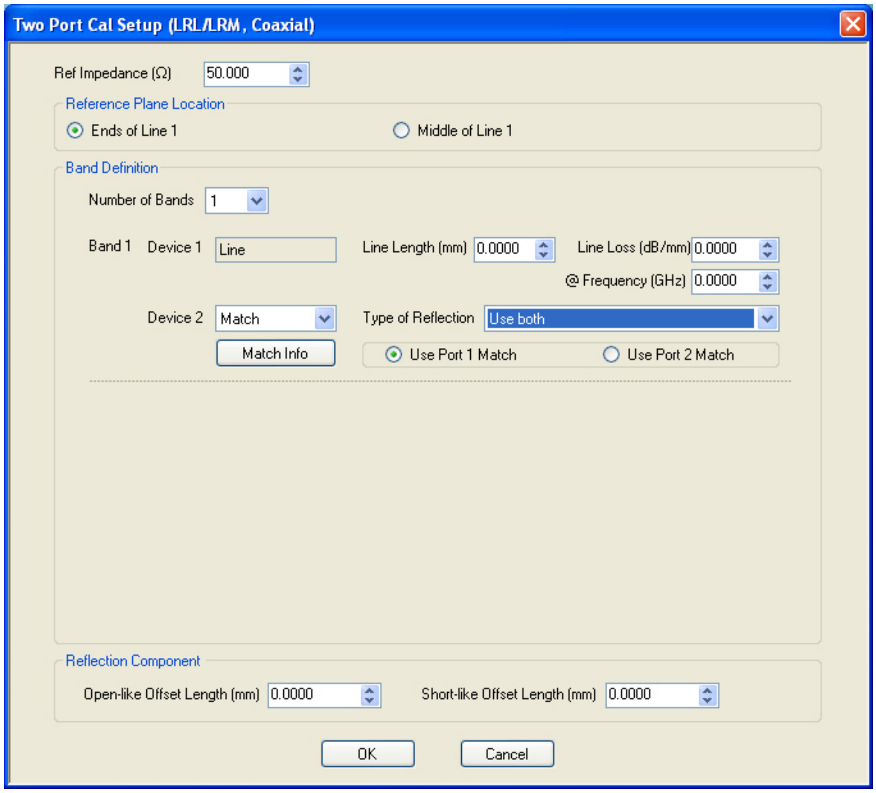
Typical parameters - Band 1 LRM/ALRM - Band 2 LRL

Figure 6-2. TWO PORT CAL SETUP (LRL/LRM, COAXIAL) Dialog Box



Typical parameters - Defining the Load for ALRM (match info)

Figure 6-3. USER DEFINED MATCH DEVICES Dialog Box



Typical parameters - One Band ALRM Using Two Reflects

Figure 6-4. TWO PORT CAL SETUP (LRL/LRM, COAXIAL) Dialog Box

The Cal Merge (concatenation) utility can also be used with any other calibration types in order to cover a wider frequency range.

Reflection Offset Length and Reflection Type

Some information is requested about the reflection although a full characterization is not needed. The information is used in some root-choice activities and it only needs to be known if the reflect behaves more like an open or a short (since typically opens and shorts are used as the reflect standard). The offset length is used to dynamically move the reference planes around so the algorithm will know what the reflect looks like at any given frequency.

In the double reflect ALRM methodology it is important that the reflect standards be distinct. More specifically, they must be distinct when rotated to the reference plane at the center of line 1. Since large offset lengths will lead to many more degeneracies, this double reflect option will generally be used when offset lengths are smaller (such as in on-wafer of fixtured calibrations).

Load Model/Characterization for ALRM

When a single reflect approach is taken within ALRM, it behaves like a classical LRM. For slightly more advanced use, complete load models can be entered for the two matches independently. The same model as described for SOLT applies.

At the highest level, two reflects are measured per port to allow more optimized information to be obtained. When the double reflect methodology is selected, an optimization routine can be selected which can lead to a load model. The structure below is used (similar to that for the general model except no capacitance). The resistance element is assumed known (whether from DC measurements or other parametric data). The inductance and transmission line parameters can be optimized over given ranges.

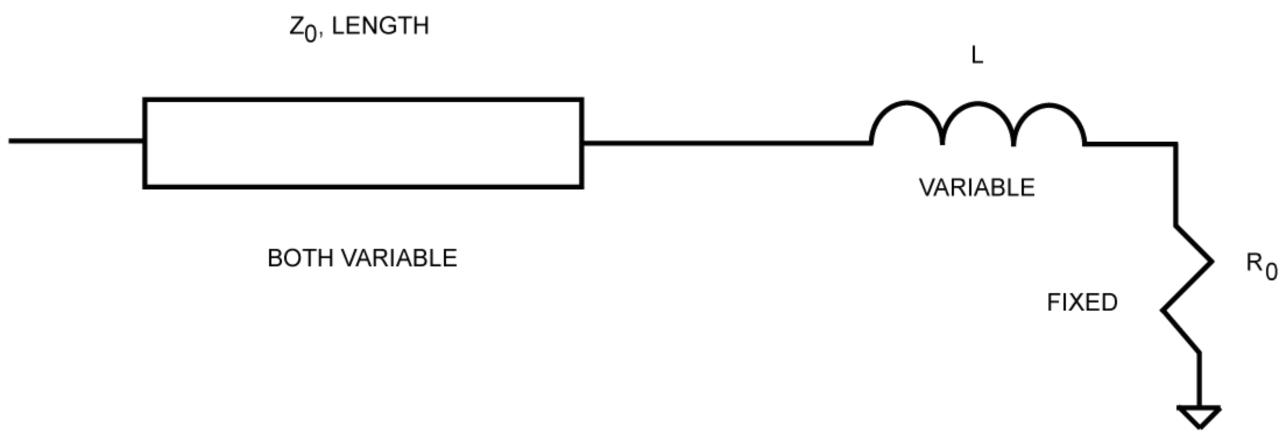
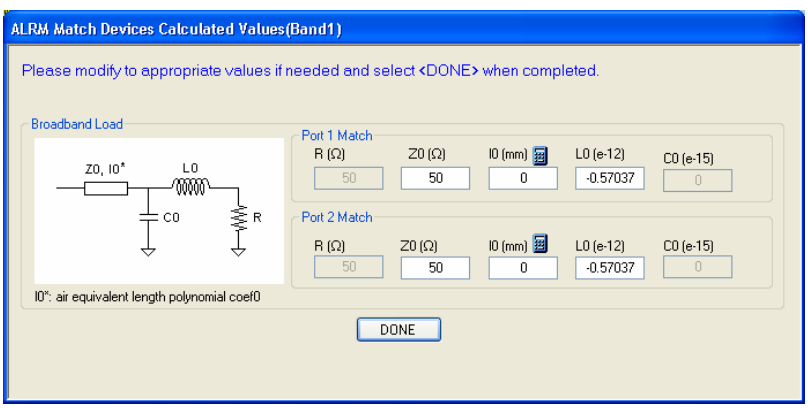


Figure 6-5. Load Model/Characterization for ALRM

The dialog box (Figure 6-6 below) pertaining to this model will appear after the main calibration steps are complete. At that point, the fit model can be used (default) or modified values can be entered. A model will be suggested by the algorithm but can be overridden in this dialog.



Typical parameters - Load Model Selection

Figure 6-6. ALRM MATCH DEVICES CALCULATED VALUES (BAND 1) Dialog Box

The dialog boxes shown above are for coaxial or non-dispersive line types. For waveguides and microstrips, the only change is the addition of items at the top of the dialog to specify the media (see Figure 6-7 and Figure 6-8 below).

An example LRL/ALRM setup dialog for a waveguide line type is shown here. Note the cutoff and dielectric constant line items that are added.

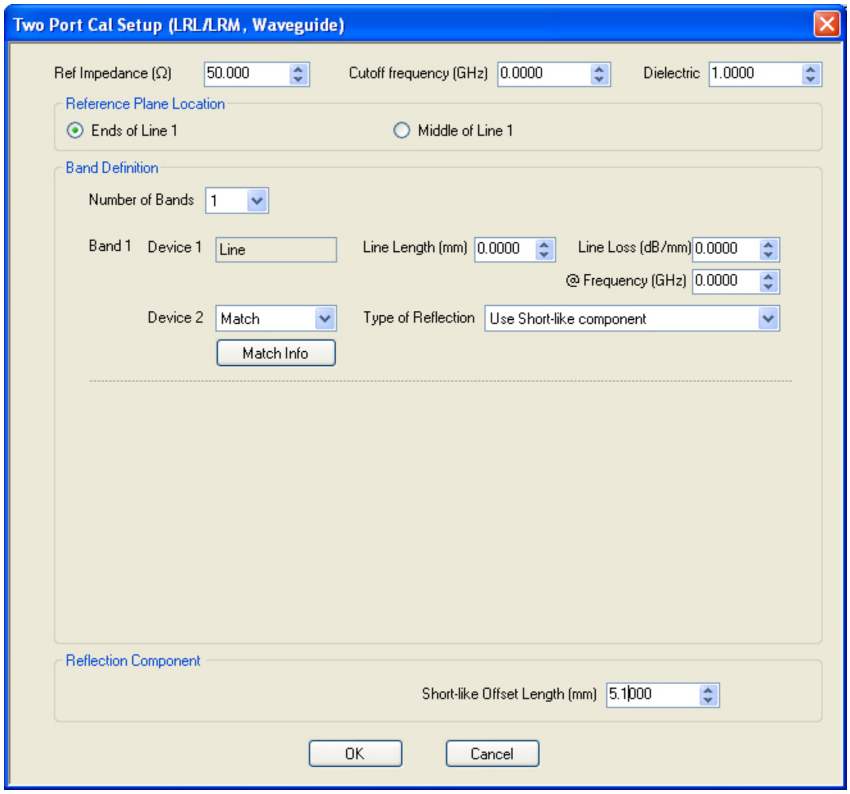


Figure 6-7. An Example LRL/ALRM Setup Dialog for a Waveguide Line Type

An example LRL/ALRM setup dialog for a microstrip line type is shown here. Note the media line items that have been added (the microstrip info sub-dialog is described earlier).

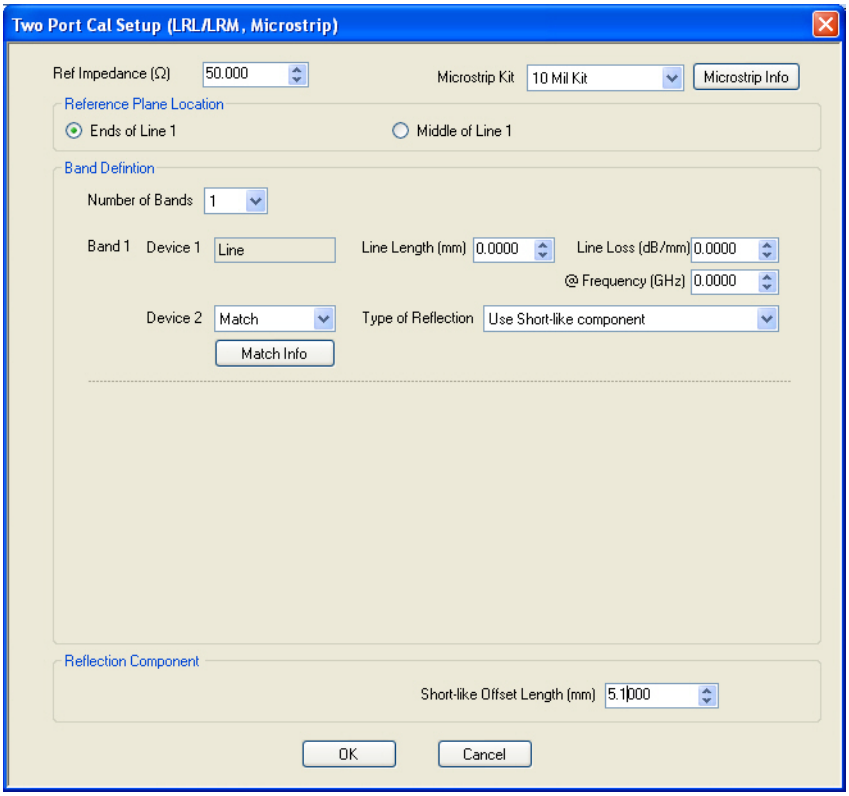


Figure 6-8. An Example LRL/ALRM Setup Dialog for a Microstrip Line Type

When using the double-reflect ALRM method, it is important to note that the reflections must produce distinct reflection coefficients when rotated to the central reference plane. When the reflect offset lengths start to become large, this gets to be more difficult over large frequency ranges. In an on-wafer environment when the offset lengths are typically very short, this does not present a problem but it can be an issue in coax. Since the load modeling is most commonly an issue in high frequency on-wafer measurements, this behavior is usually consistent with the applications.

6-3 LRL/LRM Calibration Step-by-Step Example

The following example presumes an MS4640A Series VNA on a coaxial setup. On-wafer scenarios can be accommodated by modifying the entries in Step 4 below. It is assumed that a mating reference plane pair can be created (either MF in coax or zero length-thru compatible). In this example, a full 2-Port LRM calibration is performed, although a number of other options are discussed along the way. The implications of these options are further explained in the calibration overview section.

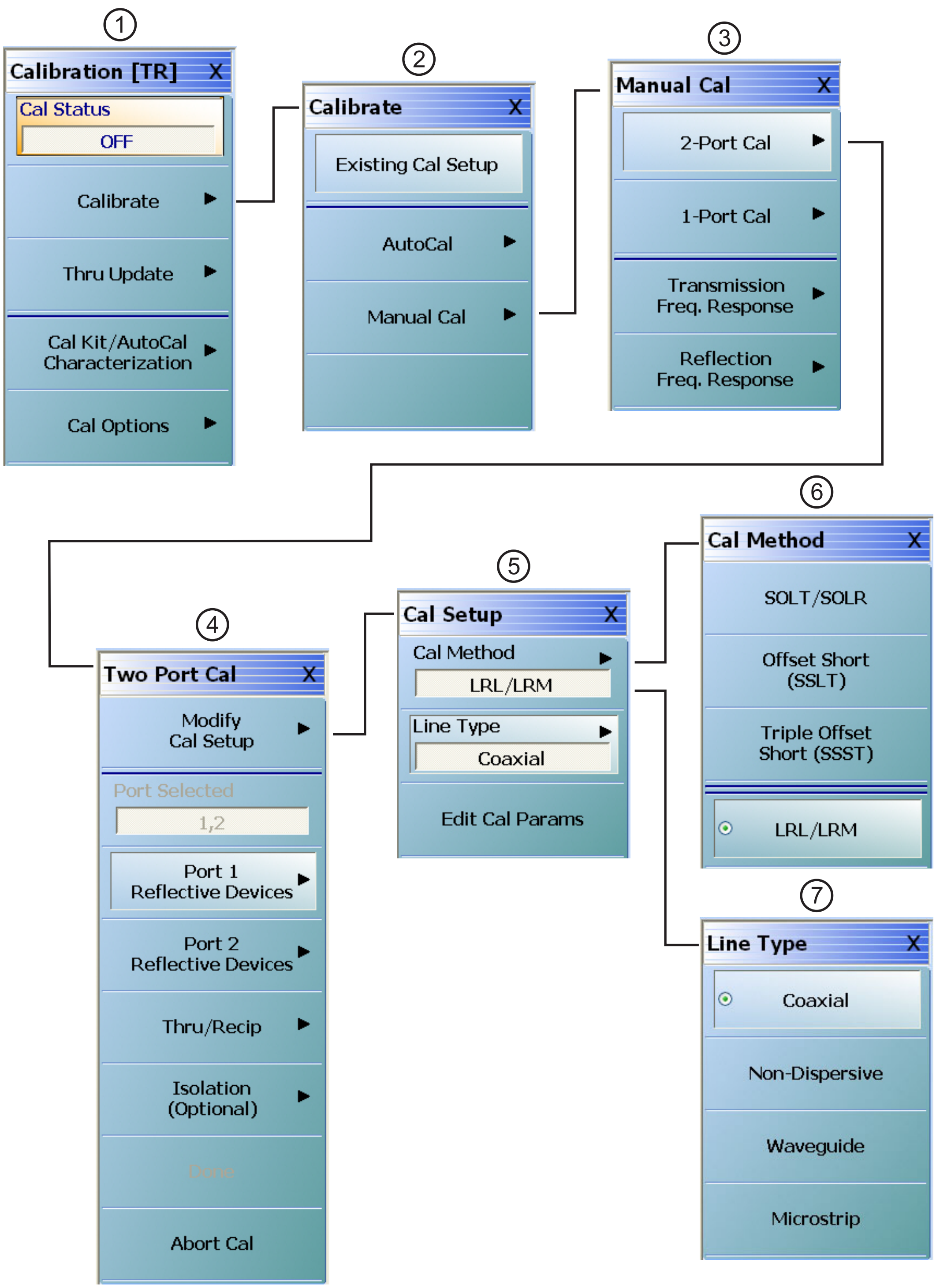


Figure 6-9. Calibration Menu Set for LRL/LRM Coaxial (1 of 2)

1. CALIBRATION menu	5. CAL SETUP menu
2. CALIBRATE menu	6. CAL METHOD menu
3. MANUAL CAL menu	7. LINE TYPE menu
4. TWO PORT CAL menu	

Figure 6-9. Calibration Menu Set for LRL/LRM Coaxial (2 of 2)

Procedure

1. Setup the desired frequency range (**FREQUENCY** menu), power (**POWER** menu) and IFBW/averaging (**AVERAGING** menu). As a default, the IFBW will be 1 kHz and the averaging will be off which is adequate for many applications. The default power level will vary depending on instrument model and options but will often be adequate for all passive and many active device measurements
2. Navigate to the TWO PORT CAL menu.
   - MAIN | Calibration | CALIBRATION | Calibrate | CALIBRATE | Manual Cal | MANUAL CAL | 2 -Port Cal | TWO PORT CAL

Note	If a previous cal exists, the Thru Update button will be active. See “Through (Thru) Update” on page 9-1 for more information.

3. Select Modify Cal Setup and on the CAL SETUP menu, select a Cal Method of LRL/LRM and a line type of Coaxial.
4. Select Edit Cal Params to open the TWO PORT CAL SETUP (LRL/LRM, COAXIAL) calibration components dialog box.

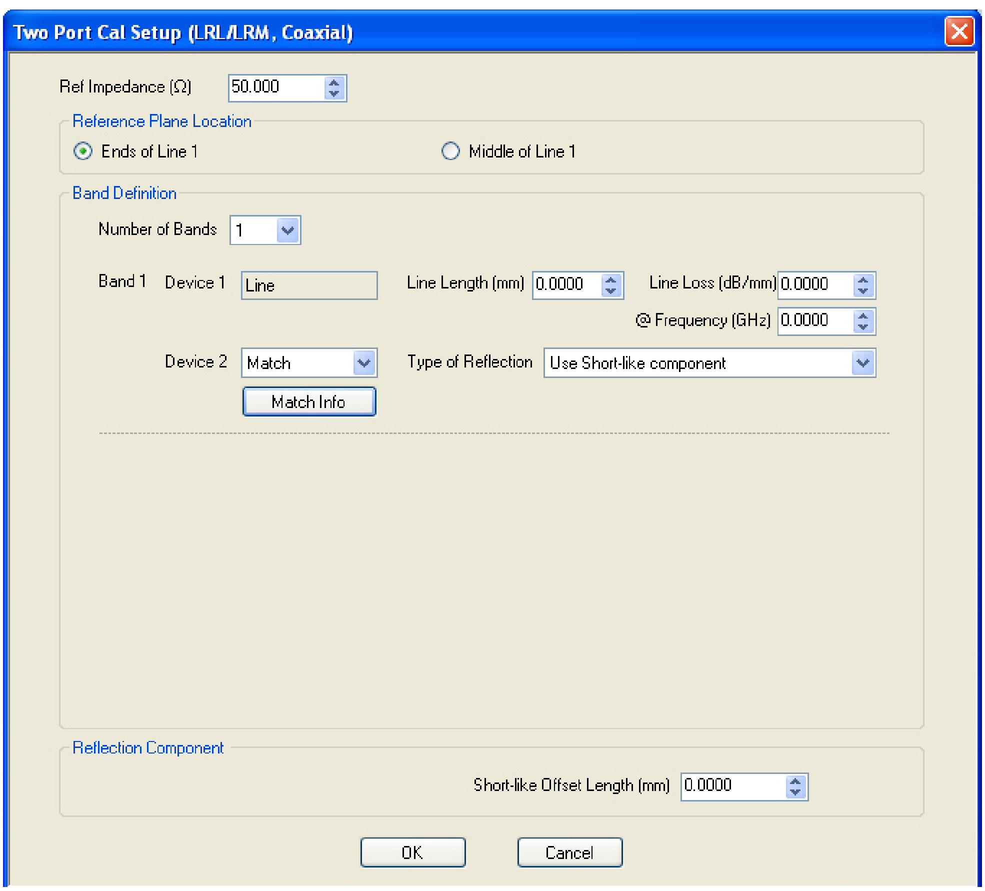


Figure 6-10. Calibration Setup Dialog - TWO PORT CAL SETUP (LRL/LRM, COAXIAL) Dialog Box

5. On the TWO PORT CAL SETUP (LRL/LRM, COAXIAL) dialog box, set the following:

a. The Reference Impedance establishes the impedance for the load definition, reference plane changes and Smith chart plotting. The default is 50 ohms.

b. Select Ends Of Line 1 as the Reference Plane Location. Since this example uses a zero length line, the choice makes no difference.

c. For Number of Bands, select 1. For an LRL calibration, instead of LRM as in this example, the bandwidth of the calibration will be limited by the difference in lengths between the lines. Two bands can be used (with 3 or 4 lines) to cover a larger bandwidth.

d. For this example, set Band 1 Device 1 to Line with a Line Length of 0 and Line Loss of 0 dB/mm. The reference frequency for the loss can be entered as 0. In general, this forces no loss scaling with frequency and the line loss value entered will be used at all frequencies.

e. Set Band 1 Device 2 to Match since we are performing an LRM calibration. A specific match (or load) model may be entered under Match Info, but this example uses the default of 50 ohms.

f. For the Type of Reflection select Use Short-like Component. This implies the impedance is usually less than the reference impedance but it need not be precise. This information is used to help in root selection. Enter the Short-like Offset Length in the Reflection Component section at the bottom of the dialog box.

g. Click OK to accept the entries and close the dialog box. Select Back at the bottom of the Cal Setup menu to return to the previous level TWO PORT CAL menu.

6. The menu-by-menu procedure is shown in the figure below.

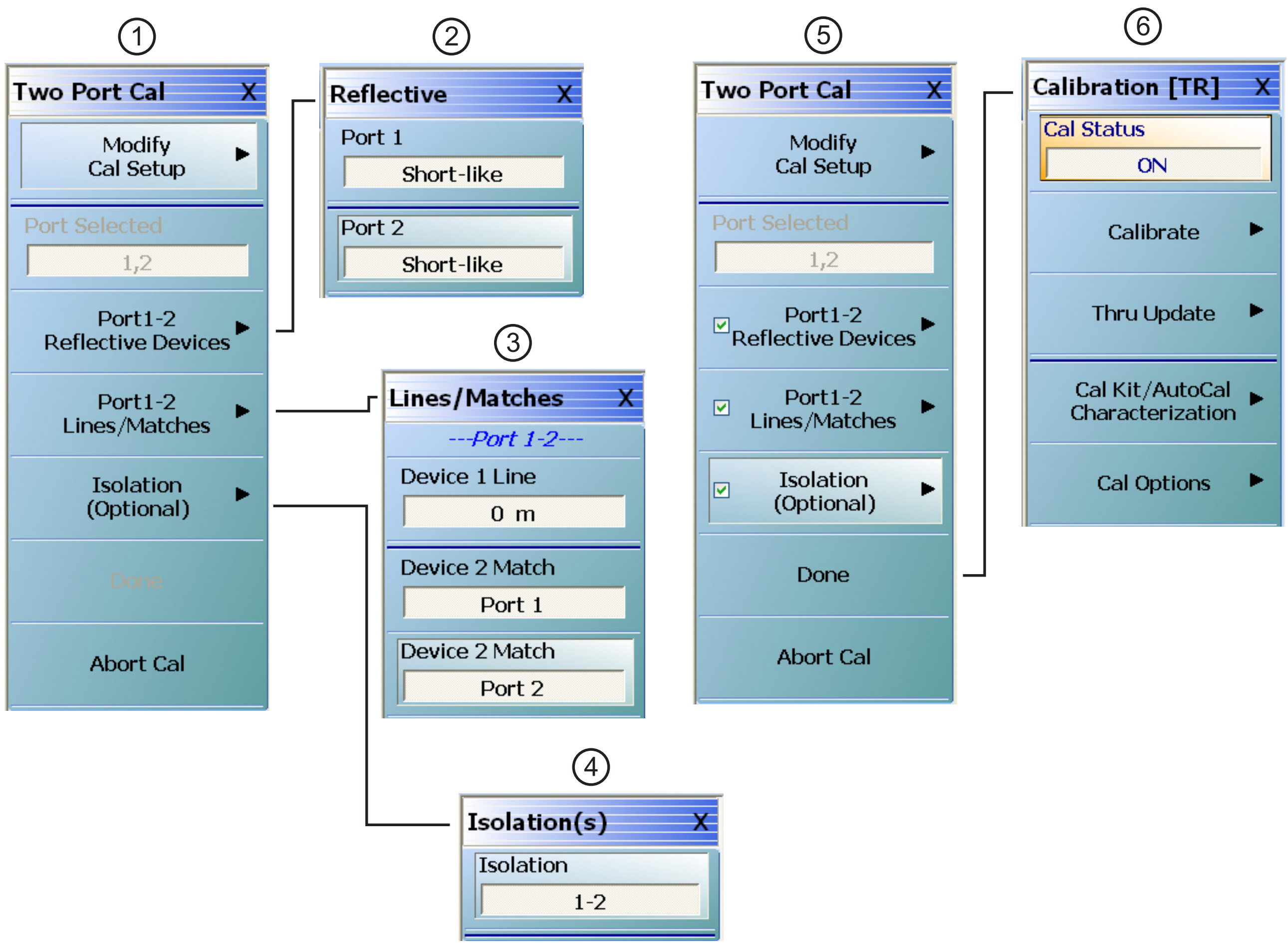


Figure 6-11. Two Port LRL/LRM Coaxial Calibration Procedure Menus (1 of 2)

1. The TWO PORT CAL menu with link/completion buttons for Port 1-2 Reflective Devices, Port 1-2 Lines/Matches, and Isolation (Optional). The Done button is not available. 2. REFLECTIVE Port 1-2 Menu 3. LINES/MATCHES Menu	4. Optional ISOLATIONS Port 1-2 Menu 5. TWO PORT CAL menu after all calibration procedures successfully completed. Note Done button is available. 6. CALIBRATION Menu with Cal Status set to ON.

Figure 6-11. Two Port LRL/LRM Coaxial Calibration Procedure Menus (2 of 2)

7. On the TWO PORT CAL menu (above in Figure 6-11 – #1), select the Port 1-2 Reflective Devices button and its linked REFLECTIVE menu (Figure 6-11 – #2). In this example, the short-like reflective device must be measured at both ports. After the device is connected to a given port, click the corresponding button (a check mark will then appear after the measurement). Click on Back when done with this step to return to the TWO PORT CAL menu.
8. Connect the reference planes together to form the 0 (zero) length line. Select Port 1-2 Lines/Matches and on the LINES/MATCHES menu (Figure 6-11 – #3), click on Device 1 Line (0m). Sequentially connect the load (or loads if two models were entered for two physically separate loads) and click the corresponding buttons. For this example, repeat for **Device 2 Match** at **Port 1** and then Device 2 Match at **Port 2**. As before, check marks will appear when a given step is completed. Click BACK when completed and then DONE.
9. An optional isolation step using the Isolation (Optional) button and the linked ISOLATIONS menu (above Figure 6-11 – #4) is available but is generally not recommended. If desired, terminate **Port 1** and the end of the cable attached to **Port 2** before clicking on the Isolation 1-2 button.
10. When all procedures are complete (at Figure 6-11 – #5), the Done button on the TWO PORT CAL menu is available. Click on Done. The focus returns to the CALIBRATION menu (at Figure 6-11 – #6) where the Cal Status button is set to ON.

Chapter 7 — Receiver Calibrations

7-1 Receiver Calibration 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.

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:

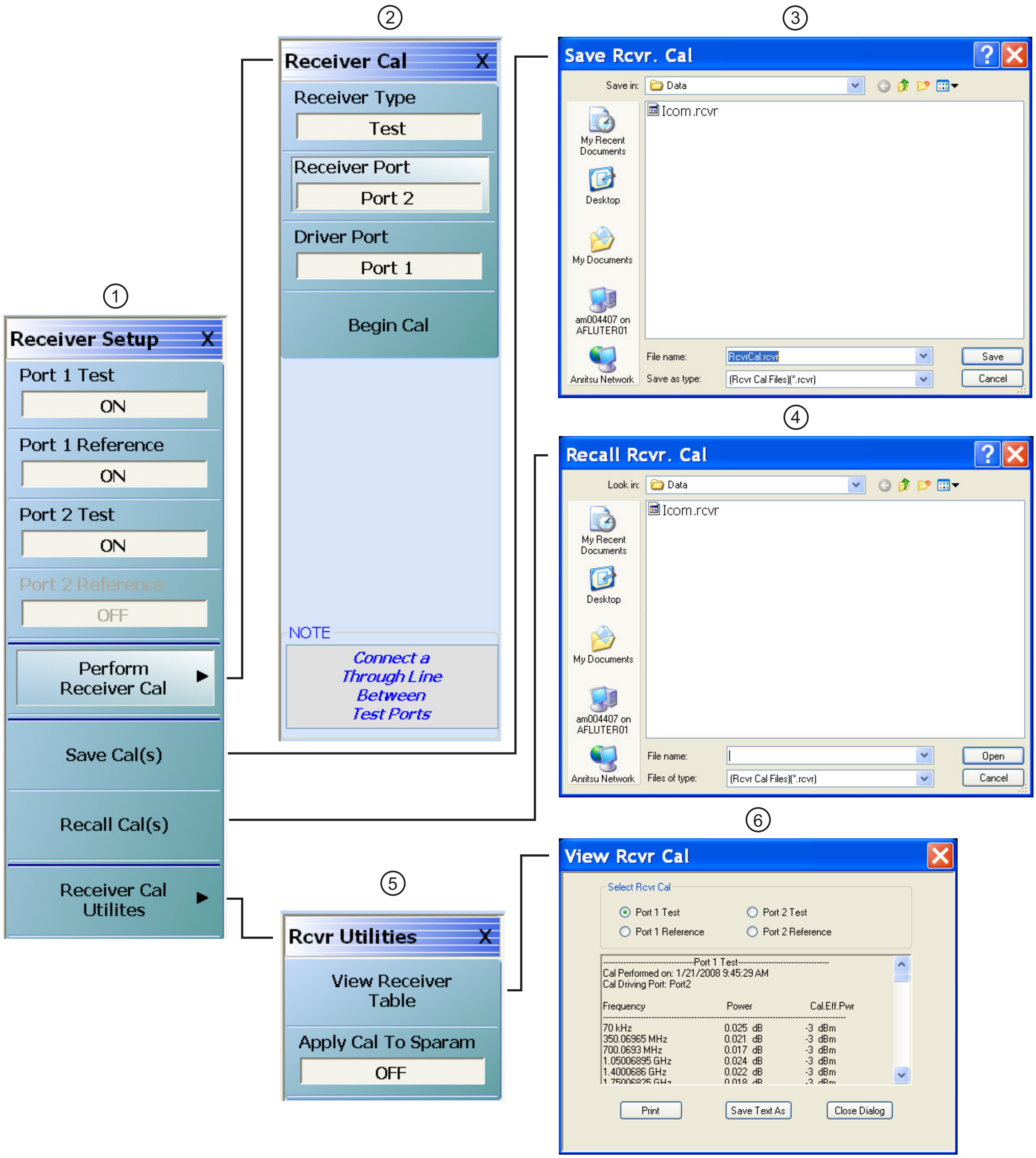
- Harmonics
- IMD and IP3, and other multi-tone distortion measurements
- Mixer conversion loss (in the simpler scalar cases)
- Noise figure measurements
- Other times when the VNA is just used as a channelized receiver

7-2 Receiver Calibration Concepts

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 the Sweep Types portion of this Measurement Guide and in the Operation Manual.

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 7-1.



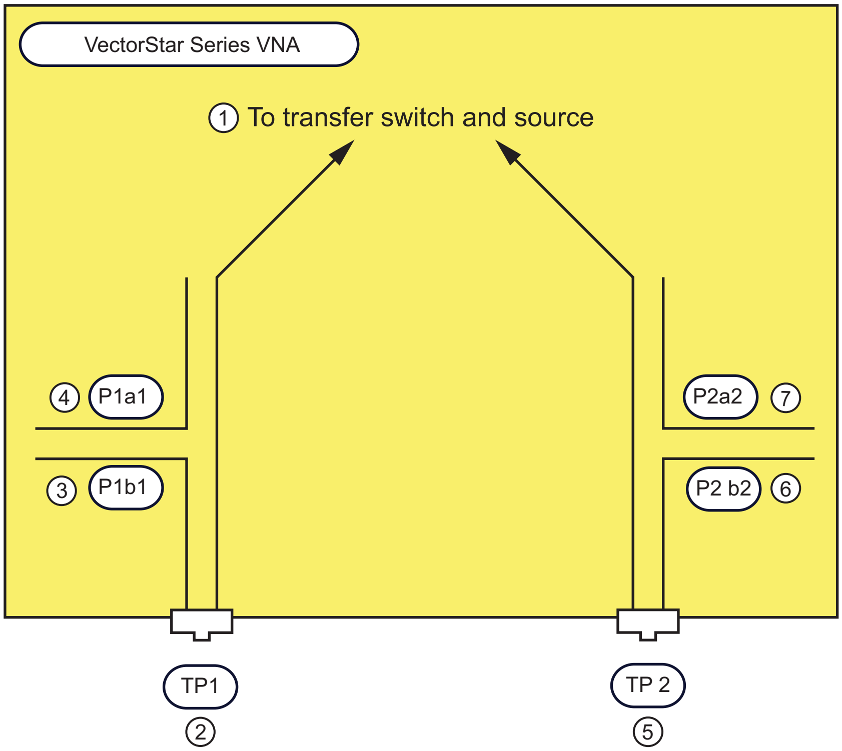
1. RECEIVER SETUP menu
   MAIN | Power | POWER | Receiver Cal | RECEIVER SETUP
2. RECEIVER CAL (CALIBRATION) menu
3. SAVE RCVR. CAL (RECEIVER CALIBRATION) dialog box
4. RECALL RCVR. CAL dialog box
5. RCVR UTILITIES menu
6. VIEW RCVR CAL dialog box

Figure 7-1. RECEIVER SETUP Menu

There are four different receiver calibrations possible (since there are four receivers in the MS4640A Series VNAs) 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.

7-3 Setting Up Receiver Calibrations

To get started, it will help to take a closer look at the architecture of the MS4640A Series VNAas suggested by Figure 7-2.



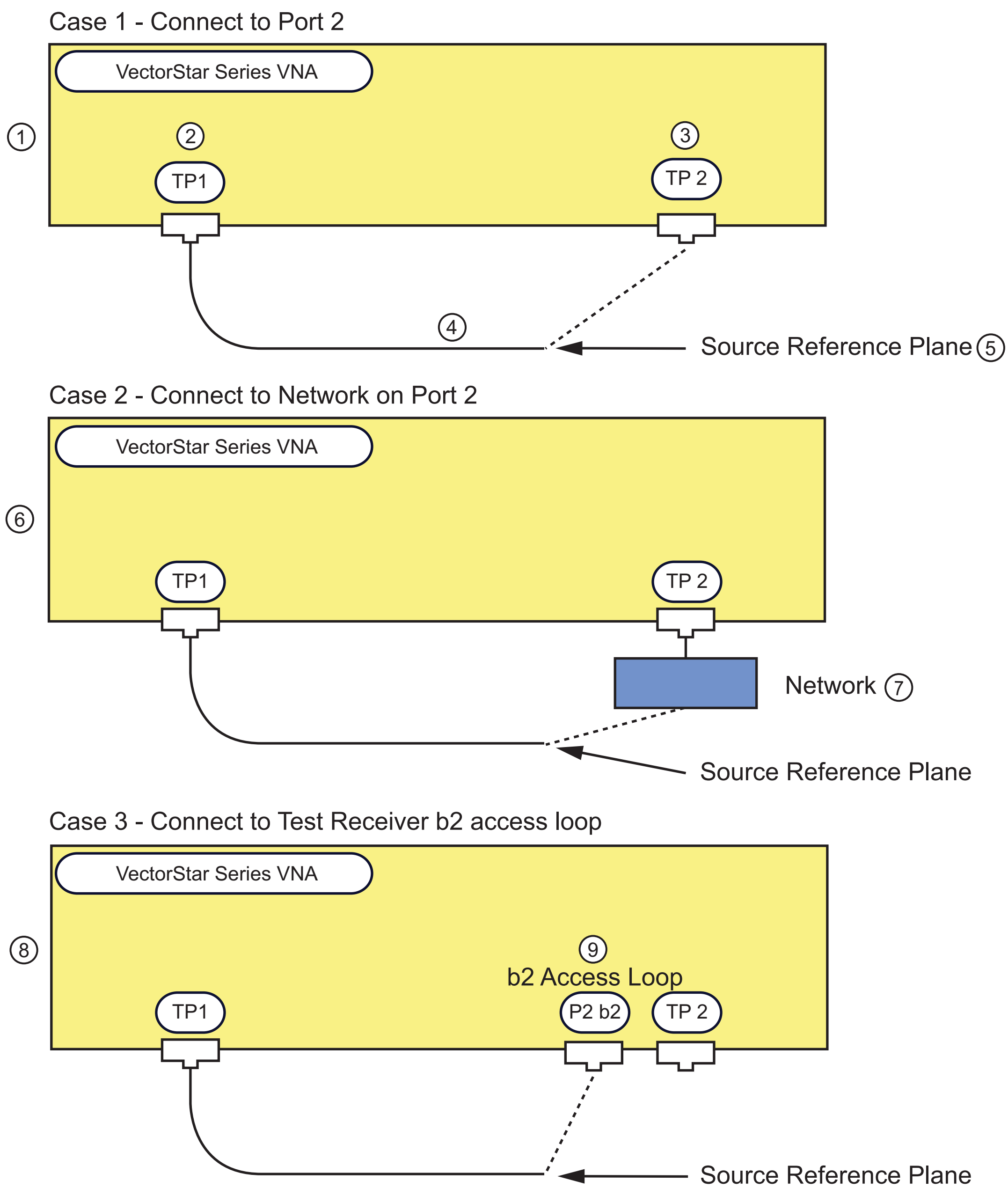
1. To transfer switch and source.	5. TP2 – Test Port 2
2. TP1 – Test Port 1	6. P2a2 – Reference Receiver Port a2
3. P1a1 – Reference Receiver Port a1	7. P2b2 – Test Receiver Port b2
4. P1b1 – Test Receiver Port b1	

Figure 7-2. Simplified Block Diagram of the MS4640A Series VNAs

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 7-3. 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.



Case 1 – Port 2 Direct	**Case 2 – Network Connected to Port 2**
1. Case 1 – Connect to Port 2	6. Case 2 – Connect to Network Connected to Port 2
2. Test Port 1	7. Network attached to Port 2
3. Test Port 2	**Case 3 – Port 2 b2 Access Loop**
4. Test Cable (f-m)	8. Case 3 – Connect to Port 2 b2 Access Loop
5. Source Reference Plane	9. Port 2 b2 Access Loop – Requires VNA equipped with Option 051, 061, or 062.

Figure 7-3. Three Different Receiver Reference Planes

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 calibration 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:

- **Cable**

  A cable is needed to reach the receiver reference plane and it is not desired that this cable loss be neglected
- **Preamplifier**

  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**

  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 7-4.

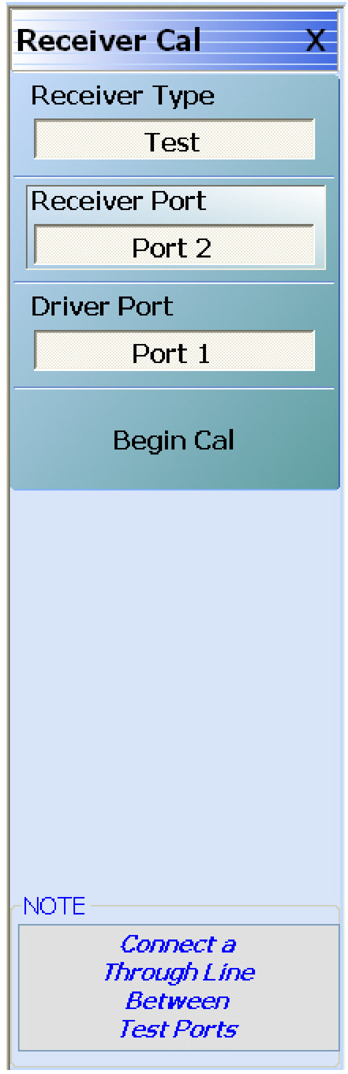


Figure 7-4. RECEIVER CAL (CALIBRATION) Menu

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 7-1 menu.

7-4 Receiver Calibration Utilities

The RCVR UTILITIES (Receiver Utilities) menu is shown in Figure 7-5.

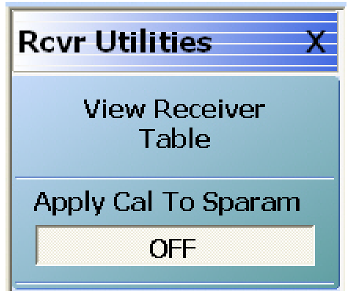


Figure 7-5. RCVR (RECEIVER) UTILITIES Menu

The View Receiver Table button displays the calibration values. This is sometimes valuable as a troubleshooting aid or to gain some more insight into the signal levels in a particular setup. An example Receiver Calibration Table is shown in Figure 7-6. In this example, the table refers to the port 2 test calibration (b2).

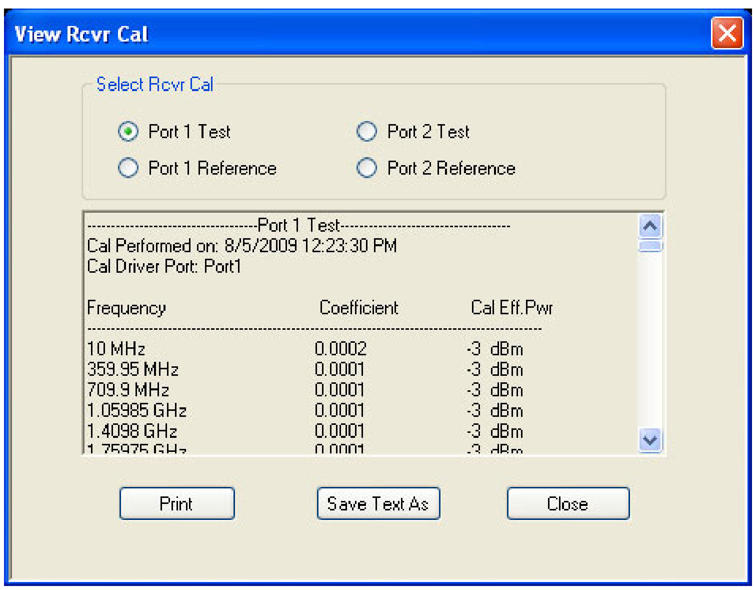
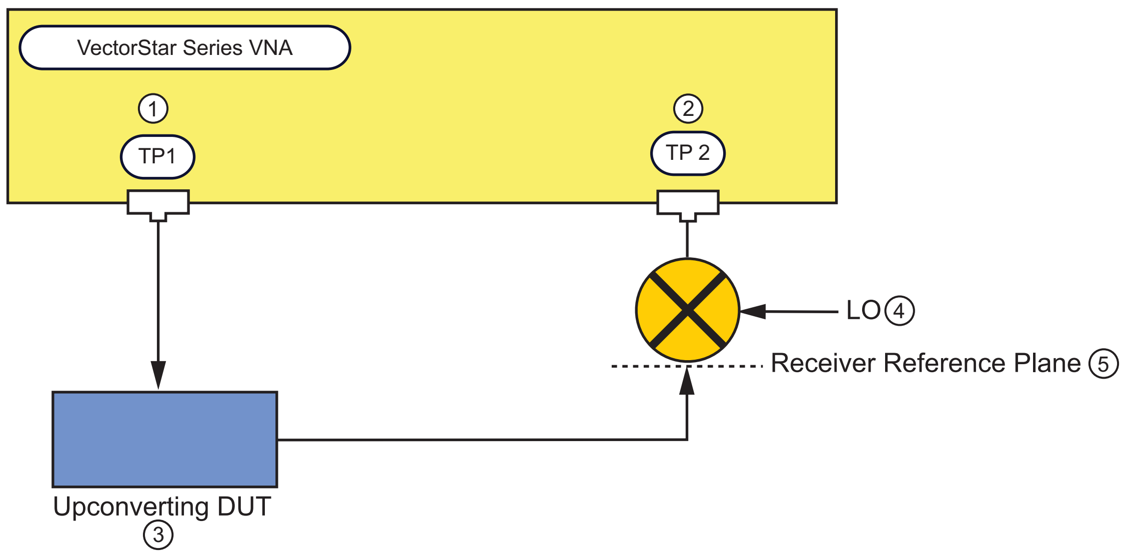


Figure 7-6. VIEW RCVR CAL (RECEIVER CALIBRATION) Dialog Box – Typical Receiver Calibration Table

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 7-7 that uses multiple source control (see separate section in this measurement guide and multiple source application notes for more information).



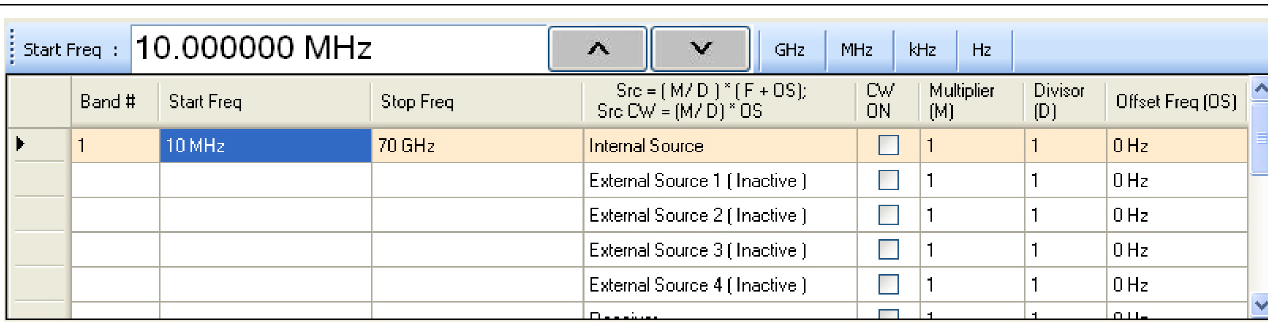
1. Test Port 1	4. LO (Local Oscillator)
2. Test Port 2	5. Receiver Reference Plane
3. Upconverting DUT	

Figure 7-7. Example of a Frequency-Translated Receiver Reference Plane

The DUT in this case is up converting (for example, to mm-Wave frequencies) and a down converter is used to bring the DUT output back to within range of the MS4640A Series VNA. 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 7-8).

- MAIN | Application | APPLICATION | Multiple Source Setup | MULTIPLE SOURCE


Start Freq : 10.000000 MHz GHz MHz kHz Hz

Band #	Start Freq	Stop Freq	Src = [M/ D] * [F + OS]; Src CW = [M/ D] * OS	CW ON	Multiplier (M)	Divisor (D)	Offset Freq (OS)
1	10 MHz	70 GHz	Internal Source	☐	1	1	0 Hz
			External Source 1 (Inactive)	☐	1	1	0 Hz
			External Source 2 (Inactive)	☐	1	1	0 Hz
			External Source 3 (Inactive)	☐	1	1	0 Hz
			External Source 4 (Inactive)	☐	1	1	0 Hz

Figure 7-8. Receiver Source Equation From Multiple Source Mode

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).

7-5 Receiver Calibration Uncertainties

The uncertainty in a receiver calibration is important since it forms a bound on possible uncertainty in many of the measurements listed in the introduction. Since there are many possible setups, we cannot provide a blanket result but can show how this uncertainty can be computed.

Source Side

- Power calibration accuracy (assuming it is used): set by the power meter/sensor and mismatch between the power sensor and the source reference plane.

Receiver Side

- Mismatch between source reference plane and receiver reference plane
- Linearity of the receiver
- Trace noise of the receiver

Receiver linearity is typically better than 0.05 dB as long as one is a few dB away from the compression limits. See the VectorStar VNA data sheet for more information:

- **VectorStar MS4640A Series VNA Technical Data Sheet (TDS) – 11410-00432**

Trace noise is typically less than 0.01 dB as long as one is above –10 dBm port equivalent power. The mismatch contribution depends on where the reference planes are. If both return losses are on the order of 20 dB, there could be a contribution of 0.08 dB (best case scenario). The source side uncertainty can be, at best, 0.1 dB but is commonly several tenths.

Typically, these components are combined in an RMS sense and may be as low as 0.5 dB composite. As suggested above, the actual value will be a strong function of the setup being used. The power meter and VNA uncertainty application notes should be consulted for additional information.

Chapter 8 — Adapter Removal Calibrations and Network Extraction

8-1 Introduction

This chapter describes various methods for handling cases of non-insertable DUTs. In some coaxial cases, this can be handled with a special class of adapter removal calibrations. More generally, de-embedding can be used to remove the effects of fixtures or adapters required to execute the measurement. The de-embedding process itself will be covered in a later chapter but the means of evaluating the network to be de-embedded will be addressed here.

While it is usually desired to perform a 2-Port calibration with mating connectors of the same type, this is sometimes not possible based on the connectors of the device to be tested. Examples of this include:

- The DUT has one N port and one GPC-3.5 port
- The DUT has two female SMA ports and it is not desired to use a non-zero length thru
- The DUT has one fixtured port and one SMA port
- The DUT has one waveguide port and one coaxial port

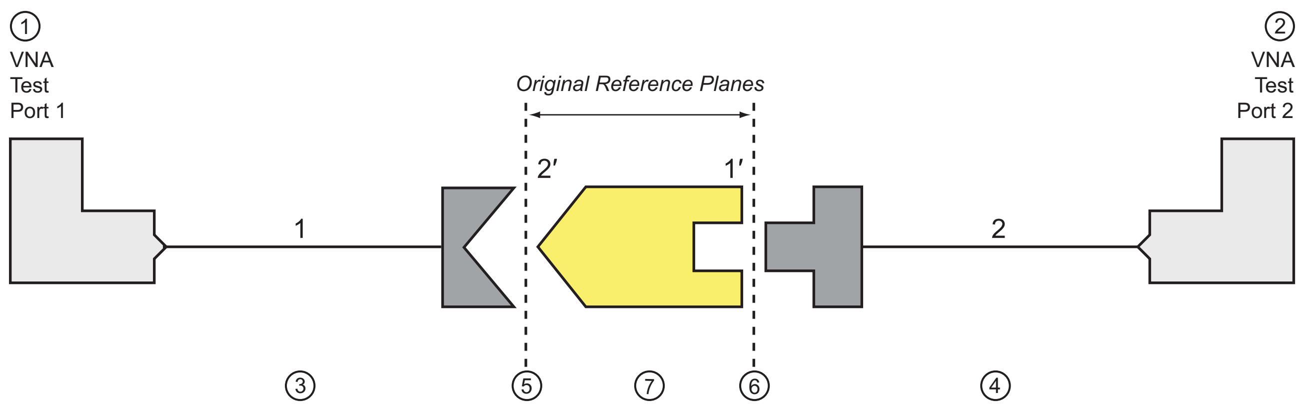
What these examples share is that completing the through line between the effective test ports requires some kind of adapter or fixture. Since the adapter has some phase length, loss, and mismatch, its effects should be removed for a high quality calibration. Adapter removal is a utility to characterize this adapter and remove its effects from a calibration.

In the more general case of de-embedding, a means of determining the network to be de-embedded must be available. Techniques similar to adapter removal, that is a measurement using one or more calibrations, can be used to extract these parameters. As such network extraction can be viewed as a generalization of adapter removal.

8-2 Two Related Sets of Reference Planes

The concept of the adapter removal relies on the existence of two related sets of reference planes with one set on either side of the adapter (see Figure 8-1 below). Assuming one can perform a full calibration at each set of reference planes, there is enough information to extract the behavior of the adapter itself. When the calibration is being performed at the reference planes on the left (between Ports 1 and 2'), the adapter behavior is embedded in the characteristics of Port 2'.

Similarly, when the calibration is being performed between Ports 1' and 2, the adapter behavior is embedded in that of Port 1'. Since each of these two calibrations involve mating connector types, these are far easier to perform than the direct 1-2 calibration. It will not be shown here, but the use of the two calibrations provide nearly enough information to extract the parameters of the adapter itself. Figure 8-1 shows the structure of the adapter removal calibration. Two calibrations are performed at the two sets of reference planes shown (between Ports 1 and 2', and between 1' and 2), which allows a determination of the adapter behavior. After the adapter removal, the resulting calibration will be between Ports 1 and 2.



1. Test Port 1	5. Original Reference Plane 2', when adapter is connected to Port 2 Test Cable
2. Test Port 2	6. Original Reference Plane 1', when adapter is connected to Port 1 Test Cable
3. Port 1 Test Cable	7. Adapter to be calibrated
4. Port 2 Test Cable	

Figure 8-1. Adapter Removal Block Diagram

Caveats and Limitations

There are two caveats to this procedure.

First, only the $S_{12}S_{21}$ products of the adapter can be determined from this procedure, not the two transmission terms individually. However, since only the product is needed to de-embed the adapter effects, this is not much of a problem. Most adapters are passive and reciprocal anyway, so the individual terms could be determined if necessary.

Second, there is a complex square root operation involved, so a root determination is necessary. To help this, the user must enter a guess as to the electrical length of the adapter (in ps of delay). The guess need not be very accurate, just within the correct half plane. At 2 GHz, this means the error in delay entry should be less than 125 ps to ensure the correct root is selected.

In general the error must be less than $\frac{1}{(4f)}$ where f is the highest frequency being used.

8-3 Performing an Adapter Removal

Two full 2-Port calibrations must be performed and those calibrations (plus front panel setups) must be stored to the current directory on a USB memory device or hard disk. The setups for the two calibrations should be the same in terms of frequency range and number of points. Upon entering the adapter removal utility, an estimate for the electrical length of the adapter must be entered as well as the location of the two calibrations. Once this is done, the utility will generate and apply a new calibration by removing the adapter effects. The menu and help screen for this procedure are shown below (Figure 8-2).

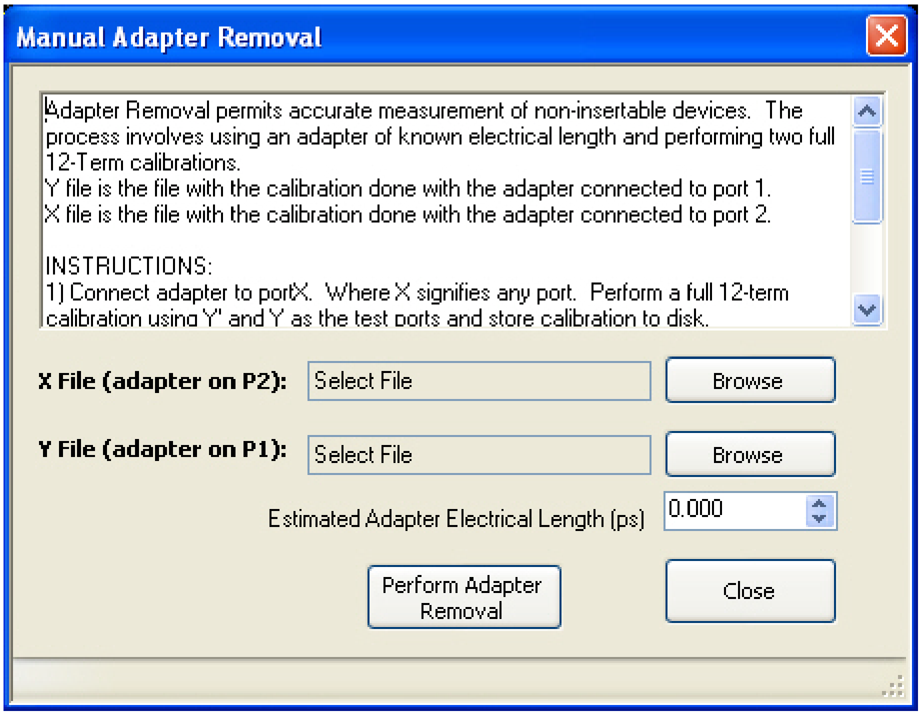


Figure 8-2. MANUAL ADAPTER REMOVAL Dialog Box - 2-Port VNAs

Example Adapter Removal

The following example should help illustrate the use of the adapter removal utility. An adapter was constructed with about 3 dB of loss and 180 degrees of phase shift at 3 GHz. This leads to an estimate of the delay length of:

$$\phi = \omega\tau \qquad \tau = \frac{\theta}{\omega} = \frac{\pi}{2\pi(3\times 10^{9})} \approx 167ps$$

(Eq. 8-1)

Since the loss of this adapter is substantial, one could not simply use reference plane extensions to remove the phase shift and hope for an accurate result.

The two calibrations described earlier were performed and stored to the hard disk and the adapter removal was executed. A through was then connected without the adapter in place. Normally this would not be possible (since the whole reason for using the adapter removal was for situations when a thru would be difficult), but this example adapter was constructed just to show that the algorithm functions correctly. The results are shown in below (Figure 8-3).

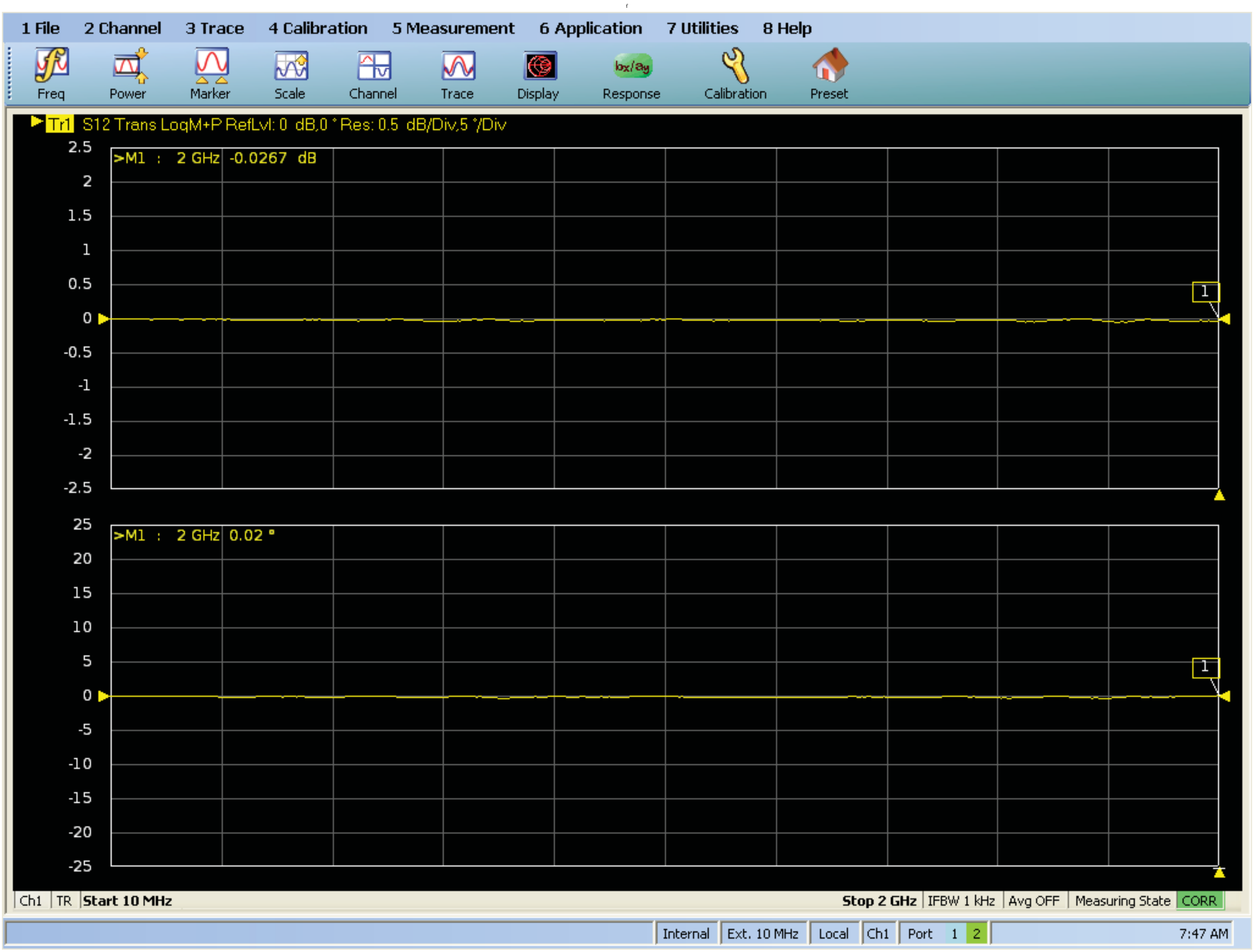


Figure 8-3. VNA Trace Display with Result of Adapter Removal

The through without the adapter was connected after executing the adapter removal utility and the near-perfect through values for S_{21} show that the algorithm successfully removed the adapter from the calibration. As expected, the thru without the adapter shows nearly zero insertion loss and phase shift, and a very good match. Any residuals are largely due to cable flex. Had this connection been made with one of the initial two calibrations applied, S_{21} would have shown about 3 dB of gain since the adapter had been built into each calibration.

8-4 Adapter Removal with AutoCal

In the AutoCal-specialized version, adapter removal primarily refers to the case of a gender incompatibility when it is not desired to use test port converters (for example, an M-F AutoCal unit used to establish M-M reference planes). A separate menu item shown below (see Figure 8-5) is provided for AutoCal adapter removal to speed up the process since fewer manual steps are needed. In this calibration sequence, an adapter that can mate the desired reference plane connectors is used as a part of the calibration.

There are two possible ways to accomplish this, both using a pair of calibration sequences to remove the effects of the adapter. In both of the cases below, it is assumed all connectors are from the same family. If not, as with a special inter-series AutoCal unit, this AutoCal-specific adapter removal technique cannot be used. Instead, see the standard adapter removal section.

For an example of the mechanics of the AutoCal module and adapter calibration process, see the figure below (Figure 8-4). Other example figures are available in Chapter 2, "AutoCal Procedures":

- Figure 2-12, "Precision AutoCal 36585V-2MF Cable Connections for True Through" on page 2-21
- Figure 2-13, "AutoCal True-Through Connections" on page 2-22
- Figure 2-14, "AutoCal True-Through Connections - Module Removed" on page 2-24
- Figure 2-16, "Precision MF AutoCal 36585K-2MF, Adapter Removal, Internal Thru" on page 2-28

MF AutoCal Unit With M-M or F-F Reference Planes

The figure below (Figure 8-4) shows a typical **M-F AutoCal Module** with M-M reference planes.

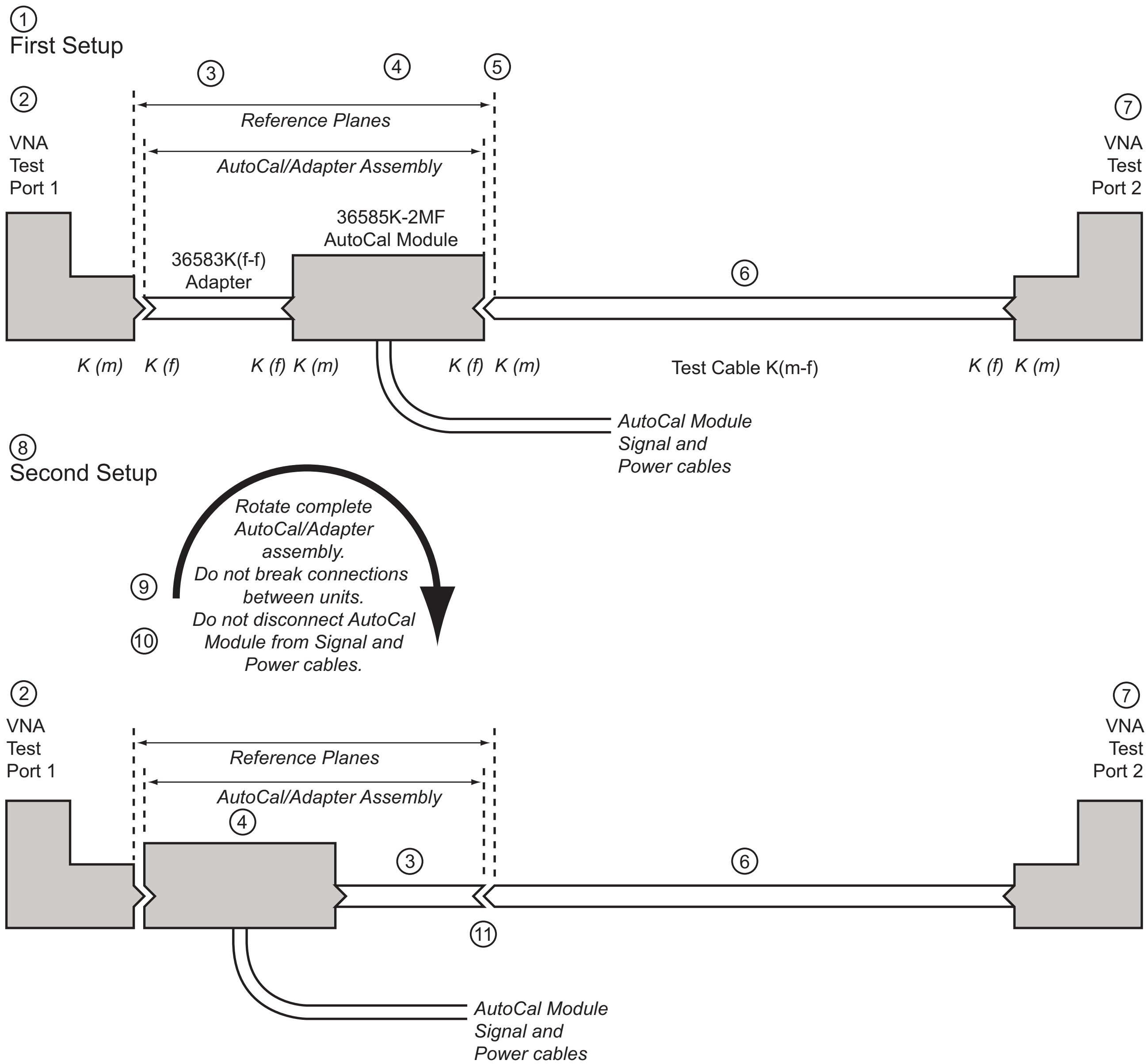


Figure 8-4. AutoCal M-F Module, M-M Reference Planes, and Adapter Removal Calibration (1 of 2)

Part 1 – AutoCal Adapter Removal Procedure	Part 2 – AutoCal Adapter Removal Procedure
1. First setup for the Adapter Removal procedure. 2. VNA Test Port 1 3. 36583K (f-f) Adapter 4. 36585K-2MF AutoCal Module – For the duration of the calibration, the K (f-f) Adapter and the AutoCal Module must be connected as an assembly. Do not disassemble or disconnect from its Power and Signal cables. 5. Resultant calibration reference planes. 6. K (m-f) Test Cable 7. VNA Test Port 2	8. Second setup for the Adapter Removal procedure. 9. After the first calibration, rotate the complete assembly so that the AutoCal K (f) connector is connected to VNA Test Port 1. Do not disconnect the Adapter from the AutoCal module. 10. Do not disconnect the AutoCal Module from its Power or Signal cables. 11. Connect the 36583 K (f-f) adapter to the Test Cable K (m-f). The reference planes remain in place. The user is guided through the remaining steps of the procedure.

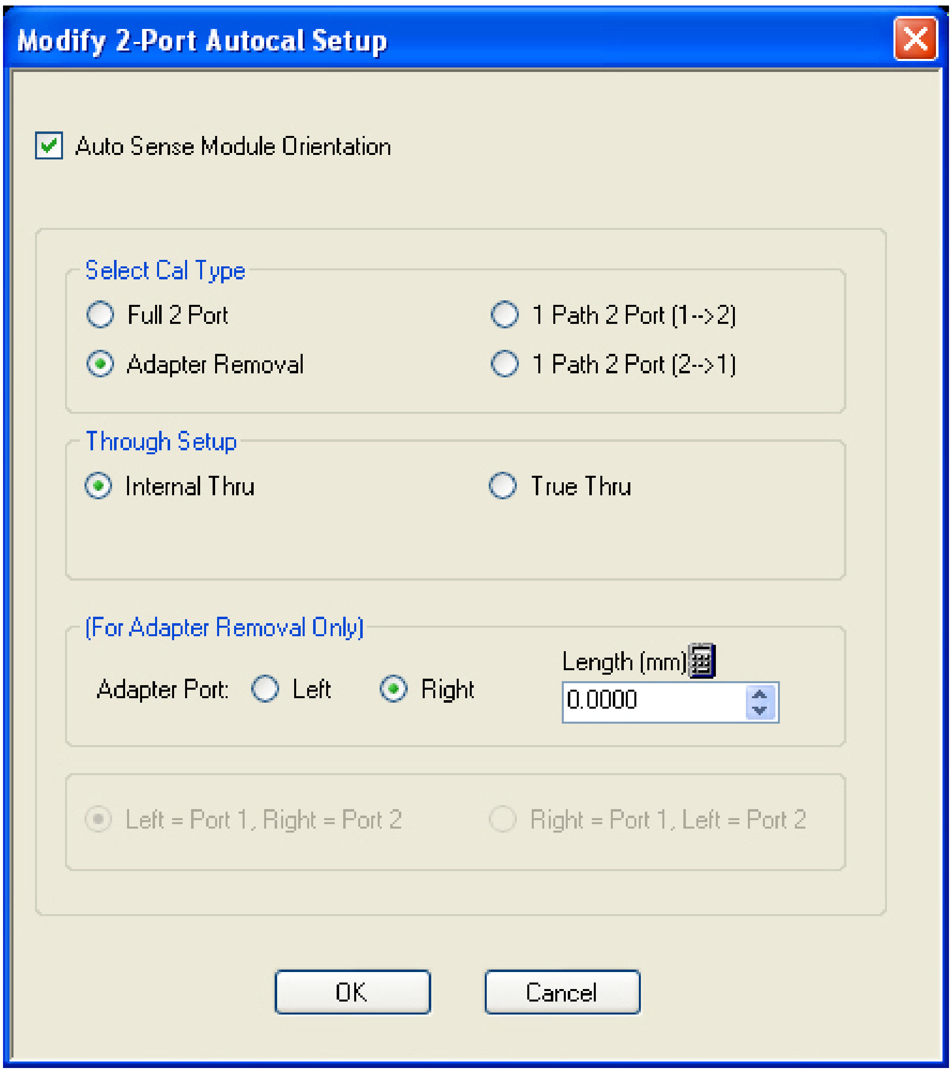
Figure 8-4. AutoCal M-F Module, M-M Reference Planes, and Adapter Removal Calibration (2 of 2)

1. Place the **adapter** on the port of the **AutoCal** unit. The instrument will ask which **port** the adapter is on
2. Connect the **AutoCal** unit and the system will perform the first auto calibration
3. Flip the **AutoCal and adapter assembly** around so that the VNA port connections have changed (do not remove the adapter from the AutoCal assembly).
4. The system will perform a second auto calibration.

M-M or F-F AutoCal Unit With MF Reference Planes

1. Place an **adapter** on the port of the **AutoCal** unit. The instrument will ask which port the adapter is on.
2. Connect the **AutoCal** unit and the system will perform the first auto calibration.
3. Direct-connect the desired MF reference plane (which is, of course possible, by definition here).
4. The system will perform some additional measurements on this thru connection and complete the calibration.

Note	For the 36581x and 36582x AutoCal modules, which only come in M-F versions, only the first type of AutoCal adapter removal will be available.



MODIFY 2-PORT AUTOCAL SETUP Dialog Box - Auto Sense ON - Adapter Removal - Internal Thru

Figure 8-5. AutoCal Setup Dialog with Adapter Removal Selected

8-5 Network Extraction

De-embedding is covered in detail in Chapter 10, "Calibration and Measurement Enhancements" but since the generation of files for some de-embedding exercises is so closely tied to adapter removal; it will be briefly discussed now. De-embedding is the removal of the effects of a network from a set of data. This network could represent an adapter or fixture among other things. To perform the de-embedding, the parameters of this network must be known. While there are many methods of deriving these parameters (including simulation), measurement in some way is often preferred. Because of the complex and incompatible media that may be involved, techniques using multiple calibrations (in different connectors or different media) or techniques using a pair of adapters/fixtures back-to-back are sometimes employed.

For the two port VNA, there are four types of extraction techniques available and are shown in the NETWORK EXTRACTION dialog box shown below in Figure 8-6.

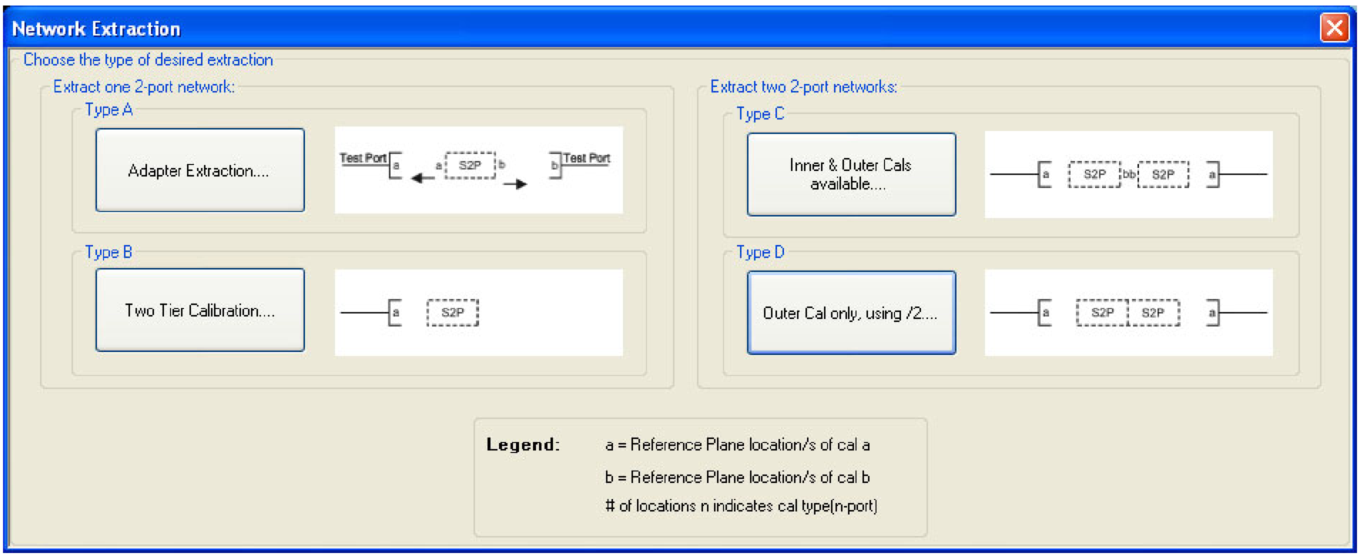


Figure 8-6. NETWORK EXTRACTION Dialog Box - 2-Port VNAs

Type A - Two Full 2-Port Cals

Two full 2-Port calibrations are performed; one each with the adapter/fixture attached to one port then the other. A single S2P file describing the adapter/fixture is generated. This is directly the method of adapter removal except the parameter file is generated explicitly rather than the calibration being directly modified.

Type B - Two Tier Two 1-Port Cals

A two tier calibration, some times called 1-Port de-embedding or the Bauer-Penfield technique. Here a one port cal is performed and then another one port cal is performed with the adapter/fixture in place. This is very similar to type A except a thru connect is not required and the far-end match is determined differently. A single S2P file is generated.

Type C - Inner and Outer Cal

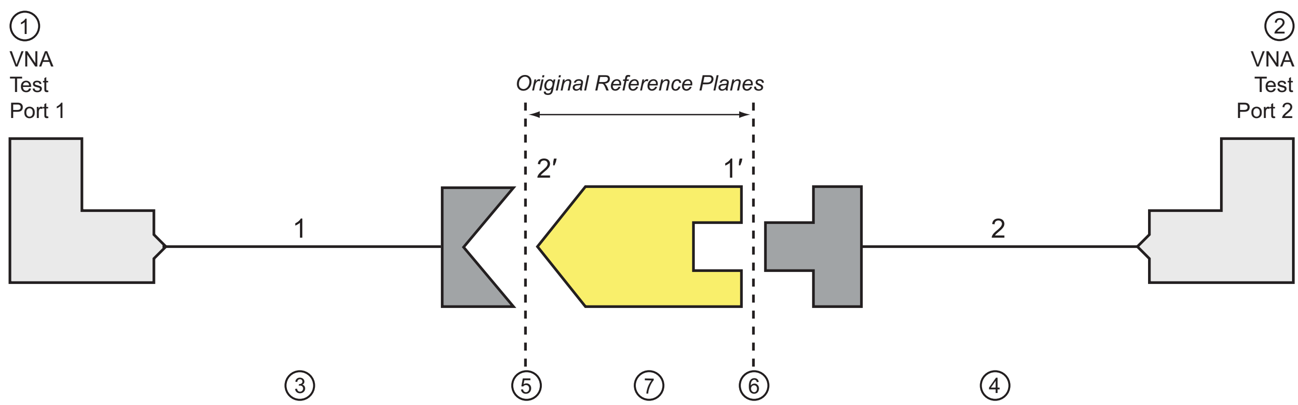
This is the network extraction method available in earlier generations of Anritsu VNAs where full 2 port calibrations are performed at the outer plane (often coaxial or waveguide) and at the inner plane (often a fixtured environment). Two S2P files are generated in this case.

Type D - Outer Cals Using the Divide-By-Two Method

This simplified method is used when standards at the inner plane are difficult to create (as in a complicated fixture structure). Two adapter/fixture “halves” are connected back-to-back and the combination measured using a single outer cal. Assuming the interconnect between the two halves is well-matched and the two halves are identical, S-parameters can be extracted. The match at the inner plane is assumed good (since no other information is available) so this technique is best used when the overall adapter/fixture return loss is quite high. Two S2P files are generated.

8-6 Network Extraction: Type A

As discussed above, the type A extraction uses exactly the same procedure and algorithm as adapter removal. Instead of directly modifying the calibration to remove the effects of the adapter/fixture, however, the S-parameters of the adapter/fixture are exported to an S2P file for later de-embedding or other uses. The reference plane diagram is repeated below for convenience. Two full 2-Port calibrations are required, one with the adapter on **Port 1** (so the cal is between 1’ and 2) and one with the adapted on **Port 2** (so the cal is between 1 and 2’).



1. Test Port 1	5. Original Reference Plane 2’, when adapter is connected to Port 2 Test Cable
2. Test Port 2	6. Original Reference Plane 1’, when adapter is connected to Port 1 Test Cable
3. Port 1 Test Cable	7. Adapter to be calibrated
4. Port 2 Test Cable	

Figure 8-7. Adapter Removal Block Diagram

The calibrations are performed and then the setups saved typically as an active channel CHX file type. The extraction dialog is shown below where these files are retrieved to perform the process. After “Perform Extraction” is selected, a new dialog will appear asking for the file name where the S2P data should be saved.

As with adapter removal, a few caveats apply

- The two calibration files must have the same frequency lists (i.e., same frequency range and same number of points).
- The cal algorithms and media types may be different but they must both be full 2-Port cals
- The adapter is assumed to be reciprocal ($S_{12} = S_{21}$).

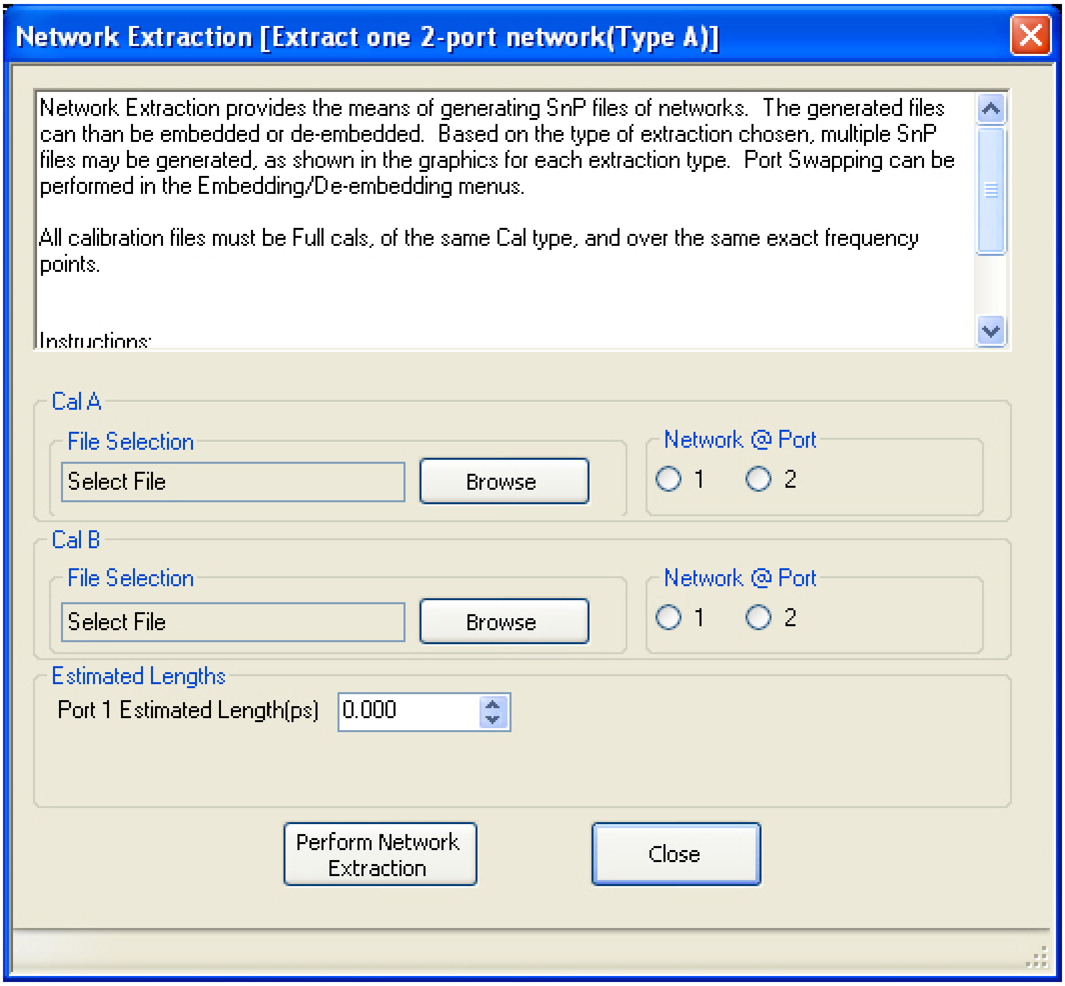
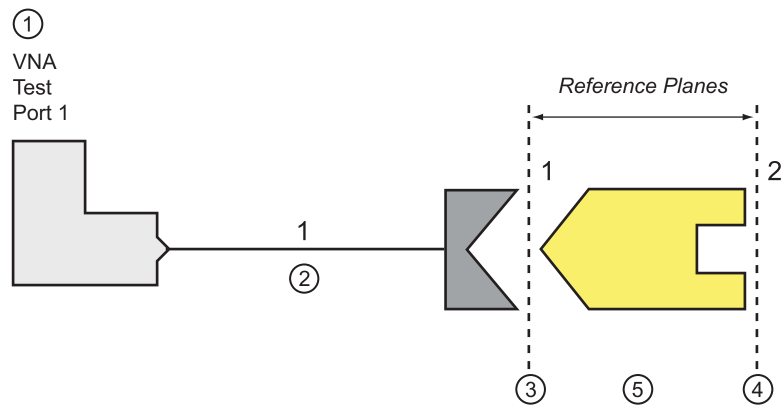


Figure 8-8. NETWORK EXTRACTION Dialog Box - Extract One 2-Port Network - Type A - 2-Port VNAs

8-7 Network Extraction: Type B

The Type B extraction is a simplification of Type A in that it only requires a pair of one port cals. This can be useful if a thru connect is difficult because of adapter/fixture configuration issues. This particular algorithm has a long history and is covered in the literature extensively (for example, *R. Bauer and P. Penfield, "De-embedding and unterminating," IEEE Trans. Micr. Theory Tech., vol. 22, pp.282-288, Mar. 1974.)*. As suggested by the figure below, a cal is performed at Plane 1 (often a coaxial or waveguide cal) and a second cal is performed at Plane 2 (could also be coaxial or waveguide in the case of an adapter or could be more complicated in the case of a fixture).



1. Test Port 1	4. Second Reference Plane at end of Adapter DUT
2. Port 1 Test Cable	5. Adapter DUT
3. Original Reference Plane for Port 1	

Figure 8-9. Network Extraction Type B Reference Planes

As before, the cals are performed and the setups saved, typically as an active channel CHX file type. The cal files are retrieved using the dialog below.

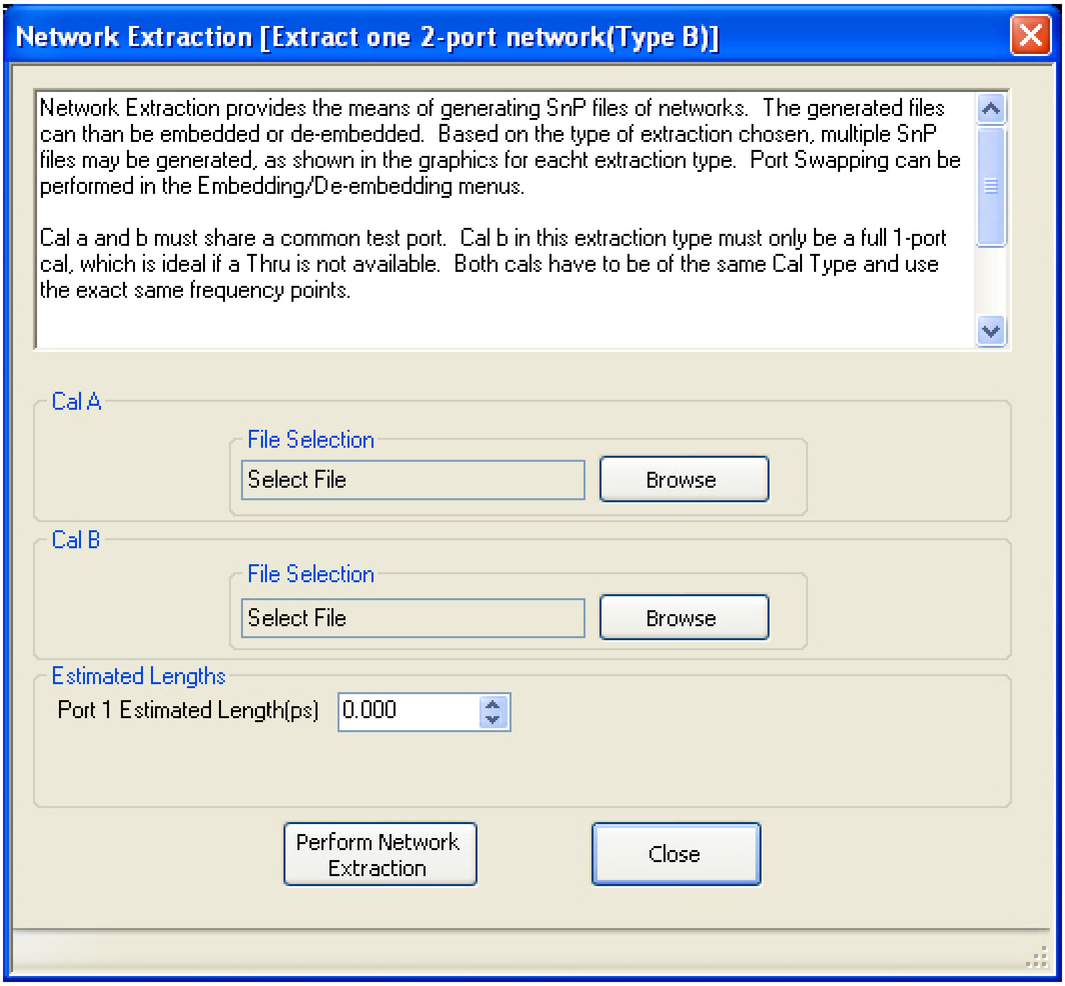


Figure 8-10. NETWORK EXTRACTION Dialog Box - Extract One 2-Port Network - Type B

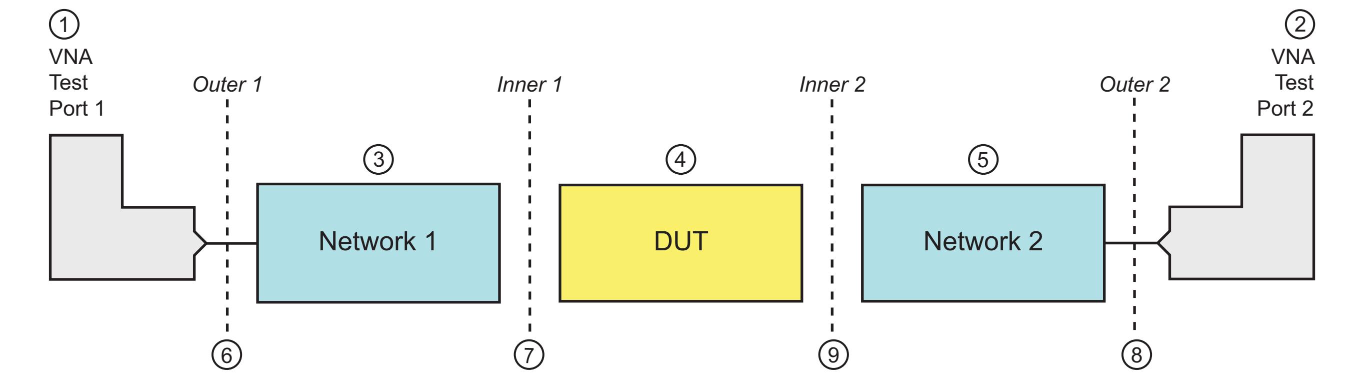
After Perform Network Extraction is selected, another dialog appears asking for the file name where the resulting S2P data should be saved. Different cal algorithms and media types may be selected but at least Cal B must be 1-Port only. Cal A can be a full two port cal or a double 1-Port cal (this way it is known how to compute the extraction). As with Type A, the adapter/fixture is assumed to be reciprocal and the frequency lists must be the same.

The results obtained with Type B may be somewhat different from those obtained with Type A since the algorithms are not the same. The main differences will be with respect to outboard match (at Plane 2 in Figure 8-9 above). In Type A, this match is determined with a full reflectometer solve while in Type B, it is determined with a source-match like extraction on the error X of the second cal. As a result, the Type B extraction of this match will be somewhat more sensitive to cal quality than will Type A (particularly with regard to the source match-determining cal components: O and S in OSL or the two shorts in SSL). The trade-off is simplicity and, in some cases, practicality.

8-8 Network Extraction: Type C

Type C is the most complete, dual fixture extraction approach offered in the VNA. It requires full 2-Port calibrations at two sets of reference planes but can fully determine the S-parameters of two networks independently.

Consider the diagram in NETWORK EXTRACTION dialog box (above in Figure 8-6). A calibration is required at the outer reference plane set and the inner reference plane set. The outer calibration can usually be done coaxially (or some other well-defined media) depending on the networks involved. The inner calibration is often more complicated and may be board- or wafer-level (and may require the user create calibration standards). Assuming these calibrations are possible, then the S-parameters of Network 1 and Network 2 can be found.



1. Test Port 1	5. Network 2 attached to Test Port 2
2. Test Port 2	6. Outer Reference Plane 1
3. Network 1 attached to Test Port 1	7. Inner Reference Plane 1
4. DUT attached to Network 1 (on left) and Network 2 (on right)	8. Outer Reference Plane 2
	9. Inner Reference Plane 2

Figure 8-11. Network Extraction Process Diagram for Type C Networks

Two port calibrations at two different reference plane sets are used to extract the S-parameters of the intervening networks (often test fixtures). The dialog for loading the two calibrations is shown in NETWORK EXTRACTION [Extract Two 2-Port Networks (Type C)] dialog box below.

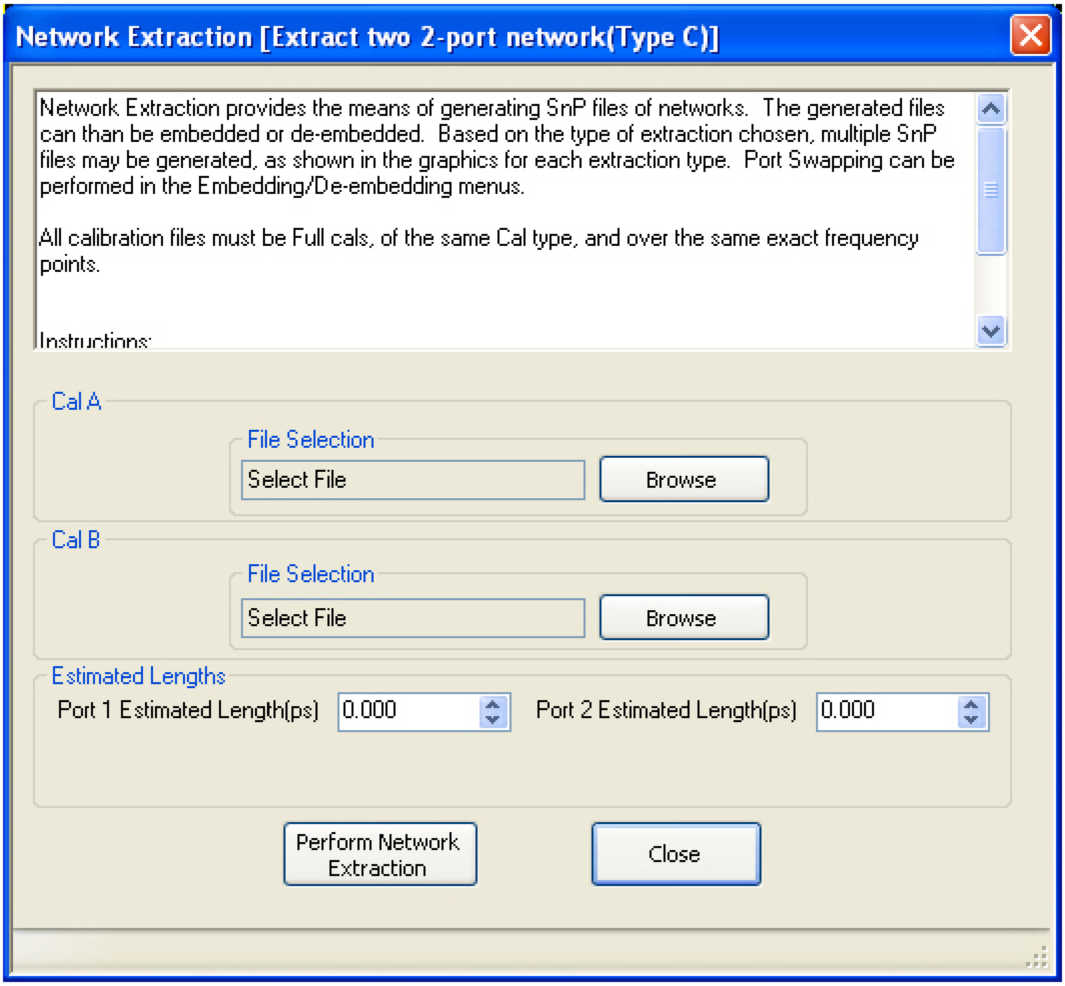


Figure 8-12. NETWORK EXTRACTION Dialog Box - Extract Two 2-Port Networks - Type C

As before, the two calibrations are performed and the setups saved, typically as an active channel CHX file type.

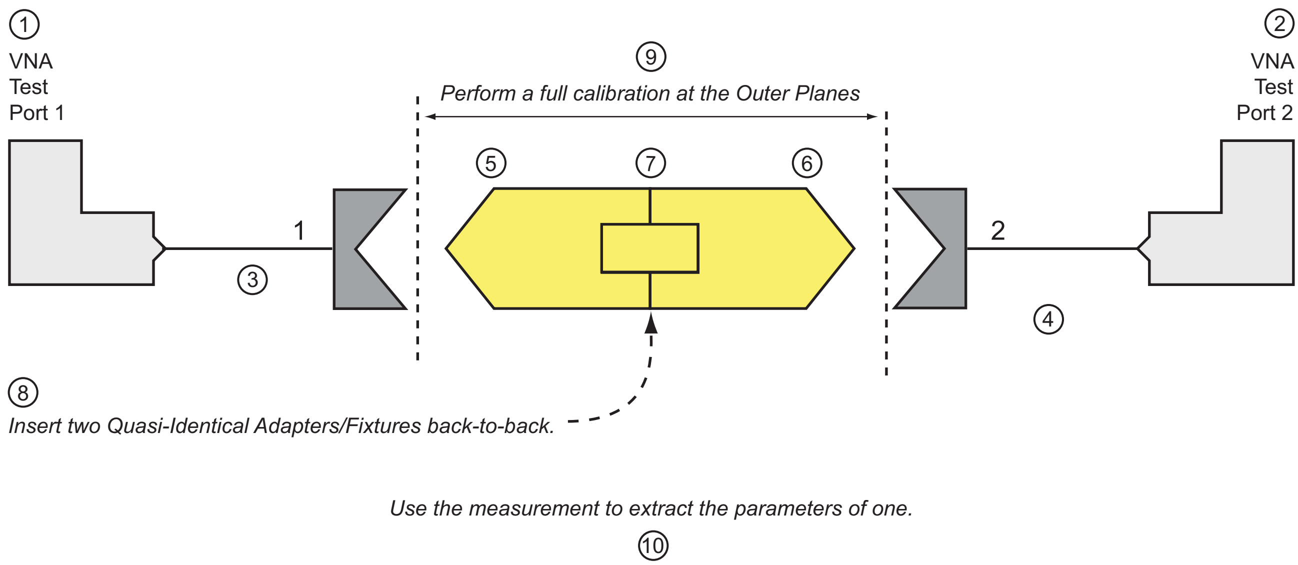
Some conditions:

- The two calibrations must be full 2-Port cals and must have the same frequency lists.
- After extraction is performed, a file dialog will appear allowing the user to indicate where the S2P files should be stored.
- The networks are assumed to be reciprocal.

Unlike Types A and B, this method determines the two fixture halves completely and independently. As a trade-off, a complete set of standards at the inner plane are now required. Algorithmically, this type is very similar to Type A except two networks are processed simultaneously. If the inner cal standards can be successfully made/acquired, the inner match values extracted will typically be more stable than those acquired with a Type B analysis for the reasons discussed in the previous section.

8-9 Network Extraction: Type D

Type D is considerably different from the other techniques in that it relies only on a single back-to-back measurement to extract parameters rather than relying on the manipulation of a pair of calibrations. A full 2-Port calibration is performed at the outer planes and two adapter/fixture "halves" are connected back-to-back as suggested in Figure 8-12 below. This simple technique is appropriate when it is just not practical to create standards at the inner plane (other than a thru connection effectively) and some estimate of the insertion loss of the fixture is needed. The technique does a minimal job of match extraction and allocates all mismatch to the outer plane of the adapter/fixture half (since no other information is available, $S_{22} = 0$). The technique is not recommended (unless there is no other option) if the adapter/fixture return loss is very poor. With a 20 dB RL, there will be generally 0.3 dB or more of insertion loss uncertainty with this technique (as opposed to ≅<0.1 dB with other techniques if good standards are available). With a 10 dB RL, it will be several dB of uncertainty. As with the other techniques, reciprocity is assumed.



1. Test Port 1	7. Adapter to Adapter Connector
2. Test Port 2	8. Insert two quasi-identical adapters or fixtures back-to-back.
3. Port 1 Test Cable	9. Perform a full calibration at the Outer Planes of the three adapters.
4. Port 2 Test Cable	10. Use the measurements to extract the parameters of one adapter.
5. Port 1 Adapter	
6. Port 2 Adapter	

Figure 8-13. Network Extraction Type D Inner and Outer Planes

The dialog is a very simple one and is shown in below. The outer calibration should be active when this procedure is called since files are not recalled as with the other techniques. Because it is sometime difficult to allocate or interpret the match terms, a check box is provided to ignore those terms altogether. In this case, $S_{11} = S_{22} = 0$ (linear) in the exported S2P file. As with the other techniques, a dialog will appear upon execution to allowing the naming of the destination S2P file.

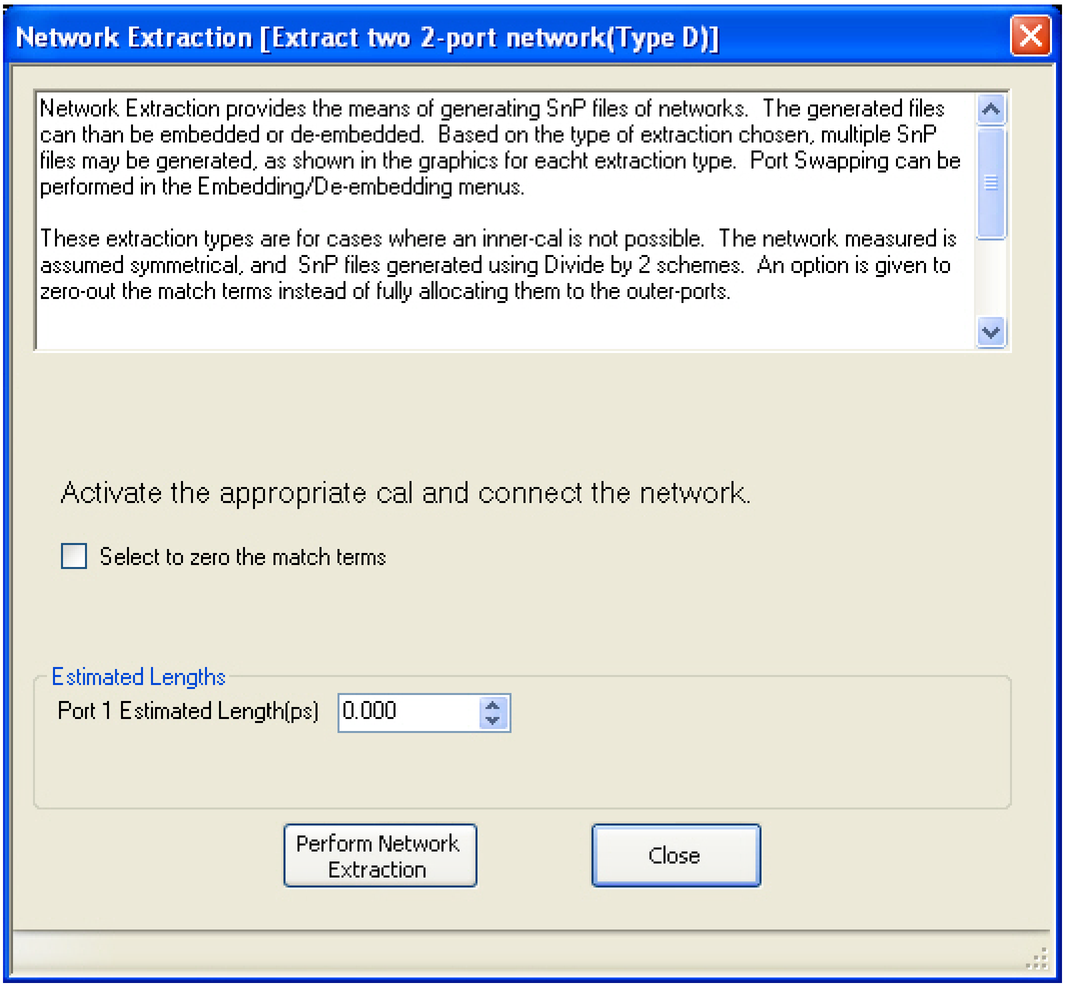


Figure 8-14. NETWORK EXTRACTION Dialog Box - Extract Two 2-Port Networks - Type D

8-10 Summary

A series of techniques have been presented for handling and studying the problem of non-insertable DUTs. Adapter removal is a 2-calibration technique for removing the effects of an adapter from a given calibration setup (e.g., when the DUT has one coax port and one waveguide port). Network extraction is somewhat more basic in that it tries to extract the S-parameters of the complicating adapter/fixture so that it can be de-embedded later. Four different types of extraction were presented with various trade-offs in cal complexity, simplicity, and uncertainty.

Chapter 9 — Other Calibration Procedures

9-1 Overview of Other Calibration Procedures

This chapter discusses other calibration procedure not covered in the previous material. These include Thru Update, Cal Merge, Hybrid Cal, and Flexible Calibrations. Although adapter removal and network extraction are on the CAL OPTIONS menu with these items, they were covered separately in Chapter 8 above.

9-2 Through (Thru) Update

A common question related to calibrations is how often the calibration must be redone. The frequency of re-calibration depends on the environment (both in terms of temperature stability and in terms of the cable/fixture construct that is being used). A calibration lifetime is often limited by the stability of the test port cables through drift or motion. Drift defects directly affect transmission tracking and load match, so if those terms could be easily refreshed, the time before the entire calibration had to be redone could be extended. This is the concept of a Thru Update.

The idea is to connect just a through line and quickly refresh the transmission tracking and load match terms without great effort. A Thru Update is a one-step calibration that can be used to refresh a current full 2-Port or 1 path-2 port calibration.

Like the thru step in other calibrations, the length of the line being used as well as its loss can be specified to ensure minimal disruption of the reference planes (see Figure 9-1). The entry methods for these parameters are the same as in the normal calibration procedures.

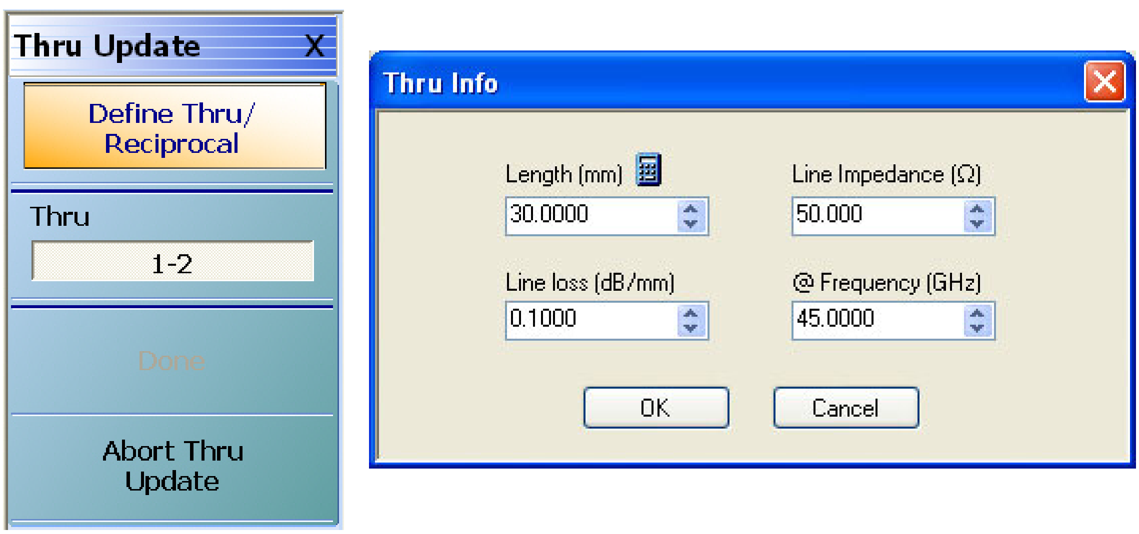
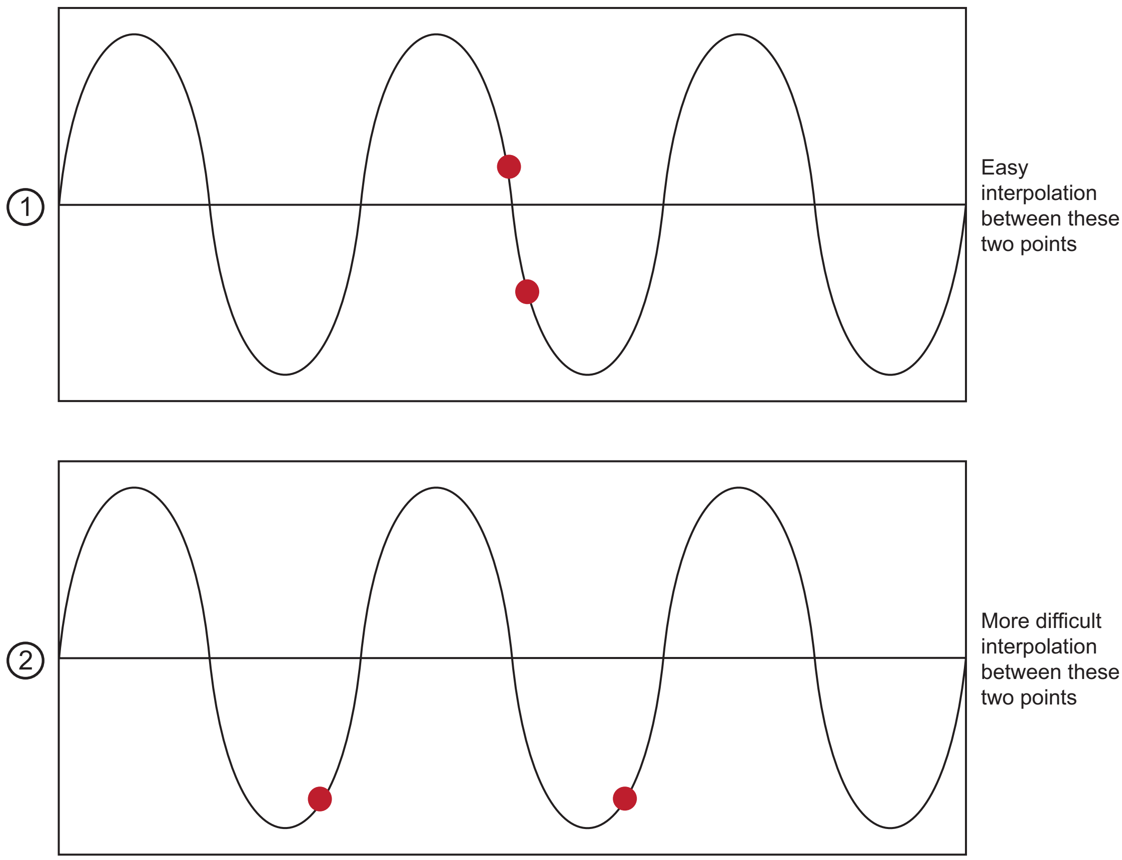


Figure 9-1. THRU UPDATE Setup Menu and THRU INFO Dialog

9-3 Interpolation

Typically, calibration is done for a specific list of frequencies and then measurements are made over that same list of frequencies. While this is most accurate, it is not necessarily convenient. If, for example, one is measuring a variety of narrow bandpass filters of different center frequencies, it may be useful to be able to zoom in to look at the passband of each filter without re-calibrating. Interpolated calibrations are allowed for purposes like this one. The theory is that the error coefficients are all carefully interpolated between calibration points to minimize possible error.

To see the cause of error, note that the cable runs within the instrument and the cables that the user provides typically result in a large electrical length. Thus the error coefficient magnitude versus frequency is often periodic in shape. If the interpolation is not performed with care, large errors can result (see Figure 9-2).



Step size, interpolation effects, and possible errors.	2. More difficult interpolation between these two points.
1. Easy interpolation between these two points.	

Figure 9-2. Effect of Step Size on Interpolation

As a general rule, the smaller the step size used during the calibration, the more successful the interpolation will be. It is desirable to keep the step size smaller than the ripple period of the coefficients which will typically range from 50 MHz to 500 MHz. The smaller number is for setups with very long test port cables and fully optioned systems; the larger numbers for setups with short test port cables and with Options 051, 061, and 062. The menu to select interpolation is shown below in Figure 9-3.

Figure 9-3. CAL OPTIONS Menu

The calibration interpolation menu will default to OFF where points used during measurement must correspond to calibration frequency points. When interpolation is ON, other points may be used. In neither case may frequencies outside of the calibration frequency range be used.

9-4 Cal Merge

When multiple calibration algorithms are needed (covering different frequency ranges) and the usual calibration approaches are not adequate, any calibrations of the same type may be combined. A common example is the broadband coaxial W1 calibration where SOLT is used at low frequencies and SSST is used at high frequencies.

This starts off as merging a pair of calibrations but the operation may be repeated any number of times. The utility simply combines the error coefficient arrays of the various calibrations while rationalizing the frequency lists as best as possible. Some points to keep in mind:

- **Frequencies**

  If all frequencies are distinct, all points will be maintained.

- **Frequency Points**

  If any frequency points are in both calibrations, the coefficients from the first calibration (see Figure 9-4) will be used.

- **Number of Points**

  The combined number of frequency points may not exceed the current limit of the instrument which is either 25,000 or 100,000 points depending on the VNA mode.

- **Calibration Small Steps**

  Since different calibration algorithms can be used, small steps may appear in the data where the calibrations overlap (assuming the cals were all of good quality).

- **Segmented Sweep**

  The combined calibration will have its frequency list and other setup information loaded in a segmented sweep structure but it is not editable.

The dialog for this utility is shown in the CAL MERGE shown below in Figure 9-4.

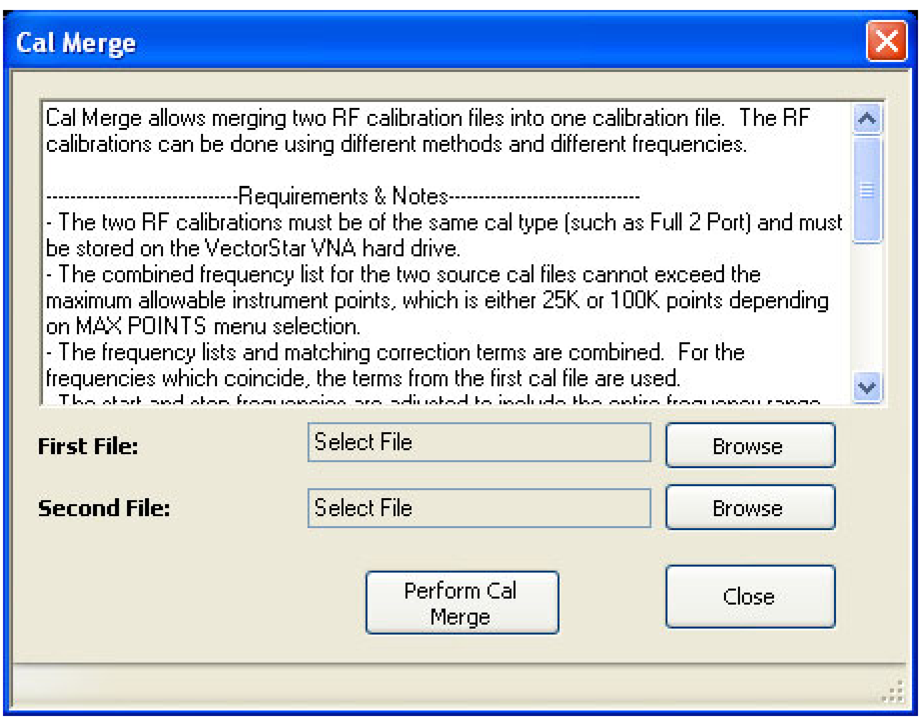


Figure 9-4. CAL MERGE Dialog Box

In the case of waveguide calibrations, an overriding cutoff frequency should be specified (for reference plane rotations and other dispersion processing events). When the merge is complete, the combined calibration will be resident in memory but will not automatically be saved. The user must save the combined calibration manually if desired.

9-5 Hybrid Calibrations

The hybrid calibration is a method of taking a pair of distinct 1-Port calibrations, together with some additional measurements, to create a new full 2-Port calibration. The "hybrid" part of the definition comes in that the two 1-Port calibrations may be with completely different connector types, media types, and/or cal algorithms. One example may be a case where it is desired to have Port 1 in coax but Port 2 in waveguide. This is conceptually similar to some of the adapter removal and network extraction discussions in Chapter 8, but here a little more flexibility is offered on the calibration side. In particular, the through completion step may be a reciprocal device only (thus bringing in SOLR concepts).

Generally the two 1-Port cals are performed in advance and the setups saved, typically as an active channel CHX file type. One enters the dialog below and specifies those cal files. Then the "through" between the two ports is specified using the usual THRU INFO dialog format. In the case of a physical through, length and loss information is specified. In the case of a reciprocal, a length estimate is requested to simplify root choice.

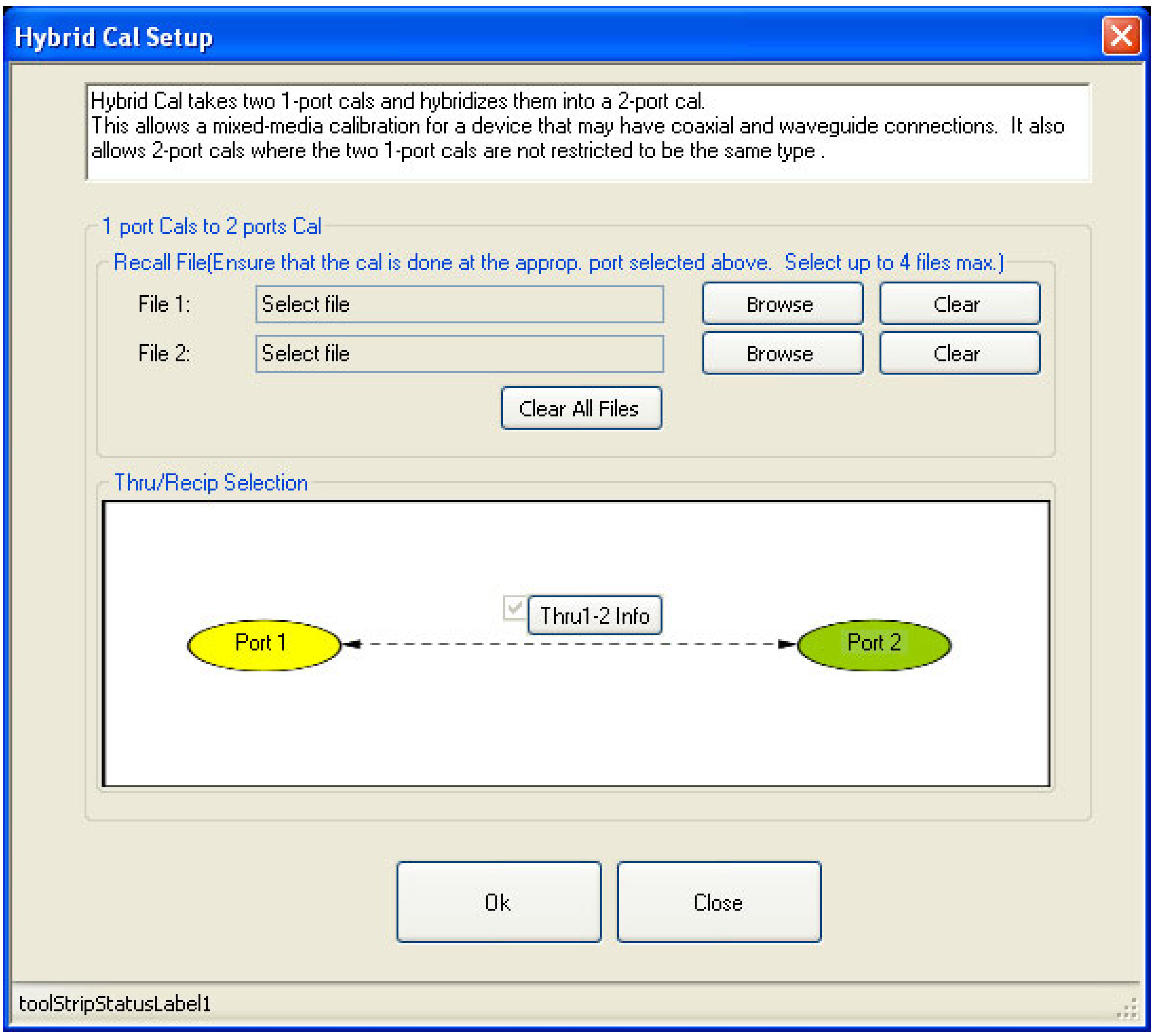


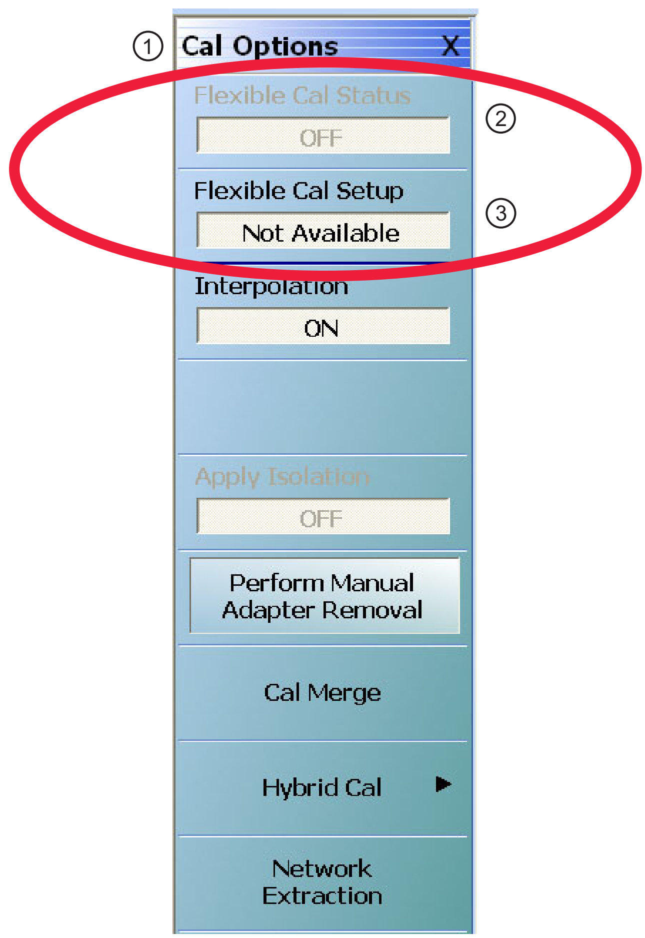
Figure 9-5. HYBRID CAL SETUP Dialog Box

As with the adapter removal and network extraction procedures, the cal files used here must be based on the same frequency lists (same frequency range and same number of points at least). In this case, the files must both describe full 1 port calibrations.

9-6 Flexible Calibration

Another selection under the CAL OPTIONS menu is a utility called Flexible Cal. The purpose of this utility is to speed measurements if the full correction capability of a given calibration is not needed and it is desired to not perform and recall a simpler calibration (to simplify a manufacturing test situation for example). For example, one may have performed a full 2-Port cal but then, for a period of time, need only measure S_{11} for a device with little transmission to Port 2. If one stayed with the parent cal, two sweeps would always be performed (Port 1 driving and Port 2 driving) even though only one is needed for the measurement. Flexible cal allows one to temporarily and quickly suspend the unneeded measurements to speed up the process.

This utility is only available when a full 2-Port cal has been performed (otherwise a subset makes little sense). If a lower order calibration has been performed, the feature will be labeled as Not Available. If a full 2-Port cal exists, the CAL OPTIONS menu will appears with the Flexible Cal Terms button highlighted. The buttons will only be available if a full 2-Port cal exists.



1. CAL OPTIONS Menu 2. Flexible Cal Status Button – Only available when a full 2-Port calibration exists.	3. Flexible Cal Setup Toggle Button – Only available when a full 2-Port calibration exists.

Figure 9-6. CAL OPTIONS Menu - Flexible Cal Status Button Highlighted

The Flexible Cal Setup button will bring up a dialog like that shown in FLEXIBLE CAL SETUP Dialog Box.

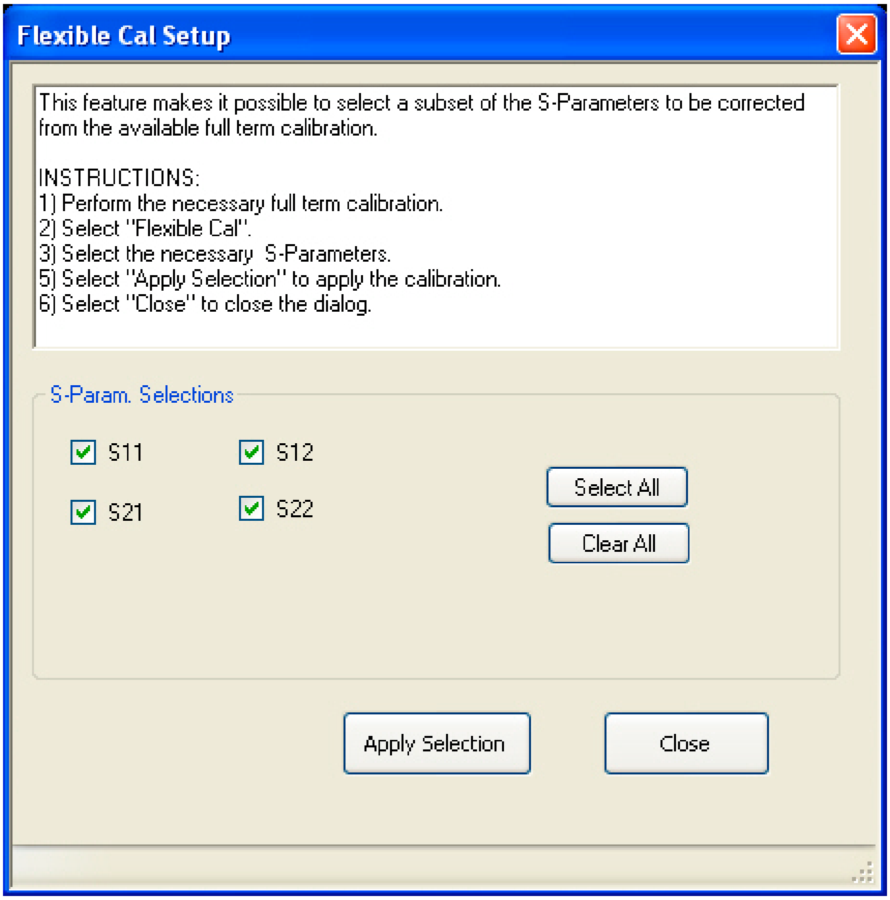


Figure 9-7. FLEXIBLE CAL SETUP Dialog Box - Full Term Cal

Instructions

This dialog is very simple to use.

Perform the necessary full term calibration. On the CAP OPTIONS menu, select Flexible Cal Setup. Select which S-parameters you wish to be measured. Unneeded sweeps will not be performed even though the parent calibration is a full 2-Port (for example, if S_{11} and S_{21} only are selected, only the Port 1-driving measurements will be performed). The highest level calibration possible based on the selected parameters will be performed. When ready, select Apply Selection then Close to close the dialog.

Examples:

- S_{11} only is selected: execute as a full 1-Port cal.
- S_{22} and S_{12} only are selected: execute as a reverse 1-path-2-Port cal.
- S_{12} and S_{21} only are selected: execute as a transmission frequency response cal.
- All four are selected: execute as the parent full 2 port cal.

Chapter 10 — Calibration and Measurement Enhancements

10-1 Chapter Overview

This chapter provides a description of functions that provide additional calibration, post-processing, and display options that increase the usefulness of the instrument data. The topics described include: embedding/de-embedding, reference-plane control and modification, and impedance transformations.

A number of functions are provided beyond the basic calibration and display tools to help post-process the data in a way that is useful. The topics described relate to virtually modifying the environment in which the DUT resides.

These topics include

- **Embedding/De-embedding**

  This is the virtual removal or insertion of networks or circuits around a DUT that may represent fixtures, launching structures, tuning elements, or other items.

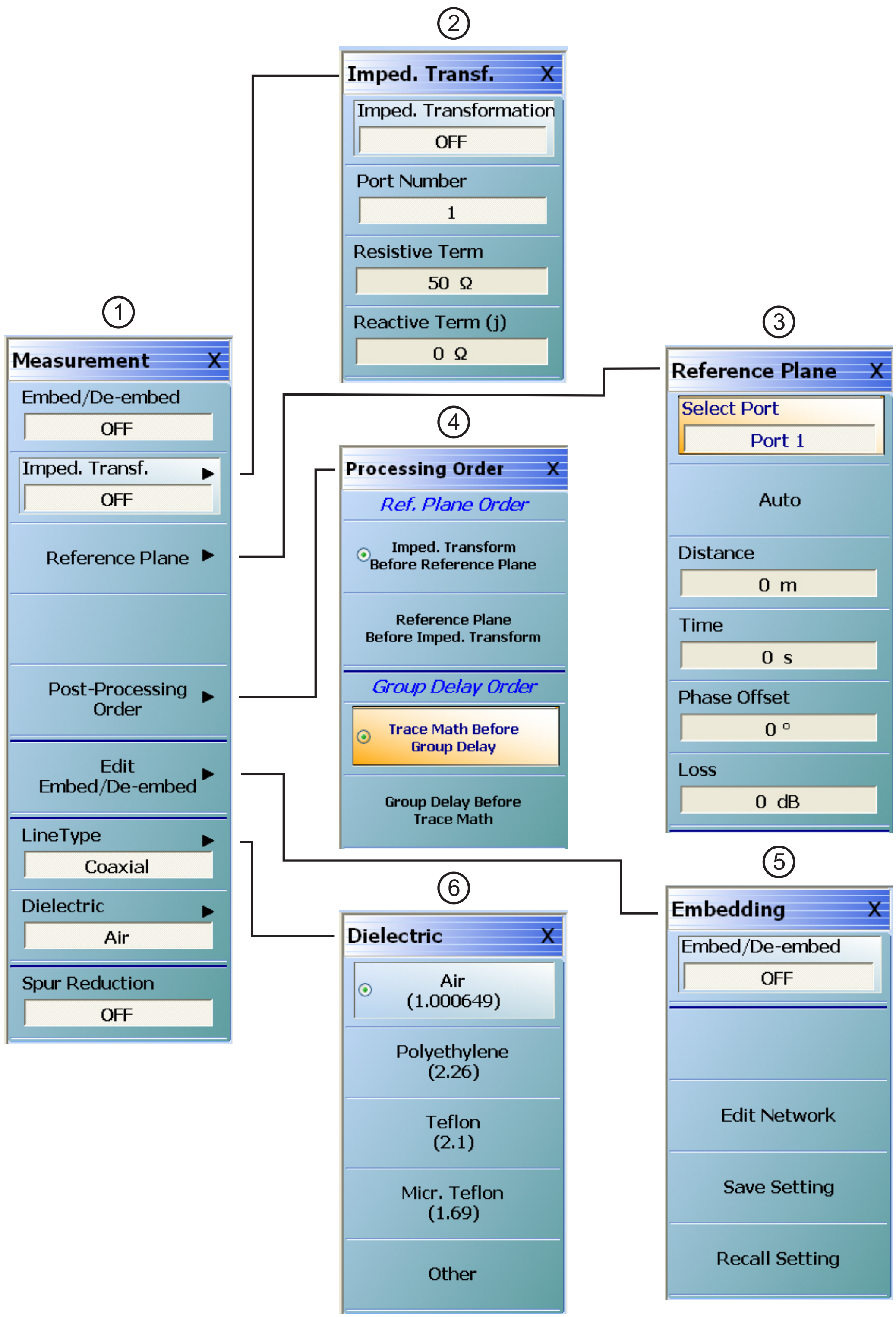
- **Reference Plane Control**

  This can be thought of as a simpler subset of de-embedding in which transmission line lengths and loss are removed from the measured data.

- **Impedance Transformation**

  When calibration components are not available in impedances other than 50 ohms, it is possible to view the data as if the VNA had been calibrated in some other impedance.

In addition, there are some clerical tasks to describe including the order of virtual operations and some conversions to other parameter formats (impedances and admittances for example). The measurements menu that contains the majority of these functions is shown below (Figure 10-10, “REFERENCE PLANE Control Menu” on page 10-13). Parameter conversions are a per-trace function (as opposed to the others which are per channel) and is listed under the DISPLAY menu.



Use menus #1, #3, #4, and #5 for Embedding/De-embedding. 1. MEASUREMENT menu 2. IMPED. TRANS. menu – Impedance Transformation	3. REFERENCE PLANE menu 4. PROCESSING ORDER menu 5. EMBEDDING menu.

Figure 10-1. The MEASUREMENT Menu Set

10-2 Embedding/De-embedding (E/DE)

The MS4640A Series VNAs are equipped with an embedding/de-embedding system. De-embedding is generally used for removal of test fixture contributions, modeled networks, and other networks described by S-parameters (s2p files) from measurements. Similarly, the embedding function can be used to simulate matching circuits for optimizing amplifier designs or simply adding effects of a known structure to a measurement. Multiple networks can be embedded/de-embedded (E/DE) and changing the port and network orientations is handled easily. An extraction utility is part of this package that allows the easier computation of de-embedding files based on some additional calibration steps and measurements.

It is extremely valuable to be able to virtually remove or add networks to the measured data as described above. The process of adding network data to measured data is termed “embedding” while the process of removing network data is termed “de-embedding.”

Embedding Tasks

Common embedding tasks are to:

- View results as if a different launch structure was present
- View results as if a new matching circuit was being used
- View results as if an added cable length or transmission line length was needed

De-Embedding Tasks

Common de-embedding tasks are to:

- Remove the effects of a test fixture
- Remove the effects of a launch or launching transmission line
- Remove the effects of a test matching circuit that will later be physically removed

The MS4640A Series VNA embedding/de-embedding engine (E/DE) is a flexible tool for performing tasks of this type. A number of different circuit element primitives are available and full S2P files can also be loaded.

Note	Circuit parameters for embedding-de-embedding network elements are stored in S2P files that can be loaded into the VectorStar.

Embedding On/Off Control

E/DE can be turned on and off with the Embed/De-embed toggle button at the top of the main MEASUREMENT menu as shown above (Figure 10-1) or with a duplicate toggle button at the top of the EMBEDDING control menu as shown below (Figure 10-2).

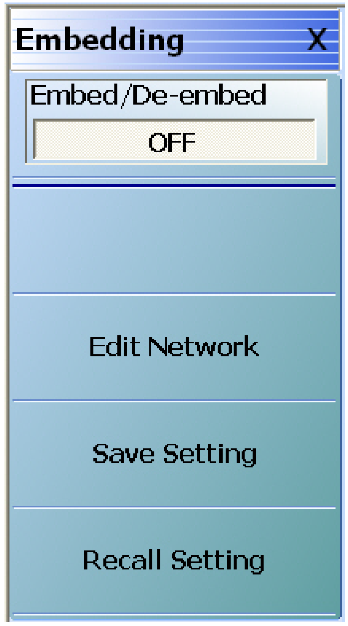
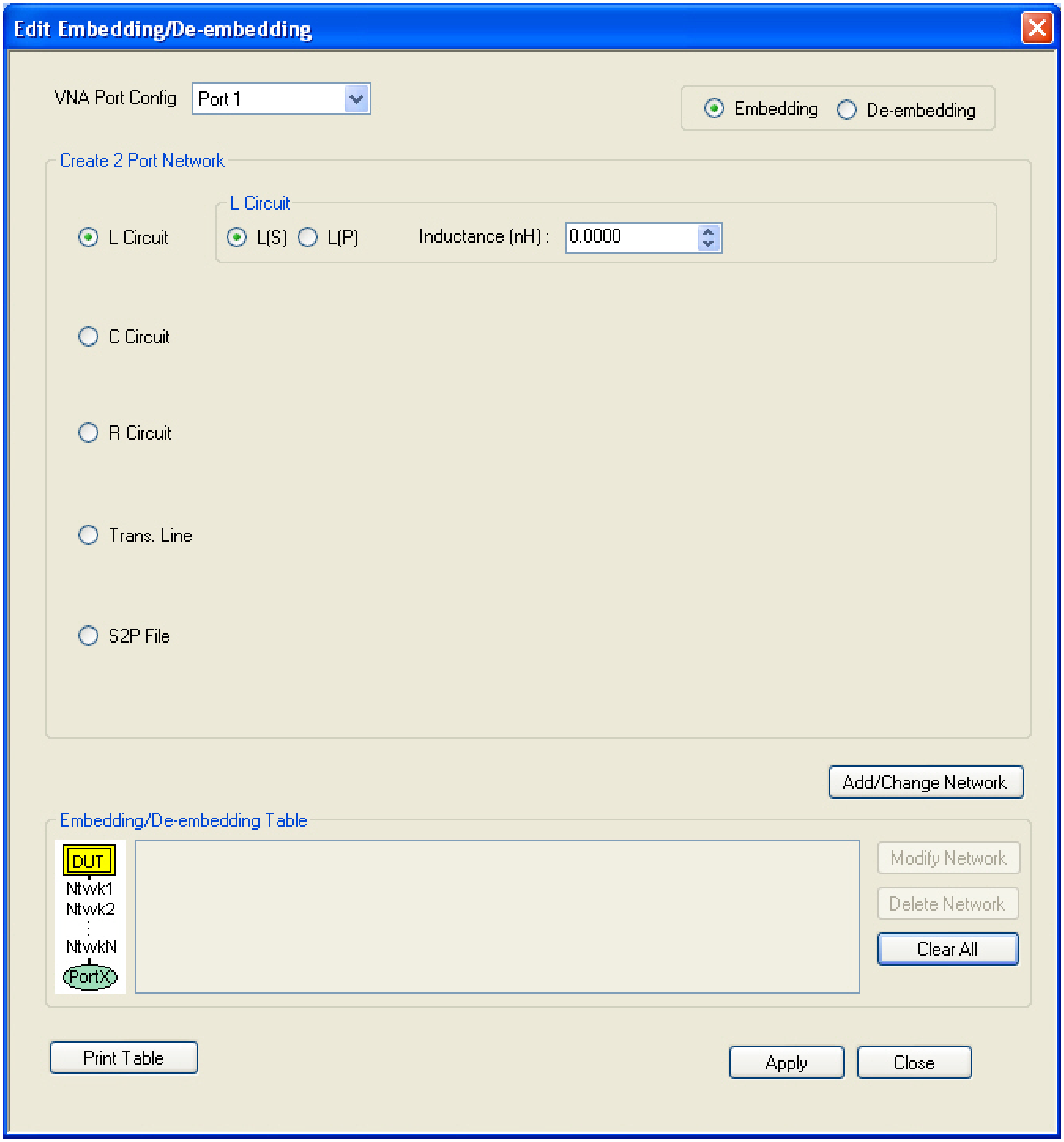


Figure 10-2. EMBEDDING Menu

Clicking on Edit Network displays the main EDIT EMBEDDING/DE-EMBEDDING dialog box. An example with Embedding, L Circuit, and L(S) selected, but with no network information entered is shown in the figure below.



L Circuit - L(S) - Embedding Selected

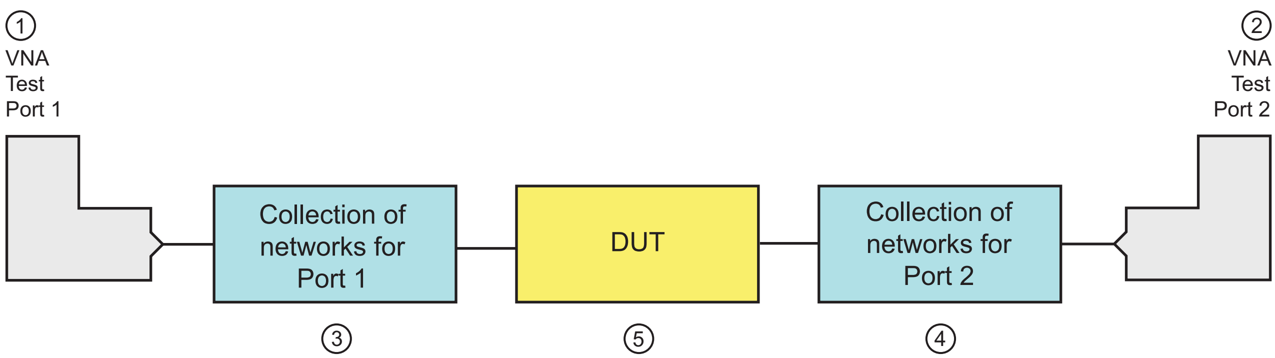
Figure 10-3. EDIT EMBEDDING/DE-EMBEDDING (2 PORT DUT) Dialog Box - L Circuit

Note	Embedding and de-embedding is setup for each port and the networks used on the two ports are entirely independent. Also, any number of networks can be cascaded at a given port and the first network entered is always nearest the DUT.

The key concepts for embedding and de-embedding are:

- Networks are setup on a per-port basis
- The networks used on the two ports are entirely independent
- Any number of networks can be cascaded at a given port

The first network entered is always nearest the DUT. The pull-down menu at the top of Figure 10-3 shows which port's networks are currently being edited. The diagram in Figure 10-4 illustrates the independence concept.



1. Test Port 1	4. Collection of networks attached to Port 2.
2. Test Port 2	5. DUT attached to Port 1 networks (at left) and Port 2 networks (at right).
3. Collection of networks attached to Port 1.	

Figure 10-4. Global EDE Diagram Showing Independence of Port Networks

Types of E/DE Networks

There are five types of networks that can be entered:

- Inductive elements
- Capacitive elements
- Resistive elements
- Transmission lines
- .S2P-defined, file-based networks

In the Edit Embedding/De-embedding dialog box in Figure 10-3 above, the radio button for entering an LC network has been selected. An additional version of the dialog box is shown in the figure below where a C(S) network has been selected.

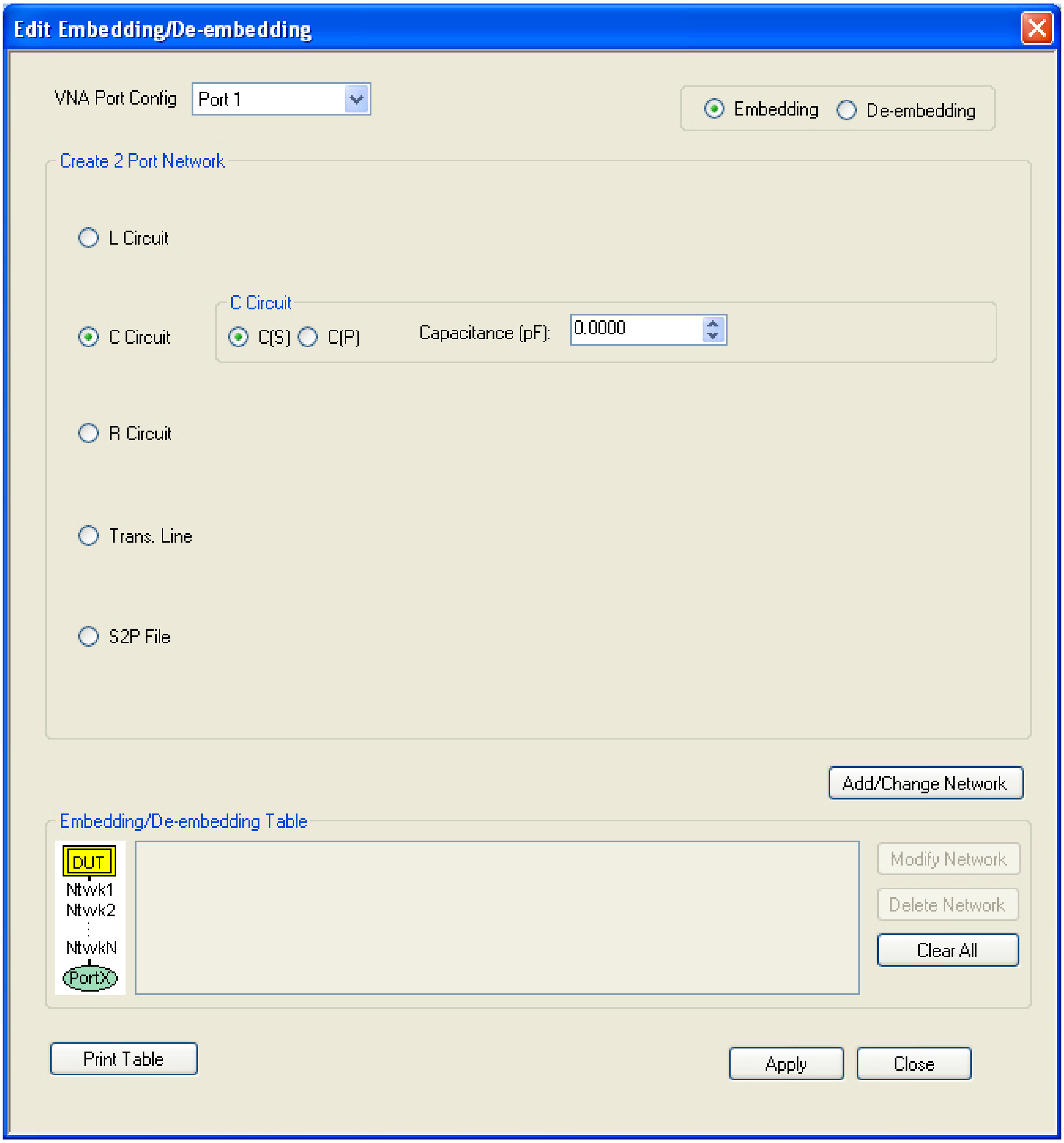


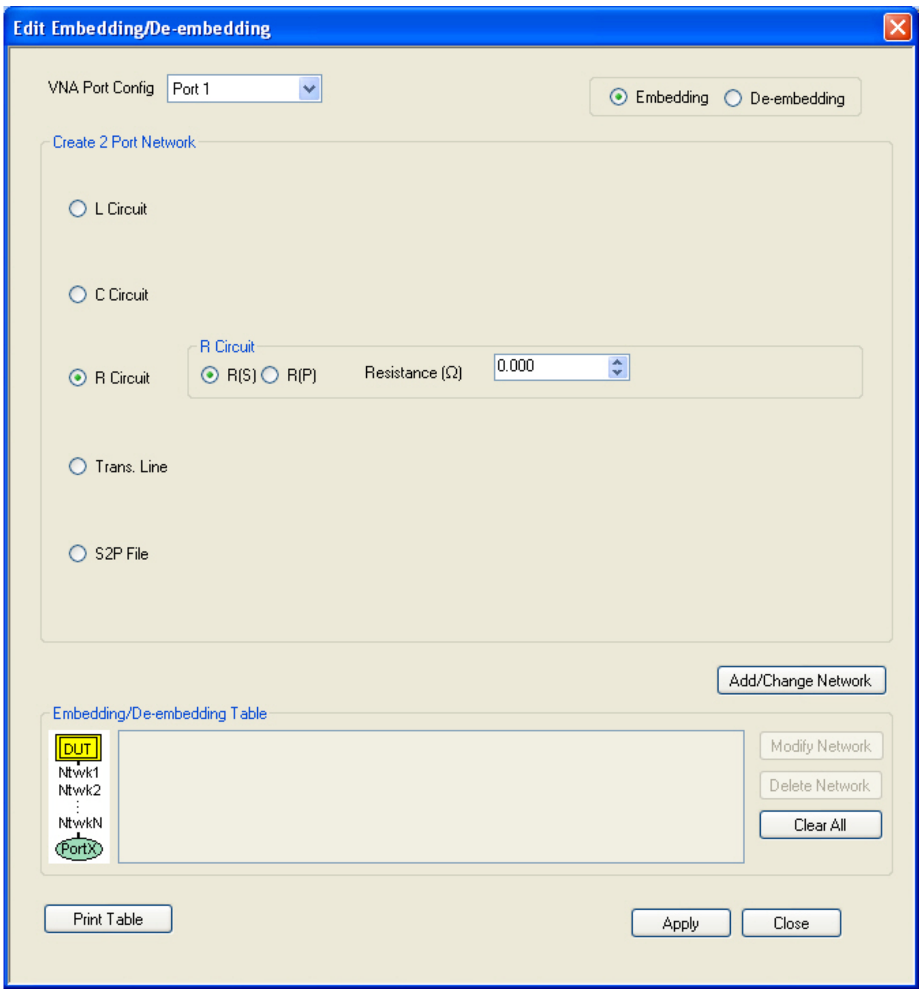
Figure 10-5. EDIT EMBEDDING/DE-EMBEDDING - C Circuit

Entry Mode for Resistive Elements

The entry mode for these resistive elements is shown in the E/DE dialog box below (Figure 10-6). Both series (denoted by an (S)) and shunt (to ground) elements (denoted by a (P) for parallel) are allowed and selectable with the radio buttons. Since this element is symmetric, no orientation knowledge (with respect to DUT port and VNA port) is needed. The default units are:

- Inductance: nH
- Capacitance: pF
- Resistance: Ohms

It should be emphasized that the shunt or (P) elements are always shunting to ground (not to the other port). If cross-port elements are desired, then the multiport version of the instrument should be used with an appropriate calibration.



Resistive Element Entry

Figure 10-6. EDIT EMBEDDING/DE-EMBEDDING Dialog Box - R Circuit Setup Selected

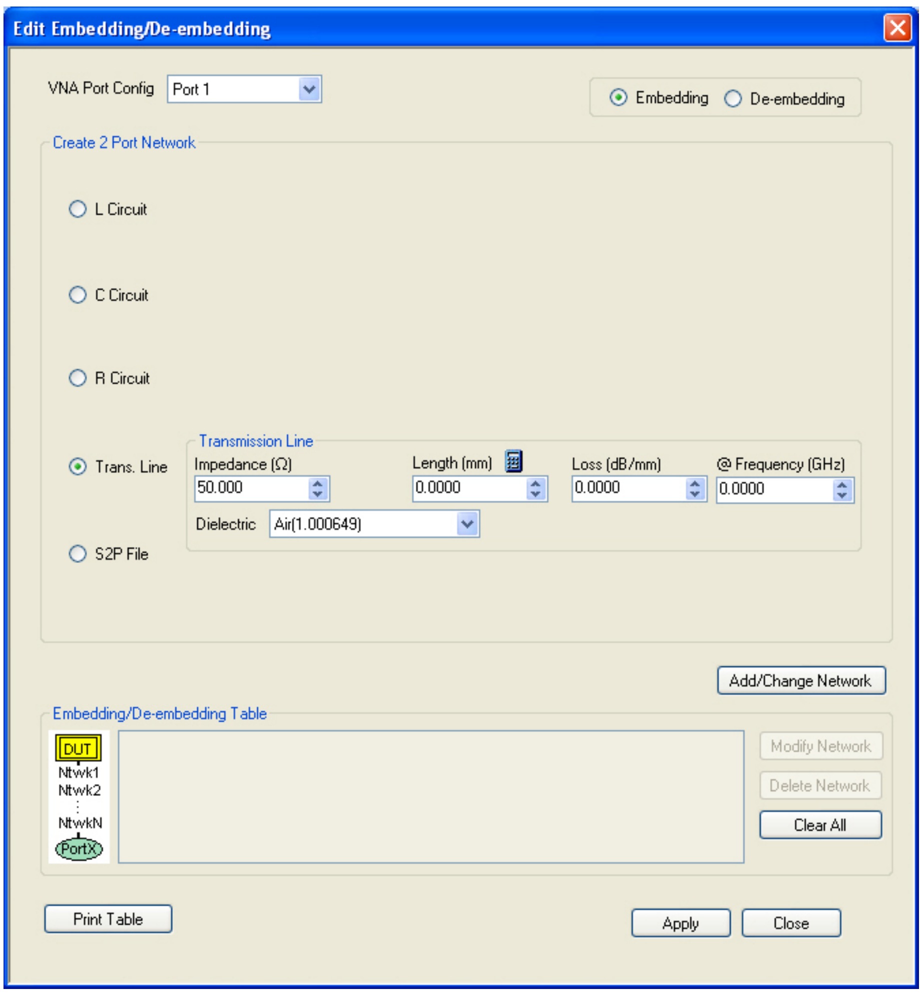
Entry Mode for Transmission Lines

Transmission line entry is illustrated in the E/DE dialog box below (Figure 10-7). As with transmission line entry in other parts of the system, loss can be entered along with a reference frequency. The loss at other frequencies will be computed using:

$$Loss\ (f) = Loss\ (f_0) \times \sqrt{\frac{f}{f_0}}$$

(Eq. 10-1)

As elsewhere in the system, if a 0 (zero) frequency reference is entered, the loss value entered will be used as a constant at all frequencies.



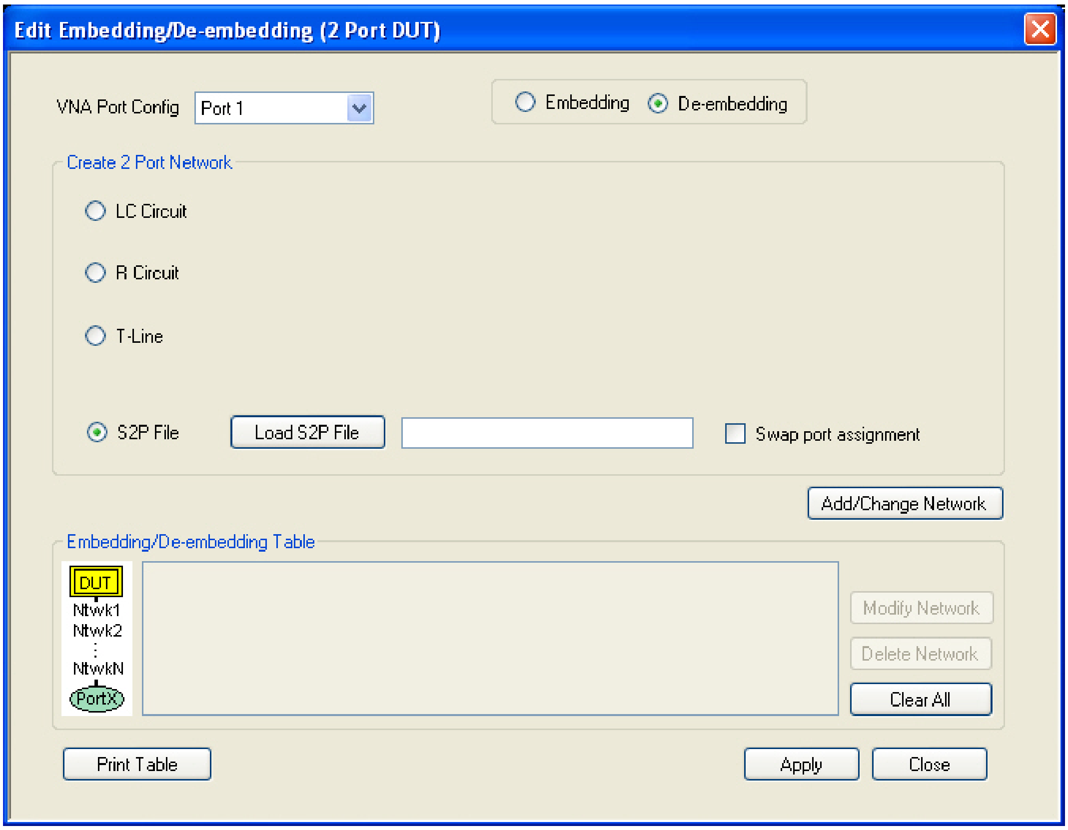
T-Line Selected - Transmission Line Element

Figure 10-7. EDIT EMBEDDING/DE-EMBEDDING Dialog Box

Physical line length is normally entered here along with a dielectric constant but the calculator icon shown in above in Figure 10-7 can be used (which links to the AIR EQUIVALENT LENGTH CALCULATOR dialog box) if only a time delay is known. Again, since this element is symmetric, no orientation knowledge is needed.

Entry Mode for S2P Defined File-Based Networks

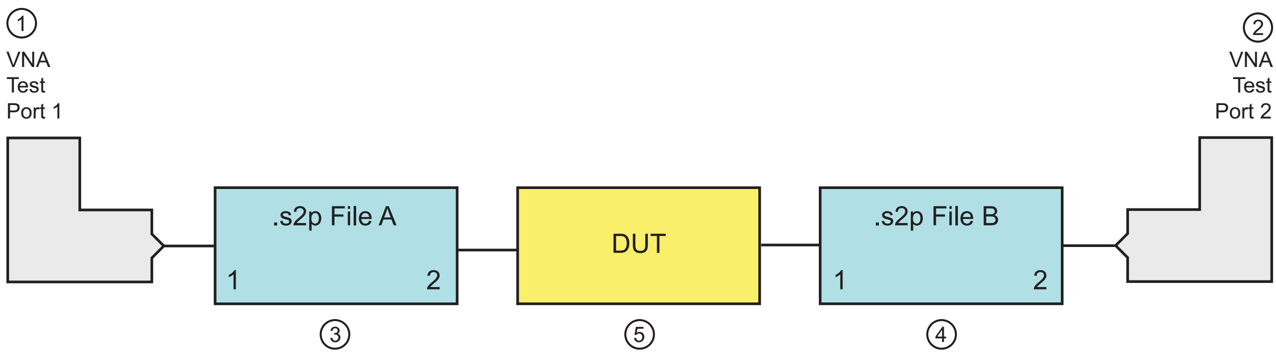
Finally, direct file entry of network S-parameters is shown in the E/DE below (Figure 10-8). A standard S2P file format is assumed and the headers will be interpreted. The system will attempt to interpolate the provided data the best it can in the context of the current channel sweep range. If there is no overlap between the sweep range and the file frequency range, an error will be generated.



S2P File - File-Based Element Entry

Figure 10-8. EDIT EMBEDDING/DE-EMBEDDING Dialog Box

Note	Note that the network Port 2 is always assumed to be closer to the DUT regardless of which VNA port is involved, as shown in Figure 10-9. If "Swap port assignment" is checked, the relationship is reversed.



1. Test Port 1	4. .s2p File B – Port 1 to left, Port 2 to right.
2. Test Port 2	5. DUT
3. .s2p File A – Port 1 to left, Port 2 to right.	

Figure 10-9. Orientation of Loaded S2P Files

Saving and Recalling Embedding Network Configuration

Once a set of networks (consisting of one or more individual networks) is defined, the E/DE configuration information can be saved to a file using the Save Setting button on the EMBEDDING menu (Figure 10-2, "EMBEDDING Menu" on page 10-4). Similarly, a stored E/DE setup can be recalled by using the Recall Setting button on the EMBEDDING menu.

The current E/DE setting is also saved as part of the master setup save (under the menu bar FILE menu) but multiple embedding and de-embedding circuits can be saved in these menus as well.

10-3 Reference Plane Control

A simplified means of performing de-embedding (and embedding in some contexts) can be accomplished using reference plane control. The function of this control is to remove transmission line lengths from the data. By entering a time or distance, this length of line will be removed (negative lengths are allowed to effectively add length). Various dielectrics and the full dispersion choices (see calibration section of the Measurement Guide for more information) are available as shown in the REFERENCE PLANE control menu below (Figure 10-10). The ports are handled independently, as in E/DE, and the current port being affected is indicated by the toggle at the top of the menu.

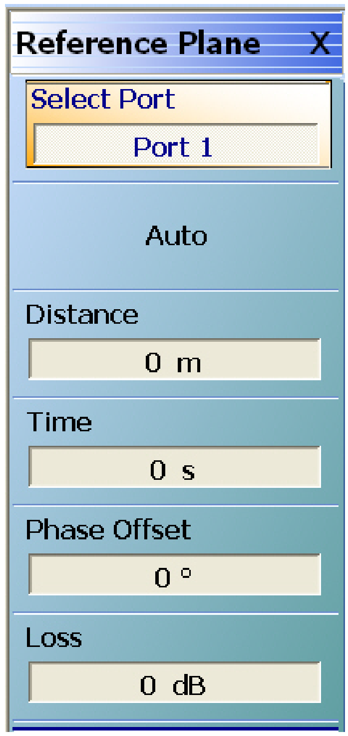
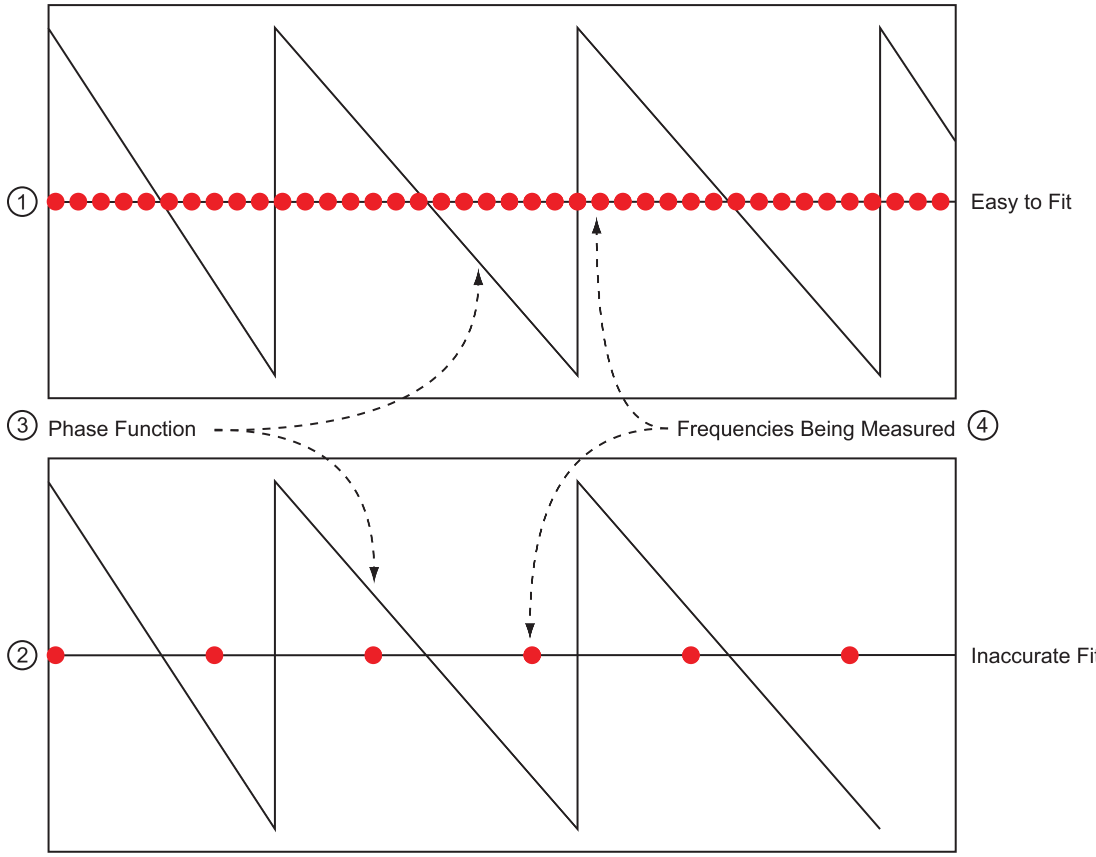


Figure 10-10. REFERENCE PLANE Control Menu

Auto Button Functions

The Auto button performs a best fit operation to the current phase data to estimate the equivalent line length. It will attempt to generate a line length that, when removed, will make the phase flat. This routine will be less accurate if the DUT has very non-linear phase (a dispersion function not matching that selected) or if the DUT is electrically long relative to the current frequency step size. This latter problem, related to aliasing, occurs because not enough information is being collected relative to the true behavior of the DUT phase function (see Figure 10-11 below). Increasing the frequency point density can help this problem.



1. Easier to Fit – Small frequency step size compared to phase function is easier to fit and yields higher accuracy. 2. Inaccurate Fit – Larger frequency step size compared to phase function is can produce inaccurate results.	3. Phase Function 4. Frequencies being measured.

Figure 10-11. Auto Reference Plane Function, Frequency Step Large Relative to Phase Period

The auto reference plane function can produce inaccurate results if the frequency step (the distance between the red ovals in the figure above) is large relative to the phase function period.

10-4 Impedance Transformation

Most VNA calibrations are performed referenced to 50 ohms as this is usually set by the calibration kit. While some calibration kits exist for other impedances (75 ohm N and F connectors for example), they are not common and a custom impedance may be of interest. The impedance transformation function allows performance of a calibration in one impedance and then transform the result to appear as if it had been calibrated in a different impedance. As a crude example, if a 75 ohm N calibration kit is not available, but a 50 ohm kit is, neglecting issues with adapters, the 50 ohm calibration could be performed and the utility used to reference the results to 75 ohms. The IMPED. TRANS. (IMPEDANCE TRANSFORMATION) menu for this function is shown below (Figure 10-12).

The ports can be set independently by using the Port Number toggle button and can be set to any complex value except 0 (zero). Generally, a non-real value will only have meaning in a narrowed frequency range.

A calibration must be active for impedance transformation to take effect and only those ports currently calibrated will be affected.

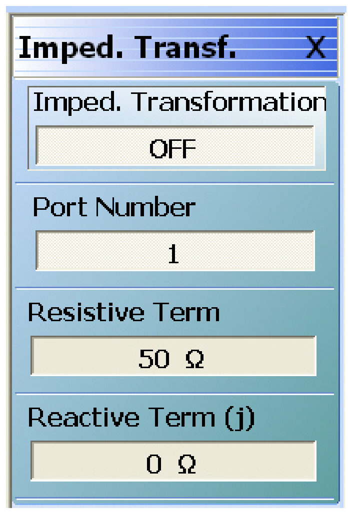


Figure 10-12. IMPED. TRANSF. (IMPEDANCE TRANSFORMATION) Menu

10-5 Processing Order

With so many post-processing choices available, it is important to note that the order of operations can matter. A few things are fixed by the way computations are performed and others are changeable to suit user needs. The sequence of computations is as follows for S-parameter measurements:

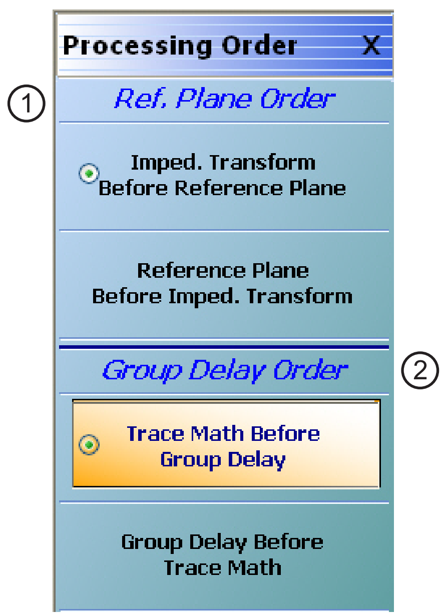
- Acquire raw data and average/filter
- Apply calibration if enabled
- Apply EDE if enabled (impedance transform and reference plane)
- Apply parameter conversions if enabled
- Apply time domain if enabled

Reference Plane Processing Sequence

The selectable item is the order in which impedance transformation and reference plane control are applied. This matters since the current impedance state determines the impedance of the line length that is adjusted using reference plane control (unlike in E/DE where the impedance can be specified). The menu to make this order selection is shown below (Figure 10-13).

Group Delay Processing Sequence

The second selectable item concerns the order of the group delay computation and trace memory. If trace memory precedes group delay (normal), then the complex operation can precede the numerical differentiation that is part of group delay. This could be useful to do a data normalization prior to connecting a DUT. If group delay precedes trace memory then the trace match will act on the final group delay result. An example might be a group delay comparison using data(-)memory.



1. Reference Plane Order controls (at top).	2. Group Delay Order controls (at bottom).

Figure 10-13. PROCESSING ORDER Menu

10-6 Conversions

While S-parameters (or the un-ratioed wave parameters) are usually the display variables of interest, conversions to other parameters may be required and are possible with the VectorStar.

1/S is sometimes plotted, particularly for oscillators and other negative resistance devices, where it is desirable to fold the outside of the Smith chart back to the inside. Equivalent impedances and admittances are commonly needed for device modeling and the Z and Y conversions can be used for this (note that these are not, in general, Z and Y parameters).

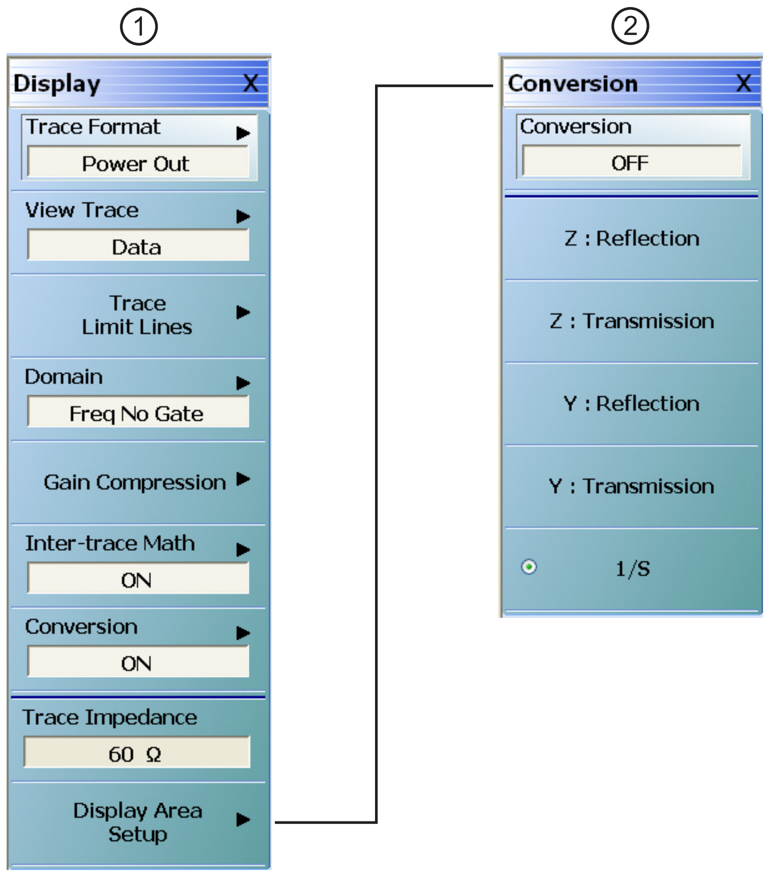
For each of these parameters, a conversion mode of reflection or transmission must be selected which indicates how the current parameter is to be interpreted. The calculations proceed as follows where X indicates the current displayed parameter such as S_{11}, S_{21}, b_1/a_1, a_2/a_1, and user-defined parameters:

$$
\begin{aligned}
Z_{reflection} &= Z_0 \frac{1+X}{1-X} \\
Z_{transmission} &= Z_0 \frac{2(1-X)}{X} \\
Z_{reflection} &= \frac{1}{Z_0} \frac{1-X}{1+X} \\
Z_{transmission} &= \frac{1}{Z_0} \frac{X}{2(1-X)}
\end{aligned}
$$

(Eq. 10-2)

Note that reflection Z or Y values here represents shunt impedances or admittances while the transmission values represent series impedances or admittances.

All of the choices available are on the CONVERSION menu shown in the figure below. Note that this function is *PER TRACE* and is located in the DISPLAY menu.



1. DISPLAY menu (on left).	2. CONVERSION menu (on right).

Figure 10-14. Conversion Control Menus

The calculations are a function of the current reference impedance which defaults to the calibration reference impedance unless impedance transform has been used (see the section above on “Reference Plane Control” on page 10-13) or the trace reference impedance has been changed.

Chapter 11 — Verification

11-1 Introduction to Verification

While there are many ways of verifying instrument performance, including the procedures described in the **VectorStar MS4640A Series VNA Operation Manual** and the **Maintenance Manual**, sometimes a simpler procedure can be useful. Verification kits available from Anritsu verify the measurement capabilities of the instrument by analyzing the measurement of artifacts that are traceable to national standards laboratories.

This chapter introduces and describes the verification process. Verification kits and software are available as a separate product and are described in detail in their associated documentation listed below:

- MS4640A Series VNA Operation Manual (OM) – 10410-00266
- MS4640A Series VNA Maintenance Manual (MM) – 10410-00268
- 366X-1 Verification Kits (3666-1 3.5mm Connectors, 3668-1 K Connectors, 3669B-1 V Connectors) and 3-2300-527 (67688) Performance Verification Software (PVS) User Guide – 10410-00270
- 366X-1 Verification Kits and 3-2300-527 (67688) PVS Quick Start Guide – 10410-00285
- 3656B W1 (1 mm) Calibration/Verification Kit and 2300-496 System PVS User Guide for the VectorStar ME/7838A/ME7828A and Lightning ME7808A/B/C BB/mm-Wave VNA Systems – 10410-00286
- 3659 0.8 mm Calibration/Verification Kit and 2300-558 System Performance Verification Software – 10410-00327

In Chapter 1, “Calibration Overview”, see “Calibration Kits, Verification Kits, and Components” on page 1-4.

11-2 Basic Concepts

There are many levels to the concept of VNA verification which, in one sense or another, is a comparison against expected behaviors.

Hardware Level

On the explicit VNA hardware level are operational checkout items such as port power, receiver signal levels, and noise levels. These items are covered in the Operation Manual. On the calibrated instrument level (which includes the VNA and the calibration kit or AutoCal) are the residual specifications (corrected directivity, source match, load match, and tracking) which are measured using traceable airlines (absolute impedance standards).

Intermediate System Level

An intermediate level which can look at overall system behavior (VNA, calibration kit, cables, environment) in a traceable fashion is through the use of a verification kit. While not intended for day-to-day use, the verification kit can provide a periodic check on system behavior without going through the rigor needed for full residual analysis (which can usually be done less often).

Comparison to Known Devices

The central idea of the verification kit is to have a collection of “known” devices (not calibration components) that have been measured with a calibrated VNA. By comparing the results to the “known” values, some measure of confidence can be gained in the measurement abilities of the VNA-under-test. The values in all cases are vector quantities so that both magnitude and phase responses are analyzed.

The “known” part of this discussion involves a process termed characterization performed on the same devices by Anritsu. Through a traceable process, a VNA at the factory is calibrated and validated against controlled standards before being used to measure the devices that go into the verification kit that is delivered to the user. By carefully controlling this process, measurement uncertainties on the characterization end can be carefully controlled. This allows a useful window to be defined as to what an acceptable measurement result is. At each frequency point, the measurement is compared to the characterization measurement in the context of the uncertainties. If the delta between the two measurements is consistent with the uncertainty window, the measurement is considered acceptable at that point.

Metric of Comparison

The metric of comparison, termed E_n, is a check to see if the measurement differences are consistent with the uncertainty windows of both the characterization and the verification measurements. The quantity is shown below:

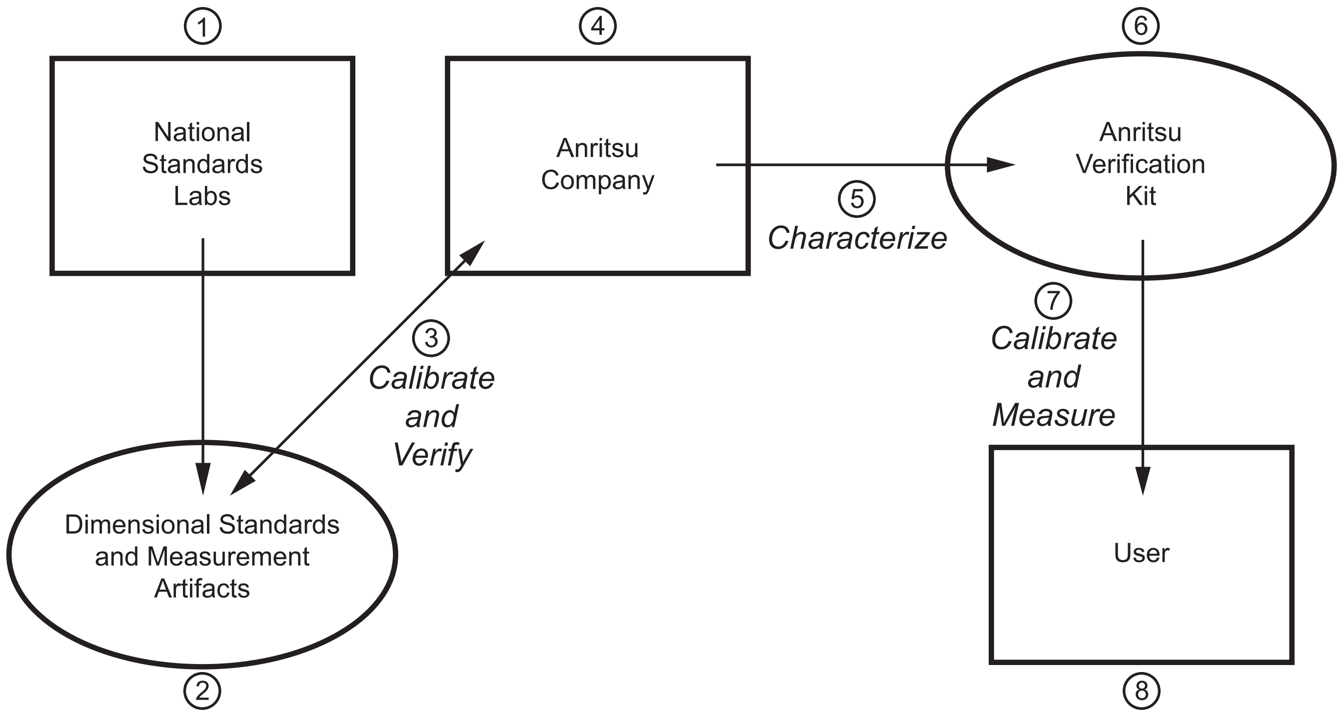
$$E_n = \frac{\left| S_{xy}^{char} - S_{xy}^{ver} \right|}{\sqrt{(U_{xy}^{char})^2 + (U_{xy}^{ver})^2}}$$

(Eq. 11-1)

The numerator contains the S-parameters measured during characterization (by Anritsu) and during verification (by the user), and the denominator contains the respective uncertainties. These uncertainties are calculated based on the VNA, the calibration kit, and repeatability. If this quantity E_n is less than 1, then the measurements during the two phases are within the overlap of the uncertainties and can be considered “equivalent” and, in some sense, verified.

Verification Kit Creation Process

The general process of the creation and use of a verification kit is shown in Figure 11-1.



1. National Standards Labs.	5. Characterization processes for verification kits.
2. Dimensional standards and measurement artifacts.	6. Anritsu Verification Kits with characterization data.
3. Calibrate and verify using artifacts.	7. Calibrate instruments and measure DUTs.
4. Anritsu Company processes and standards.	8. Verification kit used to verify instrument calibration.

Figure 11-1. General Process of the Creation and Use of a Verification Kit

A national standards laboratory (through standards and measured artifacts) helps validate the calibration and Anritsu which is then used to characterize the verification kit sent to the user.

It is important to note that the results are influenced by not only the instrument, the calibration kit, and the verification kit, but also the cables, the environment (temperature, humidity and vibration), connector quality, and the care exercised by the user during calibration and measurement. It should also be emphasized that this is not a measurement against absolute standards (which is the case for the residuals measurement process) but is a study of an “equivalent” measurement; the same devices measured with the instrument at the user site versus those devices measured with a controlled instrument at Anritsu (under traceable conditions).

11-3 Verification Kit Components

The three main verification kits for the MS4640A Series VNAs are those corresponding to 3.5 mm, K, and V connectors:

- 3666-1 series for 3.5 mm
- 3668-1 series for K
- 3669B-1 series for V

The verification kits and their use are described in the following documents:

- **VectorStar MS4640A Series VNA 3666-1 3.5 mm, 3668-1 K, and 39669B-1 V Verification Kits and 3-2300-527 (67688) Performance Verification Software (PVS) User Guide – 10410-00270**
- **VectorStar MS4640A Series VNA 366X-1 Verification Kits and 3-2300-527 (67688) PVS Quick Start Guide – 10410-00285**

The devices in these kits are selected based on their ability to stress the envelope of possible measurement parameters while still providing a very stable and repeatable behavior. The key attribute of the devices is that of long term stability. These kits contain the following devices:

- An airline to represent a low loss, well-matched device:
  - 7.5 cm for K and 3.5 mm
  - 5 cm for V
- A stepped impedance (Beatty) airline to represent a variable match device with a range of insertion losses:
  - 7.5 cm for K and 3.5 mm
  - 5 cm for V
- A 20 dB attenuator to represent a moderate loss, well-matched device.
- A higher value attenuator to represent a very lossy device:
  - 50 dB for K and 3.5 mm
  - 40 dB for V

No Verification with Calibration Kits

Calibration kit components cannot be used for verification since the result would be biased (some calibrations force the result to match expectations for the components used during calibration). Higher loss devices could have been used but they become more difficult to characterize accurately and the value of the verification would be reduced. Active devices with gain have not been used due to concerns about stability of the response over time. The envelope of coverage of the existing standards is illustrated in Figure 11-2, "Regions of Parameter Coverage of Verification Kit Component" on page 11-5. Each standard has a regime of coverage in terms of insertion loss and return loss; when combined, the entire kit reasonably exercises a wide variety of parameter values.

The diagram in Figure 11-2 illustrates the regions of parameter coverage of the various verification kit components. The regions are not drawn to scale.

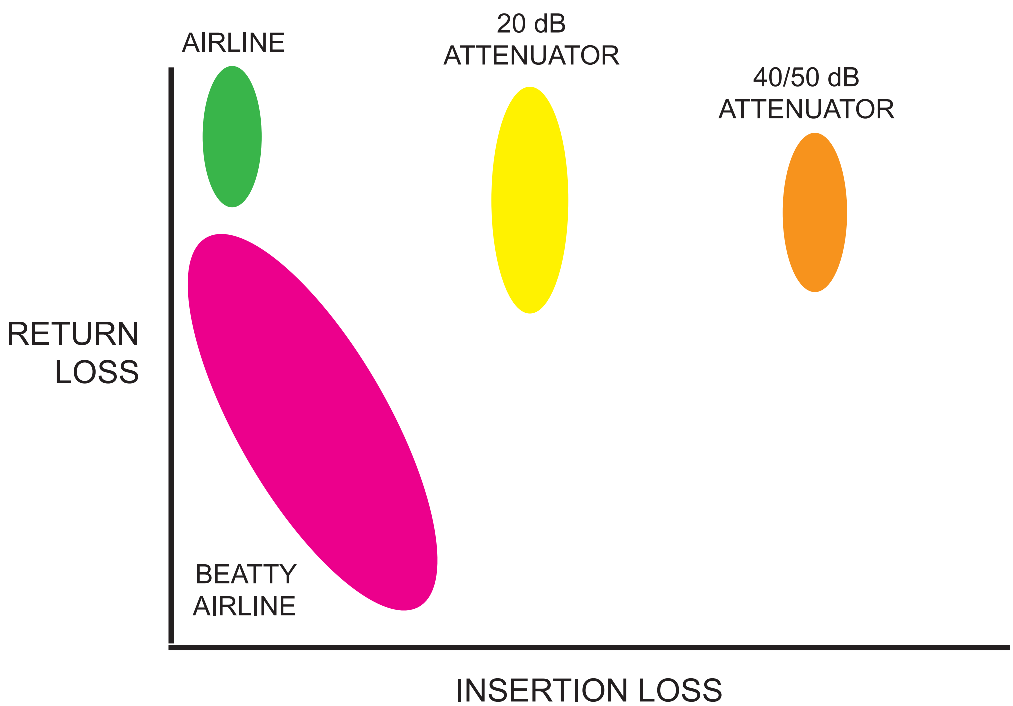


Figure 11-2. Regions of Parameter Coverage of Verification Kit Component

For the MS4640A Series VNAs, the verification comparison is valid for calibrations performed with the calibration kits listed under each verification kit:

- **3668-1 K Verification Kit**
  3652A-1 K Manual Calibration Kit or the 36585K-2MF Precision AutoCal Module
- **3669B-1 V Verification Kit**
  The 3654D-1 V Manual Calibration Kit or the 36585V-2MF Precision AutoCal Module
- **3666-1 3.5 mm Verification Kit**
- The 3650A-1 SMA/3.5 mm Manual Calibration Kit

Other combinations of calibration kits with verification kits are not supported. Verification kits based on other connector types such as GPC-7 or N exist for other Anritsu VNAs but the MS4640A Series VNA verification software does not support all of these.

11-4 Verification Kit Software

The application provided with the verification devices prompts calibration of the VNA, acquires measurements of the devices, and compares those measurements against the characterization values generated by Anritsu (these values ship with the verification kit). The software also generates reports indicating the outcome of the verification. More information is available in the user guide provided with the verification kit:

- 366X-1 Verification Kits (3666-1 3.5mm Connectors, 3668-1 K Connectors, 3669B-1 V Connectors) and 3-2300-527 (67688) Performance Verification Software (PVS) for MS4640A Series VNAs User Guide – 10410-00270
- 366X-1 Verification Kit and 3-2300-527 (67688) PVS Quick Start Guide – 10410-00285
- 3656B W1 (1 mm) Calibration/Verification Kit and 2300-496 System PVS User Guide for the VectorStar ME/7838A/ME7828A and Lightning ME7808A/B/C BB/mm-Wave VNA Systems – 10410-00286
- 3659 0.8 mm Calibration/Verification Kit and 2300-558 System Performance Verification Software – 10410-00327

Chapter 12 — Measurement Setup Requirements

12-1 Chapter Overview

This chapter provides general measurement setup fundamental concepts, requirements, and options for different types of measurements. Specifically, this chapter describes channels, traces, limit lines, external analog input/output, averaging, and smoothing and organizes their configuration in the same hierarchy. Channel is the highest level configuration with up to 16 channels possible, each with a different frequency range, power level, IF bandwidth, and RF calibration. On a per-channel basis, traces are lower level concepts that represent a data group with up to 16 traces per channel. Limit lines are described with setup tasks and test functionality. External analog input/output is described with setup issues, range, functions, resolution, and accuracy. A description of averaging and smoothing with their available functions and the effects on measurements conclude the chapter.

12-2 Channels and Traces Introduction

Two of the central concepts in the MS4640A Series VNA family that will enable the maximum functionality of the system are channels and traces.

Channel Concept

At a high level, the channel defines the sweep configuration and the calibrations for a measurement. Sixteen channels are possible and each can have a different frequency range, different power levels, different IF bandwidths and different RF calibrations (among other things). In a sense, 16 distinct VNAs within one instrument are possible with each one executing sequentially.

Trace Concept

The trace is a lower level concept that represents a data group. Sixteen traces are allowed per-channel and each can represent a different response parameter, can be on a different graph type, and have certain different levels of post-processing applied to it.

The objective of this section is to explore how the channels and traces can be setup, what possibilities are available, and what configurations are commonly used. Many of the functions of the VNA can be separated into per-channel and per-trace groups; the delineation of these functional groups is also an important part of this section.

12-3 Channels and Traces General Concepts

The hierarchy of setups is illustrated in Figure 12-1. At the highest tier is per-system, these are variables that apply to all measurements on a given physical instrument. There are very few of these variables and they include:

- Step attenuator settings
- Bias tee on/off
- Certain portions of the hold system and certain triggering functionality
- AutoCal characterization files and cal kit files (are accessible from any channel)
- SnP and text file header/format setups
- Blank frequency display (security feature)
- Interface setup items (GPIB addresses, network config, touchscreen setup, …)

Per-System Variables

These variables are often per-system to prevent a setup scenario that could significantly shorten the life span of the hardware. In the case of hold and triggering, it also allows an entire measurement suite to be somewhat more easily controlled externally. Others fall more in the category of utilities that are somewhat per-system in nature. The hierarchy of system, channel, and trace setup information is shown below. Generally, N (the channel count) may be up to 16 (except when more than 25,000 points in a sweep are needed) and M (the trace count) may always be up to 16.

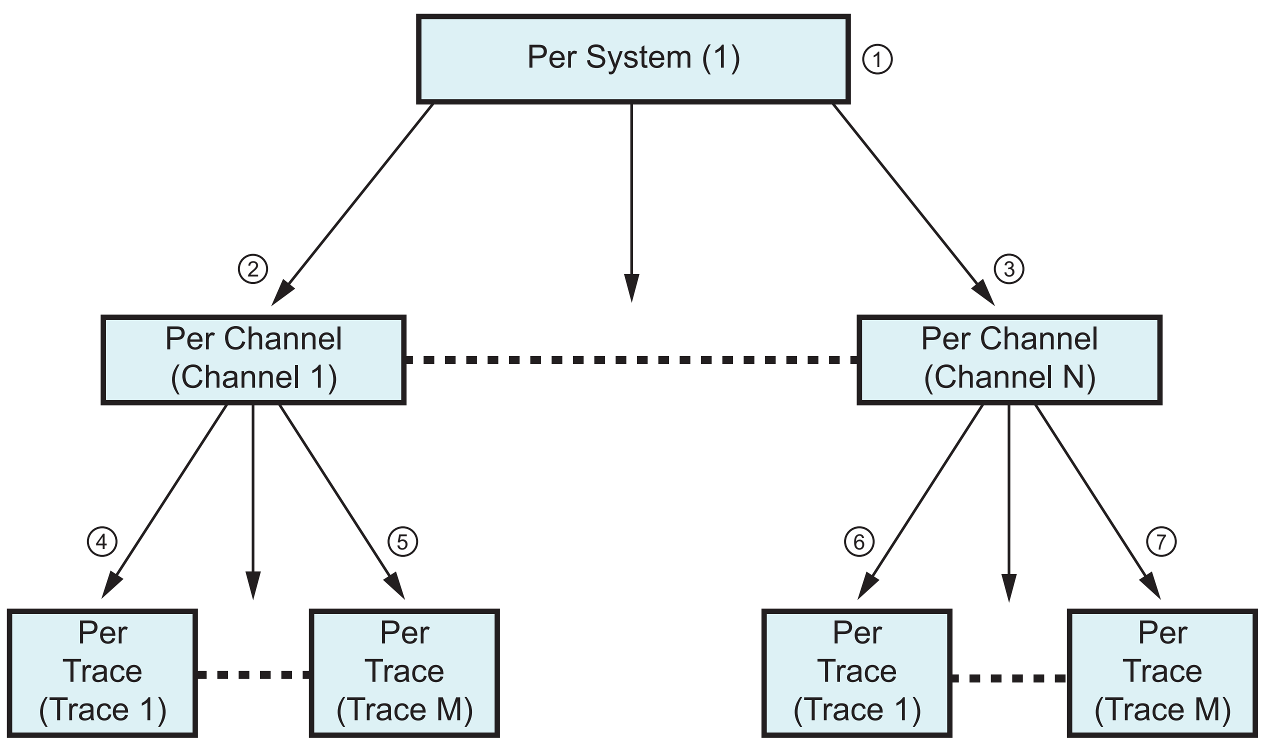


Figure 12-1. Setup Information Hierarchy (1 of 2)

Setup Hierarchy – System, then Channels, and then Traces 1 – Per System Settings – These settings affect the entire instrument such as the maximum number of measurement points as either 25,000 or 100,000.	2 – Per Channel Settings – If in 25,000 point mode, from 1 (one) to 16 channels can be configured. If in 100,000 point mode, only one channel is available. 3 – Per Trace Settings – Each configured channel can have from 1 to 16 traces. Each trace can be configured as a separate measurements, with separate markers, and a different display method. Each trace can have up to 12 total measurement markers and one (1) reference marker.

Figure 12-1. Setup Information Hierarchy (2 of 2)

Per-Channel Variables

The second tier is that of the channel. As mentioned in the overview, the channel can almost be thought of as a separate virtual VNA. Although this term has been used differently in the past with other Anritsu VNAs, in the MS4640A Series VNA Series family, it includes a separate frequency list, separate calibrations and separate sweep control.

Per-Trace Variables

The third tier is that of the trace. As discussed above, this can be thought of as a data element (for example, S_{21} data for a given channel-based sweep setup). The per-trace flexibility mainly comes under the heading of post-processing and display.

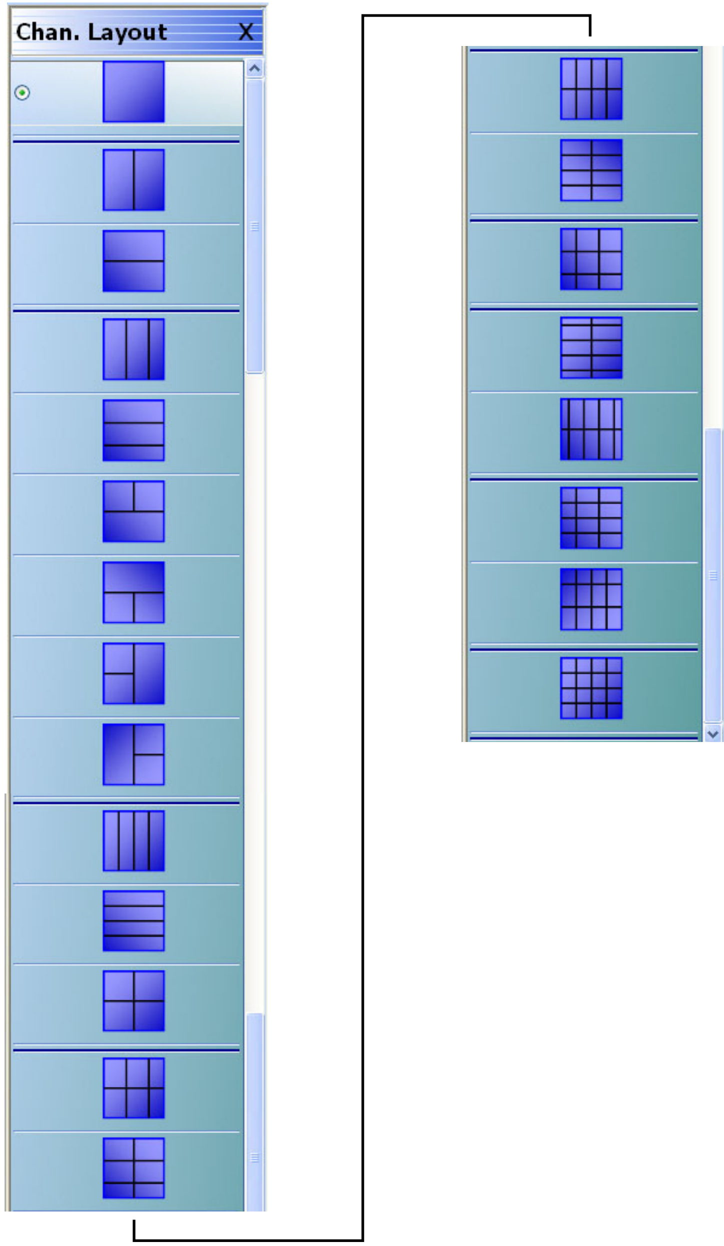
Note	For historical reference, the 37xxxX family of Anritsu VNAs was limited to 1 channel and 4 traces. Although it may be somewhat confusing, in those instruments, what we now call traces were, then, called channels. This discrepancy was difficult to avoid when transferring to modern usage of the terminology.

12-4 Channels and the Channel Menu

The channel menu itself is fairly simple. While the system defaults to 1 channel (under a preset command), here a different number of channels may be selected. The active channel (indicated by a thick white border) may be selected by clicking on that channel's window or it can be incremented using this menu (Chan. Next and Chan. Previous). The button Chan. Max can be used to force the active channel to occupy the entire data screen area. Note that the other defined channels will continue to sweep even when this mode is entered. The Chan. Max command is a toggle and can be undone by clicking it again. Chan. Max can also be accomplished by double-clicking the channel area away from a specific graph (that leads to Trace Max discussed later). These commands are illustrated in the top level menu shown in Figure 12-2.

Figure 12-2. CHANNEL Menu

Once a given number of channels is selected, the layout of those channels is selected in a submenu shown in Figure 12-3. Note that selecting a layout with more channels will update the channel count since gaps in the sweep processing are not allowed. Because there are many combinations of channels possible, this window is quite lengthy (shown in two parts in Figure 12-3).



The instrument menu has a right-side scroll bar to access the entire menu.

Figure 12-3. CHAN. LAYOUT (CHANNEL LAYOUT) Menu

The number of channels available first depends on the VNA maximum point setting which in turn depends on the VNA model number.

- If the VNA is set to 100,000 point mode, only one channel is available, with up to 16 traces.
- If the VNA is set to 25,000 point mode, up to 16 channels can be defined, each with up to 16 traces.

If multiple channels are available in the VNA, any number of channels can be configured between 1 and 16 channels.

Using the CHAN. LAYOUT menu shown in Figure 12-3 above, layouts are limited to values 1, 2, 3, 4, 6, 8, 9, 10, 12, or 16 channels.

Only those values corresponding to semi-symmetric layouts are allowed as suggested by the channel layout menu and other entries will be coerced.

Once the number of channels and the layout has been selected, it then remains to define each of the channels. The sweep control parameters apply to the active channel so one may cycle through the channels entering values as needed. Alternatively, the setups for a channel may be copied through the setup save/recall mechanism since setups can be saved on a per-channel basis. Note that save/recall can also be applied to all channels.

It has been discussed that most sweep-setup parameters are per-channel in nature. To clearly delineate when these apply, the per-channel functions include:

- Frequency
- Power (although step attenuator settings, for units with Option 061 or 062, are per-system)
- Option 061 Active Measurement Suite with Two (2) Attenuators Option 062 Active Measurement Suite with Four (4) Attenuators Calibrations (RF, power, receiver, etc.); this includes the calibration reference impedance
- Embedding/de-embedding and reference plane extensions
- Multiple source control settings (to include broadband/mm-Wave)
- Impedance transformations (note that this is distinct from impedance parameter conversions which are a post-processing calculation on trace data)
- Post-processing order
- Media type (dielectric constants, coaxial vs. waveguide, etc.)
- Hold functionality (portions can be per-system)
- Trigger functionality (portions can be per-system or per port as well as per-channel)
- Analog out (rear panel)

Maximum Number of Points Setup

One additional behavior associated with channel count relates to the maximum number of points that may be defined in a sweep. Normally this limit is 25,000 pointsMS4640A Series VNAand this value can be used with any number of channels.

The VNA mode can be switched to a maximum of 100,000 points, but in this case, only one (1) channel is allowed. This mode is selected with the MAX. POINTS menu (shown below in Figure 12-4) which is available at:

- MAIN | System | SYSTEM | Setup | SETUP | Max Points Setup | MAX. POINTS

This selection itself is, of course, per-system since the selection determines the number of channels that will be available.

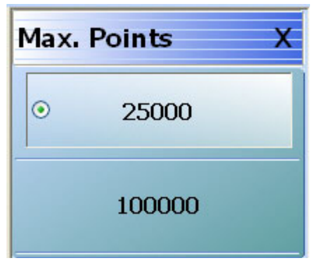


Figure 12-4. MAX. POINTS (MAXIMUM POINTS) Menu

An example of a three-channel setup is shown in Figure 12-5. In this case, all three channels have different frequency ranges, the same IF bandwidth was used in each, and the first channel (at Figure 12-5 – #1 on the top or Ch1) is active as indicated by the thick white border.

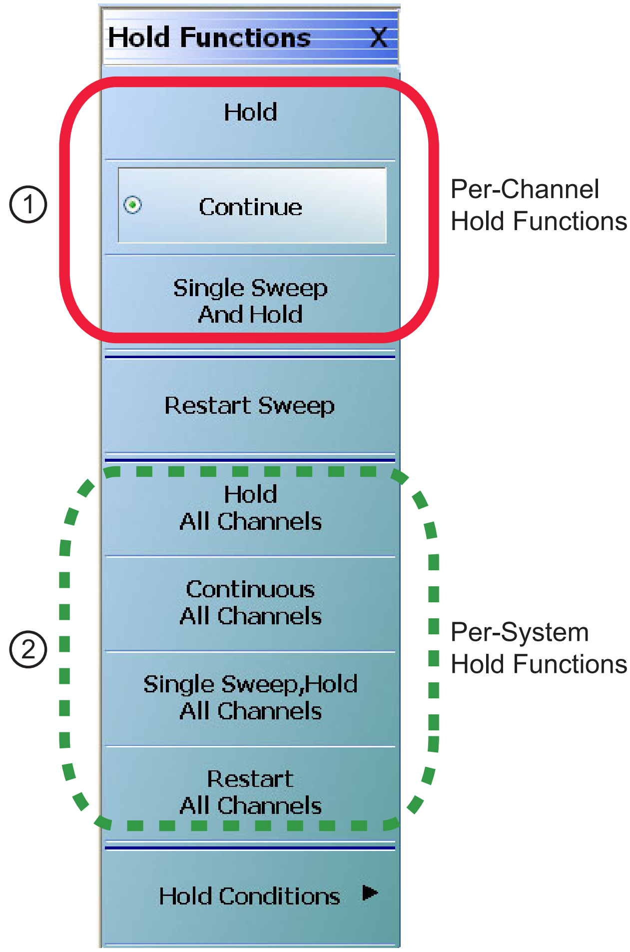
1 – Channel 1 (Ch1 at top) is the active channel is active (note white border) and measuring S22.	2 – Channel 2 (at middle) is measuring S21. 3 – Channel 3 (at bottom) is measuring S11.

Figure 12-5. Typical Three-Channel Display

Generally, the sweeps for each channel are executed sequentially. That is, all of the sweeps for Channel 1 are performed first followed by all of those for Channel 2, and so on. Hold events and triggering events can be per-channel or per-system (and some subsets of the channel as well.) These menus are shown in Figure 12-6 for hold events and Figure 12-7 for triggering events. The HOLD FUNCTIONS menu is available from the SWEEP SETUP menu.

- MAIN | Sweep | SWEEP SETUP | Hold Functions | HOLD FUNCTIONS

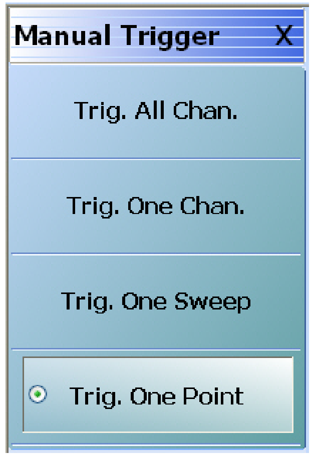
Note that while triggering can be done per-point and per-port, it still refers to the setup of the channel and it is never reduced to measurements related to a trace. As these hold and trigger functions are used, the actual measurement sequence can, of course, change. The HOLD FUNCTIONS menu shown below to illustrate some per-system aspects (green dashed circle) of the hold function as opposed to the usual per-channel functions at the top of the menu (red circle).



1 – Per-channel hold functions (at top).	2 – Per-system hold functions (at bottom).

Figure 12-6. HOLD FUNCTIONS Menu

The Manual Trigger menu is shown below to illustrate per-channel behavior (second button), per-portion-of-channel behavior (third and fourth buttons), and per-system behavior (first button). Other trigger modes have analogous behaviors.



Trigger One Point selected

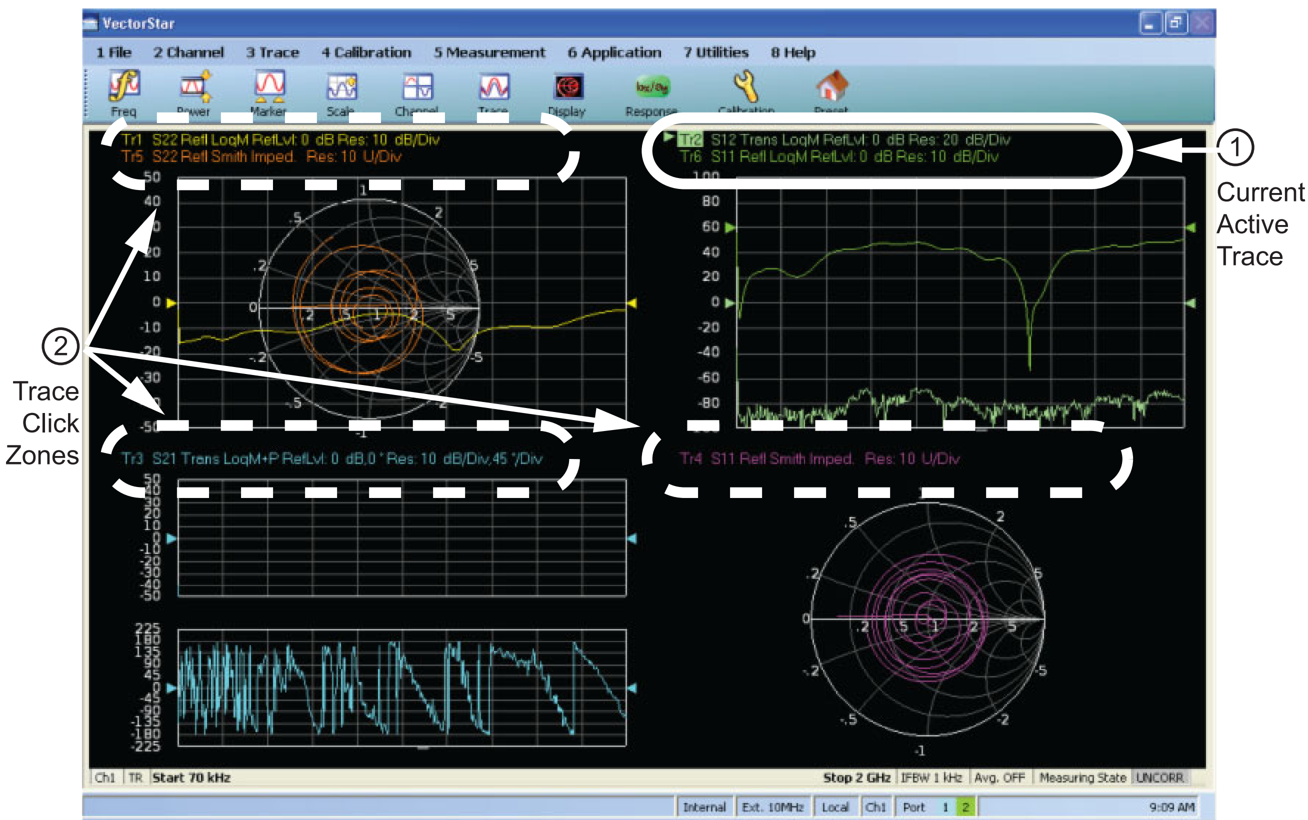
Figure 12-7. MANUAL TRIGGER Menu

12-5 Traces

In some sense, the main trace menu is a parallel of the channel menu. Again, the number of traces in the active channel may be specified and one can rotate through the traces using Trace Next and Trace Previous. One can also make a trace active by clicking on its annotation line as suggested by Figure 12-8. The active trace is denoted by an inverse color field around the trace number (Tr2 in Figure 12-8).

As with channels, the Max function causes the trace (in this case) to occupy the full graph region of the channel. Also as with the Chan. Max, this button is a toggle. Double-clicking on the graph area of the active trace will have the same function as clicking on the Trace Max button. The main Trace menu showing these functions is shown in Figure 12-9.

The area around the annotation line where one can make a trace active with a direct click is shown below. A double click near the active trace graph area maximizes that trace. Trace 2 (upper right) is currently active in this setup as evidenced by the inverse video.



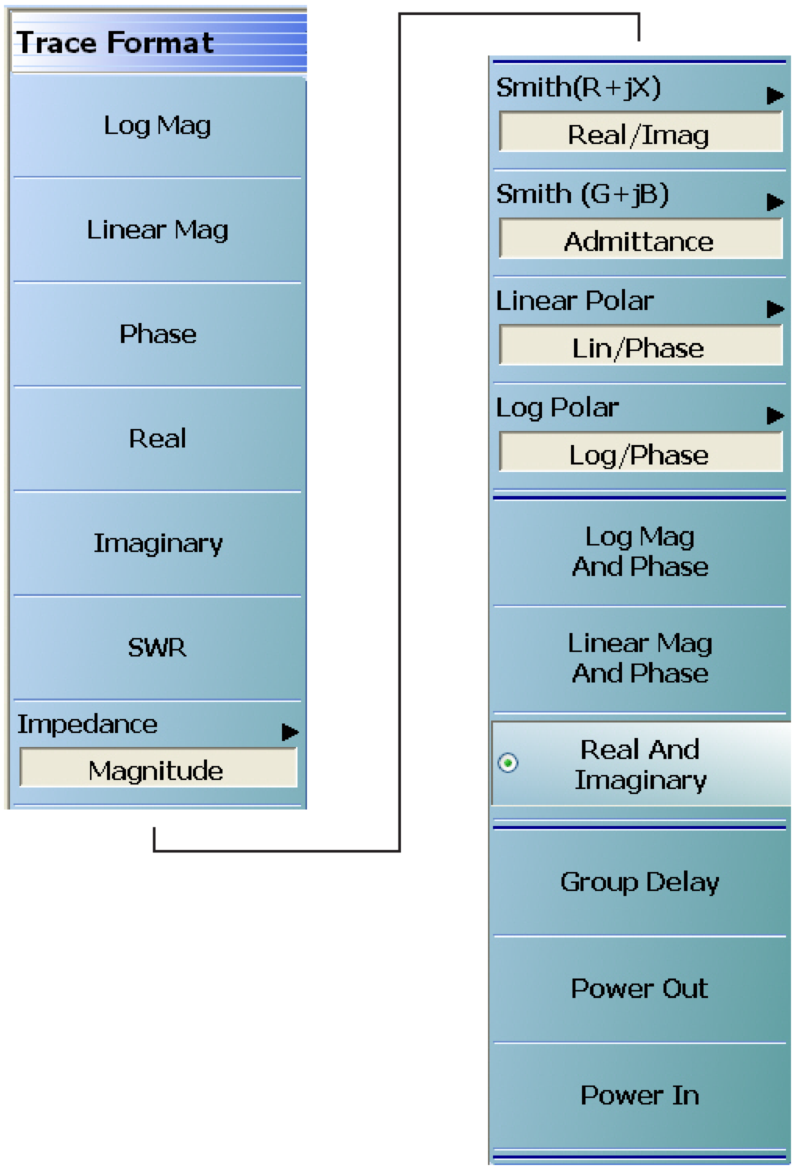
1 – Current active trace (at top).	2 – Trace activate click zones (at left and bottom right).

Figure 12-8. Trace Activate Click Zones

TRACE menu with four traces selected

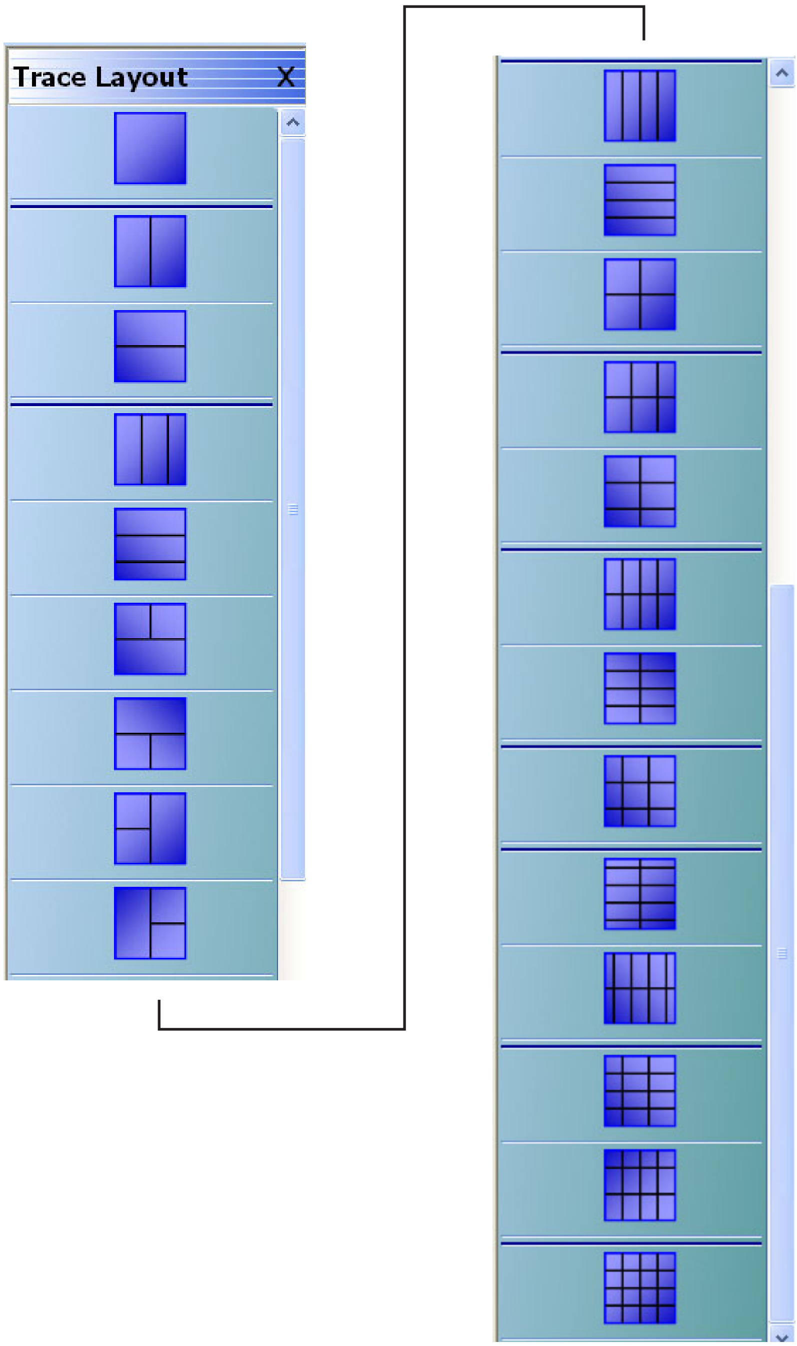
Figure 12-9. TRACE Menu

As with the channel system, there is also a layout submenu for traces (see Figure 12-10 for this long menu). Here, however, one may have any number of traces on any graph configuration and the number of traces will not be coerced based on the layout choice. If the number of traces exceeds the number of graph areas selected in the layout, the traces will be overlaid in a sequential fashion that will minimize the number of overlays. As with channels, only certain numbers of graph areas (in the case of traces) are allowed that are semi-symmetric (1, 2, 3, 4, 6, 8, 9, 10, 12, 16) but, unlike channels, blank areas in the graph area grid are allowed if the trace count is less than the graph count.



The actual TRACE menu is continuous with a right-side scroll bar.

Figure 12-10. TRACE FORMAT Menu



The actual TRACE LAYOUT menu is continuous with a right-side scroll bar.

Figure 12-11. TRACE LAYOUT Menu

For example, if five traces are selected but the trace layout is chosen to be three graph areas (vertically oriented), then the traces will be assigned as follows:

- Top graph area: traces 1 and 4
- Middle graph area: traces 2 and 5
- Bottom graph area: trace 3

Of course, a 16-way overlay can be arranged by activating 16 traces but selecting the single graph area (top of the trace layout menu).

Once the number and layout of traces have been defined, usually each trace must be individually configured. In this sense, trace configuration generally applies to post-processing tasks such as graph manipulation, and some analysis tasks such as time domain that are not directly tied to a sweep configuration.

Per-Trace Variables

Per-trace variables include:

- Trace format (graph type)
- Trace memory and math functions (to include inter-trace math which is sort of a hybrid but is defined on a per-trace basis)
- Scale (although autoscale can also be per-channel or per-system)
- Trace impedance (which is different from reference impedance set during a calibration)
- Domain (time domain and frequency w/ time gate)
- Smoothing
- Conversions
- Limit lines
- Markers (although markers can be optionally coupled between traces within a channel)
- Response (S-parameter, un-ratioed parameter, ext. analog in)

Complex Trace Setup Example

A fairly complex trace setup example is shown in Figure 12-11 below. This example covers multiple graph types and scaling options as well as different transformations applied to the data in certain traces. Here Trace 3 is in time domain while the others are frequency domain. Most of the traces represent S-parameters but Trace 6 is in an impedance conversion mode (reflection impedance, covered in another section of this measurement guide). The symbols at the end of the annotation line provide information about these trace definitions. Some of the abbreviations that may appear in brackets at the end of the annotation line are shown in Table 12-1 below. Details on these functions can be found in other sections of this measurement guide and the VectorStar Operations Manual.

Table 12-1. Trace Labels and Annotations *(1 of 2)*

Abbreviation	Definition
FGT	Frequency domain with time gating
TLP	Time domain low pass
TBP	Time domain bandpass
D&M	Data and memory
D/M	Data memory math
D+M	
D-M	
D-M	
M	Memory
Tr1/Tr2	Inter-trace math (other trace numbers and other operators possible)
Zt	Conversions: impedance for transmission
Zr	Conversions: impedance for reflection
Yr	Conversions: admittance for reflection
Yt	Conversions: admittance for transmission

Table 12-1. Trace Labels and Annotations *(2 of 2)*

Abbreviation	Definition
1/S	Conversions: reciprocal S-parameters

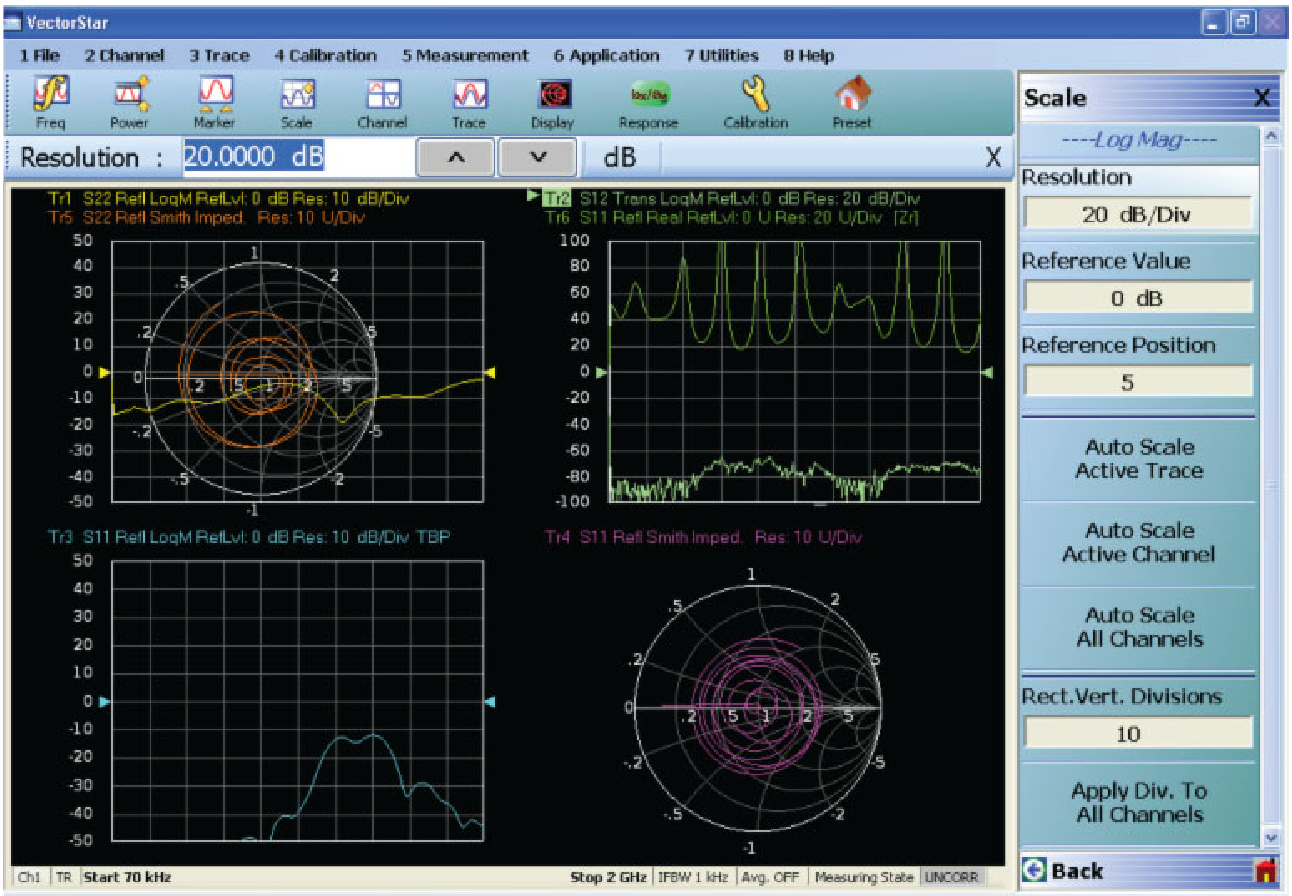


Figure 12-12. Multi-Trace Display with right-side SCALE menu

Figure 12-11 on page 12-14 above also illustrates an example of a function, auto scale in this case, available on per-trace, per-channel and per-system levels.

12-6 Overview of Limit Lines

There are a number of relatively simple measurement topics that require some comment but are not large topics by themselves. These issues have been grouped into this miscellaneous section to ensure that the information is readily available. These topics include:

- Limit lines. Setup tasks and test functionality
- External analog in. Setup issues, range, resolution and accuracy
- Rear panel analog out. Setup tasks and functionality
- Averaging and smoothing. Functions and their effects on measurements

12-7 Limit Lines

Limit lines are a powerful tool to help quickly compare a set of measured DUT data against specifications or expectations. All limit testing is per trace and, depending on firmware version, limit testing may only be available on rectilinear graph types. Upper and lower limits on any parameter may be set and these may be separated into many frequency bands. There is a limit of a total of 50 segments (upper and lower combined) per trace. The main limit line menu is shown in Figure 12-13.

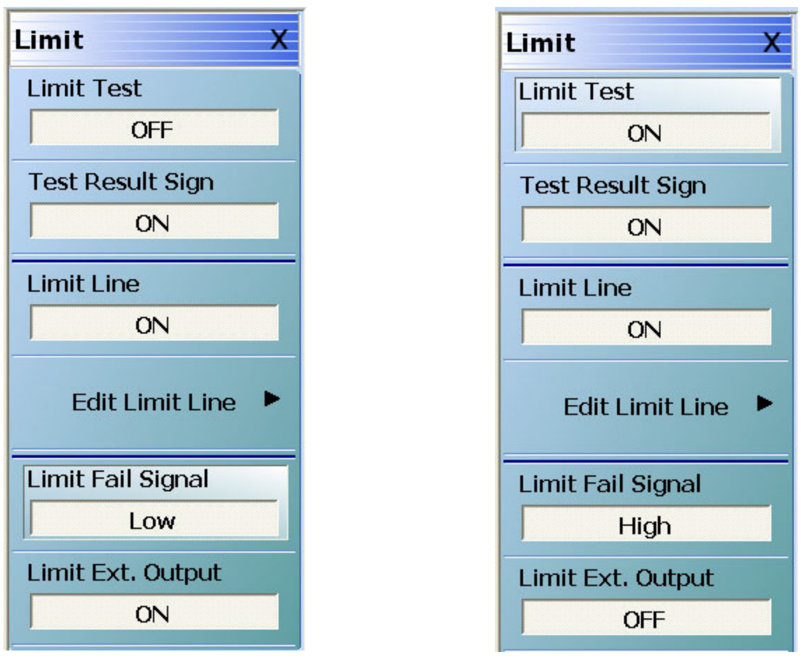


Figure 12-13. LIMIT Menu - Various Functions Toggled ON or OFF

The toggle buttons on the top level of this menu are straightforward:

Limit Test

The Limit Test button enables comparison of the data to the limit lines existing (this is per trace). The results of the test (pass or fail) will appear in the upper right corner (see Figure 12-15) of the graph for that trace.

Test Result Sign

The Test Result Sign button enables a large graphic displaying the pass/fail result. This will be in the middle of the screen (see Figure 12-15 on page 12-19 below) and is visible from a large distance. The Limit Test must be on for this sign to appear. If any limit tests fail, the large fail sign will appear with a notation of which channel has failed.

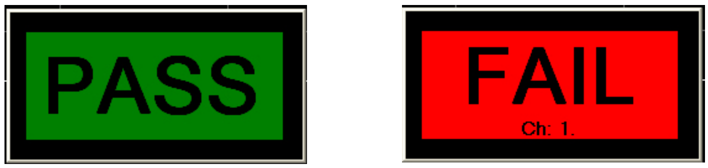


Figure 12-14. Pass and Fail Signs Configured by the LIMIT Menu

Limit Line

Displays the current limit lines on the data graph. The limit lines will appear in red. Failing points are marked with a red dot.

Limit Fail Signal

Determines the state of the external limit status bit for a fail condition (see next item). High or Low (in a 3.3V logic sense).

Limit Ext. Output

The Limit External Output button enables a signal on pin 1 of the rear panel **External I/O** connector that will change state on limit failure. If any activated limit test fails, the bit will go to the fail state. This bit will be active only if Limit Test is ON. In the figure below, the small annunciator in the upper left appears if Limit Test is ON, the large center graphic appears if Test Result Sign is ON, and the red limit lines appear if Limit Line is ON. If a test on a channel fails, the large center graphic includes a notation of which channel has failed.

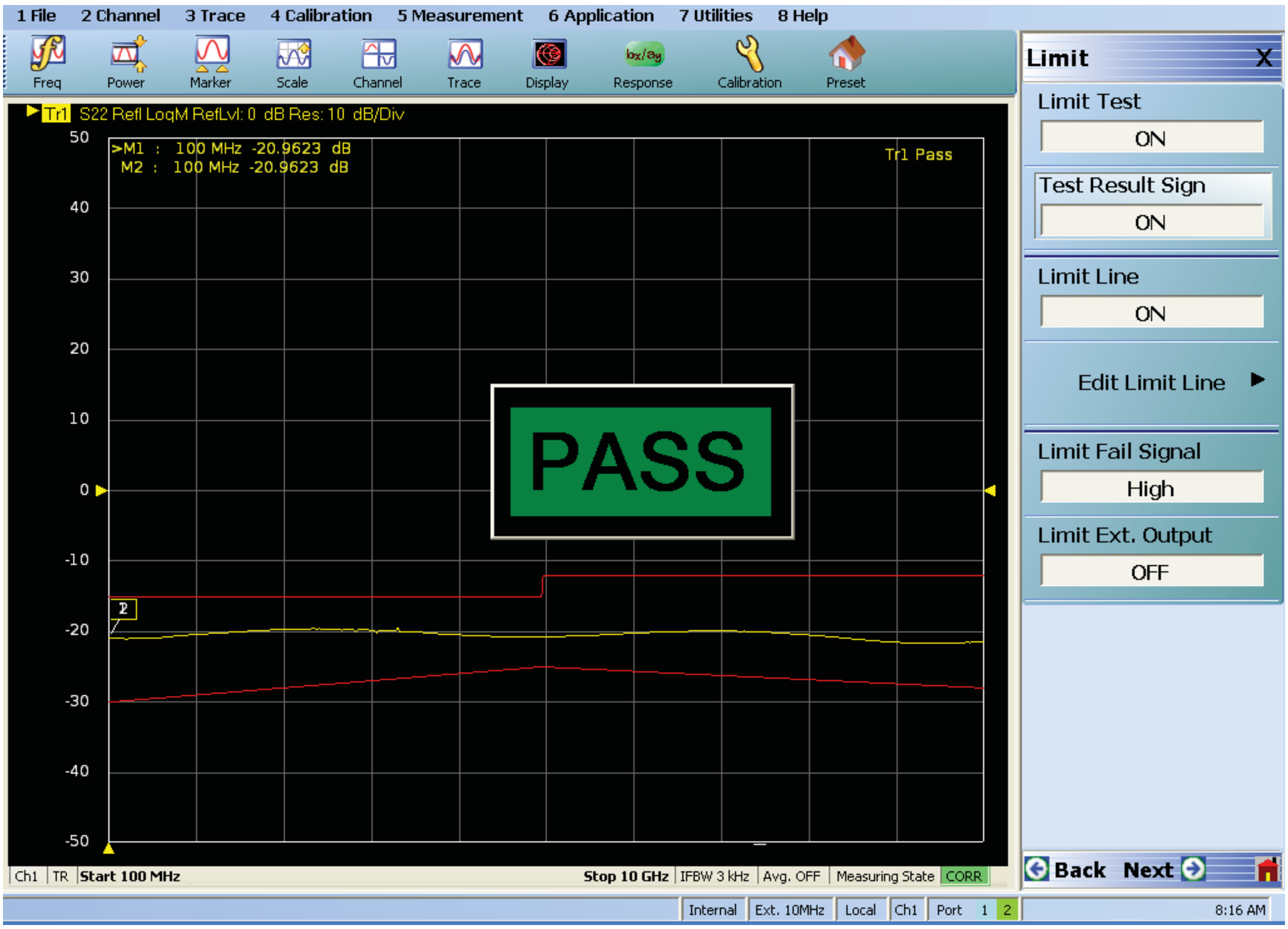


Figure 12-15. LIMIT Menu and Limit Pass Sign Example on Main Display

A more complex, multi-channel example showing some of these concepts is shown in Figure 12-16. Note the dependence of the Test Result Sign on the limit testing going on in multiple channels. Only Trace 1 on Channel 2 has failed, but the overall result will be reported as a failure.

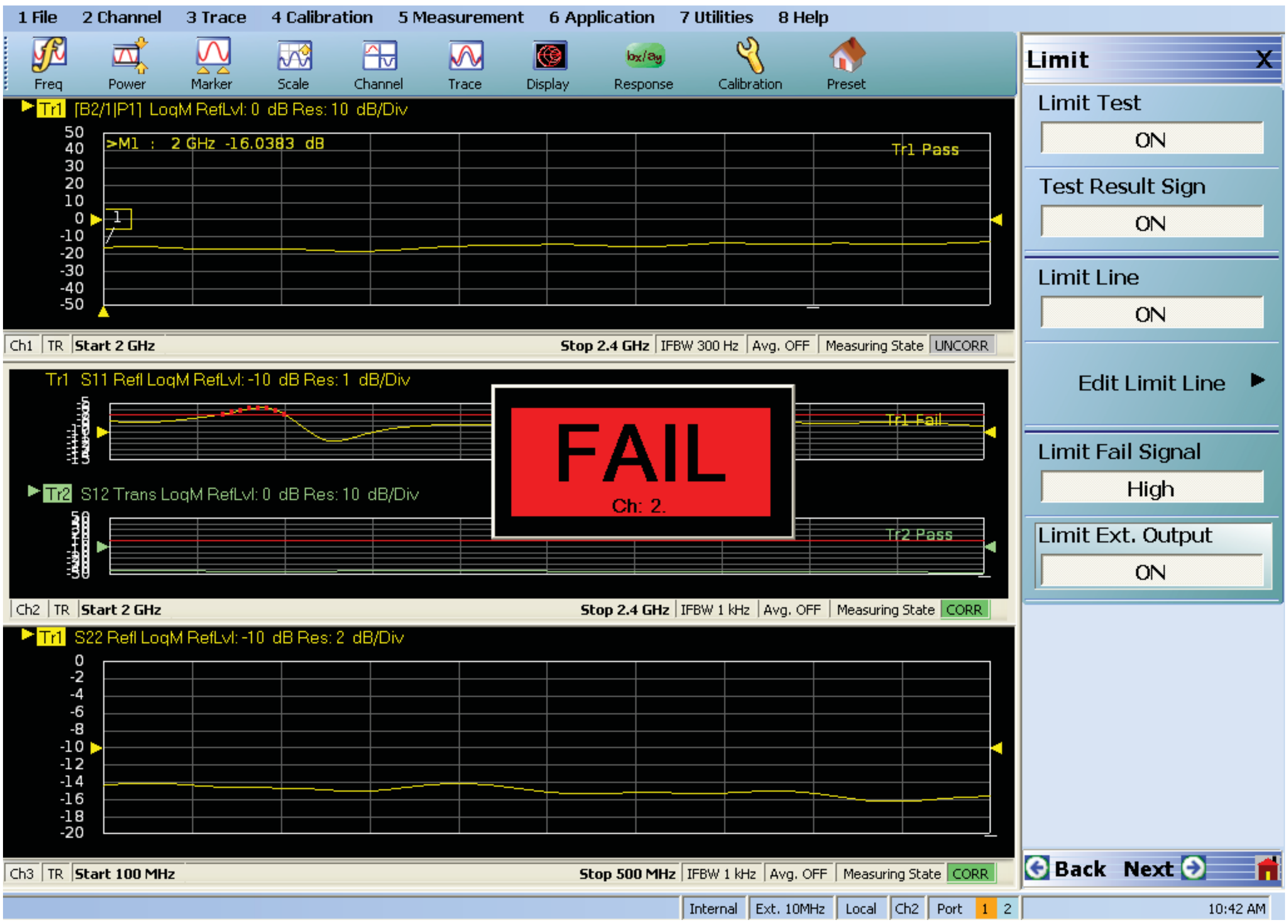


Figure 12-16. LIMIT Menu and Limit Fail Sign Example on Main Display

Editing of Limit Lines

The editing of the limit lines is controlled on the one submenu and that is shown in Figure 12-17. When entering this menu, the limit line table will appear at the bottom of the screen (not unlike the multiple source and segmented sweep tables). Initially, the table will often be empty. If a limit line set was created on another trace, those values may appear here but they may be cleared or edited. The limit line tables may be saved and recalled separately using this menu (much like segmented sweep tables) or they may be saved and recalled as part of the global setup (use commands under the File menu to do this).

Edit Limit Line Menu

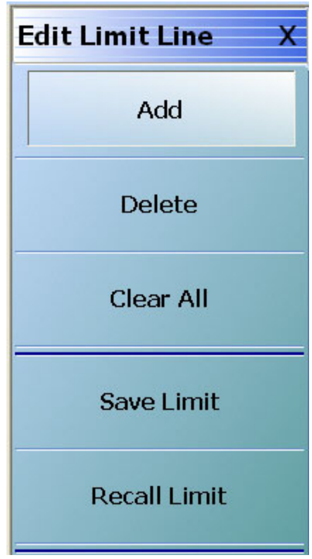


Figure 12-17. EDIT LIMIT LINE Menu

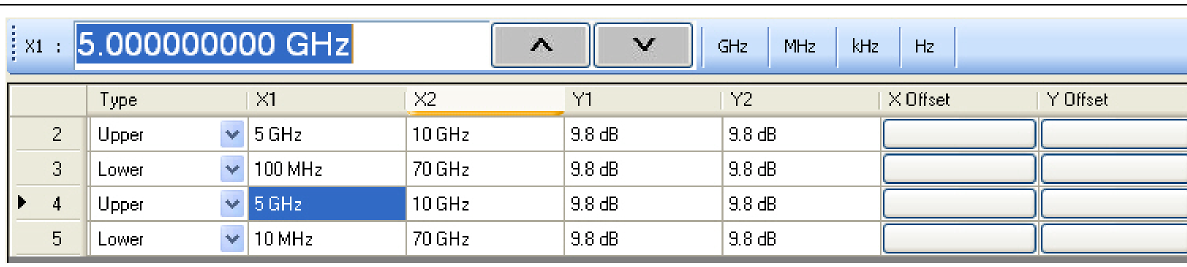
An example limit line table is shown in Figure 12-18 using two upper limit segments and two lower limit segments. For each segment, a number of things need to be entered: Upper or lower: Use the pull-down to indicate if it is an upper limit or lower limit. Another option on the pull-down is “off” to enable suspension that segment.

X1 and X2

The constraints of the segment in the X-direction. Usually this variable will be frequency (segmented or linear frequency sweeps) but it could be time (time domain) or power (power sweep). If two segments cover the same frequency range (or portions thereof), the first segment will have precedence.

Y1 and Y2

The constraints of the segment in the Y-direction. These will have units of the graph type for the active trace (dB in the examples here).



	Type	X1	X2	Y1	Y2	X Offset	Y Offset
2	Upper	5 GHz	10 GHz	9.8 dB	9.8 dB		
3	Lower	100 MHz	70 GHz	9.8 dB	9.8 dB		
4	Upper	5 GHz	10 GHz	9.8 dB	9.8 dB		
5	Lower	10 MHz	70 GHz	9.8 dB	9.8 dB		

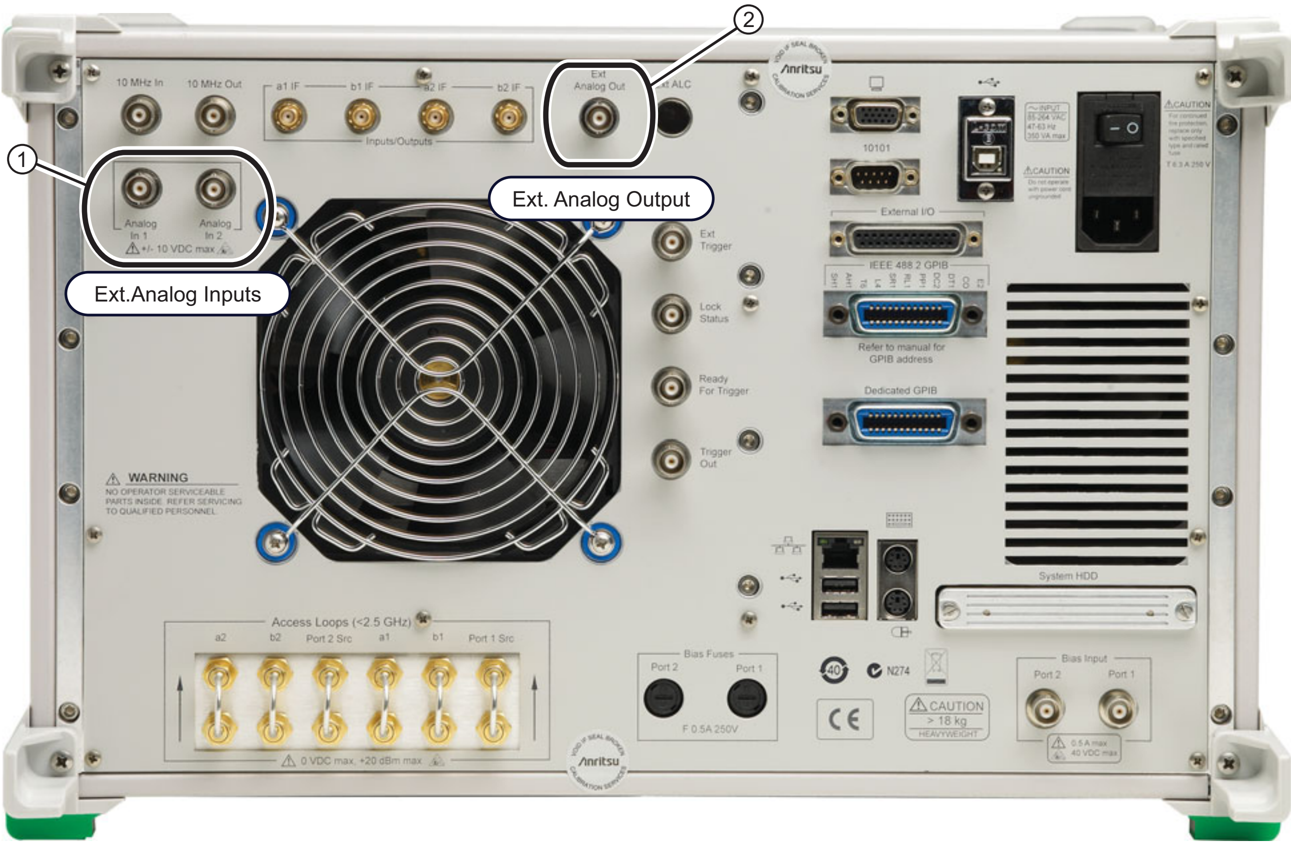
Figure 12-18. Limit Line Table

The X offset and Y offset values allow one to shift both indices in a row by a constant amount. This can be useful in copying multiple rows and, for example, incrementing by a fixed frequency offset.

12-8 External Analog In

Overview

The VectorStar MS4640A-Series VNA has two external analog inputs (Figure 12-19) where the voltages may be plotted on the same graph types as S-parameters and un-ratioed parameters. Examples include the use of external power detectors or external current probes (to measure amplifier current draw as a function of frequency or power for example). Like everything else on this menu, it is a PER-TRACE selection.

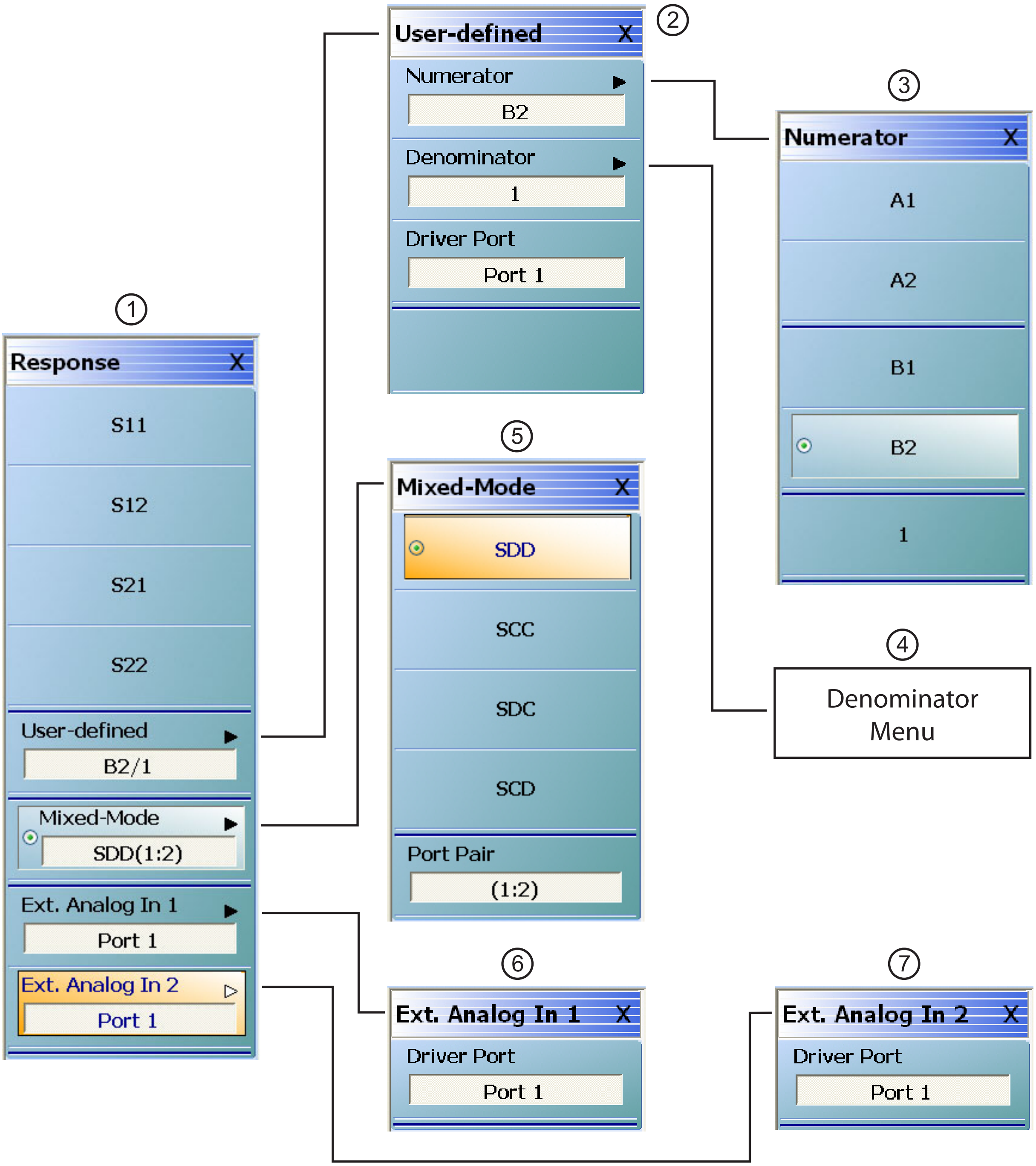


MS4647A VNA Rear Panel Example. 1 – External Analog Input Ports (at upper left)	2 – External Analog Output Port (at upper center)

Figure 12-19. Rear Panel External Analog I/O Ports

Response Menu

These are selectable on the response menu as shown in Figure 12-20 on page 12-23 below. The submenu allows a choice of which port is driving during that particular analog in measurement. This port selection may be important particularly with the use of external power detectors.



1 – RESPONSE menu	5 – MIXED-MODE menu
2 – USER-DEFINED menu	6 – EXT. (EXTERNAL) ANALOG IN 1 menu
3 – NUMERATOR menu	7 – EXT. ANALOG IN 2 menu
4 – DENOMINATOR menu (not shown, the same as NUMERATOR menu)	

Figure 12-20. RESPONSE Menu and Submenus

Rear Panel External Analog Input Ports

These rear panel ports route through a multiplexer to an additional A/D converter. Internal calibration standards are used to correct for offset and channel gain slope so the accuracies are on the order of 2 mV + 1% for absolute voltages under 5V and 2% for high voltages. The calibration is performed at power on and can be triggered from the diagnostics menus if necessary (see operation manual for details). This calibration is based on a pair of voltage references built into the instrument so a linear error model of the low frequency analog in path can be generated.

The maximum range for the inputs is ±10V and the nominal input impedance is 60 kΩ. While the input is primarily intended for DC or very low frequency measurements, it has a bandwidth of approximately 1 kHz.

12-9 External Analog Out Port

There is also one external analog output port on the MS4640A-Series VNA and it is primarily used for sweep synchronization and certain triggering tasks of external instruments or DUTs. The control menu is located under MAIN MENU | SYSTEM | REAR PANEL OUT. and is shown in Figure 12-21.

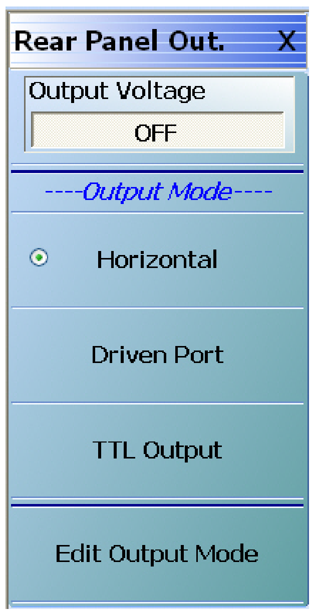
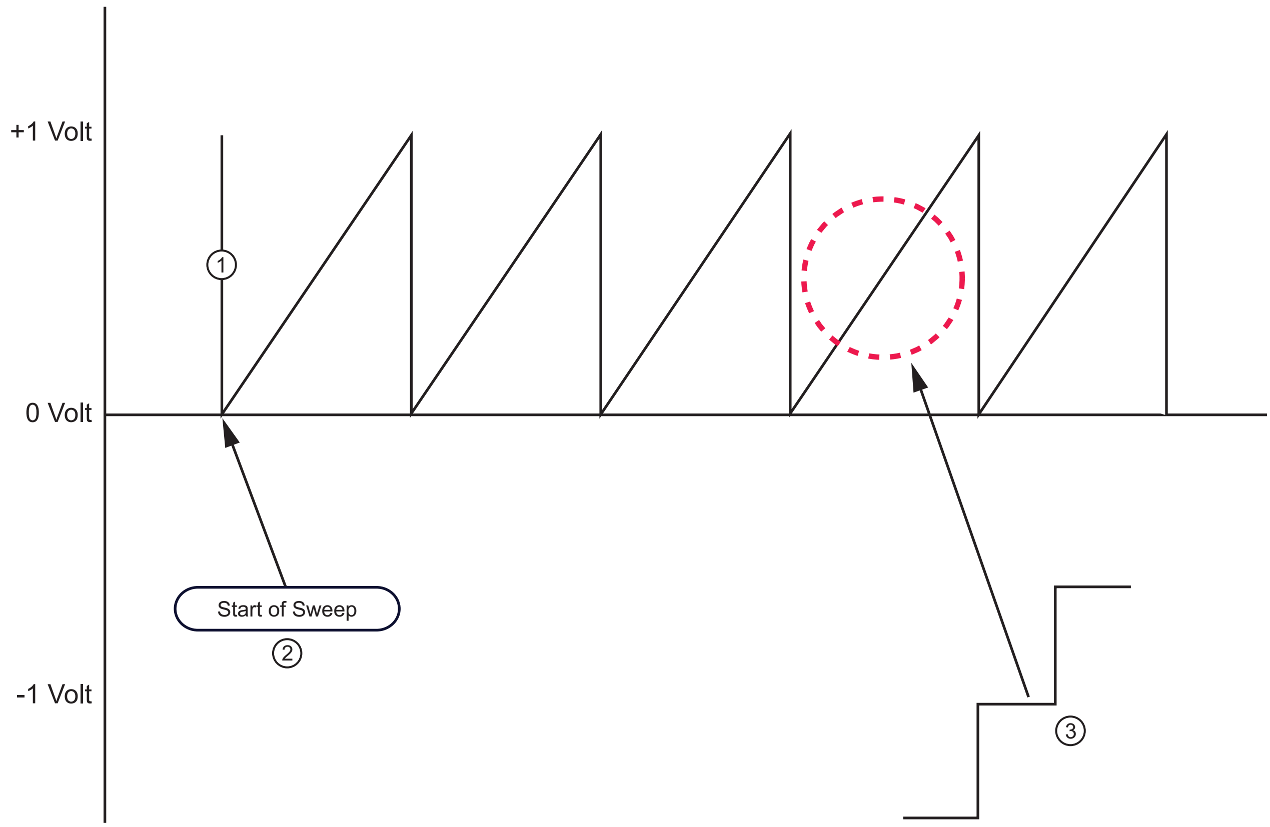


Figure 12-21. REAR PANEL OUT. (REAR PANEL OUTPUT) Menu

The top button is a toggle on/off while the next three buttons select the output mode. Horizontal is a sawtooth wave synchronized with the sweep (resetting to the start voltage at the first point of the sweep). This output really is a sequence of steps (see Figure 12-22) whose width is determined by the per point measurement time.

The horizontal output mode waveform for the settings of Figure 12-23 is shown below. The waveform is actually composed of small steps whose width represents the per-point sweep time.



1 – Horizontal sweep waveform. 2 – Start of horizontal sweep.	3 – Close-up view of waveform showing small steps representing the per-point sweep time.

Figure 12-22. Horizontal Output Waveform

Driven port produces a static voltage level that is different when port 1 is driving versus when port 2 is driving. The TTL output is a either a static logic value or a pulse (high-going or low-going) at the start of a sweep in a given direction. The details of the output are controlled in a dialog launched by the Edit Output Mode button (see Figure 12-23).

For the first two modes, the allowed voltage range is +/- 10V with an accuracy of about 20 mV + 2%. For TTL output, the selections are high, low, high pulse, and low pulse. The pulse will occur at the start of the sweep for the given driving port and the pulse width is adjustable. Although 0 pulse width may be entered, the actual minimum pulse width is about 0.5 µs. The maximum pulse width can exceed 10 s but note that if the pulse width becomes large relative to the time to complete the sweep, the instrument will wait for the pulse cycle to complete to avoid pulse collisions on subsequent sweeps.

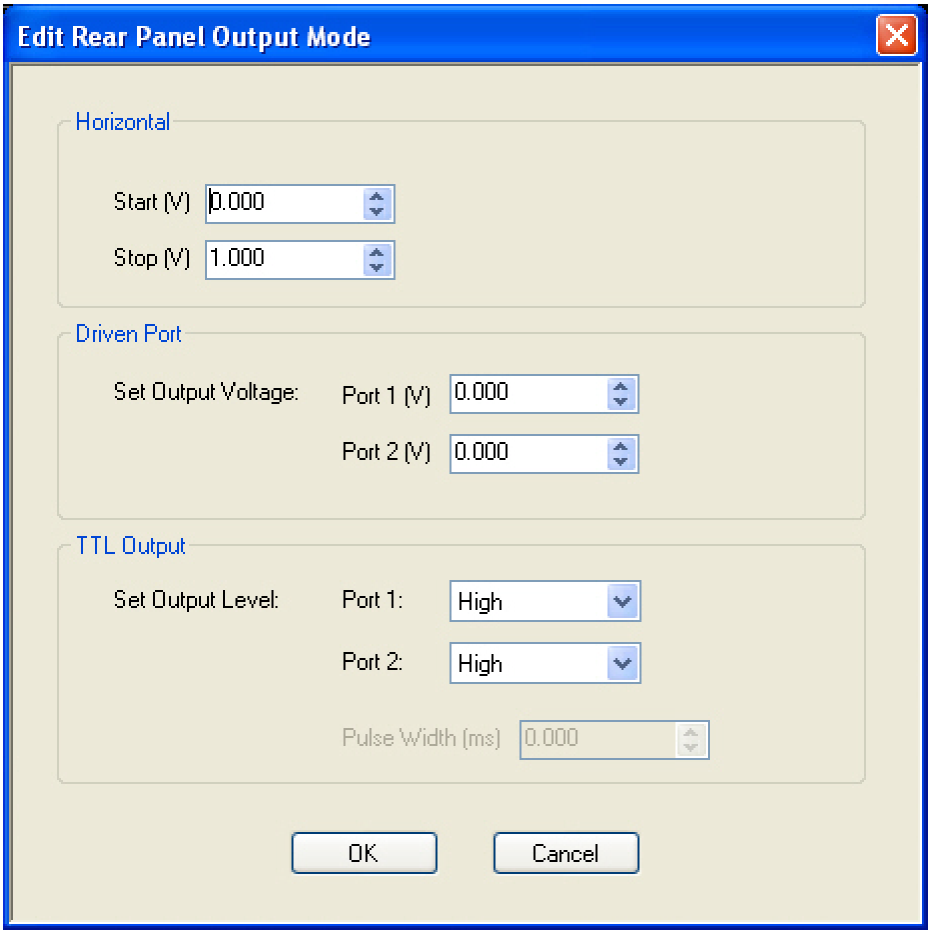
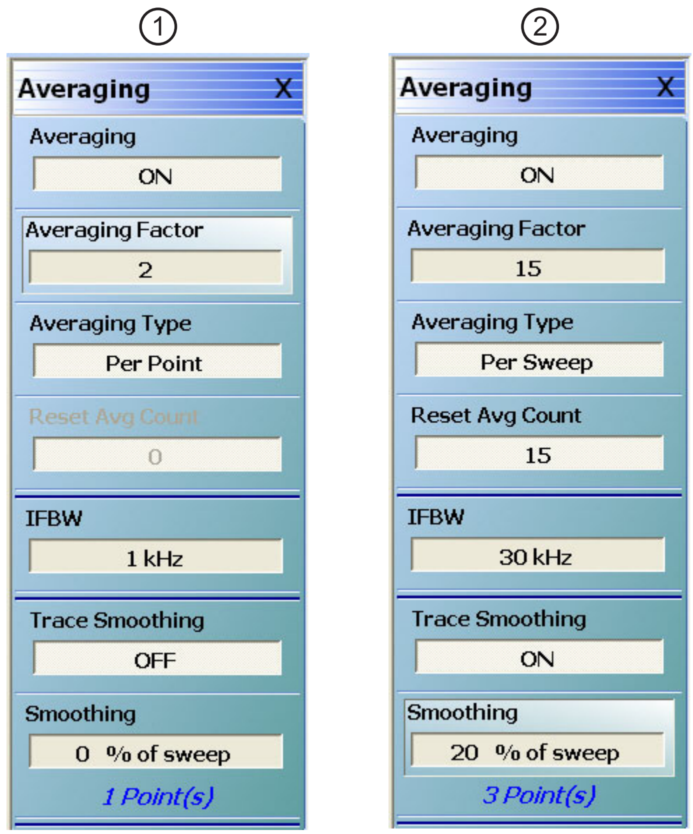


Figure 12-23. EDIT REAR PANEL OUTPUT MODE Dialog Box

12-10 Averaging and Smoothing

Overview

Averaging and smoothing are covered to a considerable extent in the operations manual but there are some measurement-related impacts that should be discussed in this section. The control menu is repeated in Figure 12-24 for reference.



1. IFBW is set to 1 kHz and Trace Smoothing set to OFF (at left).	2. IFFBW is set to 30 kHz, Trace Smoothing set to ON with Smoothing applied to 20% of the sweep (at right).

Figure 12-24. AVERAGING Menu - Both menus show that averaging has been toggled on.

Averaging

The Averaging button toggles the function OFF and ON.

Avg. Factor

The Avg. Factor (Averaging Factor) represents the number of measurements performed at each frequency point in the case of per-point averaging, and represents the number of sweeps averaged (in a running average sense) for per-sweep averaging.

Averaging Type

The Averaging Type button toggles between per-point and per-sweep averaging.

- **Per-Point Averaging**

  Per-point averaging acquires additional samples at each frequency (or power) point and performs the averaging process at that time. In this sense, it is quite similar to an IFBW reduction (adding 10 per point averages is equivalent to a 10x reduction in IFBW). Since the time between sample acquisitions is small in this case, per point averaging works best at removing high rate noise.

- **Per-Sweep Averaging**

  Per-sweep averaging averages a given frequency (or power) point's behavior on subsequent sweeps. This can be a very long time constant between samples (depending on sweep speed) so this type of averaging does best with low rate noise.

  Per-sweep averaging is performed on a rolling basis. That is, if 10 per sweep averages are selected, the most recent sweeps are used to compute the result.

  Since per-sweep averaging has a long time constant, setup changes or DUT changes can appear to have an odd effect. Powering down an active DUT, for example, may lead to an S21 display to slowly drift away since it takes some time for the gain change to work its way through the sweep count. If a setup or DUT change is made, it may be desirable to reset the averaging count.

IFBW

The Intermediate Frequency Bandwidth (IFBW) is allowed in the range of 1 Hz to 1 MHz. At lower IFBWs, additional per point averaging will have little effect.

At very low frequencies, where the IFBW may be on the order of the system frequency, there could be measurement issues. By default, the IFBW will be limited at system frequencies below 3 MHz although this can be overridden under the System menu.

Trace Smoothing

Trace smoothing is toggled OFF and ON by this button. Trace smoothing performs a weighted averaging around each frequency point using a window size set by the percentage of smoothing. Since this process combines data at different frequency points, it should be used with care since it can remove valid frequency response information.

Averaging and Smoothing Conclusions

In time domain, averaging and IFBW apply to the basic frequency domain data. Smoothing applies to the time domain data. Everything on this menu is channel-based.

Chapter 13 — Measurement - Time Domain (Option 002)

13-1 Chapter Overview

This chapter provides time domain measurement guidelines and procedures. General descriptions, key concepts, and example procedures are prevented for time domain measurement modes of low pass, bandpass and gating.

13-2 Introduction

The time domain option offers the ability to transform the native frequency domain data of the MS4640A Series VNA into time domain information for TDR-like displays, distance-to-fault analysis, and general spatial-based circuit and network troubleshooting. Uses for time domain include:

- Identifying the location of significant mismatches/discontinuities in a launch structure in a fixture or PC board
- Finding and quantifying defects in a cable assembly
- Identifying the characteristics of a discontinuity (inductive or capacitive) in a transition within a fixture or on-wafer
- Determining semi-quantitatively the impedance levels in a cascaded series of transmission lines.

There are a significant number of choices in how to configure the transformations that this section will cover. To begin, time domain is a per-trace invocation so that, within a given channel, frequency domain and time domain traces can be freely mixed on any response parameter. Note that since there is a single x-axis readout per channel, and it will be in the units of the active trace (either frequency or time range, not both at the same time will be displayed). Time domain and the TIME DOMAIN menu is accessed from the DISPLAY menu and its top level selections are shown in Figure 13-1 on page 13-2.

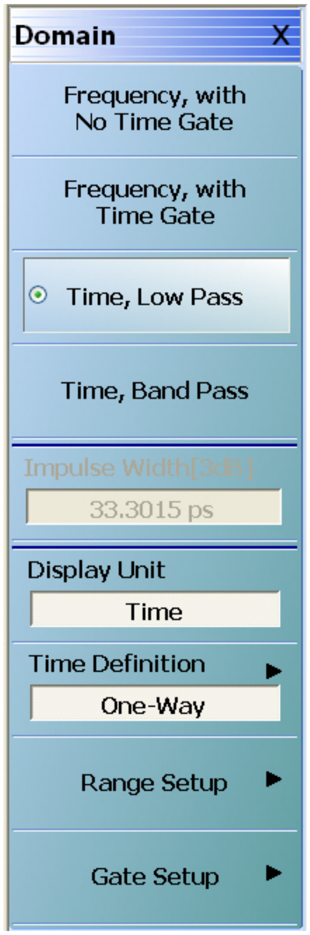


Figure 13-1. DOMAIN Menu - Top Level Domain Menu

13-3 Basic Time Domain Modes

The four basic modes of the Time Domain menu are:

- **Frequency With No Time Gate**

  This is the regular frequency sweep mode.

- **Frequency With Time Gate**

  This is frequency domain data that has passed through time domain where a gate is applied to exclude certain data (such as to remove certain defects) before returning to the frequency domain.

- **Time, Low Pass**

  A time domain mode where frequency content fairly close to DC is available (start frequency no more than about 10 step sizes). Step response (like a TDR) processing is available and resolution is better but this mode may not be available for all frequency lists. The selection will be greyed out if incompatible.

- **Time, Bandpass**

  A time domain mode for any frequency list. Only impulse response can be displayed, defect identification tools are more limited, and resolution is a factor of 2 worse than in lowpass (for the same sweep width) but it can be used for any frequency sweep. This is the only choice in band-limited scenarios such as waveguide.

13-4 General Concepts

Chirp-Z Transform

The time domain functionality is provided by a chirp-Z transform (in most cases) of the available frequency domain data for that parameter. Since the transform simply treats the frequency domain values as input data, any parameter can be transformed (including mixed-mode and differential S-parameters). Unratioed parameters are less useful since they do not contain phase information that the transform relies upon.

The chirp-Z transform is, in a macro sense, very similar to the Fast Fourier Transform with the exception that the output range can be variable. This allows the ability to specify an arbitrary time range to look at while maintaining the desired point count. A different algorithm is used with dispersive media, such as waveguide and microstrip where the time-frequency relationship is more complex, but the functionality remains the same.

Defects as Impulse Functions in the Time Domain

Defects can be considered to be impulse functions in the time domain. This sum of impulses transforms to a sum of complex exponential in the frequency domain. While these produce the characteristic ripples seen in frequency domain data of mismatched systems, the frequency domain data can be hard to interpret as to the location of the defects causing the ripples. This is the value of a time domain analysis.

One-Way or Round Trip Time

One question that arises is whether the time (or distance) plotted represents a one-way or round trip time, particularly in the case of reflection measurements. The time definition menu, shown in Figure 13-2, controls this behavior. When in Auto, the system will always display one-way times and detects whether the measurement parameter is reflection or transmission to help sort that out. If using user-defined parameters or unusual loop-access configurations, going to manual control may be needed. The transform itself will generate a round-trip time for reflection and a one-way time for transmission without any intervention from the system.

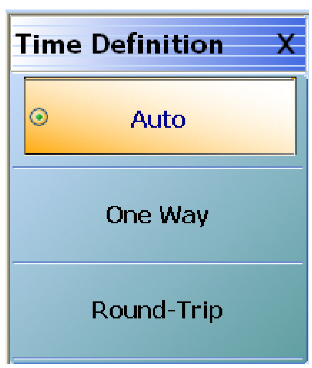


Figure 13-2. TIME DEFINITION Menu

13-5 Low Pass Mode

Low pass mode assumes the existence of data near DC which enables the ability to compute step responses and to create a pure real transform. While any graph type can be used (except Imaginary which would have a flat line), Real is sometimes the most valuable since information about the defect can be determined. An example plot showing a short at the end of a small transmission line length of approximately 100 ps appears in Figure 13-3. Both the impulse response and step response are plotted on real graph types. Many aspects of this plot will be discussed in this section including the impulse and step presentation of the same data.

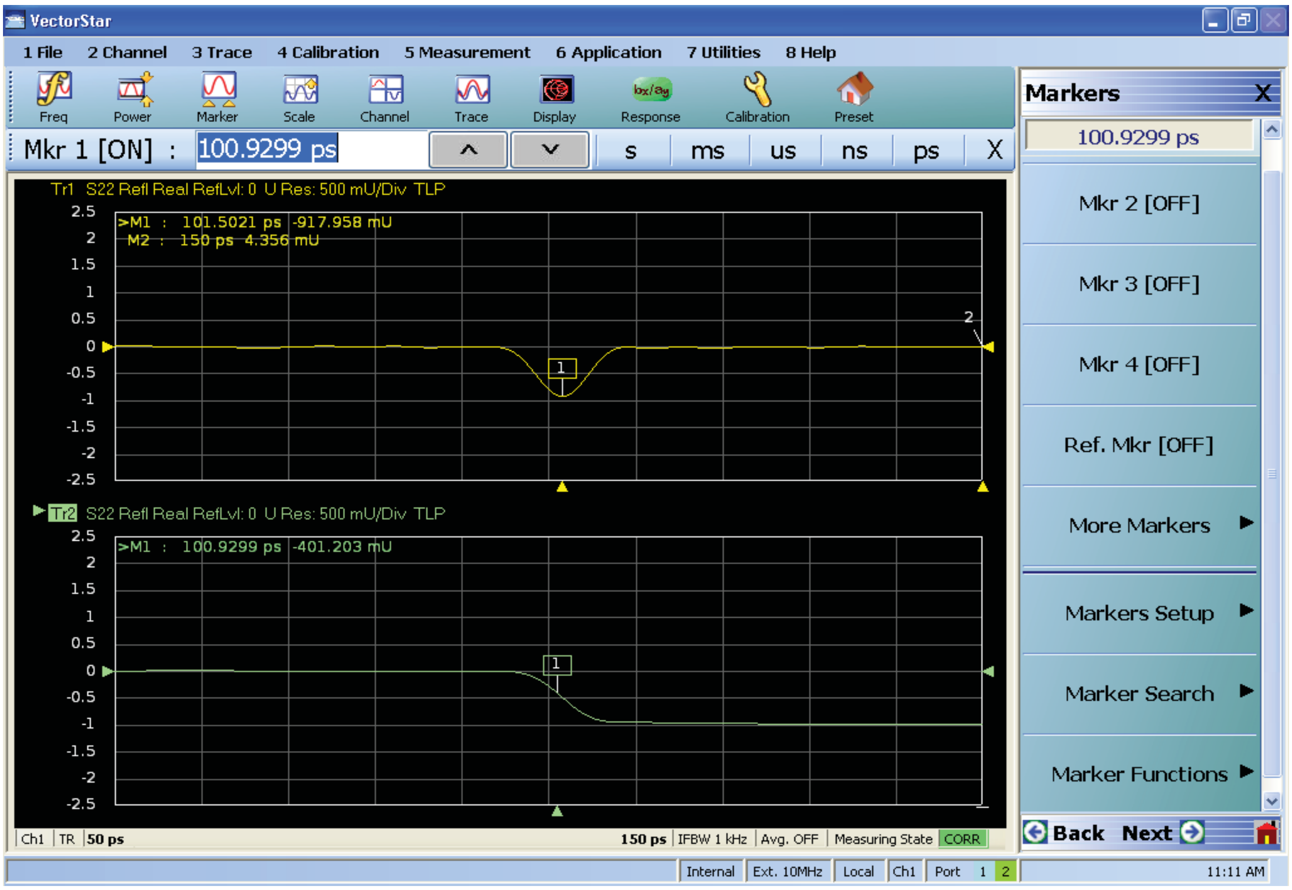


Figure 13-3. Example Low-pass Time Domain Plot

Many of the other submenus change slightly depending on which mode is selected so the remaining subsections will be partitioned according to the mode.

Range Setup Menu Functions

The Range Setup menu for low-pass time domain is shown in Figure 13-4. The top button, Display Unit, toggles between Time and Distance and is a duplicate button to the Display Unit button on the TIME DOMAIN menu (Figure 13-1).

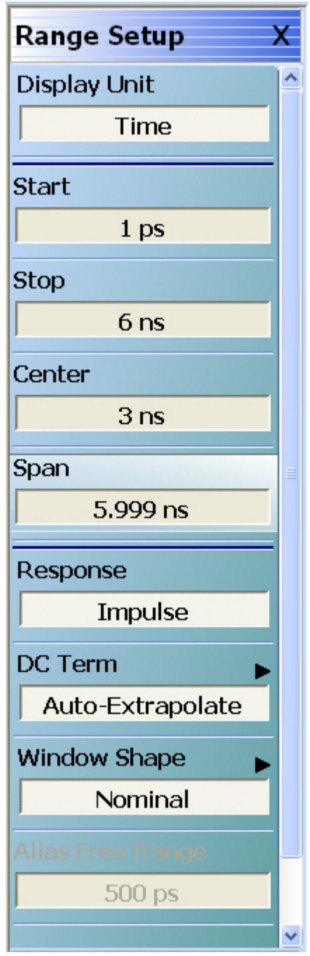


Figure 13-4. RANGE SETUP Menu - Time, Low Pass Domain

The fundamental output of the transform depends on the non-dispersive or dispersive nature of the media. In the case of non-dispersive media (to include coax), time is the fundamental output of the transform and distance is calculated using the media information on the measurement menu. In the case of dispersive media (waveguide or microstrip), distance is the fundamental output and time is calculated from that.

The Start, Stop, and Center buttons all invoke field tool bars that allow user-input for each value (in distance or time); with the Span button displaying the calculated result. There are few limits to what may be entered but extreme entries may not always be useful due to constraints of resolution and alias-free range. These limits are determined by the frequency list used as well as the window selected.

Resolution is interpreted as impulse width (the width of a singular defect) while alias-free range is the maximum time range that can be studied before defects start repeating themselves (due to the cyclical nature of the transform). To help, the resolution (impulse width) is displayed as a read-only variable on the main time domain menu (Figure 13-1) and the alias-free range is displayed on this range menu as a read-only variable.

The response choice is either Impulse or Step. The step response, which allows a TDR-like display is simply an integration of the impulse response which is the natural output of the transform. However, since the VectorStar MS4640A VNA cannot get all the way to DC, some additional information is needed to perform this integration. To see this consider:

$$\text{ImpulseResponse} = \Im^{-1} X(DC) + \{X(\text{sweepRange})\}$$

$$\text{ImpulseResponse} \approx A \cdot X(DC) + \Im^{-1}\{X(\text{sweepRange})\}$$

$$\text{StepResponse} = \int_0^t [A \cdot X(DC) + \Im^{-1}\{X(\text{sweepRange})\}]dt$$

(Eq. 13-1)

DC Term Menu

Since the DC value ends up being integrated from time 0 (zero), the value used here is quite important and the choices to compute this value are shown in Figure 13-5. The default choice is to allow the system to auto-extrapolate from existing frequency data to estimate the DC value.

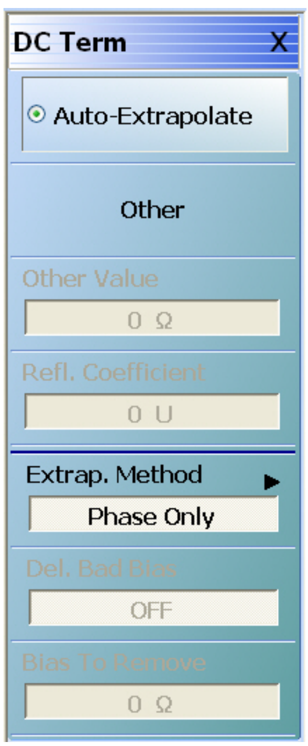


Figure 13-5. DC TERM Selection Menu

There are options on how the extrapolation is done, as shown in Figure 13-6.

Figure 13-6. The DC Term EXTRAPOLATION Menu

The default method, Mag-Phase, extrapolates both portions as would be expected and is energy-conserving. For cases where the start frequency is low and the DUT loss changes slowly over frequency, sometimes the magnitude may be assumed constant and only the phase function need be extrapolated (most common with long cable assemblies). The other option allows a table of low frequency values to be entered (two-column, tab-delimited). If the DUT is well-known, extrapolation can be avoided altogether by entering the DC impedance.

Window Shape Menu

The last item on the Range Setup menu is the Window Shape selection button which displays the Window Shape submenu shown in Figure 13-7.

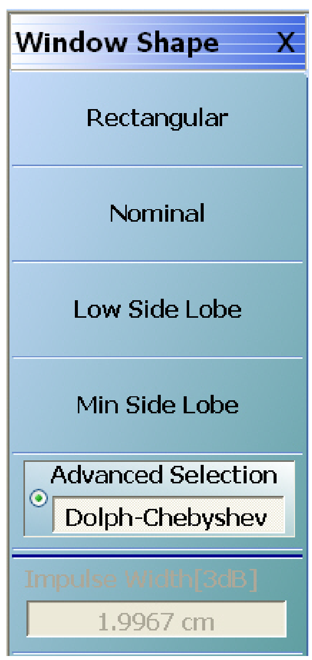


Figure 13-7. WINDOW SHAPE Menu

Since the frequency range of the VNA is finite, the frequency domain data will have a discontinuity at the stop frequency. This introduces side lobes in the time domain data that can obscure smaller defects and hamper separation of defects. The window provides some pre-processing of the frequency domain data to reduce the severity of the discontinuity and hence the side lobe level. This also reduces resolution but is unavoidable.

The Nominal window is the default and provides about half of the resolution of Rectangular (no window) but with an approximate 30 dB reduction in side lobe levels. The Nominal window is advised for most applications.

Since the window so strongly affects resolution, the Impulse Width display is repeated on this submenu to help determine the impact on the desired measurement.

An example of how the window shapes affect the impulse data (main lobe width and side lobe level being traded-off) is shown in Figure 13-8. Here the same data appears with the four different window selections. For this plot, data was saved to TXT files and plotted externally.

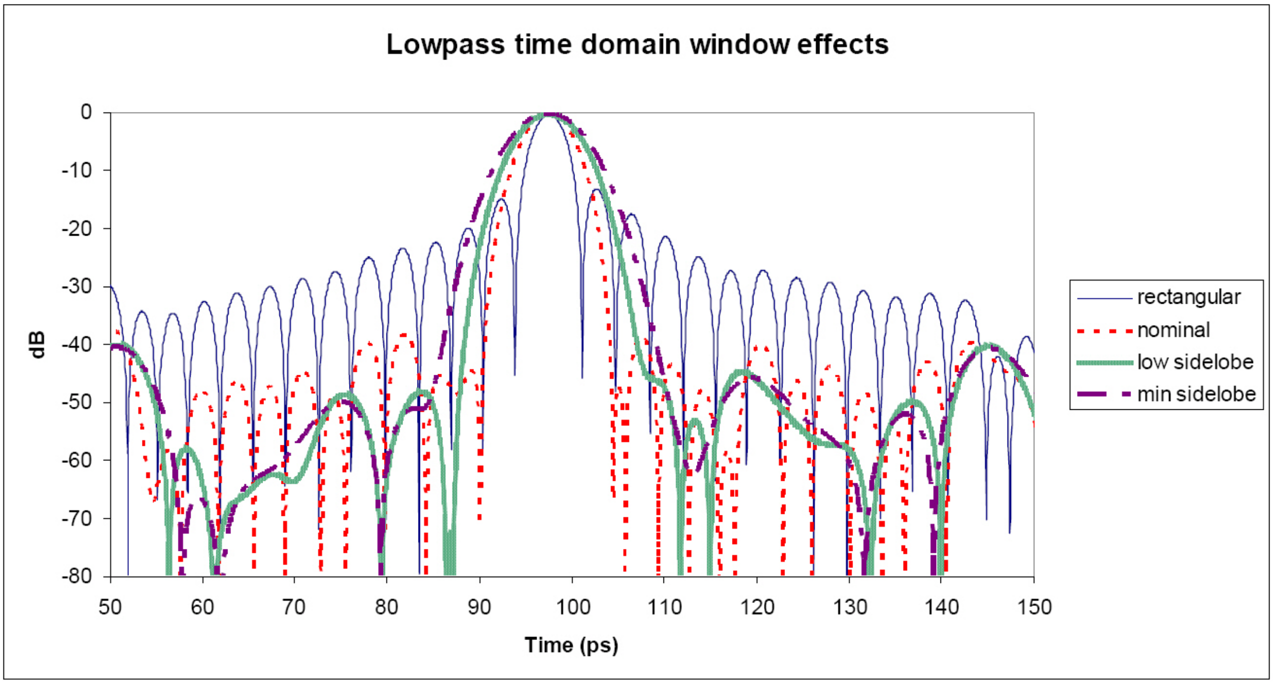


Figure 13-8. Effects of Window Shapes Plot

The Advanced Window selection button brings up the dialog shown in Figure 13-9 that has the previous four choices along with two new parameterized windows, Kaiser-Bessel and Dolph-Chebyshev.

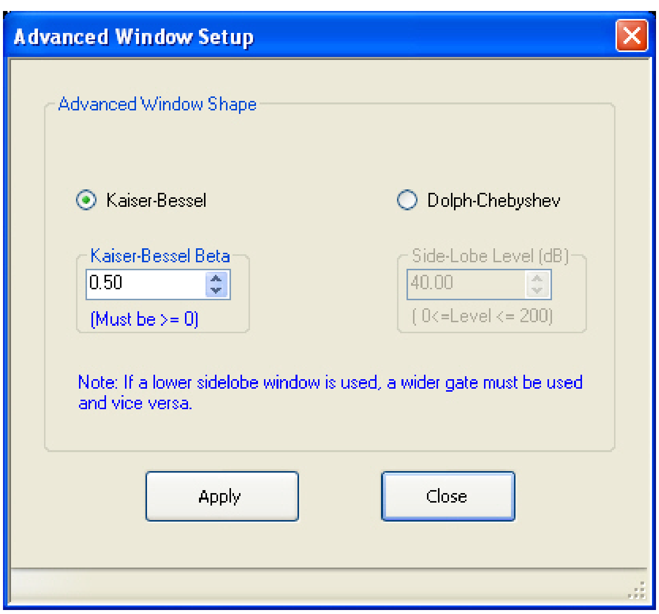


Figure 13-9. Advanced Window Setup Dialog

The dialog for advanced window setup makes two new window choices available (Kaiser-Bessel and Dolph-Chebyshev). The Apply button must be used for a radio-button selection to take effect.

These two new window types allow for a finer selection of the trade-off between side lobe level and resolution. For the Kaiser-Bessel window, a larger Beta value leads to lower side lobes, but a wider main lobe width (and hence poorer resolution). For the Dolph-Chebyshev window, the side lobe level is parameterized explicitly (in absolute dB) and a larger value leads to a wider main lobe width as well. The windows for two parameter values for each of these windows are shown in Figure 13-10 along with the rectangular window for comparison.

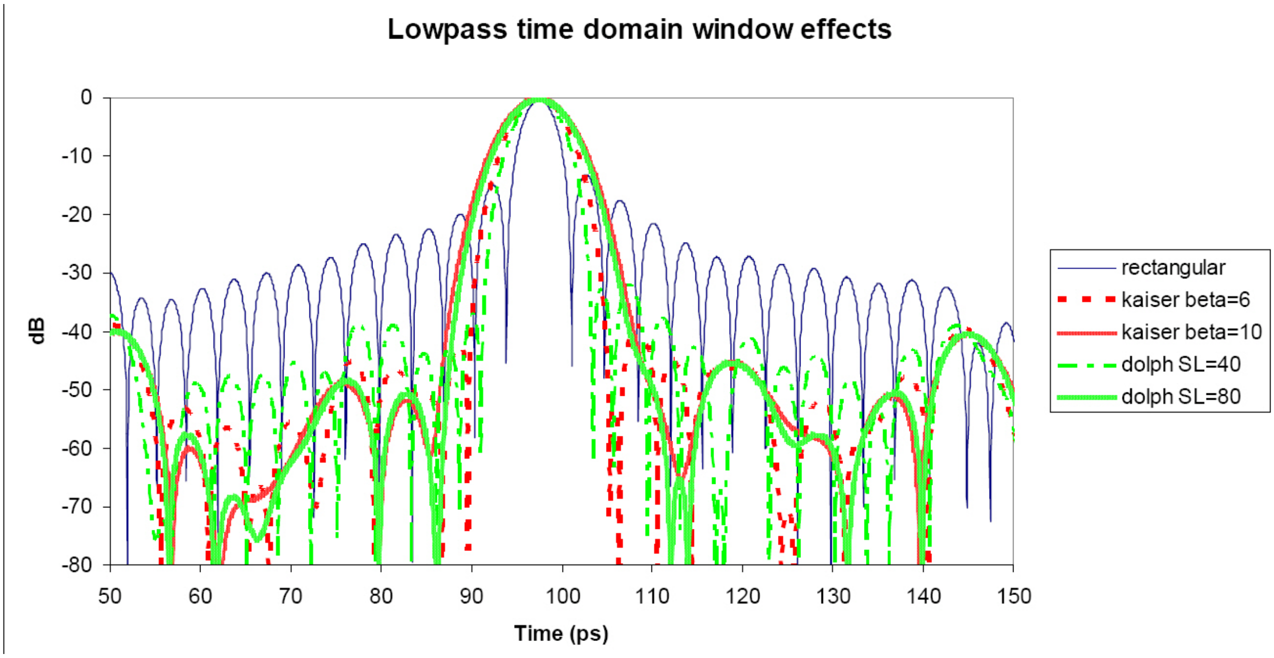


Figure 13-10. Effects of Window Shapes Plot with Advanced Windows Selection

The approximate relationship between these parameters and the main lobe width (null-to-null) is suggested in Figure 13-11. Here, everything is scaled relative to a rectangular window (a nominal window is at 2, a low side-lobe window is at 3, and a minimum side-lobe window is at 4 on this scale) and the y-axis is normalized relative to the lobe width of a rectangular window.

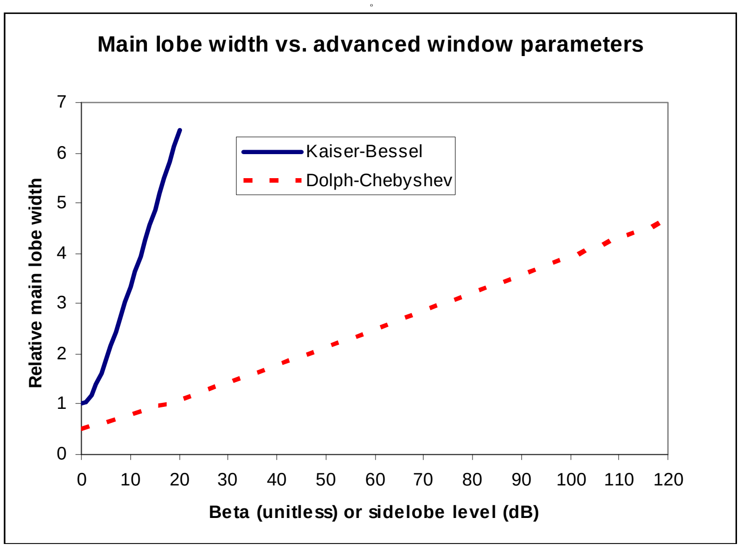


Figure 13-11. Comparison of Lobe Width vs. Window Parameters

13-6 Bandpass Mode

The Bandpass Time Domain mode is similar to low pass but a few menu items change. Any graph type can be used with bandpass mode but log magnitude and linear magnitude are the most common. The top level of the time domain menu is repeated in Figure 13-12 for convenience. This menu level does not change between the time domain modes. An example measurement (of a short on a transmission line like in Figure 13-2) is shown in Figure 13-17. Here, a real and imaginary plot is shown to illustrate the difference from the pure real low pass time domain result but this graph type is not commonly used in practice.

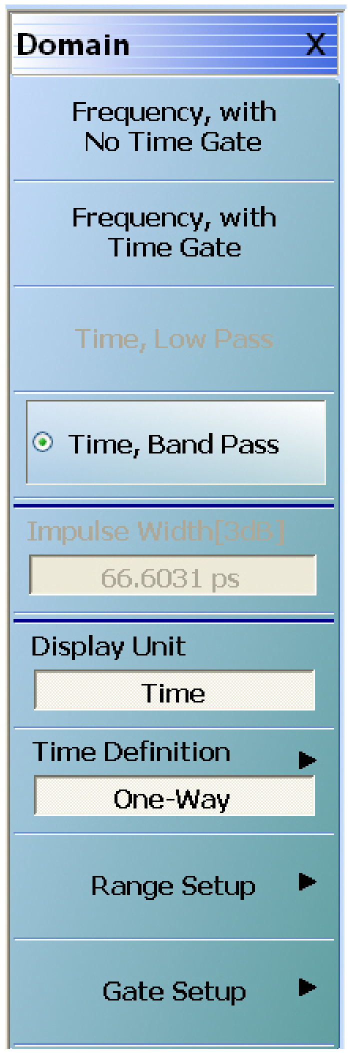


Figure 13-12. Top Level DOMAIN Menu - Time, Band Pass Selected

An example bandpass time domain plot is show below for a short at the end of a transmission line. In a log magnitude display, there is a single impulse of approximately unity amplitude near the 100 ps mark.

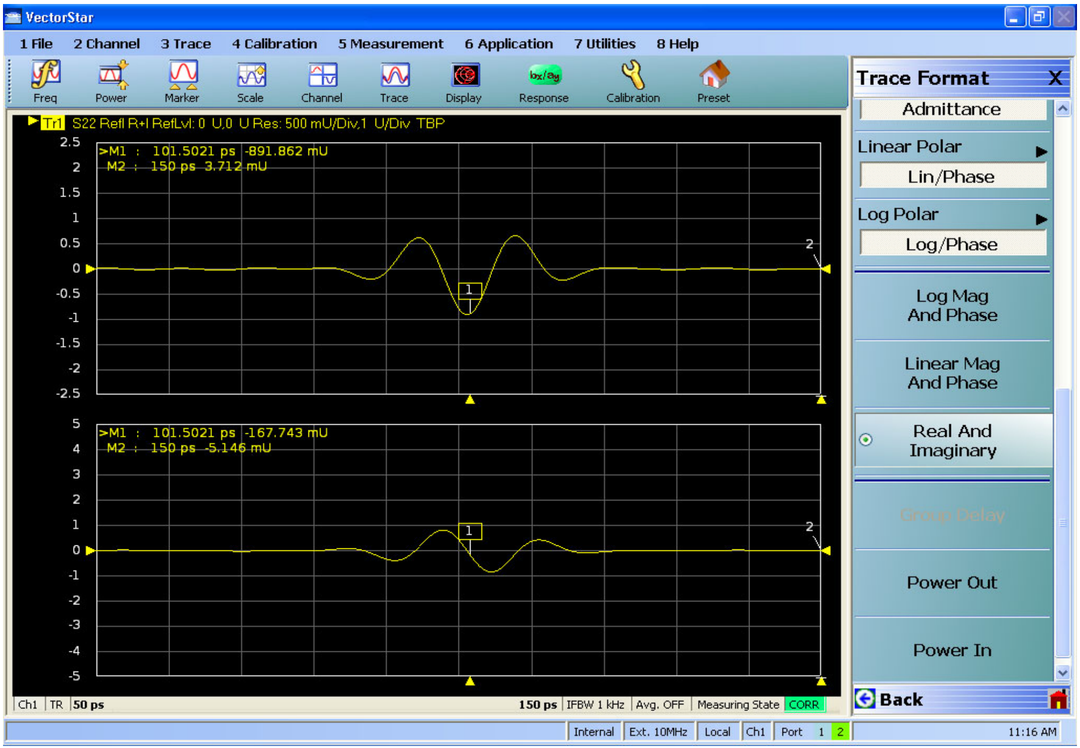


Figure 13-13. Example Band-pass Time Domain Plot

The range menu for bandpass mode is shown in Figure 13-14. The differences here are that the response choice and DC terms are gone since they do not apply to this mode, and a new item appears: Phasor Impulse.

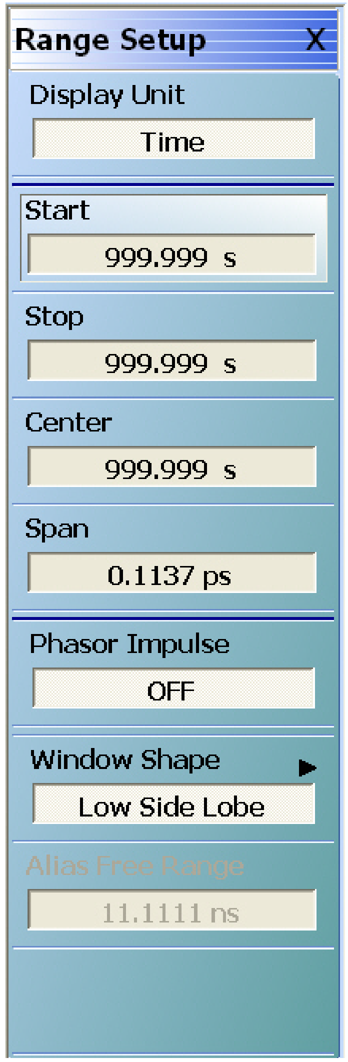


Figure 13-14. RANGE SETUP Menu for Bandpass Time Domain

In low pass mode, the sign of the data can be used to provide some hints as to the nature of the defect (inductive or capacitive). It is less obvious in bandpass mode since the time domain data is complex. A function termed Phasor Impulse Mode is an attempt to simulate the data reduction of low pass mode when operating in bandpass mode. It is only correct if the defect can be described by a single defect (a single complex exponential in the frequency domain). The range should be adjusted to have one peak on screen occupying a reasonable fraction of the span. The Phasor Impulse function processes this single peak to produce a pure real transform carrying sign information much like lowpass mode (positive for inductive, negative for capacitive).

The window shapes have the same effect as in low pass but the starting resolution is only half that of low pass (the window effects are multiplicative). The window effects are illustrated in Figure 13-15 and correspond to the measurement of Figure 13-13 on page 13-11, but expressed in log magnitude. Note the trade-off of side lobe height for main lobe width and that the lobe width is twice that for low pass (Figure 13-8 on page 13-8).

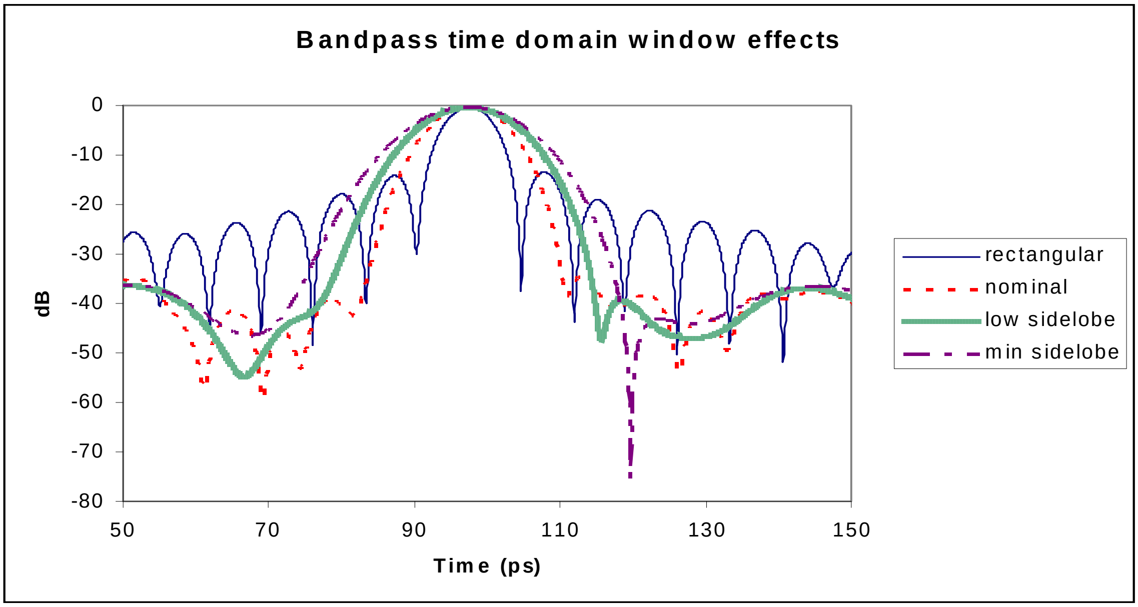


Figure 13-15. Window Effects in Bandpass Time Domain

As with lowpass time domain, the Advanced Windows are also available. Some example results are shown below compared to the rectangular window for a few parameter values.

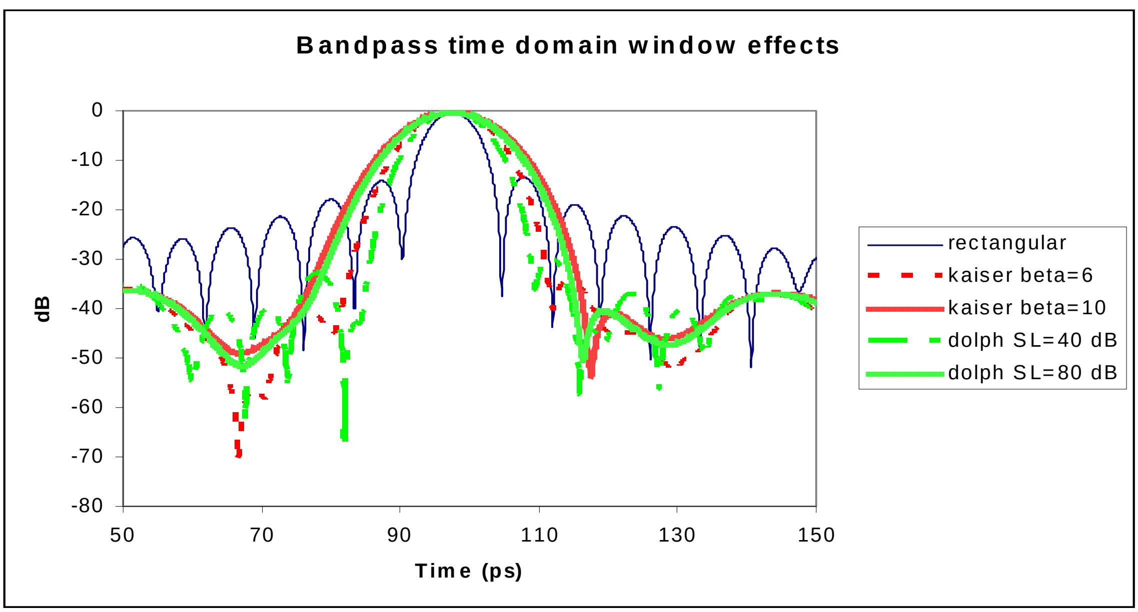


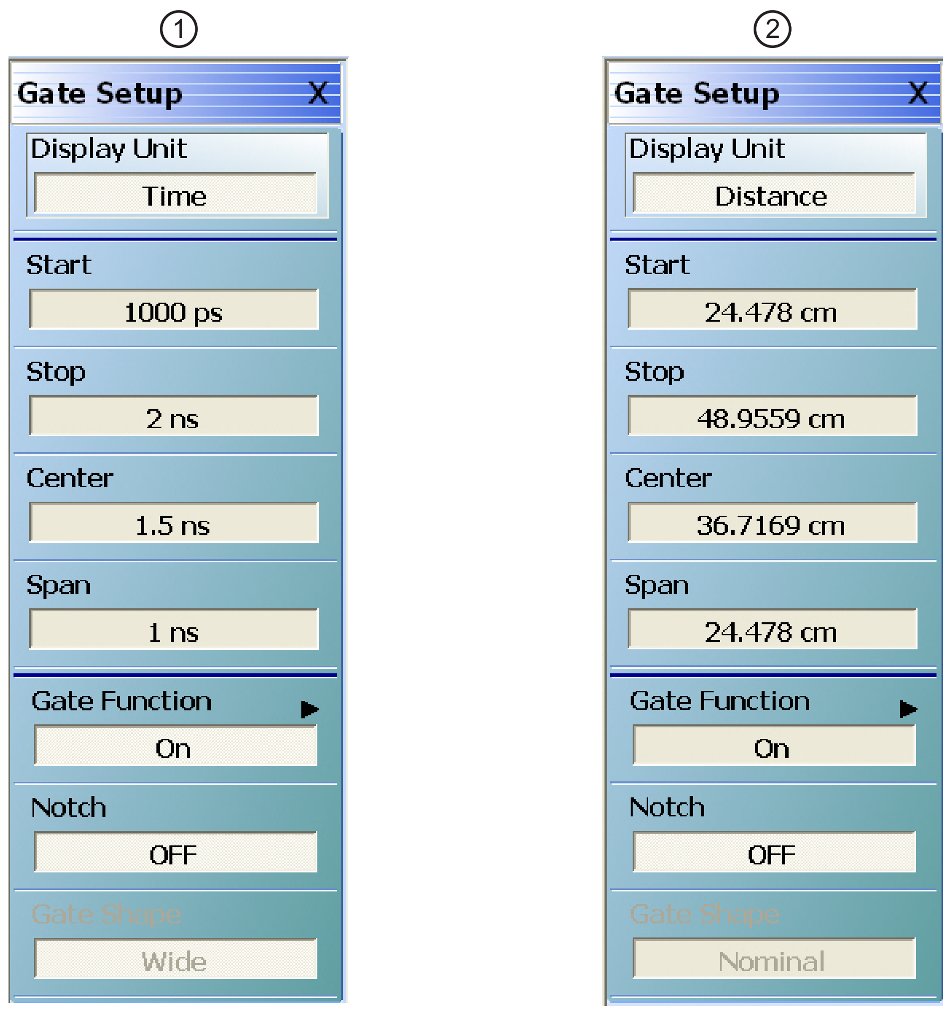
Figure 13-16. Window Effects in Bandpass Time Domain (advanced window types)

13-7 Gating

Both lowpass and bandpass work similarly with regards to gating. Gating is the process of selecting or deleting certain defects to study. This can be left in time domain but, more commonly, the gated results are fed back through the forward transform to get the frequency domain result corresponding to the modified defect scenario just created.

Gate Menu

The Gate menu looks much like the Range Menu. The Display Unit toggle button and Start, Stop, Center, and Span buttons (for the gate this time) control values as described in the sections above.



1. Time units (at left)	2. Distance units (at right)

Figure 13-17. GATE SETUP Menu

The Notch toggle selects the polarity of the gate. When notch is OFF, the gate will keep everything between start and stop. When notch is ON, the gate will reject everything between start and stop. The main submenu, Gate Function, is shown in Figure 13-18.

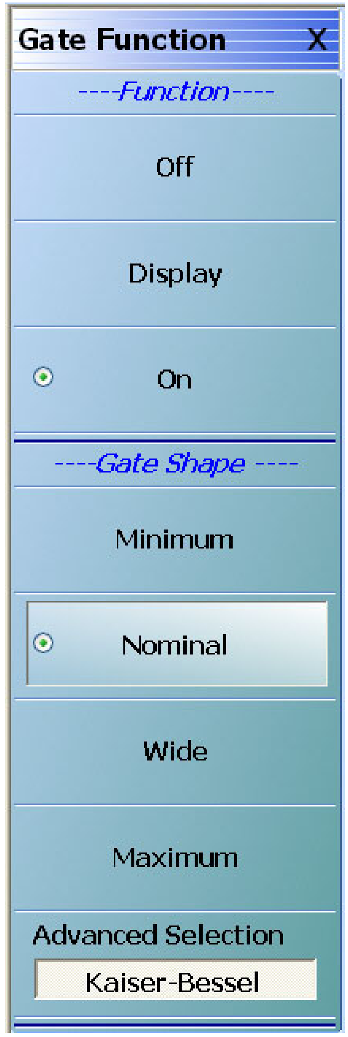


Figure 13-18. Gate Function Submenu

The default gate shape is nominal. By default, the gate is off. Selecting Display will allow the gate function to be drawn on screen (using the current graph type for the active trace). This can be helpful in visualizing what is being included in the gate. Turning gate on will apply the gate to the current time domain data.

The gate shape is analogous to the window selection. If the data was truncated with a sharp gate (minimum, akin to rectangular), maximum resolution in used determining the gate but ripple is introduced in the frequency domain. For more gradual gates, the resolution in separating defects decreases, but the size of the artifacts added to the frequency domain data decreases as well.

The window and gate shapes cannot be selected entirely independently since they interact through the transform. In particular, the use of a very sharp gate with a low side lobe window can lead to large errors. The allowed combinations are shown in the table below. If an invalid combination is selected, the variable not being currently modified will be changed to the nearest valid value.

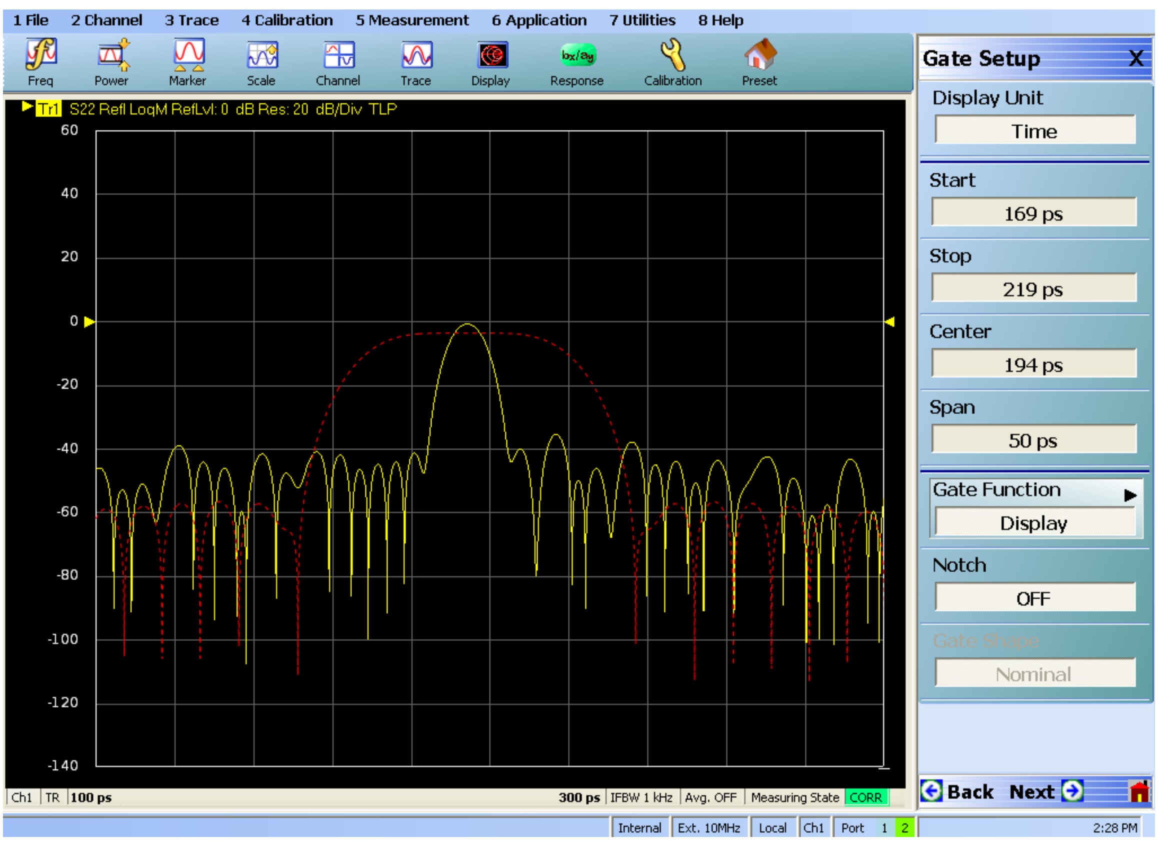
Table 13-1. Window Type and Gate Shape Allowed Combinations

Window/Gate	Minimum	Nominal	Wide	Maximum
Rectangular	OK	OK	OK	OK
Nominal	OK	OK	OK	OK
Low side lobe	No	OK	OK	OK
Minimum side lobe	No	No	OK	OK

With the advanced gates and windows, selections are not precluded although substantial errors can result if values are chosen without caution. If a more aggressive window is chosen (larger beta or side lobe level), then the gate must be wider (wide or maximum; larger beta or side lobe level).

DUT Example - Gate and Window Nominal

To work through an example, a DUT consisting of a short at the end of a slightly mismatched transmission line is used. It is desired to examine the short more closely in frequency domain, excluding the effects of the transmission line. In Figure 13-19, the gate is in display mode surrounding the desired reflection. Both gate and window are set to nominal in this case.



Gate is the red dashed line

Figure 13-19. Gate in Display Mode Example

Next the gate is turned to on. In Figure 13-20, the suppression of the time domain information outside of the gate area is seen.

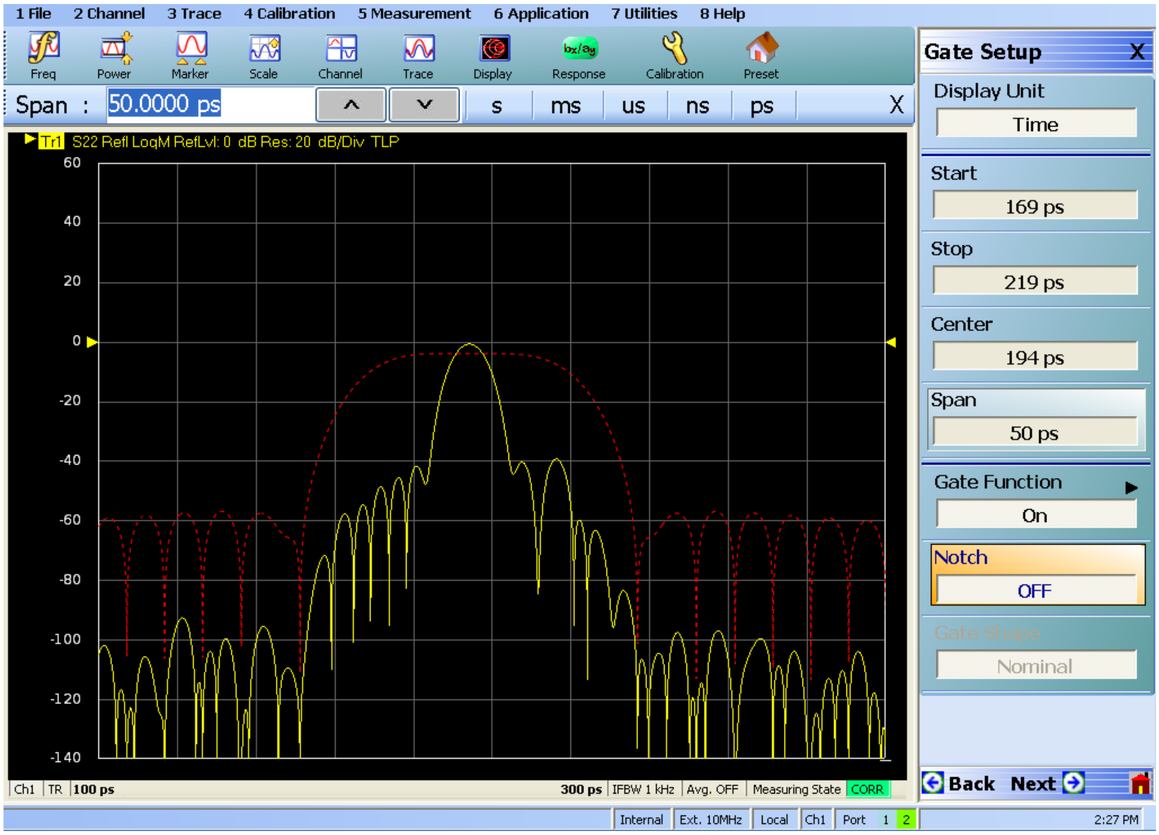


Figure 13-20. Gate Turned On Example

Finally, frequency with time gating is activated and the result is shown in Figure 13-21. The result from frequency without time gating is shown in memory as a darker trace. The time gating has removed much of the ripple due to the mismatched transmission line and residual source match of the instrument.

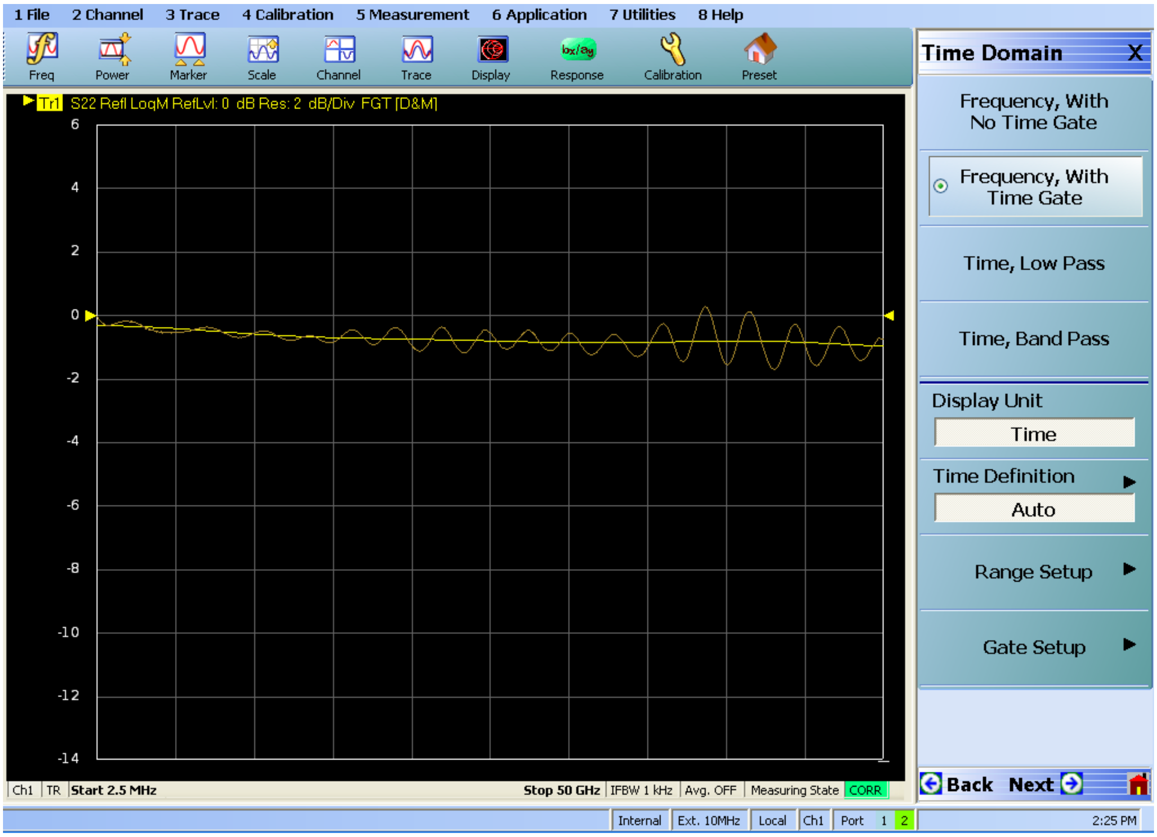


Figure 13-21. Frequency with Time Gating Example

Chapter 14 — Measurement - Sweep Types

14-1 Chapter Overview

This chapter covers the different sweep types available with the VectorStar MS4640A Series VNA to increase measurement functionality.

14-2 Introduction

A number of different sweep types are available within the MS4640A Series VNAs include

- Traditional frequency sweep (defined by a start frequency, a stop frequency and a number of points)
- Log sweep (with a constant ratio or logarithmic step size)
- Power sweep (frequency is constant and power is defined by a start value, a stop value, and a number of power points). Gain compression will be covered as a part of power sweep.
- Frequency-based segmented sweep (frequencies are defined individually or in sub-spans, that are monotonically increasing)
- Index-based segmented sweep (frequencies are defined individually or in sub-spans and can be in any order; all plotting is in terms of index rather than frequency because of the possible direction changes)
- Power sweep (swept frequency) which is a limited multi-dimensional sweep mode that allows the evaluation of gain compression across swept frequency.

The setup complexities in regular frequency sweep and power sweep are minimal and will only be discussed briefly. The segmented sweep possibilities are considerably larger and some explanation will help in setting them up.

The SWEEP SETUP and SWEEP TYPES menus are shown in Figure 14-1 and Figure 14-2

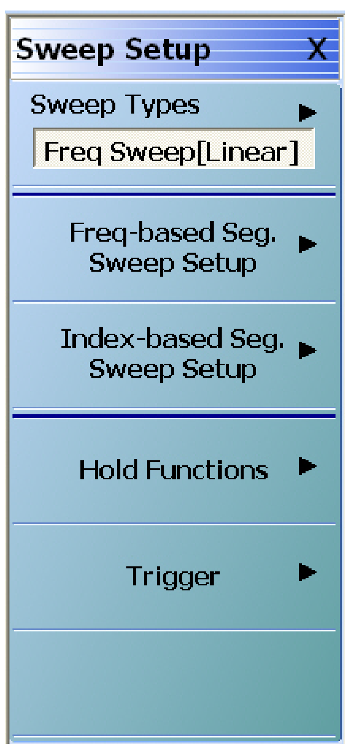


Figure 14-1. SWEEP SETUP Menu

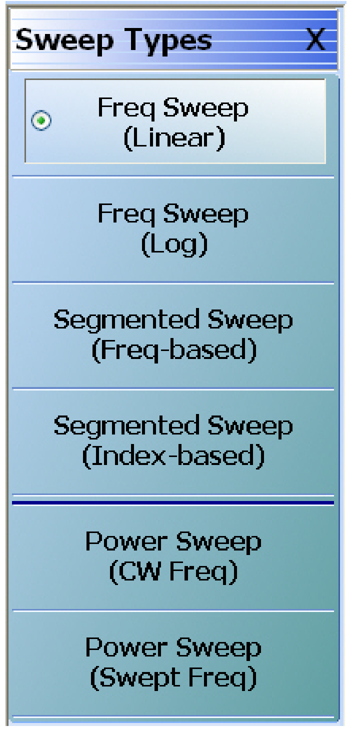


Figure 14-2. SWEEP TYPES Menu

14-3 Setting Up Traditional Frequency Sweeps (Linear and Log)

A traditional frequency sweep is based on a start frequency, a stop frequency, and a number of points (or, alternatively, substitute center/span for start/stop). The number of points is not confined to certain preset values. The minimum number is two (otherwise use CW mode) and the maximum number is usually 25,000.

A mode allowing 100,000 points is also available, but operation is limited to a single channel.

Power entry while in frequency sweep mode is accomplished through the Main Power Menu and the Power Cal Menu for frequency sweep, as shown in Figure 14-3 and Figure 14-4.

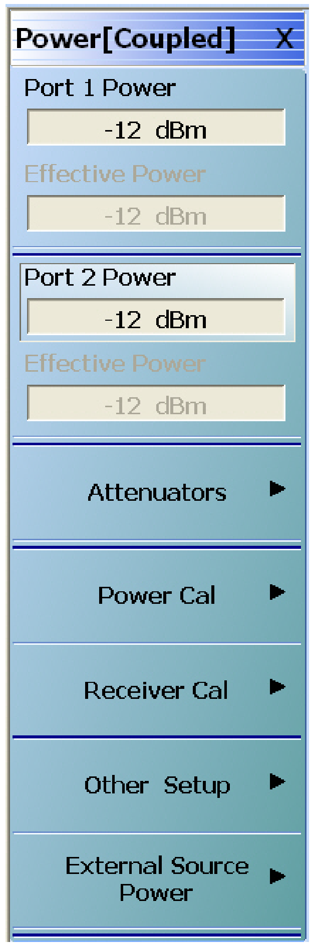


Figure 14-3. Main POWER Menu - Port 1 and Port 2 Coupled – Attenuators Installed

Figure 14-4. POWER CAL Menu

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 for with reasonable precision. A common setup for executing this calibration is shown in Figure 14-5.

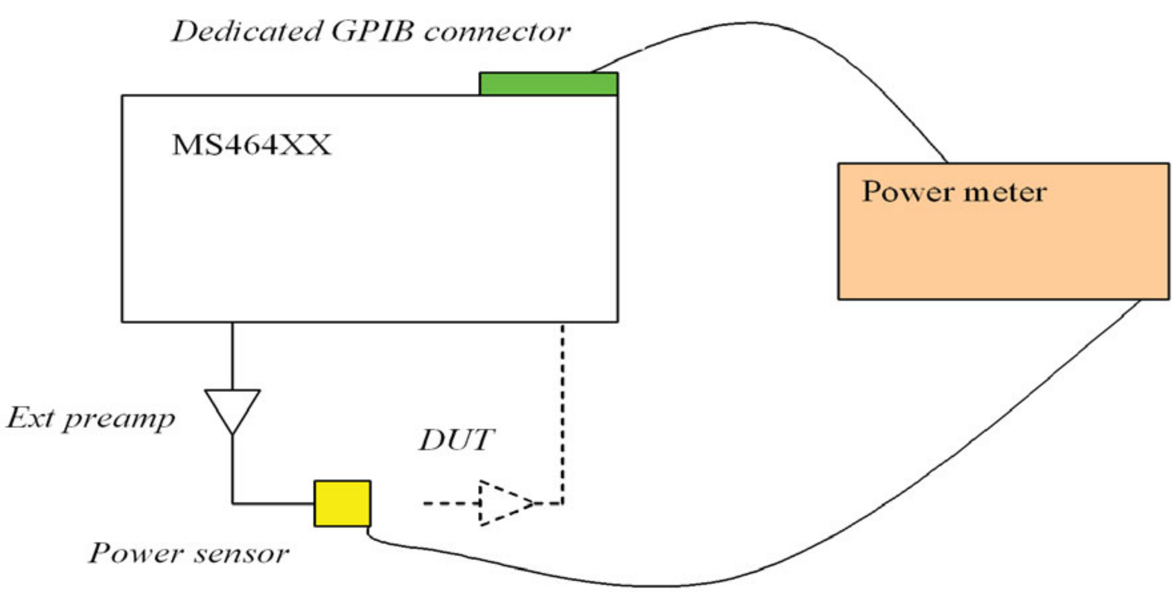


Figure 14-5. Port 1 Power Calibration Example Setup

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 14-6.

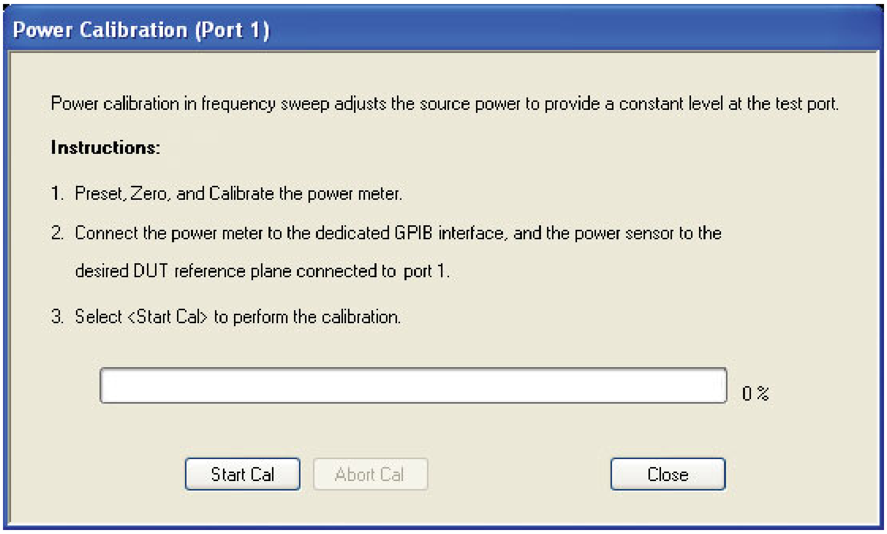


Figure 14-6. POWER CALIBRATION (PORT 1) Dialog Box

All of the above discussion applies to both linear and log versions of swept frequency. In log sweep, the frequency list is calculated using a constant ratio step as opposed to a constant step size in linear frequency sweep. Also, the graticule for rectilinear plots while in log sweep will change to reflect that modified frequency list. An example is shown in Figure 14-7. Integral numbers of decades of lines will always be used.

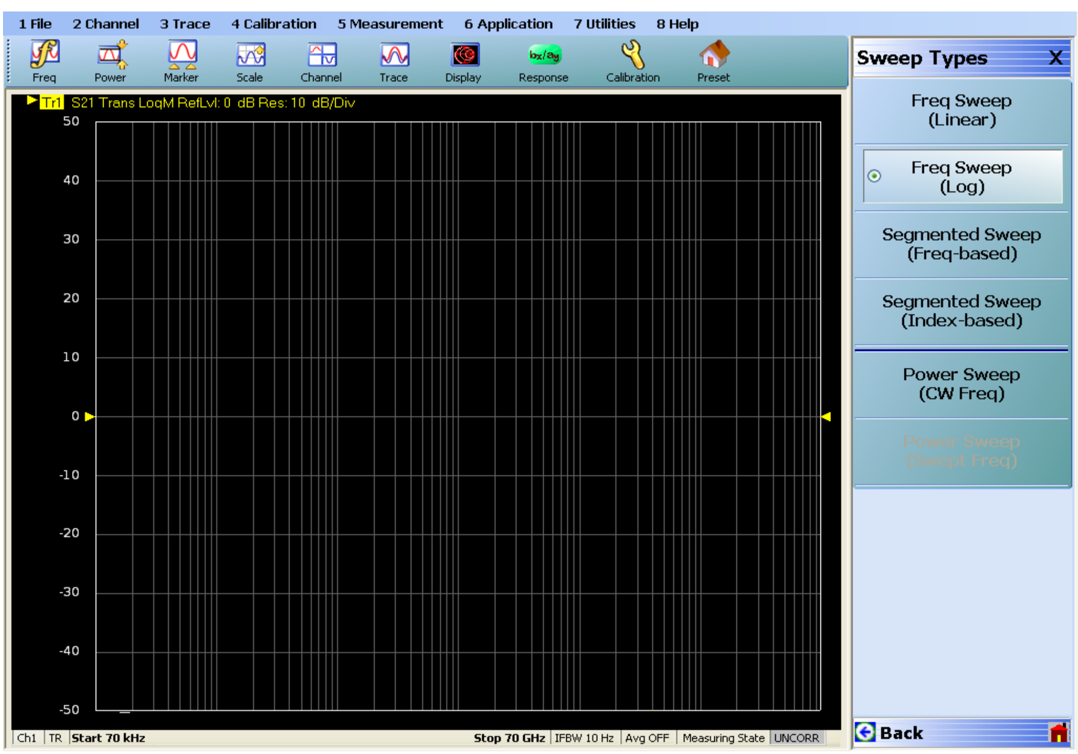
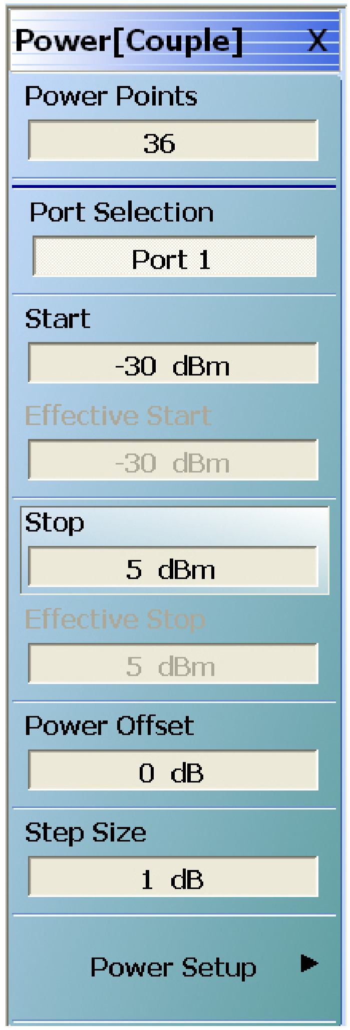


Figure 14-7. Example Graticule for the Log Sweep Type

14-4 Setting Up Power Sweeps

A power sweep is valuable for making gain compression and other power dependent semi-linear measurements. The frequency is set at a single CW value and the power range is specified in a way analogous to frequency sweeps as suggested by Figure 14-8.



Sweep Type set to Power Sweep (CW Freq)

Figure 14-8. Main Power Sweep Menu - POWER [COUPLE] Menu

As with the regular power control in frequency sweep, the power at the two ports may be coupled or uncoupled. This feature takes on new importance in power sweep in that the two ports may drive with completely different power ramps. The number of points in these two power sweeps must, however, be the same. As with all sweep types, different attenuator settings in different channels is not permitted to avoid potential attenuator damage in fast sweeping scenarios.

Power offset is an important entry for cases when an external preamplifier, large pad, or other network may be in use between the port and the DUT plane. By entering a value here to approximate the net gain of the external networks, the effective power fields will be updated accordingly and any power calibrations performed will be more efficient. Note that source-side attenuator settings are also reflected in the effective power fields.

Some of the more detailed controls are on the power setup level of the power menu located on the POWER SETUP menu (see Figure 14-9). The coupling control and port selection (when uncoupled, duplicate of first level) is located here as is the single power selection items. This entry allows one to put the system in constant power (and constant frequency) and is often used for making DUT adjustments prior to full power sweep measurements. The receiver cal and external source power submenus are covered in other sections of this measurement guide (Receiver Calibration and Multiple Source control respectively).

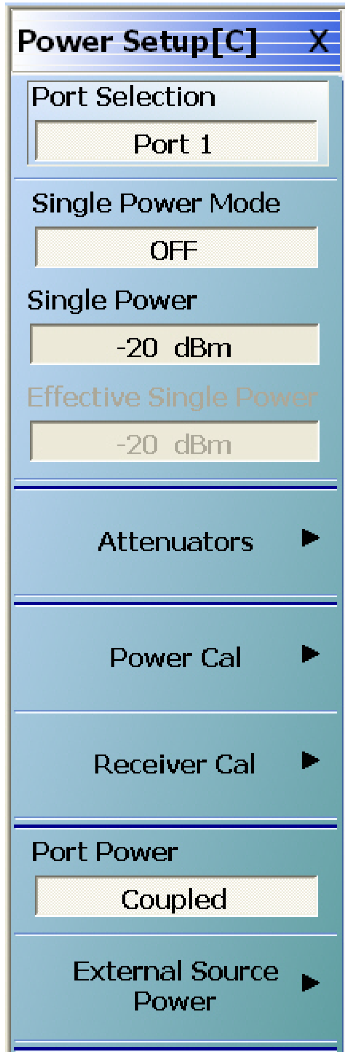


Figure 14-9. Second Level Power Sweep Setup Menu - POWER SETUP[C] Menu

The power calibration while in power sweep mode allows an accuracy enhancement of the power levels delivered to the DUT. A power sensor will be connected to the port selected and then at each power point in the power sweep, the system will adjust the control loops to deliver that power to within 0.1 dB. The Power Calibration menu is shown in Figure 14-4 and the dialog executing the calibration is shown in Figure 14-11.

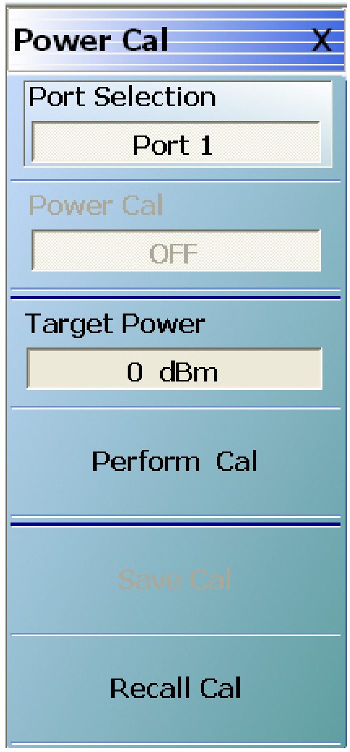


Figure 14-10. POWER CAL Menu

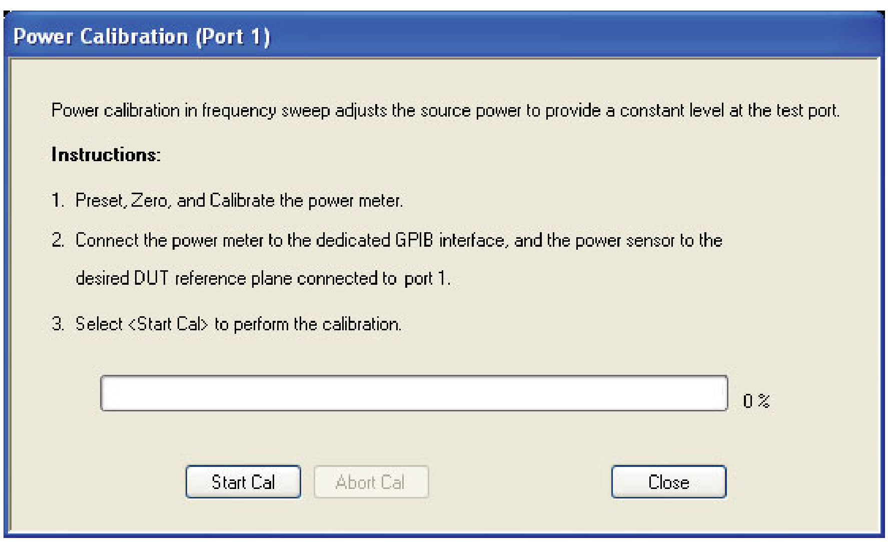


Figure 14-11. POWER CALIBRATION Dialog Box

Gain Compression

Although not a sweep type by itself, gain compression is often thought of as the main application of power sweep. As such, a trace-based utility is provided to simplify the gain compression measurement.

The objective is to provide a marker-like function for quickly finding the X-dB compression point of an amplifier or other DUT. While this is typically performed on S21, it is allowed on any ratioed parameter so that, for example, match deviations can be quantified during compression. The gain compression function is trace-based unlike the sweep type so it can be invoked on some traces (S21 for example) and not on others (b2/1 to monitor output power for example).

The main gain compression menu (located under Display while in power sweep) is shown in Figure 14-12. The second button toggles on and off the indicator for the active trace (the indicator is denoted by a "**C**" on screen and will be located at the desired compression point. The top button activates continuous normalization of the trace to the value of the first point in the power sweep. This allows for easier visualization of the compression process but is not necessarily needed for the measurement.

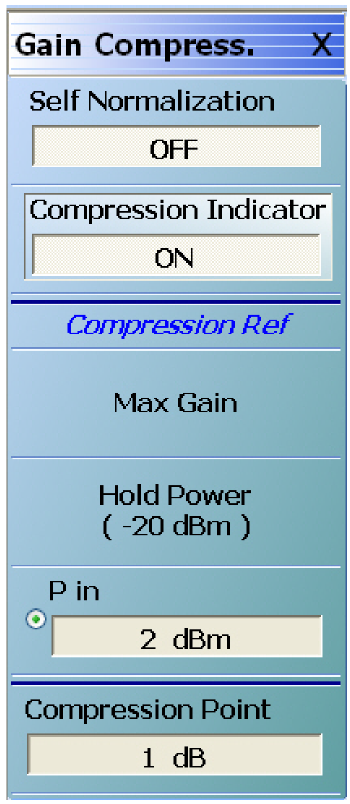


Figure 14-12. GAIN COMPRESS. (GAIN COMPRESSION) Menu - Power Sweep CW Set

Note	The Hold Power value is read-only and comes from the HOLD menu.

The middle three buttons determine how the compression point is to be measured. That is, the X-dB compression marks a decay of X dB from what value? Commonly, this is done from a low power level which is often the hold-state power (see the hold functions menu under Sweep Setup). The reference can also be set to the maximum output power point and this may be useful in cases of gain expansion. Finally, the reference may be set to the point corresponding to an arbitrary, entered input power value.

The compression point can be entered separately and common values are 1 dB and 0.1 dB. Note that this value is allowed to be negative so certain levels of gain expansion can be sensed.

An example measurement showing these features is illustrated in Figure 14-13. The input power corresponding to the compression point is readout in the upper right corner of the screen. The compression indicator “**C**” picks out the 1 dB compression point at an input power of ~3.5 dBm.

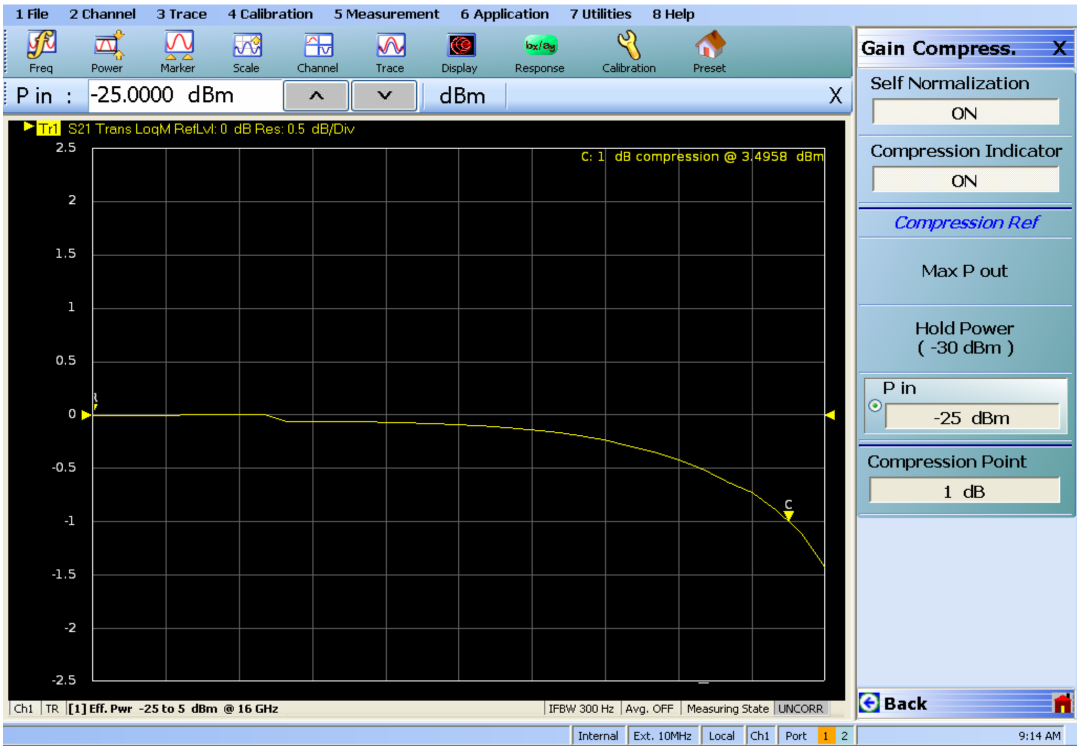


Figure 14-13. Gain Compression Example

14-5 Frequency-Based Segmented Sweep

In many applications, having a simple list of frequencies where the step size between points is uniform is not adequate. The DUT specifications may have specifications in certain bands and certain specific frequencies that must be tested, there may be certain communications bands that must be tested, or there may be certain spot frequencies that are of interest for troubleshooting or analysis.

For these cases and others, segmented sweep allows one to put together a very arbitrary list of frequencies to sweep as well as having some control of instrument behavior that is distinct at these different points and/or segments. The entire sweep is broken into segments (a segment may contain one or many points) and in each segment, one can independently control

- IF bandwidth
- Averaging
- Port 1 Power and Port 2 Power (although the step attenuators, if installed, must be in the same position for all segments to prevent premature wear)

There is a distinction made between frequency-based and index-based segmented sweep that should be explained:

- **Frequency-Based**

  Frequency is always monotonically increasing (within a segment and between segments). Plotting may be based on the frequency or the index of the particular point (more on this later).

- **Index-Based**

  The segments do not have to be in any order with regards to frequency. Plotting is always based on the point index.

Frequency-based is most commonly used and will be discussed in this section. Index-based sweeps, which is used when reverse sweeps and particular frequency order is important, is covered in the next section.

The main menu and an example entry table are shown in Figure 14-14 and Figure 14-15. The main purpose of this menu is to aid entering data into the table and to help save and recall that data. Note that segmented sweep tables can be saved/recalled separately from this menu or they can be saved/recalled as part of the global setup using the entries under the File menu.

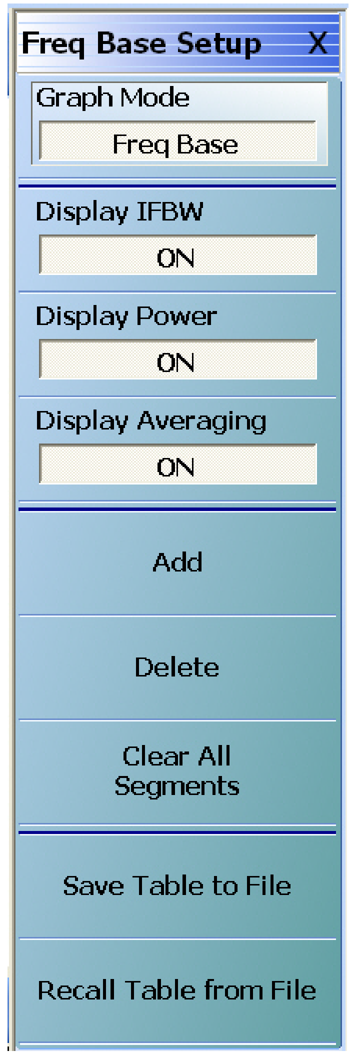
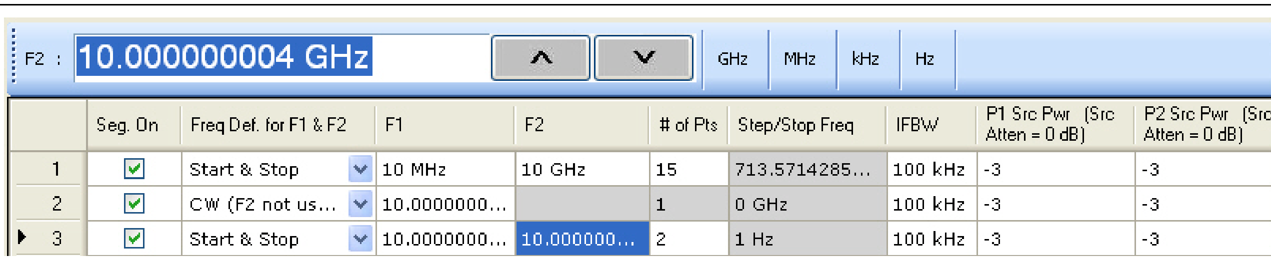


Figure 14-14. FREQ BASE SETUP (FREQUENCY-BASED SETUP) Menu



F2 : 10.000000004 GHz GHz MHz kHz Hz

	Seg. On	Freq Def. for F1 & F2	F1	F2	# of Pts	Step/Stop Freq	IFBW	P1 Src Pwr (Src Atten = 0 dB)	P2 Src Pwr (Src Atten = 0 dB)
1	✓	Start & Stop	10 MHz	10 GHz	15	713.5714285...	100 kHz	-3	-3
2	✓	CW (F2 not us...	10.0000000...		1	0 GHz	100 kHz	-3	-3
3	✓	Start & Stop	10.0000000...	10.000000...	2	1 Hz	100 kHz	-3	-3

Figure 14-15. Tableau Entry Table for Frequency-based Segmented Sweep

The table will start with one segment and the start, stop and number of points must be defined. The pull-down item in Column 3 allows an alternatively specified start and step or a CW frequency. The step or stop frequency (which depends on the pull-down selection) will appear as a read-only field in Column 7. The IFBW, power and averaging columns can be enabled on the setup menu and entered separately by segment. The current source attenuator setting will appear in the column header and may not be changed by segment (will read 0 dB if the attenuators are not installed). If the display of these fields is not enabled, the values for those variables set in regular frequency sweep mode will prevail for all segments.

The Add, Delete, and Clear All functions are obvious. The delete function applies to the current row as indicated by the caret in column 1.

As with the multiple source tables, there are two ways to enter numbers

- Click on the cell and the text entry box above the table becomes active.
- Click twice on the cell and type directly into the cell. Frequency units must be entered and must have a space between the number and the units.

If an invalid number is entered in any field, the system will change the value to the nearest valid entry.

The one remaining item on the setup menu for frequency-based segmented sweep is graph mode, which controls how the x-axis is setup for all plotting activities but does not affect the sweep itself. In Frequency-based graph mode, the x-axis will be in frequency and all segments will be plotted where those frequencies lie. While correct, this can lead to an odd-looking display if the segments are disjointed as shown in Figure 14-16.

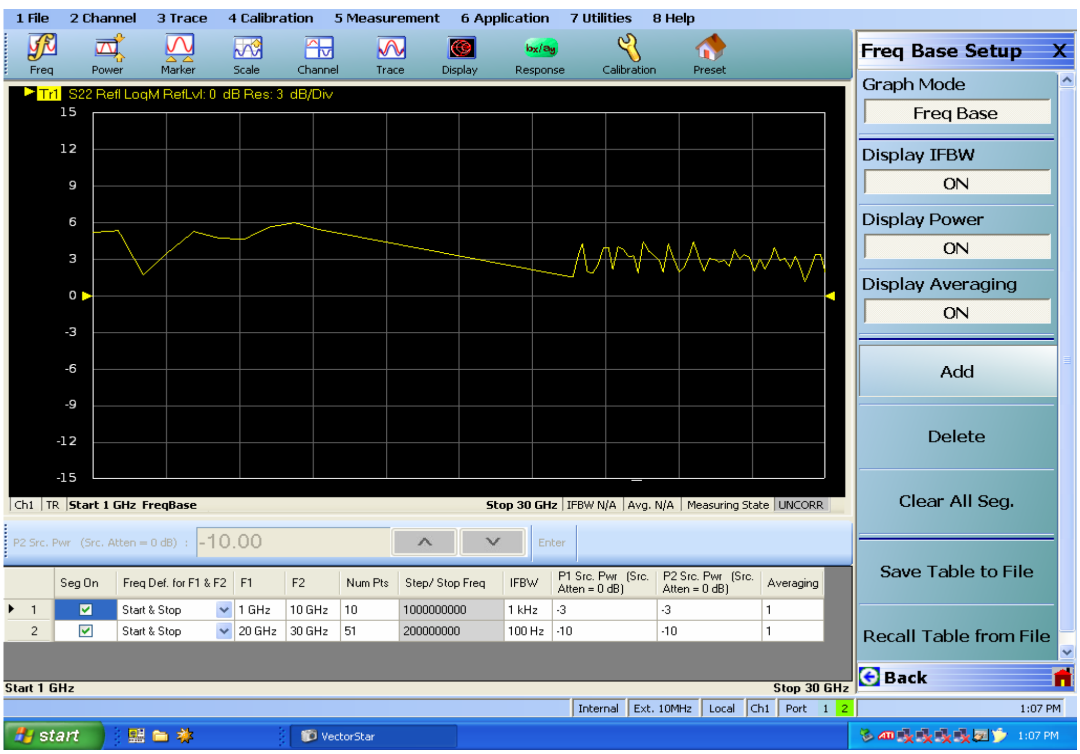


Figure 14-16. Frequency-Based Graph Mode

Since Segment 1 covers 1-10 GHz and Segment 2 covers 20-30 GHz, there is a gap in frequency where no measurements are made. For the purposes of plotting in this graph mode, the two areas are connected by a single line segment. Note that the point spacing in the plot precisely matches the frequency spacing.

When all of the data points plotted without regard to proportional frequency separation are required. For these occasions, the Index-based graph mode is available and an example is in Figure 14-17 for the same setup as Figure 14-16. Here, the x-axis is point index so all plotted points are equally spaced in the x-direction and the frequency based segmented sweep is disjointed.

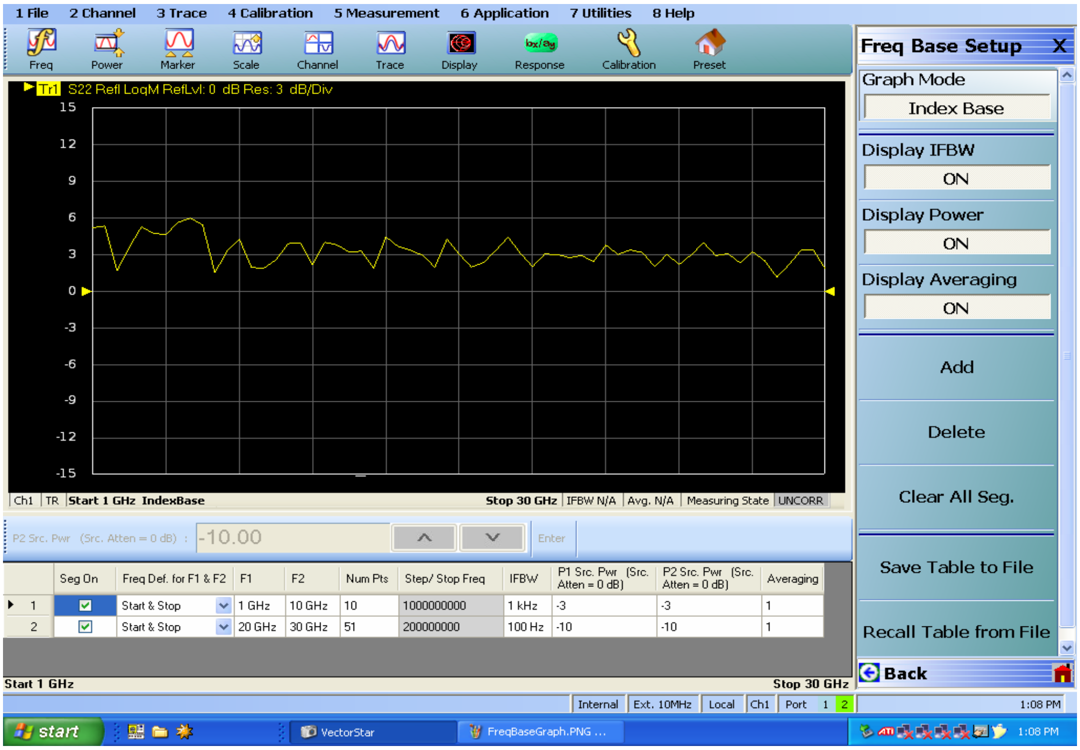


Figure 14-17. Index-Base Graph Mode

It is important to keep separate the concepts of frequency- vs. index-based for the graph mode (which only controls how things are plotted) and frequency- vs. index-based segmented sweep type (which determines how the points are swept by the instrument hardware).

14-6 Index-Based Segmented Sweep

In index-based segmented sweep the frequency segments may be in any order. This may be useful for particular test patterns where reverse sweeps are needed or particular frequencies must be measured before others due to DUT hysteresis. The setup menu and an example table are in Figure 14-18 and Figure 14-19.

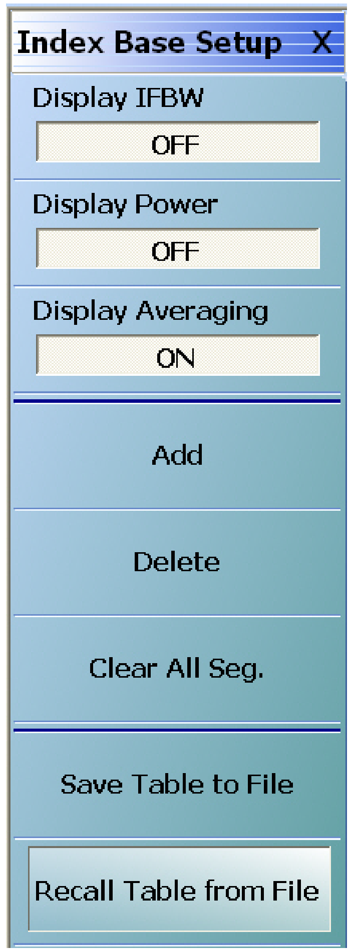
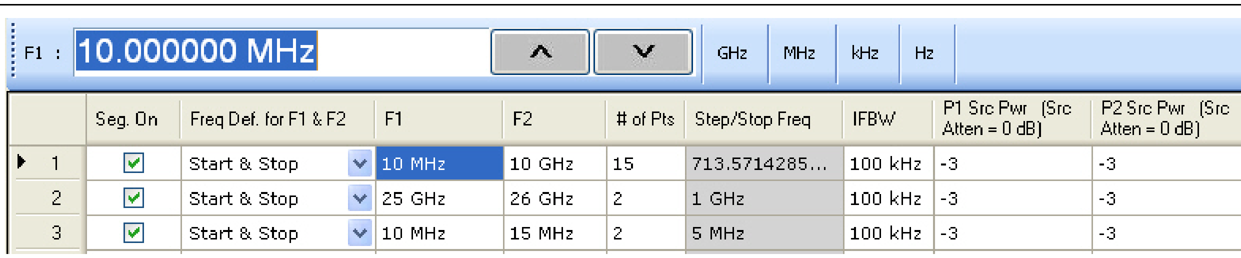


Figure 14-18. Main Menu for Index-based Segmented Sweep - INDEX BASE SETUP Menu

All plotting in this sweep type is based on the point index, which is listed in the last column of the table below.


F1 : 10.000000 MHz GHz MHz kHz Hz

	Seg. On	Freq Def. for F1 & F2	F1	F2	# of Pts	Step/Stop Freq	IFBW	P1 Src Pwr (Src Atten = 0 dB)	P2 Src Pwr (Src Atten = 0 dB)
1	✓	Start & Stop	10 MHz	10 GHz	15	713.5714285...	100 kHz	-3	-3
2	✓	Start & Stop	25 GHz	26 GHz	2	1 GHz	100 kHz	-3	-3
3	✓	Start & Stop	10 MHz	15 MHz	2	5 MHz	100 kHz	-3	-3

Figure 14-19. Tableau Entry Table for Index-based Segmented Sweep

Aside from the increased flexibility in ordering, there are few other differences relative to frequency-based segmented sweep. One exception is that there is now no choice of graph mode; it will always be index-based. In this case, it is to avoid confusing and unreadable displays where one could have many reverse tracing operations.

14-7 Power Sweep (Swept Frequency)

This specialty sweep type is a hybrid of the power sweep and linear frequency sweep types discussed earlier. The application is used to evaluate compression points across multiple frequencies without having to setup power sweeps individually at each frequency. The nomenclature and the meaning of the displays require some interpretation different from other measurements so some care is required.

When activating this sweep type, a configuration menu will appear. Most of the items are the same as in the single frequency gain compression except for the first menu item, as shown in Figure 14-20.

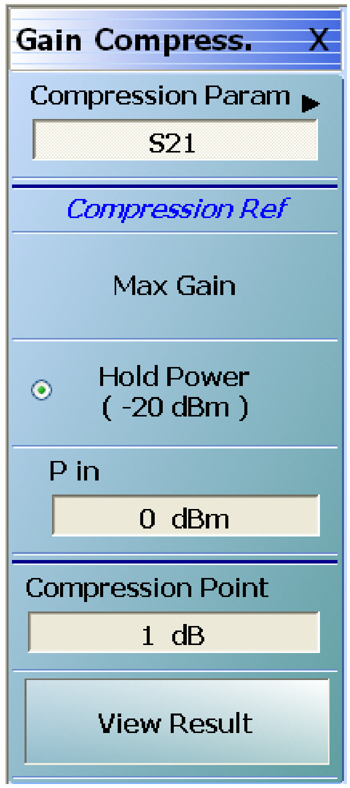


Figure 14-20. GAIN COMPRESSION Setup Menu for Power Sweep (Swept Frequency)

The compression parameter (Figure 14-21), which must be a ratioed S-parameter, is the variable that is used to find the compression point (S21 is usually used for this role).

Figure 14-21. COMP. PARAM (COMPRESSION PARAMETER) Menu

Note that the compression will be based on an S-parameter and cannot be user-defined.

The compression parameter is a per-trace selection; that is, every displayed response parameter can be referenced to compression of a different S-parameter. Commonly S21 will be used for the compression parameter in all cases but the flexibility is available.

The desired plot variables, which are set up in the usual way with trace and response menus, are then evaluated at the power producing the indicated compression level in the compression parameter. The "view result" button will display (vs. frequency) the active trace parameter at which the desired compression occurred. This display will be in tabular form in a separate dialog (Figure 14-22).

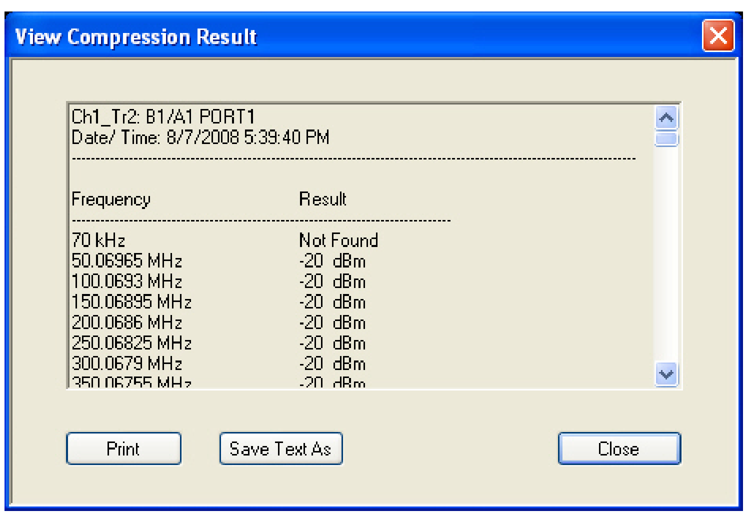


Figure 14-22. VIEW COMPRESSION RESULT Dialog Box

The dialog shows the value of the active trace parameter at the desired compression point. If the active trace has a two graph display (e.g., log magnitude and phase), there will be a third column added.

Power-Sweep Swept Frequency Example

To help understand these concepts, consider an example. We have an amplifier connected in the usual forward direction (S_{21} > 0 dB) and we wish to know the output power and the output match when at the 1 dB gain compression point at a few frequencies. Assume that sufficient attenuation is employed to prevent VNA compression and that all needed calibrations have been performed.

- At 1 GHz:
  - S_{21}
    - = 10 dB at –10 dBm input (low power) and
    - = 9 dB at +1 dBm input
  - $B_{2/1}$ (output power)
    - = 0 dBm for –10 dBm input and
    - = 10 dBm at +1 dBm input
  - S_{11}
    - = –15 dB at –10 dBm input and
    - = –17 dB at +1 dBm input
- At 2 GHz:
  - S_{21}
    - = 12 dB at –10 dBm input (low power) and
    - = 11 dB at +3 dBm input
  - $B_{2/1}$ (output power)
    - = 2 dBm for –10 dBm input and
    - = 14 dBm at +3 dBm input
  - S_{11}
    - = –17 dB at –10 dBm input and
    - = –18 dB at +3 dBm input
- At 3 GHz:
  - S_{21}
    - = 7 dB at –10 dBm input (low power) and
    - = 6 dB at –1 dBm input
  - $B_{2/1}$ (output power)
    - = –3 dBm for –10 dBm input and
    - = 5 dBm at –1 dBm input
  - S_{11}
    - = –10 dB at –10 dBm input and
    - = –8 dB at –1 dBm input

The compression points based on the compression parameter of S_{21} (input power referred) are as follows:

- 1 GHz: +1 dBm
- 2 GHz: +3 dBm
- 3 GHz: –1 dBm

Since output power and output match at 1 dB compression are of interest, one would select b2/1 and S22 as the display parameters. In this sweep type, those parameters will be evaluated at the above power levels established by the compression measurement. A plot of |b2/1| would then show:

- 1 GHz: 10 dBm
- 2 GHz: 14 dBm
- 3 GHz: 5 dBm
  (assuming a power out graph type is being used and a receiver cal is in place)

A plot of |S11| would show:

- 1 GHz: –17 dB
- 2 GHz: –18 dB
- 3 GHz: –8 dB
  (assuming a log magnitude graph type)

Any of the normal S-parameters or user-defined parameters can be selected as the display variables (just as in any other sweep type). Those most commonly used are the S-parameters (to represent amplifier quasi-small-signal behavior at the point of compression), an un-ratioed parameter to represent output power at compression (often $|b_{2/1}|$), and an un-ratioed parameter to represent input power at compression (often |a1/1|). Again, a receiver calibration is required for the representation of absolute power (input or output) and this is discussed in detail in another chapter of this measurement guide.

The plot resulting from an example measurement is shown in Figure 14-23. Here the frequency sweep range was 1-2 GHz while the power sweep range (at each frequency point) was -10 to +5 dBm. The display parameter is output power (|b2/1|) while the compression parameter is S21.

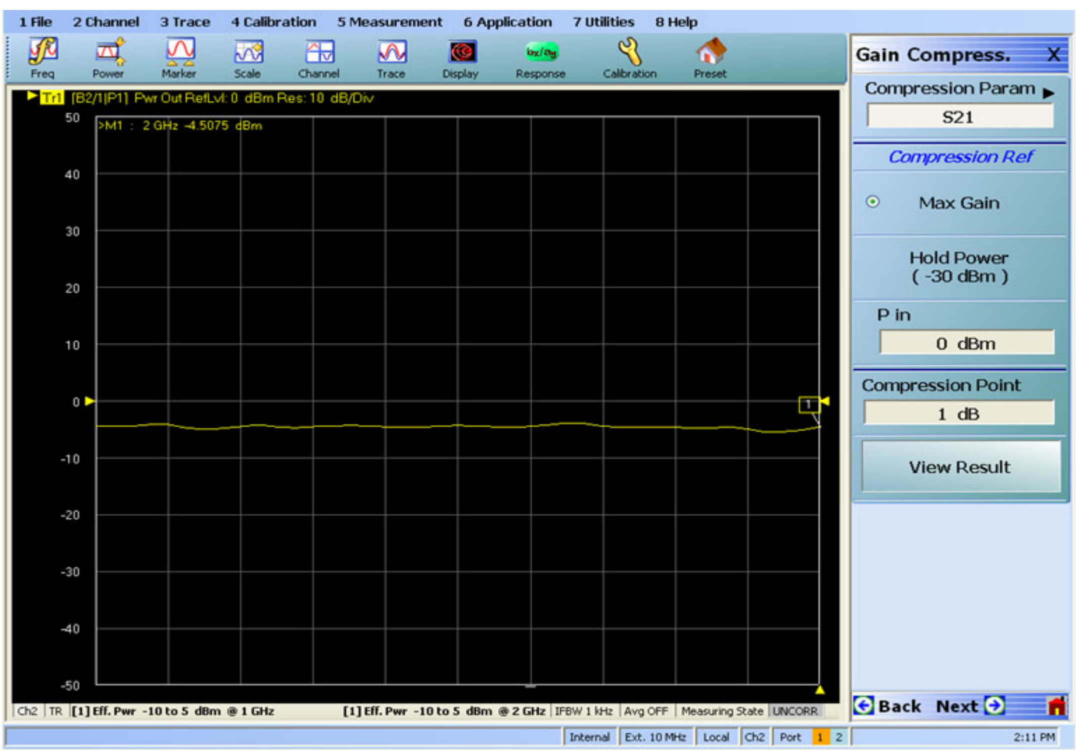


Figure 14-23. Example Plot from Power Sweep with Swept Frequency

Some points of note:

- Frequency range is setup using the normal frequency menu. The only constraint is that a maximum of 401 frequency points can be used.
- The power sweep range is setup as with CW power sweep. The usual limits on power points apply.
- If one wants to look at the actual gain compression curve ($|S_{21}|$ vs. power for example), setup a 2nd channel since power sweep (CW) and power sweep (swept) cannot be combined in the same channel.
- S-parameter calibrations are basically handled as in linear frequency sweep. If performed while in this sweep type, they will be conducted at the start power. The same error coefficients will be applied at all power levels. If the calibration was performed in linear frequency sweep, the point count will be coerced in this sweep type to get under the 401 point limit (interpolation will be used if it is active).
- Receiver calibrations are normally required for accurate plots of output power and can be performed in this sweep type or in other sweep types as long as the appropriate frequency range is covered.

Chapter 15 — Reciprocal Measurements

15-1 Chapter Overview

This chapter describes the reciprocal concept (SOLR or unknown thru approach) measurements.

15-2 Introduction

The previously discussed SOLT and offset short calibration techniques all require a known “thru (or through)” as part of the full 2 port (or 1p-2p) calibration. The “thru” is really a defined transmission line having known length, known loss, and assumed perfect match (under most conditions). There are certain cases when this is not possible:

- Coaxial cal when the two ports are different connector types
- On-wafer when the “thru” is a meandering transmission line of imperfect match
- A calibration that must take place through a test set (coax or waveguide) with unknown (and highly frequency dependent) loss and match

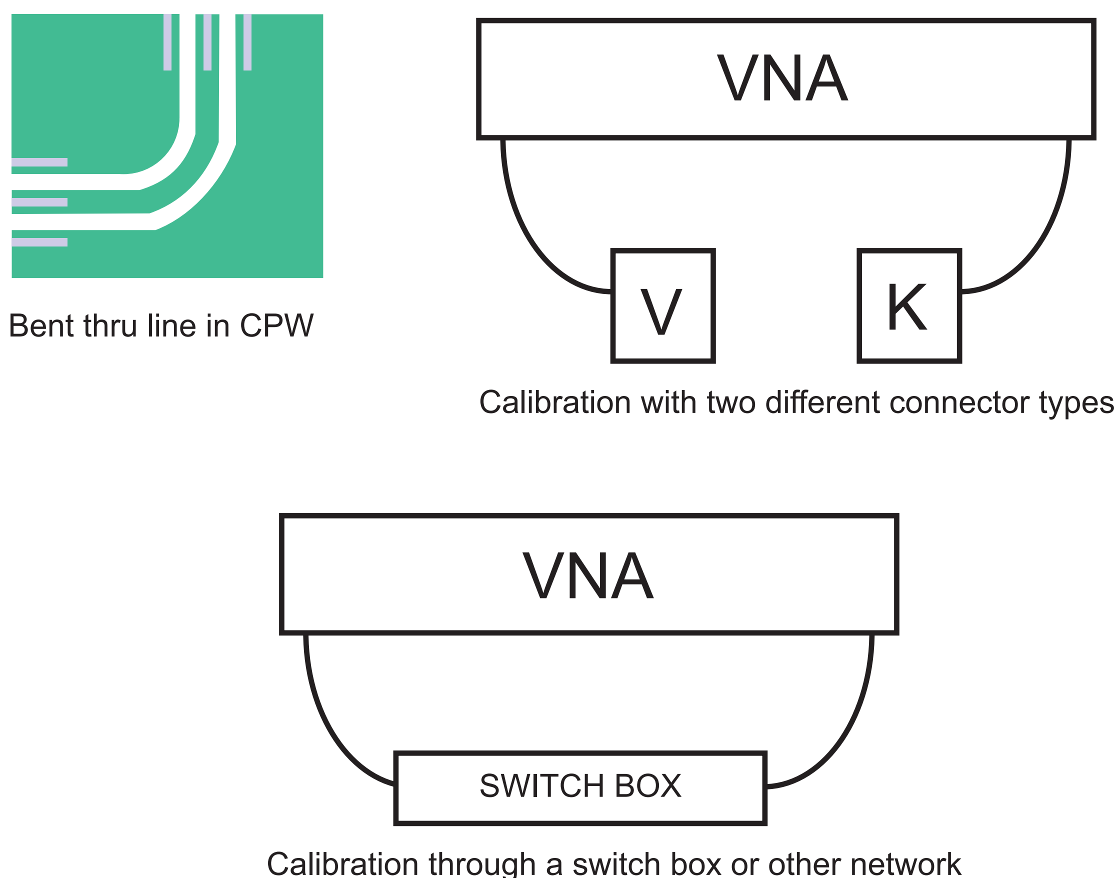


Figure 15-1. Illustration of SOLR or “Unknown Thru” Calibration

For these cases, and others when the “thru” cannot be very well-known, there is the Reciprocal option (also known as the unknown thru). In this case, the same reflect standards are used, but no assumption is made about the “thru” except that it be reciprocal (i.e., S21=S12; no assumption made about S11 and S22). In practice, there are some limits to this.

The technique borrows from the LRL family and uses some of the redundancy available with the fully-defined families to reduce knowledge needed about something (the thru in this case). The resulting cal will generally not be quite as accurate as the regular thru version if the thru met the conditions described above. It will, however, be better than using the regular thru version when the thru has unknown loss or match.

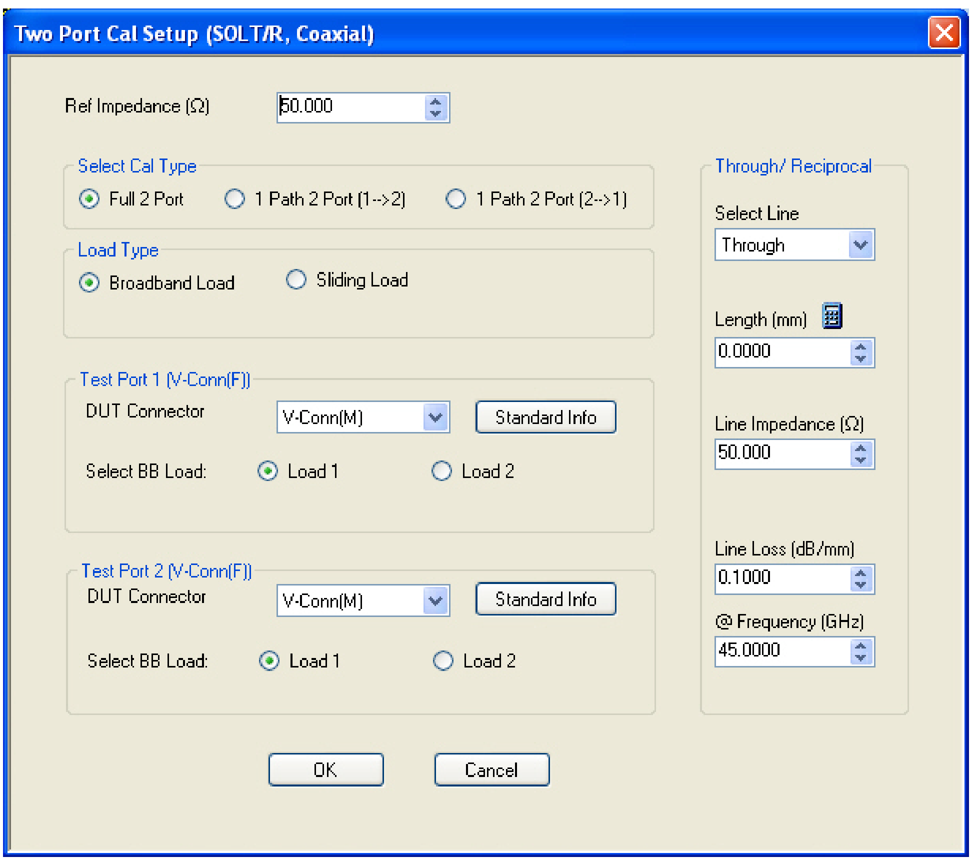
15-3 Line Length Estimate

A line length estimate (electrical delay or free space equivalent length) is needed to help with root choice but this is not a critical parameter. Typically, one needs only be within a half-wavelength of the correct length at the maximum desired calibration frequency.

If the match of the reciprocal network is worse than -8 dB or the loss exceeds ~20 dB, the reciprocal treatment will start to degrade but a calibration will be possible. Since such a network is at the limits of de-embedding capability, there are few choices except to consider 1p-2p processing with scalar de-embedding.

15-4 SOLR Calibration

For SOLR, the “select line” field would be chosen as “reciprocal” instead of “through” and the length field would be the estimate of length for root choice that was discussed above (see Figure 15-2). Note that the same variants are possible for offset short and triple offset short calibrations.



Typical calibration setup dialog for SOLR (Short-Open-Load-Reflection)

Figure 15-2. TWO PORT CAL SETUP (SOLT/R, COAX) Dialog Box

Chapter 16 — Broadband / mm-Wave Measurements (Option 007)

16-1 Overview

This chapter describes the hardware control and user options that are available for the VectorStar MS4640A Series VNAs, allowing work above the basic 70 GHz limit of the VectorStar family. Calibration, measurement, and troubleshooting approaches and tips are covered.

16-2 Introduction to Broadband and Millimeter Wave

Broadband and millimeter-wave (mm-Wave) measurements using external modules are important applications that allow work above the 70 GHz basic limit of the MS4640A Series VNA family. Part of the APPLICATIONS menu is devoted to making these measurements simple and straightforward to do.

Some key points:

- **3738 Broadband/Millimeter-Wave (BB/mmWave) Mode**

  In classical 3738-based broadband/mm-Wave mode, two external Anritsu synthesizers are used to form the base RF and LO to drive the external modules. These synthesizers are controlled to provide the correct frequency and powers to these modules. The application also controls an external test set (3738X) that handles transfer switching and IF processing. This mode applies to OEM mm-Wave modules from OML, Inc. and Virginia Diodes, Inc. along with any others that meet the frequency plan and signal level assumptions (see appendix)

- **3739 Broadband/Millimeter-Wave (BB/mmWave) Mode**

  In modular broadband/mm-Wave mode, external synthesizers are not used. The MS4647A VNA in conjunction with the 3739x Test Set handles the RF and LO requirements to drive the modules. This mode applies to the Anritsu 3743x, MA25300A, and 3744x modular mm-Wave components as well as to OEM mm-Wave modules from OML, Inc. and Virginia Diodes, Inc. along with any others that meet the frequency plan and signal level assumptions. Option 08X is required to use this mode.

Note	When using MA25300A BB/mm-Wave modules, the 3739C Test Set is required.

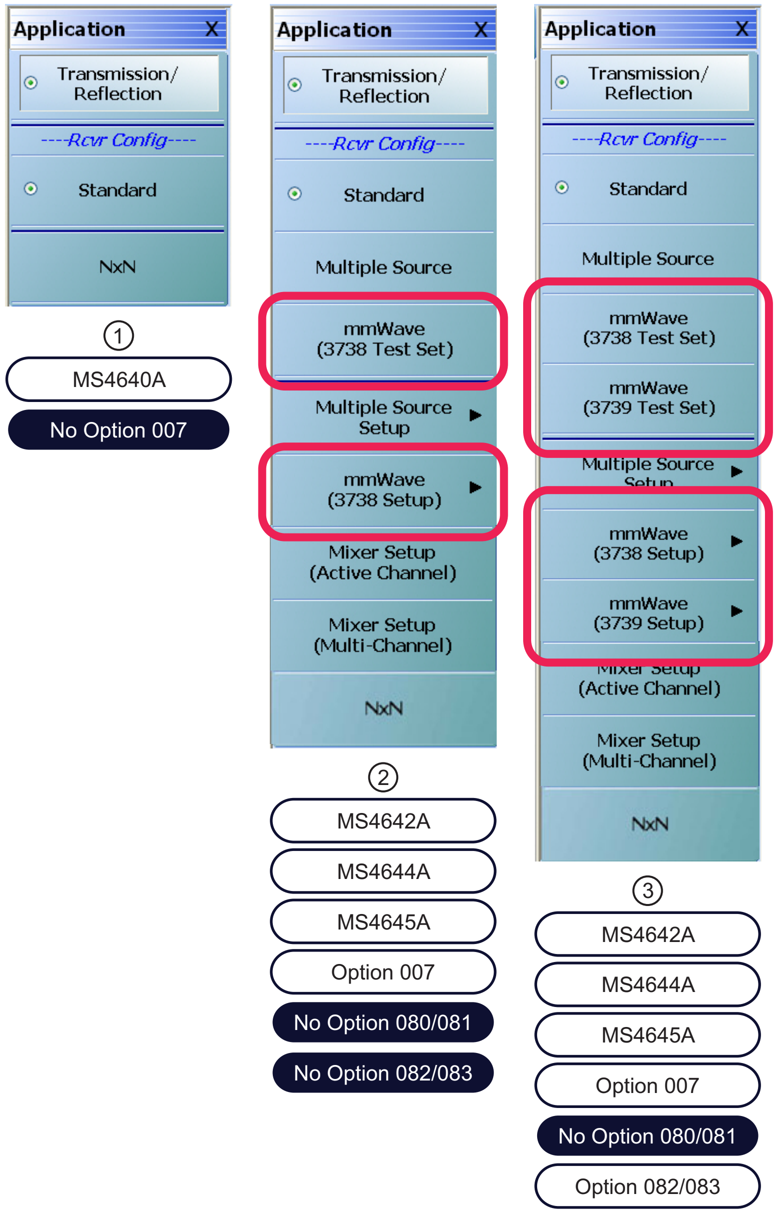
- **Continuous Sweep**

  In broadband mode, one continuous sweep is possible from 70 kHz to 110 GHz (OEM versions), 125 GHz (with the 3743A modules), or 145 GHz (with MA25300A modules, operational to 150 GHz). In mm-Wave mode, just the external modules are used.

- **RF Calibrations**

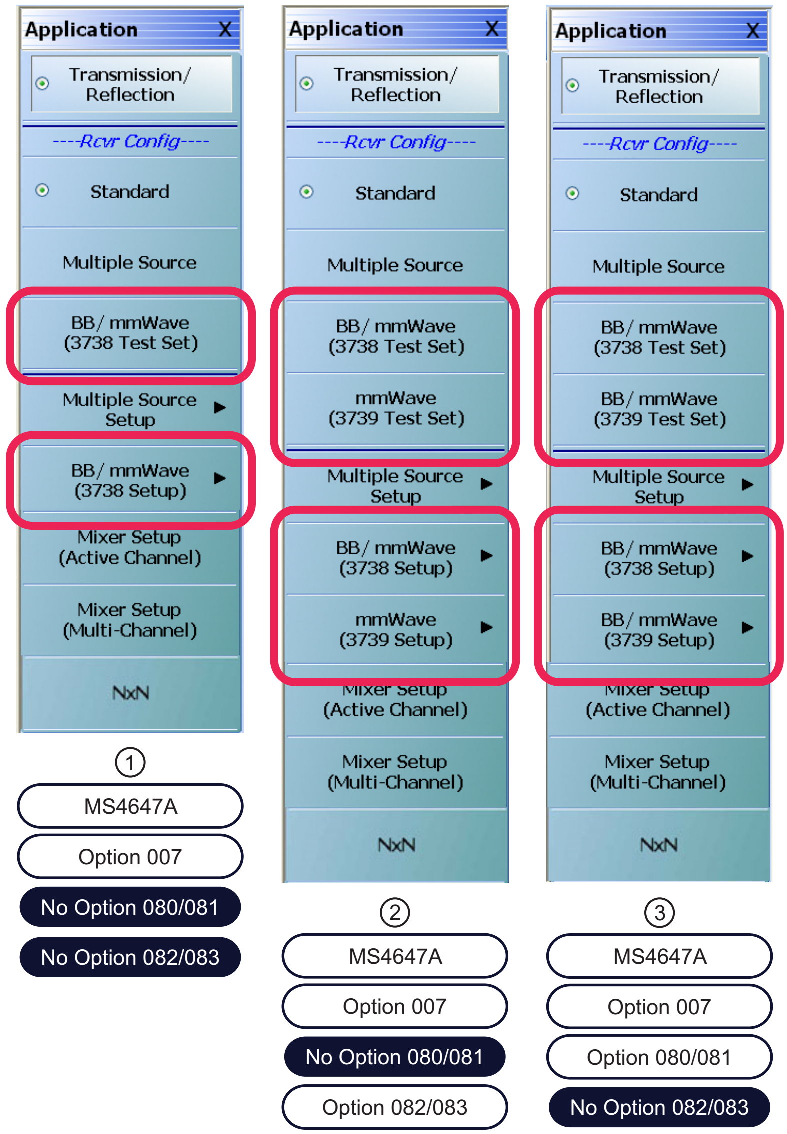
  All RF calibrations are supported in both of these modes although certain algorithms may be more optimal for the frequencies involved. Cal merge is particularly useful in broadband mode where one will often want to mix algorithms

The main APPLICATION menu is shown here with the broadband and mm-Wave selections highlighted.



1. APPLICATION menu default appearance for any VNA when Option 007 Receiver Offset is not installed.
2. APPLICATION menu, Multiple Source button, and Multiple Source Setup button – For MS4642A, 44A, and 45A VNAs when Option 007 Receiver Offset is installed but Option 082/083 is not installed. Option 080/081 is not available for these VNAs.
3. APPLICATION menu, Multiple Source button, and Multiple Source Setup button for model MS4644A and MS4645A VNAs when Option 007 Receiver Offset and Option 082/083 is installed. Option 080/081 is not available for these VNAs.

Figure 16-1. APPLICATION Menu – Multiple Source Selections – MS4642A, MS4644A, and MS4645A

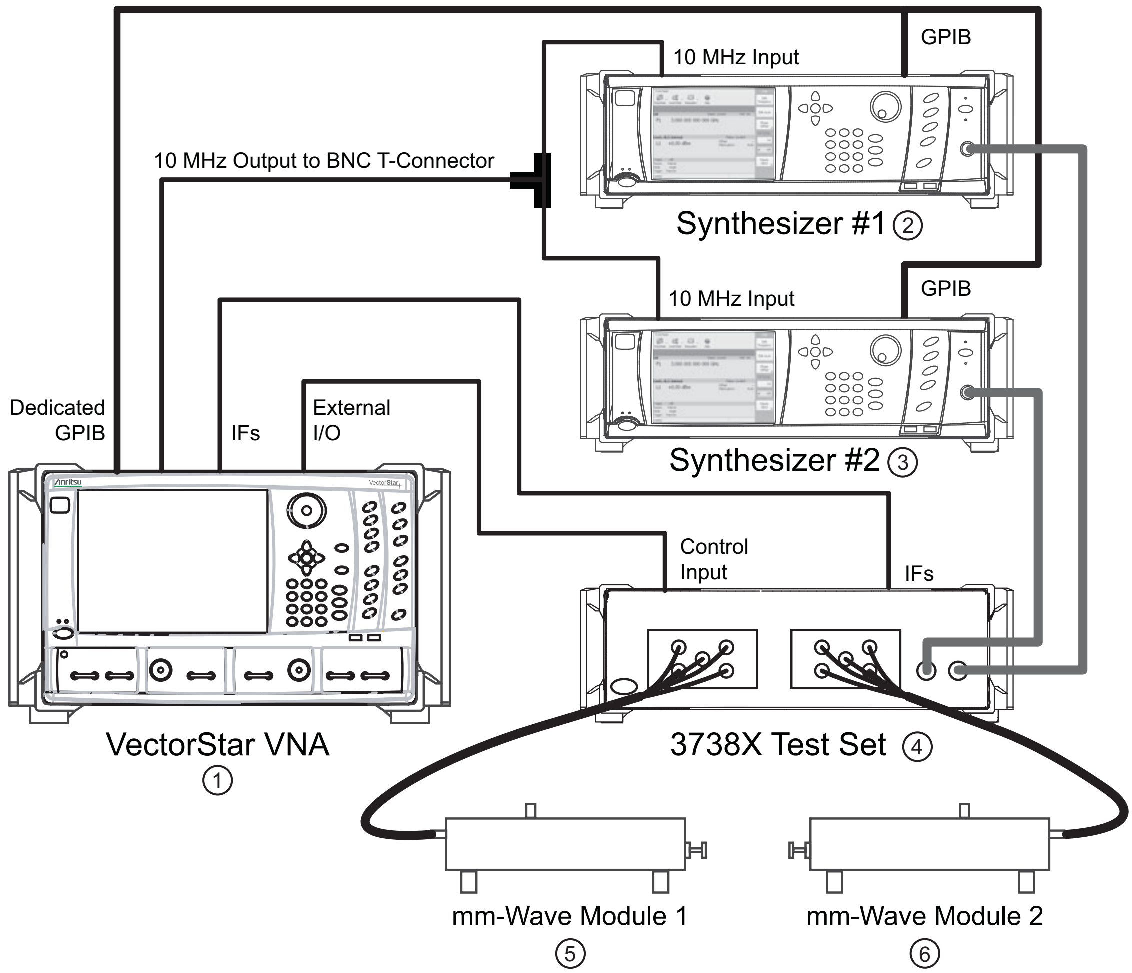


1. APPLICATION menu, Multiple Source button, and Multiple Source Setup button – For MS4647A VNAs when Option 007 Receiver Offset is installed but Option 080/081 or Option 082/083 is not installed. Note that Option 080/081 and Option 082/083 are mutually exclusive.	2. APPLICATION menu, Multiple Source button, and Multiple Source Setup button – For MS4647A VNAs when Option 007 Receiver Offset and Option 082/083 is installed but Option 080/081 is not installed. 3. APPLICATION menu, Multiple Source button, and Multiple Source Setup button – For MS4647A VNAs when Option 007 Receiver Offset and Option 080/081 is installed but Option 082/083 is not installed.

Figure 16-2. APPLICATION Menu – Multiple Source Selections – MS4647A

16-3 Physical Setup

Broadband and mm-Wave modes are remote-control intensive, so much of the setup work revolves around setting up communication to the external synthesizers and the external test set (3738X). Of course, some care must be taken with the IF, RF and LO connections but the issues here are typically the usual ones of connector and cable care. The control and reference connections are illustrated in Figure 16-3.



1 – VectorStar Series VNA	4 – 3738X Test Set
2 – Synthesizer #1	5 – mm-Wave Module 1
3 – Synthesizer #2	6 – mm-Wave Module 2

Figure 16-3. Broadband and mm-Wave Setup

Some things to point out:

- The IF cables from the 3738X test set to the MS4640A (both rear panel) are not shown here.
- The External I/O connector is used to supply simple control bits to the 3738X test set. These bits are level-sensitive only, asynchronous, and low speed and there is no addressing so this connection is relatively simple to administer.
- The synthesizers are synchronized to the 10 MHz reference of the MS4640A 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. For more information, see:
  - **MS464xA Series VNA Technical Data Sheet and Configuration Guide – 11410-00432**
- The cable bundles between the test set and the mm-Wave modules supply analog signals, bias and simple control information. Anritsu-supplied bundles should be used here in most cases.
- 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 (see Figure 16-4 below, the menu is located under in the SYSTEM menu group:
  - MAIN | System | SYSTEM | Remove Interface | REMOTE INTER. | Ext. Sources | EXT. SRC ADDR.

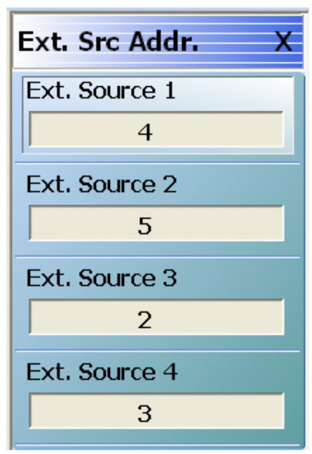


Figure 16-4. EXT. SRC. ADDR. (EXTERNAL SOURCE ADDRESS) Menu

- Note that in broadband/mm-Wave mode, External Source 1 is defined as the LO and External Source 2 is defined as the RF. Ensure that the RF/LO connections between the synthesizers and the 3738X test set match this designation. If it is desired that other external sources be used, multiple source mode should be used instead of broadband/mm-Wave.
- For most mm-Wave modules, the synthesizers must have a maximum frequency of at least 20 GHz and a minimum frequency of no more than 2 GHz. For the control software to operate, the synthesizers must be from Anritsu.
- Normally the IF signals from the mm-Wave modules are routed through the 3738X test set (amplifiers and some switching) on their way to the rear panel of the MS4640A Series VNA. Depending on the setup, the IF signals can sometimes be routed directly to the VNA.

The system will poll the GPIB bus for the external synthesizers periodically including when the broadband/mm-Wave mode is activated and when its menus are accessed. If unsure if a connection has been established, check the EXTERNAL SOURCE CONTROL menu (under multiple source setup) to see if they are ACTIVE as in Figure 16-5 below. In broadband and mm-Wave modes, the External Sources 1 and External Sources 2 should be automatically activated if they are detected.

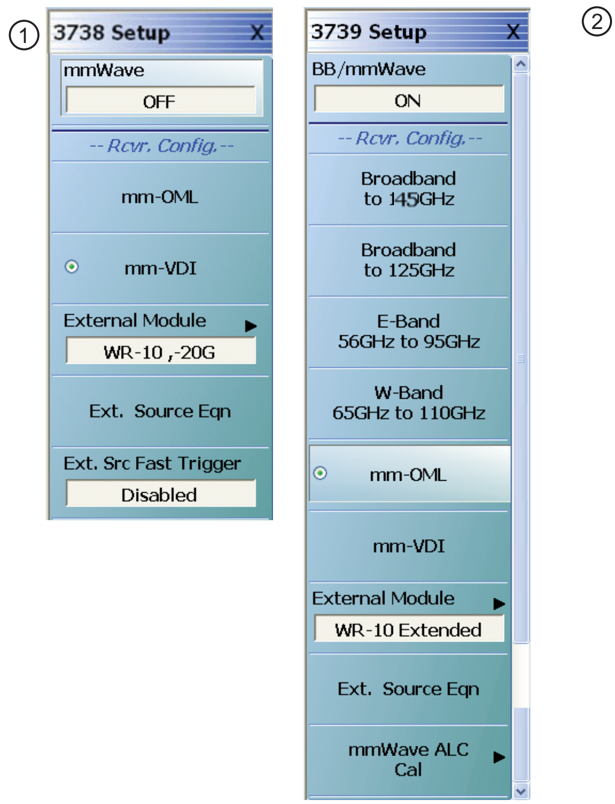
Figure 16-5. EXT. SRC. CONTROL (EXTERNAL SOURCE CONTROL) Menu

If one or both synthesizers are turned off or disconnected while in broadband or mm-Wave modes, GPIB errors or sluggish system response may be noted. It may be necessary to return to standard mode, reconnect/restart the synthesizers and then re-enter the broadband/mm-Wave mode to continue. In extreme circumstances, one may want to exit the VNA application, restart the synthesizers, and restart the VNA to establish communication.

16-4 Main Instrument Setup - BB Mode

The BB/mm-Wave Setup selection brings up the menu shown in Figure 16-6. The On/Off toggle at the top duplicates, in some sense, the Rcvr Config selection in the middle of the APPLICATION menu (turning BB/mmWave off will change the selection to standard).

The Rcvr Config selection on the setup menu toggles between broadband and mm-Wave selections. As stated above, the distinction involves whether the instrument will be allowed to couple sweeps of the internal VNA hardware with sweeps of the external modules.

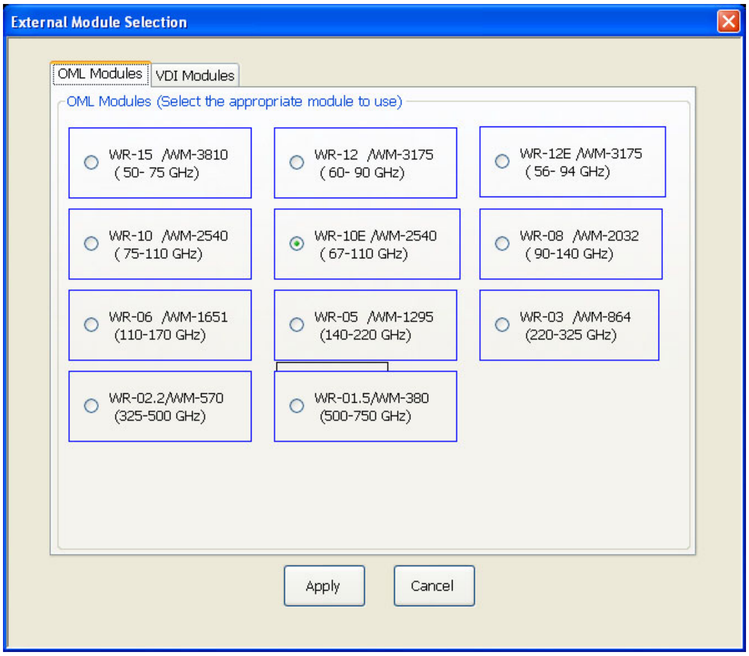


1. 3738 SETUP Menu – For non-MS4647A VNAs	2. 3739 SETUP Menu – For MS4647A VNAs

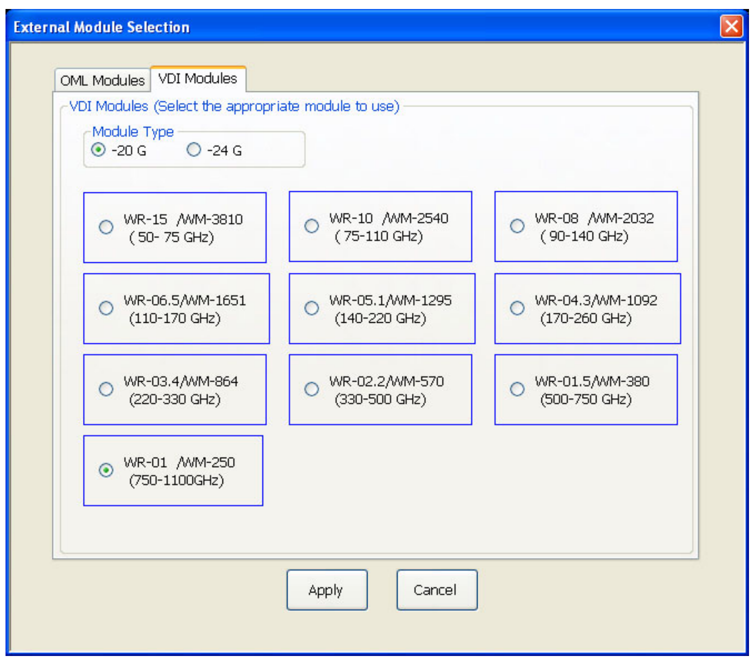
Figure 16-6. BB/MMWAVE Setup Menu

The external module selection, available only when the mode is mm-Wave (unavailable when in broadband mode), allows the selection of different module frequency ranges. This selection populates the frequency range and synthesizer control fields (harmonic number used for calculating synthesizer frequencies, etc.). These values can be overridden in the Ext. Source Equation dialog or one can go to full manual control using multiple source. Selection of the External Module button displays tabbed dialog box with current waveguide selections as shown in Figure 16-7 below.

1



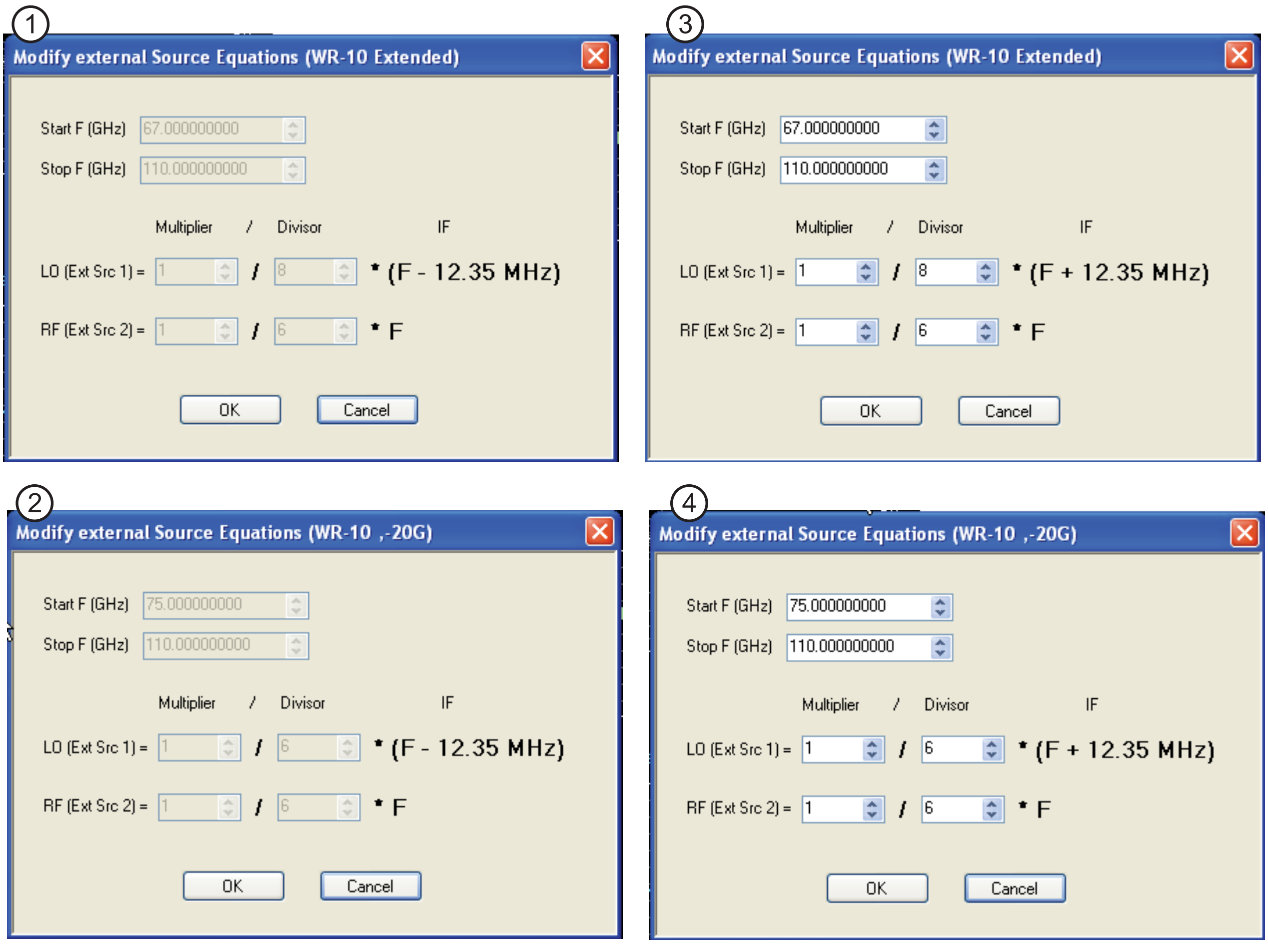
2



1. At top, the OML tab is selected and the available OML Modules are shown. Select a module radio button configure that module.	2. At bottom, the VDI tab is selected and the available VDI Modules are shown. Select a module radio button to configure that module. Note that VDI modules have two basic types at -20 G and -40G. The module type selected here must match the module being used as the two types have slightly different frequency plans.

Figure 16-7. EXTERNAL MODULE Selection Menu

The External Source Equation dialog displays the frequency ranges used by the module and the equations used to program the synthesizers. These values can be edited by the advanced user who wants to change the behavior of the modules or if new modules become available (not commonly used). There are different versions of this dialog for broadband and for mm-Wave mode (shown in Figure 16-8 below. Note the change of plus and minus signs in the frequency portion of the equations between the millimeter-wave and broadband versions of the dialog.



1. 3738 Modify External Source Equations (OML Modules)
2. 3738 Modify External Source Equations (VDI Modules)
3. 3739 Modify External Source Equations (OML Modules)
4. 3739 Modify External Source Equations (VDI Modules)

Figure 16-8. MODIFY EXTERNAL SOURCE EQUATIONS Dialog Box

Note that the IF is fixed and un-editable in these dialogs (12.35 MHz). If more advanced adjustments of the frequency plan are desired, the user should go to multiple source mode.

To enable or disable fast trigger mode when using MG37xxxX external synthesizers, click on the Ext. Src. Fast Trigger button which will bring up the dialog. Select the desired mode (ensuring needed cables are connected) and click ok to effect the mode change.

Power control is possible by using the EXT SRC POWER menu for the RF source (Ext Src 2 listed above). It should be noted, however, that the multipliers used in the mm-Wave modules have extremely non-linear power in-power out transfer curves so the use of the input power (via the menu just referenced) as control can result in violent output power changes. In some firmware versions, an open-loop power calibration can be performed to simplify this task.

From a troubleshooting point-of-view, the most typical problems involve synthesizer communications (either GPIB or fast trigger). As discussed elsewhere, resetting or power cycling of the synthesizers may be required if no problems are found with the cabling or address settings. Sometimes RF and LO cables are swapped which can result in odd ripples in unratioed parameter displays (inappropriate power levels resulting from the swap).

16-5 Modular BB - Physical and Measurement Steps

The typical setup for the modular BB system is shown in Figure 16-9 below. In contrast to the classical BB/ mm-Wave setup discussed previously, external synthesizers are not used but conditioned versions of internal VNA source and LO signals are instead routed to the modules. An option on the VNA, Option 08x provides these connection points that the test set (3739x) uses for routing to the modules (see Table 16-1 on page 16-11). Much like in the classical setup discussed before, control and power connections are provided by the test set to the modules and IF signals are taken from the modules for routing to the VNA. As with the classical mode, Option 007 (frequency offset) is required for the more elaborate frequency programming.

Two additional rear panel connections are used in this system: an external ALC connection is used between the test set and the VNA to enable leveled power control at the heads and the VNA external analog out function is used to assist in LO leveling. Note that when in Modular BB mode, the normal function of the Ext Analog Out connector is suspended.

When in Modular BB mode, the frequency plan calculations are automatically changed to account for the multiplier behavior and the allowed frequency ranges. For ME7838A and related systems (using the 3743A modules), the range is 70 kHz to 125 GHz if option 070 is installed (10 MHz start frequency otherwise). For ME7838D and related systems (using the MA25300A modules), the maximum frequency is 145 GHz.

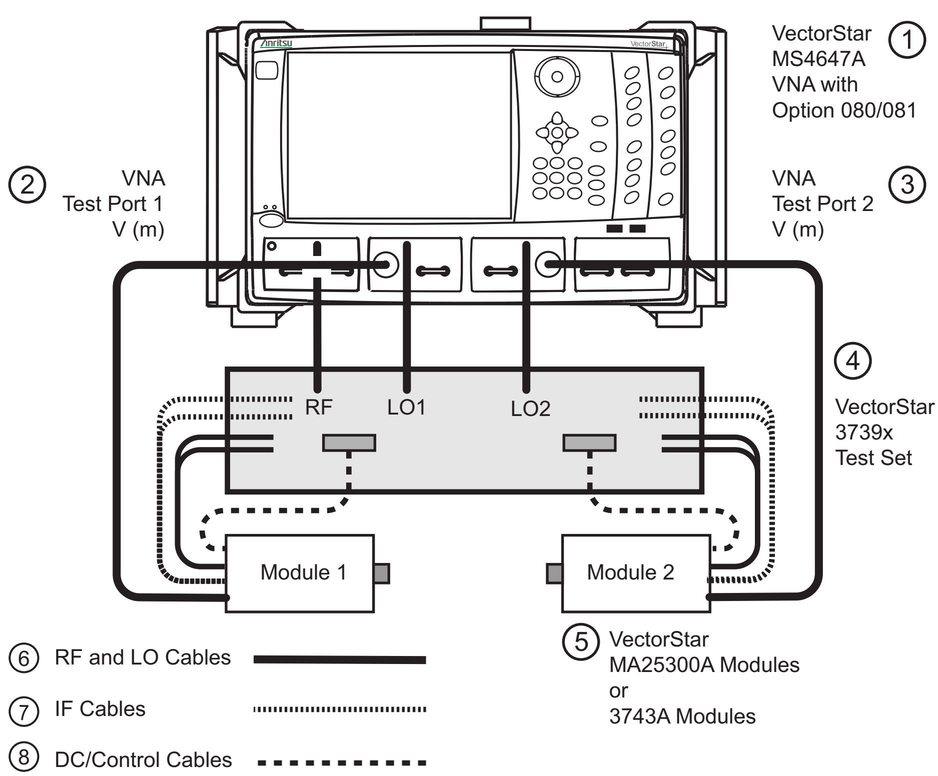


Figure 16-9. System Setup for Modular BB Mode (1 of 2)

The VNA in this figure has Option 08x which provides the **Src**, **LO1**, and **LO2** connectors shown in the figure. 1. MS4647A VNA with Option 080/081 2. VNA Test Port 1 V (m) 3. VNA Test Port 2 V (m) 4. 3739x Test Set	5. MA25300A Modules, 2 each, or 3743x Modules, 2 each, or 3744x-xx Modules, 2 each **Note: When using MA25300A BB/mm-Wave modules, the 3739C Test Set is required** 6. Heavy lines are RF and LO Cables 7. Light dashed lines are IF Cables 8. Heavy dashed lines are DC/control cables

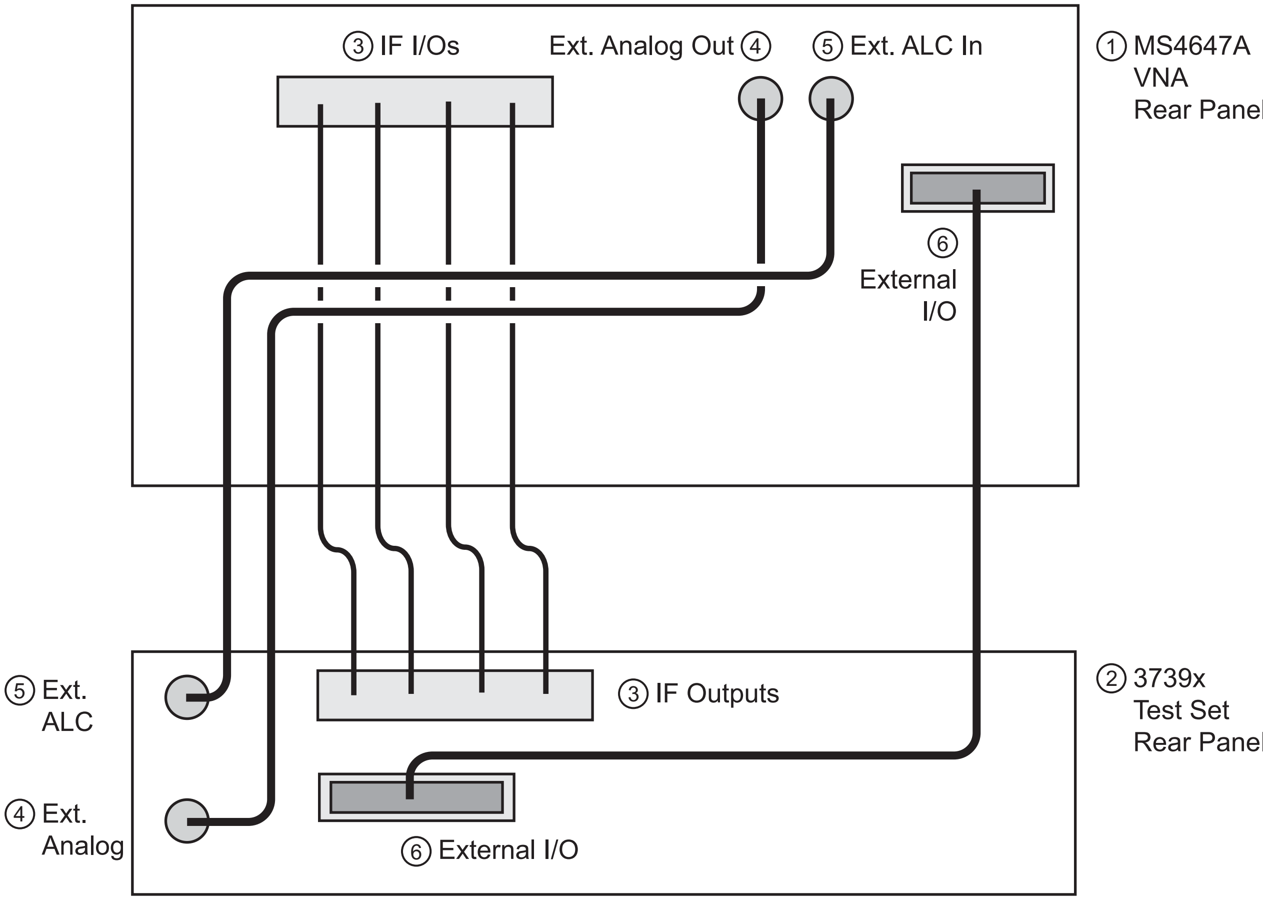
Figure 16-9. System Setup for Modular BB Mode (2 of 2)

Table 16-1. Option 08x Descriptions

Option	Description
080	For ME7838A and ME7838D systems, used for single source VNAs ***without*** Option 051, 061, or 062 where broadband operation is desired (to 125 GHz or 145 GHz with the appropriate modules).
081	For ME7838A and ME7838D systems, used for single source VNAs ***with*** Option 051, 061, or 062 where broadband operation is desired (to 125 GHz or 145 GHz with the appropriate modules).
082	For ME7838A and ME7838D systems, used for single source VNAs ***without*** Option 051, 061, or 062 where only banded operation broadband operation is desired (E and W band).
083	For ME7838A and ME7838D systems, used for single source VNAs ***with*** Option 051, 061, or 062 where only banded operation broadband operation is desired (E and W band).

In terms of completing the connections, the power/control cable ends at the module side with a snap-in microD connector. The two IF connectors are SSMC and the reference connector is closest to the middle of the module (this is also marked on the module). The V cable coming from the VNA port routes to the module V connector in the middle of the module. The K (LO) and V (Src) cables from the test set route to the appropriate outer connectors on the module. All coax connectors should be torqued properly.

The rear panel connections are shown in Figure 16-10. Two BNC-connectorized coax cables are used for routing Ext. ALC (External Automatic Level Control) and analog control signals between the test set and the VNA. A DB-25 connectorized cable is used for routing digital control signals and the IFs are routed using four SMA-connectorized coax cables.



1. MS4647A VNA with Option 080/081 Rear Panel	4. Ext Analog
2. 3739x Test Set Rear Panel	5. Ext ALC
3. IF I/Os	6. External I/O

Figure 16-10. Rear Panel Connections for the Modular BB System

A block diagram of the system is shown in Figure 16-11. The 3739x test set provides several distinct functions:

- Source power amplification and transfer switching
- LO leveling and distribution
- Generating control signals for the modules from VNA input and supplying power
- Routing and processing IF signals as necessary.

The 3739x test set includes higher power amplifiers and further LO condition circuits for use with higher mm-wave bands. The B model also includes an AUX POWER connector for a third module. This connector supplies power to the module and mimics the control signals sent to the Port 1 module. This makes the port very useful for IMD and mixer measurements. The second tone (for IMD) or the LO (for mm-wave mixers requiring a high frequency LO) can be supplied this way. The second tone for these applications could be supplied by an external synthesizer (see multiple source in Chapter 17).

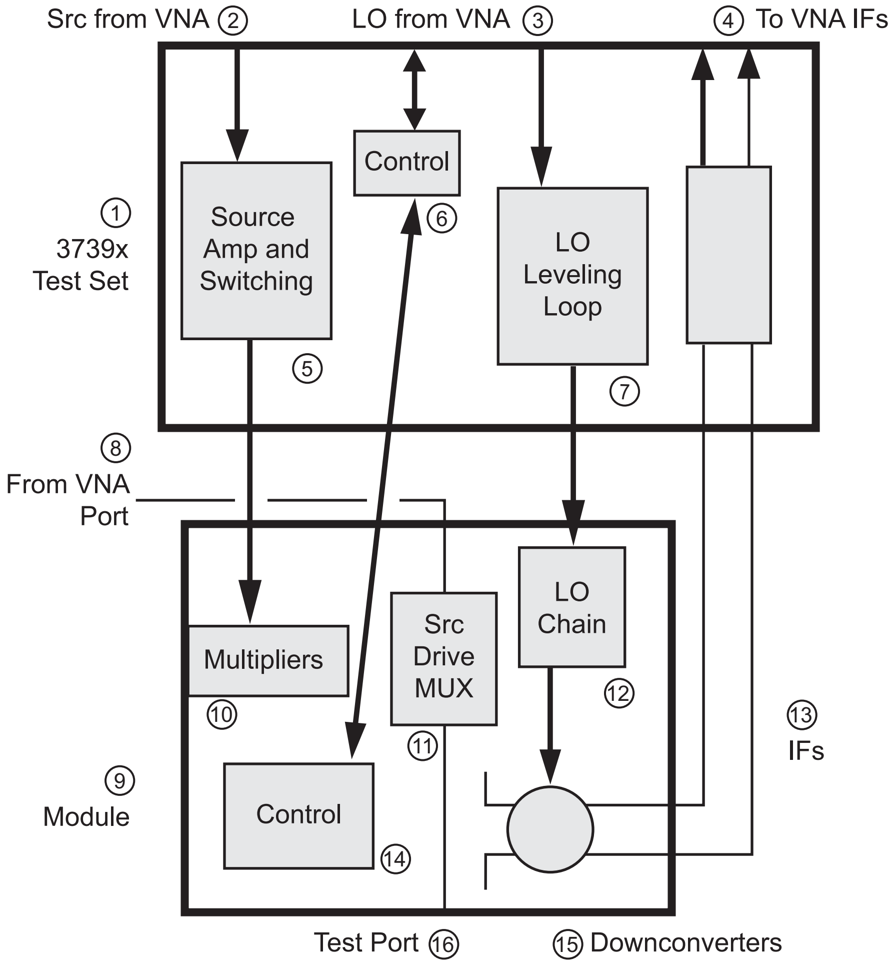
The modules themselves have several unique aspects

- A bypass path for use at low frequencies. The internal VNA source and couplers/bridges are used for lower frequency measurements.
- At higher frequencies, separate reflectometers in the module handle the measurements
- Also at higher frequencies, multipliers in the modules provide source power.
- Leveling circuitry (both source and LO) is built into the modules

There are two main breakpoint frequencies that are helpful in understanding the performance of the system:

- The break where the module receivers take over from the internal VNA receivers. This is nominally at 25.4 GHz
- The break where the module source multipliers take over for the main VNA multipliers. This is nominally at 54 GHz.

As with the classical approach discussed previously, this mode can also be invoked from within multiple source control for a more customized setup. Details of this approach are covered in Chapter 17.



The modular BB block diagram is shown above. Relative to the classical setup, the MUXing is performed in a different location and different multiplier and downconverter technologies are used.

1. 3739x Test Set
2. Src from VNA
3. LO from VNA
4. To VNA IFs
5. Source Amp and Switching
6. Control
7. LO Leveling Loop
8. From VNA Port
9. MA25300 Module or 3743A Module
10. Multipliers
11. Src Drive MUX
12. LO Chain
13. IFs to Test Set
14. Control
15. Downconverters
16. Test Port

Figure 16-11. Modular BB Block Diagram

Full power control and power sweeps are available in this mode due to the integrated leveling circuitry in the modules and test set. Flat power calibrations/linear power calibrations are also available and function as described in other chapters. An important point is that the standard Anritsu power meters are used up to 70 GHz while separate waveguide-based power meters are needed above 70 GHz. Normally an Agilent W8486A W-band sensor or equivalent is used for 70 GHz-125 GHz (for ME7838A and related systems) and an Elva-1 power meter with D-band sensor is used for higher frequencies (for ME7838D and related systems). For traceability and accuracy information, contact the factory.

The calibration routines will prompt when a different meter/sensor needs to be connected. Because of the need for adapters in many cases, the manual power offset feature may be employed on the power meters to correct for adapter loss (e.g., a W1-WR10 coax-to-waveguide adapter typically has 0.5 dB of loss at 110 GHz).

Full ALC calibrations are performed at the diagnostics menu level of the firmware and are normally only employed in service situations. When moving between Standard and Modular BB modes, the ALC calibration files automatically switch to properly handle the hardware being used in those modes.

From a troubleshooting point-of-view, miscabling of the system is the most common problem. A typical symptom is non-ratioed parameters that are very low (< – 90 dB; when at default power, a1/1 and a2/1 will typically be in the –10 to –30 dB range (uncalibrated) depending on frequency). Very low received signals can sometimes also be due to requesting a leveled power too far below specified ranges (the system will allow lower entries than specified since they may be achieved at certain frequencies).

The normal ALC range when above 54 GHz reaches down to -60 dBm, although there may be some significant drop-offs below –55 dBm (and below –50 dBm above 110 GHz for those systems operating to higher frequencies). This is possible because of the highly linear integrated UIF leveling loop based within the modules. A separate RF leveling loop is also available for frequency translating measurements (discussed in Chapter 17). Because no step attenuators are in the mm-wave part of the system, this extended ALC range is particularly useful. Since the power structures are fairly different above and below 54 GHz (with or without step attenuator possibilities), two different ALC entries are used and are labeled as such on the Power menu. An example of the wide power range and wide power sweep range is shown in Figure 16-12 (the curve flat lines at the upper end of the sweep as it reaches maximum power of ~+3 dBm for this frequency). To achieve a constant low power level in a broadband sweep, it will be necessary to use step attenuators below 54 GHz and a low base setting above 54 GHz.

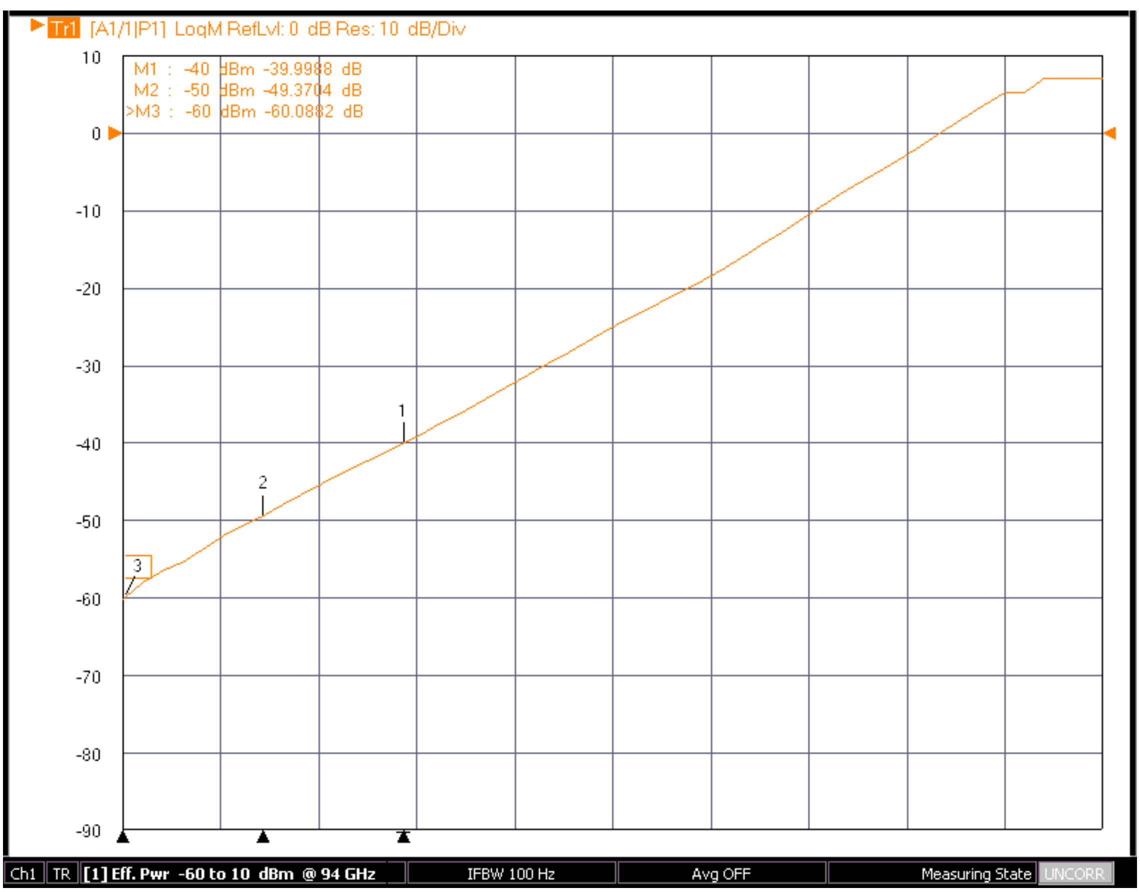


Figure 16-12. An example of the wide power sweep range available with the modular BB system.

Example:

- Broadband sweep with port power of -50 dBm
- Set the ALC level (<54 GHz) to -20 dBm and engage 30 dB of source step attenuation (assumes Option 061 or 062)
- Set the ALC level (>54 GHz) to -50 dBm

16-6 3739 MM-Wave Modes

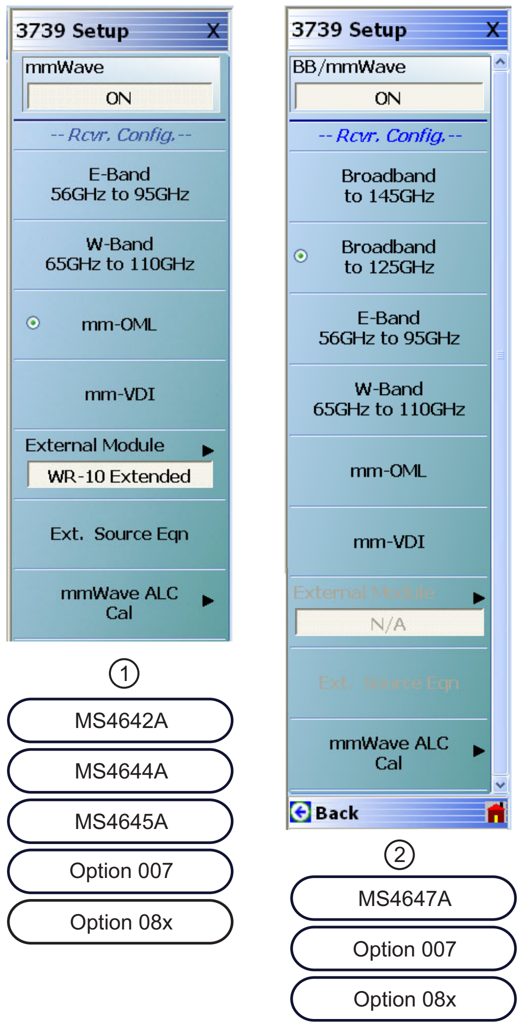
In addition to the broadband measurements described in the previous section, the 3739x test set supports a number of different banded mm-wave measurement setups that are described in this section.

The first group has been alluded to and uses banded versions of the 3743x mm-wave modules described above and are sold as the 3744x. These modules allow operation in extended E (54-95 GHz) or extended W (65 GHz to 110 GHz) bands and are convenient for purely waveguide-based applications. The corresponding options on the VNA are 082 (without step attenuators) and 083 (with step attenuators). All of the 08x options are mutually exclusive.

The broadband selection allows operation from the low frequency limit of the instrument (70 kHz or 10 MHz depending on option 070 presence/absence) to the upper limit of the mm-wave module. For ME7838A systems (using 3743A modules), the Broadband to 125 GHz selection should be used. For ME7838D systems (using MA25300A modules), the Broadband to 145 GHz selection should be used. NOTE: The system cannot tell which modules are connected (between 3743A and MA25300A) so the user MUST select the correct broadband option when one is offered.

The extended E and extended W band modes operate very similarly to the 3739 broadband mode discussed previously except that the frequency ranges of operation are more restricted. The same RF and power calibration methodologies apply and there are no other substantive user interface changes when in these modes. On the 3744x modules, the center RF connector (used for the RF pass-thru on the 3743x module) is now only used as a bias connector. The port is low-pass filtered so bias can be applied without RF leakage.

The second group is based on OEM mm-wave modules much like the 3738 test set-based systems, except the internal VNA sources are used to drive the modules and additional leveling capabilities are enabled. The 3739-based setup menu is shown below and has additions (see Figure 16-13) relative to the 3738 setup for the E and W banded solutions, as well as for a leveling calibration that will be discussed shortly. The external equation dialog has the same structure as for the 3738 setup and example for a WR-2.2 (24 GHz) module is shown in Figure 16-14.



1. The 3739 SETUP Menu for MS4642A, 44A, and 45A VNAs with Option 007 and a compatible Option 08x.
2. The 3739 SETUP Menu for MS4647A VNAs with Option 007 and a compatible Option 08x.

Figure 16-13. The 3739-based setup menu is shown here.

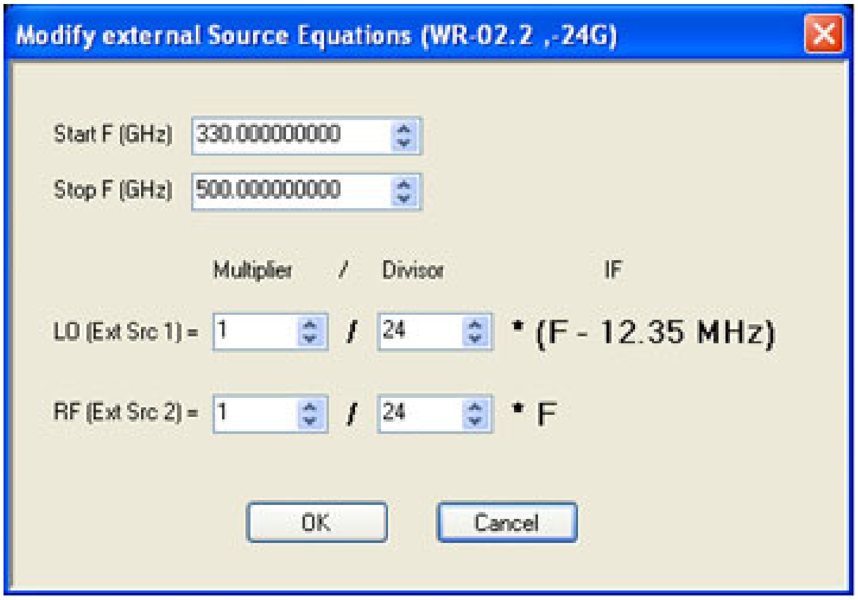


Figure 16-14. An example equation dialog box is shown here for a WR-2.2 setup.

The 3739-based mm-Wave systems have some power control options available that are not present on the 3738-based systems and they are illustrated by the mmWave ALC Cal menu shown in Figure 16-15.

Figure 16-15. mmWave ALC Cal Menu

To understand the leveling/power control options, consider the very simplified block diagram in Figure 16-16. The key point is that there are multiple locations to sample the power, but because of the very high frequencies involved, there is potentially no one ideal location.

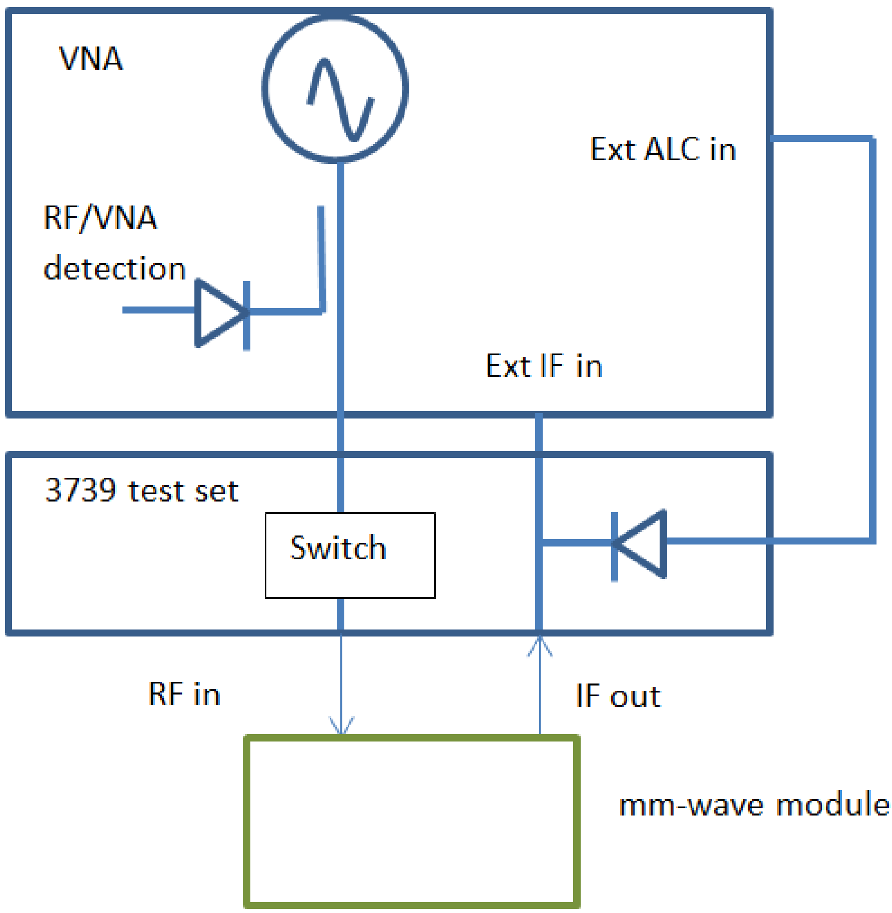


Figure 16-16. A simplified block diagram of a 3739-based mm-wave setup is shown here to help illustrate power control and leveling concepts.

In the 'VNA' mode, the standard VNA ALC calibrations are used with the existing detection system in the VNA so that the power menu settings correspond roughly to the actual RF levels being delivered to the 3739x test set. One can then have a general idea of the levels driving the module and may know the corresponding mm-wave output power levels based on data from the manufacturer. The leveling loop is closed, but in this mode the instrument has no knowledge of the relationship between mm-wave power levels and the instrument settings.

In the RF leveling mode, the same detection circuitry is used as in the VNA mode, but now a means of relating the actual mm-wave power levels is available. Because of the paucity of readily-available power measurement methods in these higher frequency ranges, the method used is somewhat indirect, but relies on the established linearity of the measurement system. The concept is illustrated in Figure 16-17. From the manufacturers' measurements (often based on quasi-optical or other techniques), a value is generally known for the saturated mm-wave power. The saturation breakpoint can be found by locally sweeping the VNA RF power until the measured IF power leaves saturation (*Pvna1*). The IF reading can be noted at this point (IF1) and it can be linked to the known mm-wave saturated power. Now the VNA plane power can be dropped and the IF magnitude recorded as a function of this setting. Based on the known receiver linearity, we can now link the IF changes to the mm-wave power level (note this is only done during the calibration step. The leveling is based on finding the needed VNA setting to get the requested mm-wave power level, and then relying on the VNA leveling loop). So if the IF level has decreased to IF1-10 dB at some input level *Pvna2*, then we can state the mm-wave power is Psat-10 dB with some reasonable level of uncertainty. The concept is to level on the VNA power plane while establishing a link to the mm-wave power so that user entries can be in the latter form.

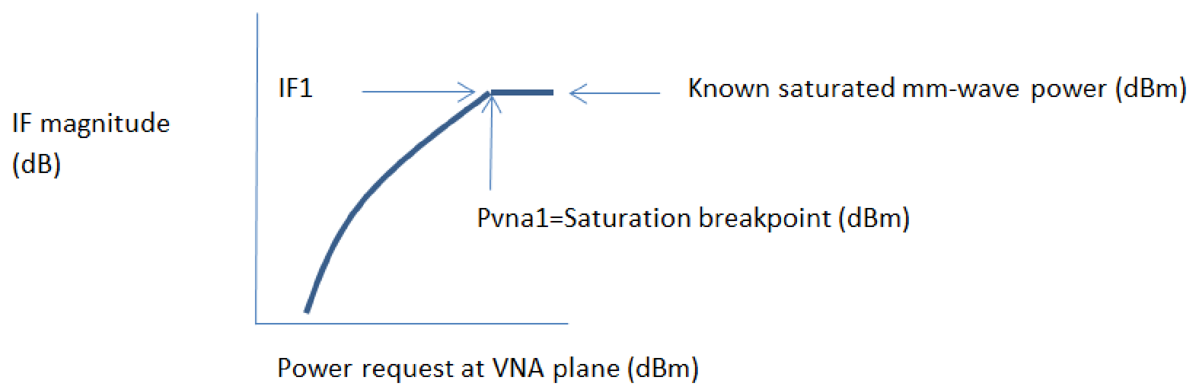


Figure 16-17. The concept of RF mm-wave leveling is illustrated here.

Since this leveling method only relies on the detection system at the VNA plane, it is useful for all measurement classes including converter and IMD measurements. Because it is leveling prior to the multipliers, it is less stable than the IF leveling to be discussed next and will provide a lower level of long term accuracy.

The calibration is accomplished using the dialog shown in Figure 16-18. The concept is that the saturated power is known at some frequencies in the band and the user is allowed to enter those values discretely. When the calibration is executed, the above power sweep and iteration scheme is executed individually at each of the frequencies requested. Note that Port 1 and Port 2 calibrations are separate since modules are rarely identical. When the calibration is completed, the calibration may be saved and recalled later using the buttons shown in Figure 16-18.

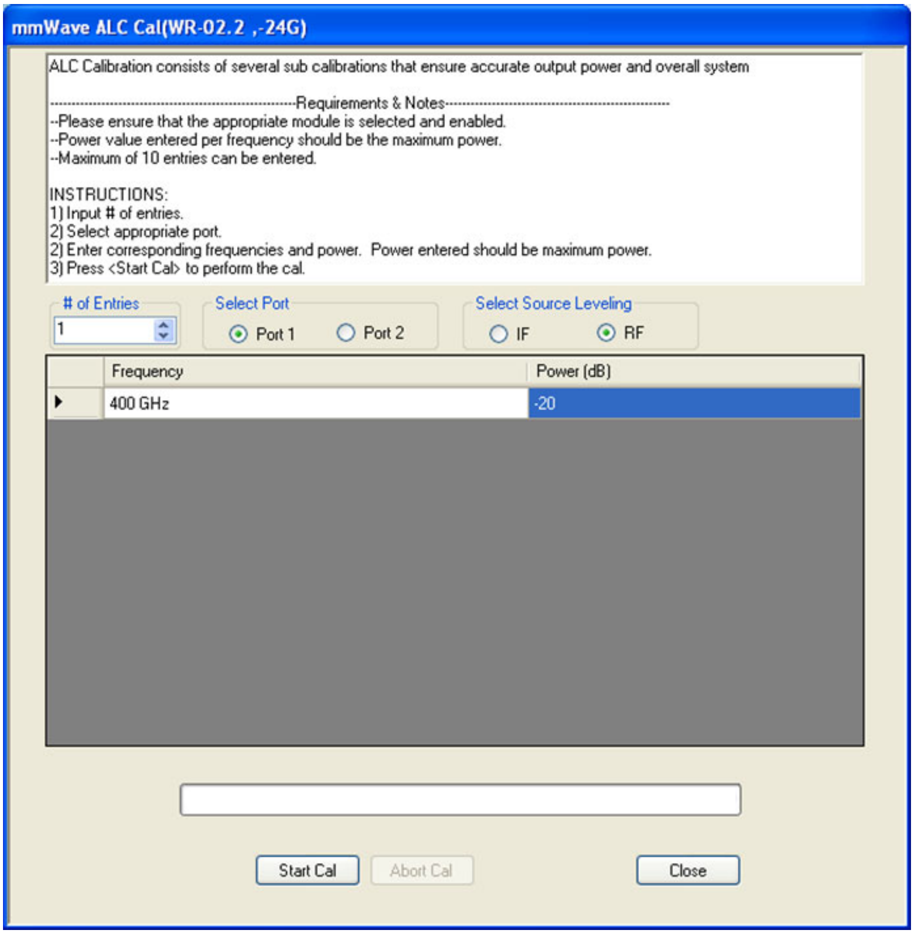


Figure 16-18. The mm-wave ALC calibration dialog as configured for a single frequency point of RF calibration on Port 1 is shown here.

The IF leveling scheme relies on sensing the IF amplitude coming out of the module directly and using that IF signal as the leveling signal. This requires that an IF be present on the reference channels so it is not appropriate for mixer or IMD measurements. Since the IF is derived post-multiplication, however, it is much more stable over time and temperature than is the RF leveling scheme discussed before. The block diagram of Figure 16-16 still applies except now the Ext ALC path shown is used for leveling.

The calibration proceeds in the same way as discussed for the RF leveling scheme and the same dialog is used (with different button selections). In both cases, since the leveling is analog, it is very fast so that the DUT rarely sees transient power spikes that can occur under purely software leveling schemes. The detected transient response time for one measurement is shown in Figure 16-19 and illustrates that a ~5 dB power request step is resolved in a few microseconds in an overdamped manner.

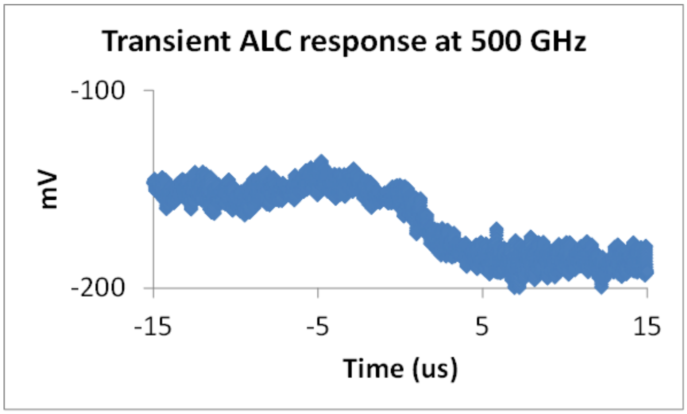


Figure 16-19. An example transient response of the mm-wave ALC system is shown here.

Both leveling schemes enable power sweeps as well as finer power control when sweeping frequency. Both modes of control can be useful for active device measurement or for other RF-sensitive or potentially non-linear situations. An example of a power sweep at 400 GHz is shown in Figure 16-20 to illustrate the range that may be possible.

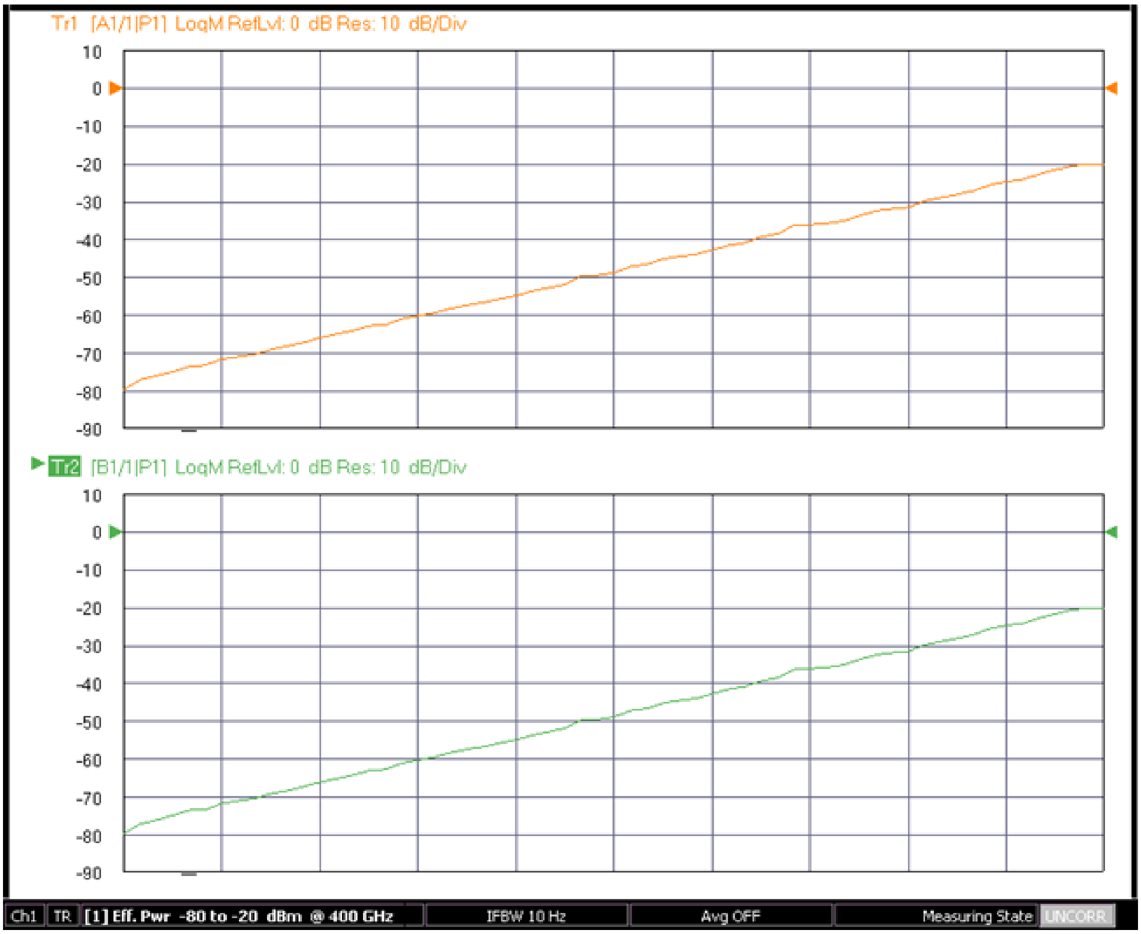


Figure 16-20. An example power sweep measurement is shown here.

16-7 Measurement Tips

While calibrations are covered in detail in another section of the measurement guide, there are some peculiarities relative to broadband and mm-Wave operation that require some comment.

- The mm-Wave bands are often executed in waveguide thus requiring that media type selection (to take care of dispersion correction).
- SOLT/SOLR are often not recommended due to the difficulty of fabricating a reasonable open standard. An open waveguide flange radiates quite effectively and, as a result, is both unstable and has a relatively high return loss.
- SSLT/SSLR are commonly used, particularly at lower frequencies and do require a good load standard. The offset short lengths must be known with some precision.
- SSST/SSSR is quite popular, particularly at higher frequencies since a load standard is not required. Accurate knowledge of the short offset lengths is critical.
- LRL is also a popular technique and is quite effective although it can be sensitive to the condition of the waveguide flanges.

Classical BB Mode

In classical broadband mode, a hybrid coupler combining the bands into a single W1 coaxial connector is typically used with a default breakpoint of 67 GHz (i.e., at 67 GHz and below, the base VNA is used for both source and receiver; at 67.000000001 GHz and above, the external modules are used for source and receiver). This structure is key to allowing the combined sweep. To calibrate this connector type, typically two calibrations are recommended: SOLT from the low frequency limit to 67 GHz and SSST from 67-110 GHz. The two calibrations are performed separately and then combined using cal merge (see calibration section for details). The only constraints are the two calibrations must be of the same type (i.e., both 1-Port S11 or both full 2-Port) and the total point count must not exceed the current maximum for the instrument (25000 or 100000). Note that other calibration types (e.g., LRL) can be successfully combined with this connector type.

Note	It is important that the system be in the appropriate 3739 receiver configuration even when performing the lower frequency calibration. This ensures that the correct receiver mode is used in the merged calibration.

In the 3739-based systems, a similar protocol is used with a 67 GHz breakpoint also typically used for ME7838A (and related) systems (W1 connector-based). For the ME7838D and related systems (using the MA25300A modules) which are 0.8 mm-connector based, a breakpoint for the calibrations of 80 GHz is typically used. In all cases, it is generally an SOLT calibration at the lower frequencies and an SSST calibration at higher frequencies.

The 1mm (W1) and 0.8 mm calibration kits both contain 3 shorts, an open, and a load for both connector genders (along with many adapters, tools and verification components). For the SOLT calibration, the coefficients are setup assuming that SHORT 1 is used for that calibration.

Modular BB Approach

In the modular BB approach, the multiplexing is instead done behind the high frequency reflectometers and happens at two disjoint frequencies instead of at a common breakpoint. This typically does not affect the calibration break frequency as the latter is more determined by the characteristics of the calibration kit. Thus when using Anritsu’s 3656B W1 calibration kit, the same 67 GHz breakpoint is commonly used for both the classical and modular broadband systems.

Some additional comments related to use of the modular BB system:

- Since the thru path of the modules is DC-connected, the internal VNA bias tees can be used (the bias routes from the VNA rear panel through the VNA front panel ports to the modules, and then to the W1 plane). For Kelvin-based measurements, Anritsu Kelvin bias tees can be mounted on the rear of the modules directly (see Figure 16-21 on page 16-26). A variety of bias tees are available with different video bandwidths and current handling capabilities are available; contact Anritsu for more information. The internal DC resistance of the modules is very low so the drop from the bias tee to the DUT can be minimized. Contact Anritsu for a detailed report.
- Because the bias tees often have 70 GHz bandwidth and are very well matched, they have little impact on system raw directivity, in part because they are positioned behind the high frequency couplers.

Figure 16-21. The connection of a Kelvin bias tee to a mm-wave module is shown here.

- Isothermal measurements are often of interest and the position of the module very close to the reference plane sometimes raises the question of thermal effects. When normally mounted, the temperature rise at a wafer probe tip is less than 1 degree C. If even low temperature rises are required for on-wafer or other applications, mounting variations are available to reduce this rise to under 0.3 degree C (about the limit of the thermometry being used). Contact Anritsu for more information.

- It is sometimes desirable to position the modules remotely (or further than the usual 1 m cables would allow) because of a complex test setup or for antenna measurement and other applications. Up to 5 m cable runs can be used with reasonable performance (power and dynamic range below 54 GHz will be affected by insertion loss changes, but mm-wave performance will not be because of saturating mixers and multipliers) and 15 m cable runs can be used in some circumstances (covering 30-125 GHz for the 3743A module). For information on configuring longer cable sets or for special modifications for even more remote applications, contact Anritsu. Trace noise and short term stability from measurements with a 15 m system are shown in Figure 16-22. This measurement was done with conventional horn antennas in a laboratory environment and mainly serves to show reasonable close-in trace performance with long cable runs.

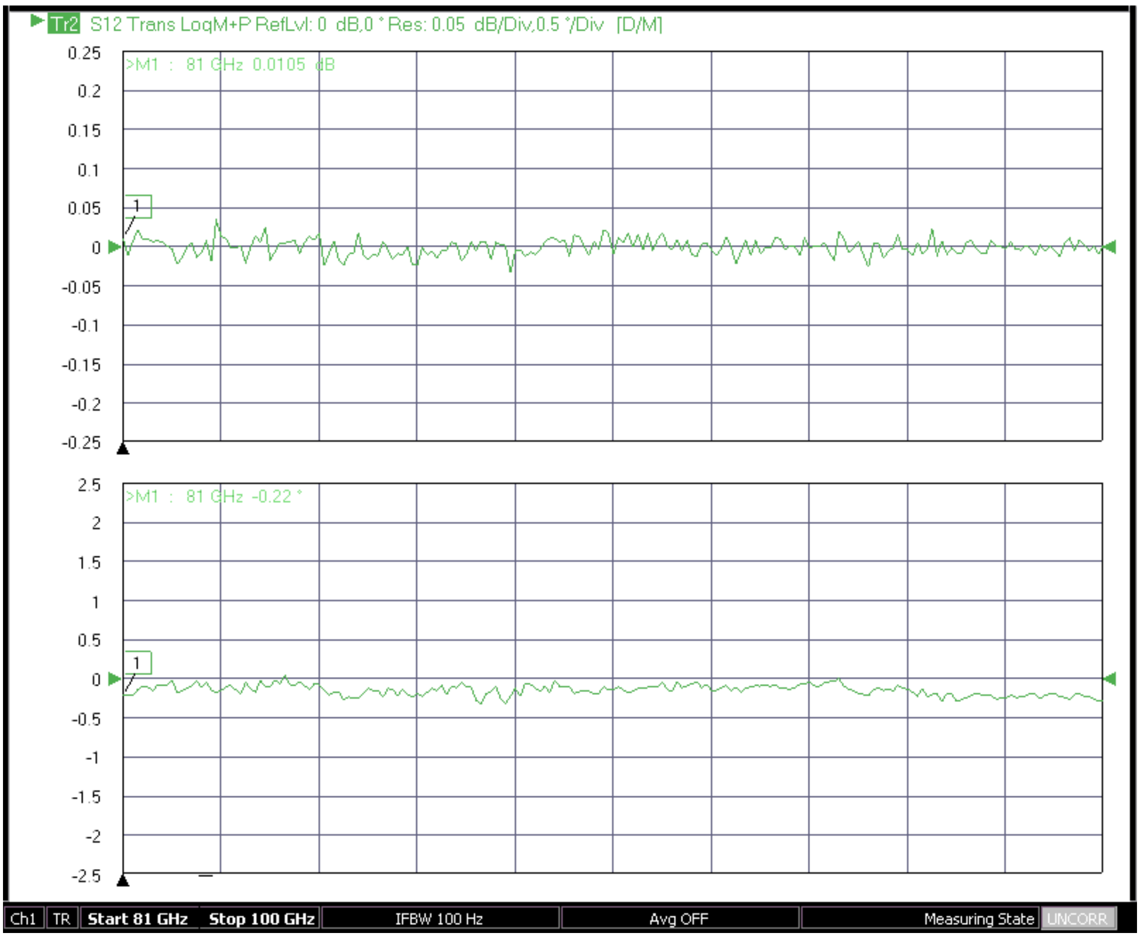


Figure 16-22. Trace noise and stability over about 1 hour are shown here for a 15 m antenna-based measurement.

- In broadband and mm-wave measurements, stability is often of interest because of the possibility of long measurement sessions or longer calibrations. It would be desirable if a calibration could last for a longer period of time to reduce the chance of invalid measurements and to reduce the overall time spent calibrating. The modular BB approach offer some advantages in having the high frequency couplers (covering 30-145 GHz) being right at the 1 mm (or 0.8 mm) connector to minimize raw directivity degradation, a small integrated package to avoid thermal gradients, and a tightly integrated control system. The result is good stability in both reflection and transmission over time as suggested in Figure 16-23. In order to optimize stability, minimizing environmental temperature variations certainly helps as does protecting the cable runs from overstress or unnecessary exposure to thermal variation.

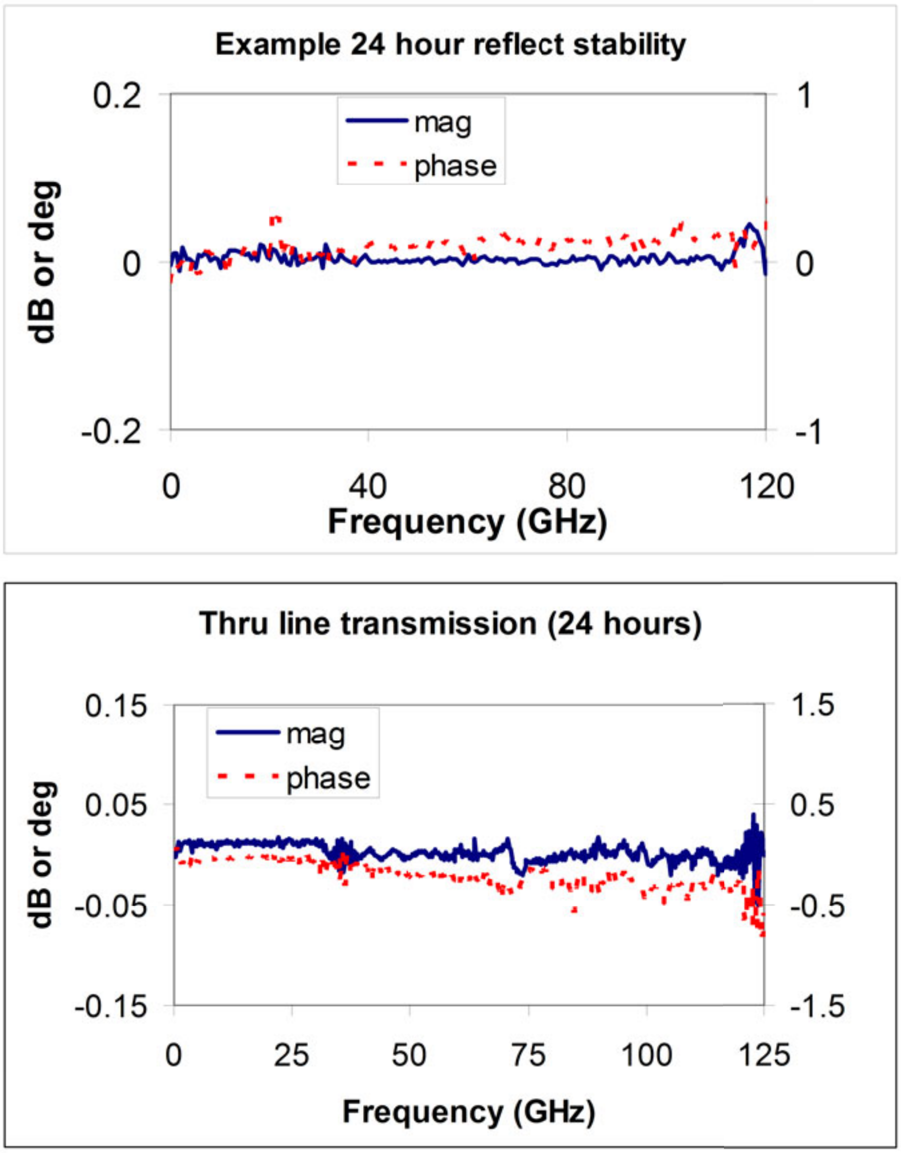


Figure 16-23. Stability data for the modular BB system.

- Waveguide-based measurements are sometimes needed. The classical approach can simply demount the mux coupler and use the exposed waveguide flange (WR-10, 75-110 GHz in that case). A variety of adapters are available for the modular BB approach in WR-15, WR-12, and WR-10 sizes (50-75, 60-90, and 75-110 GHz nominal, respectively). A bracket comes with these adapters to prevent stress from being applied to the 1 mm connector and to improve measurement repeatability. Waveguide calibration kits (3655 series) are available to support SSLT and LRL calibrations referenced to these waveguide planes. The uncertainties do not differ markedly between coaxial and waveguide-based calibrations in these bands as suggested in Figure 16-24, but the waveguide measurements can be more subject to repeatability issues depending on the physical setup and flange quality on the DUT or on any extensions (some high quality extensions are included in the calibration kits to help with the latter).

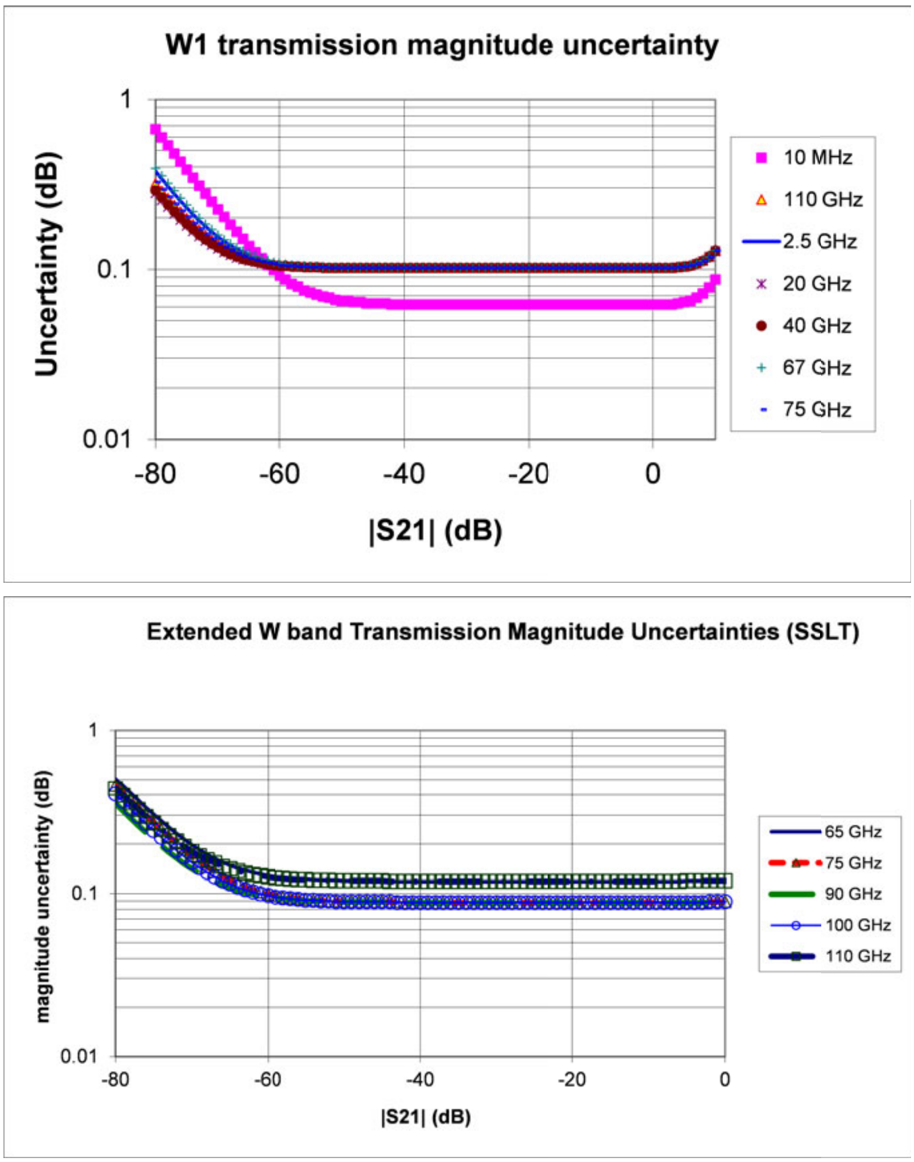


Figure 16-24. Example coaxial and waveguide uncertainty curves are shown here.

Chapter 17 — Multiple Source Control (Option 007)

17-1 Overview

Multiple source control is an application to independently control the internal source and receiver as well as up to four external synthesizers.

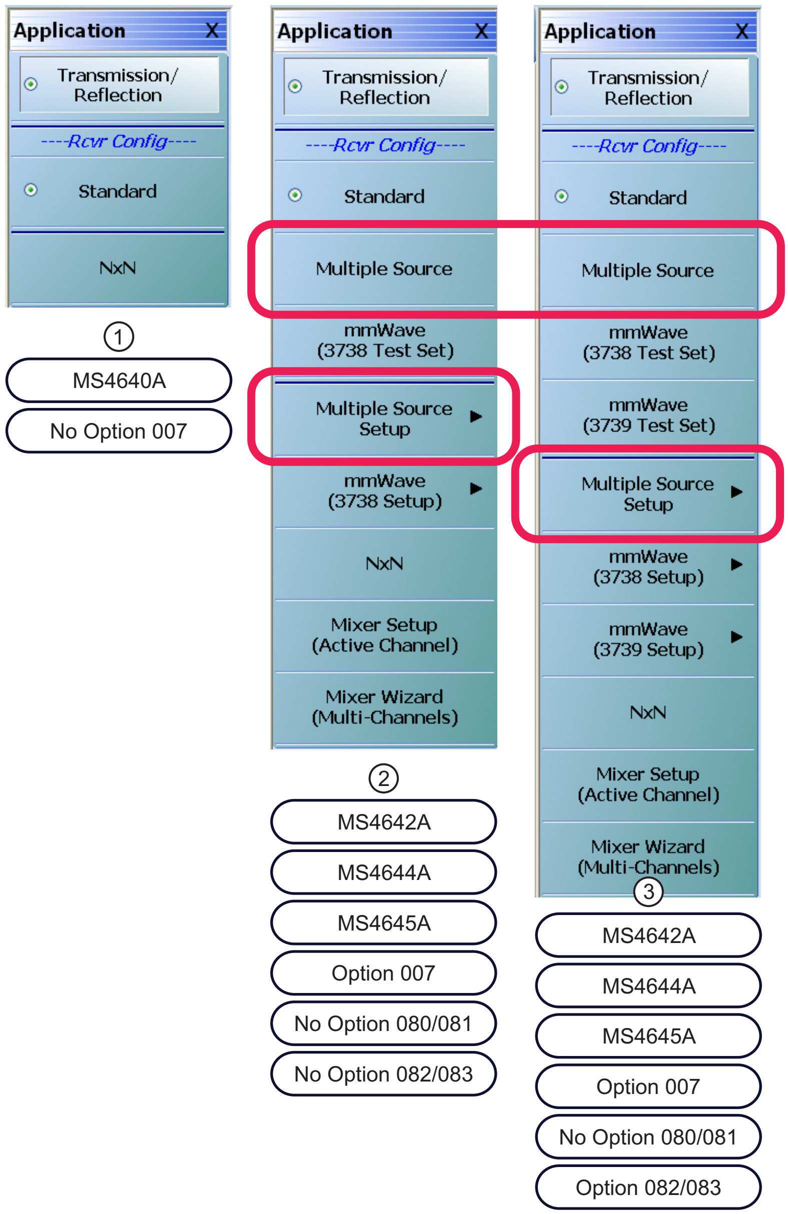
Since there are no constraints on frequency linkage (other than the ranges the hardware is capable of), a wide array of mixer, multiplier, converter and other specialized measurements can be performed. Some examples include:

- 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.

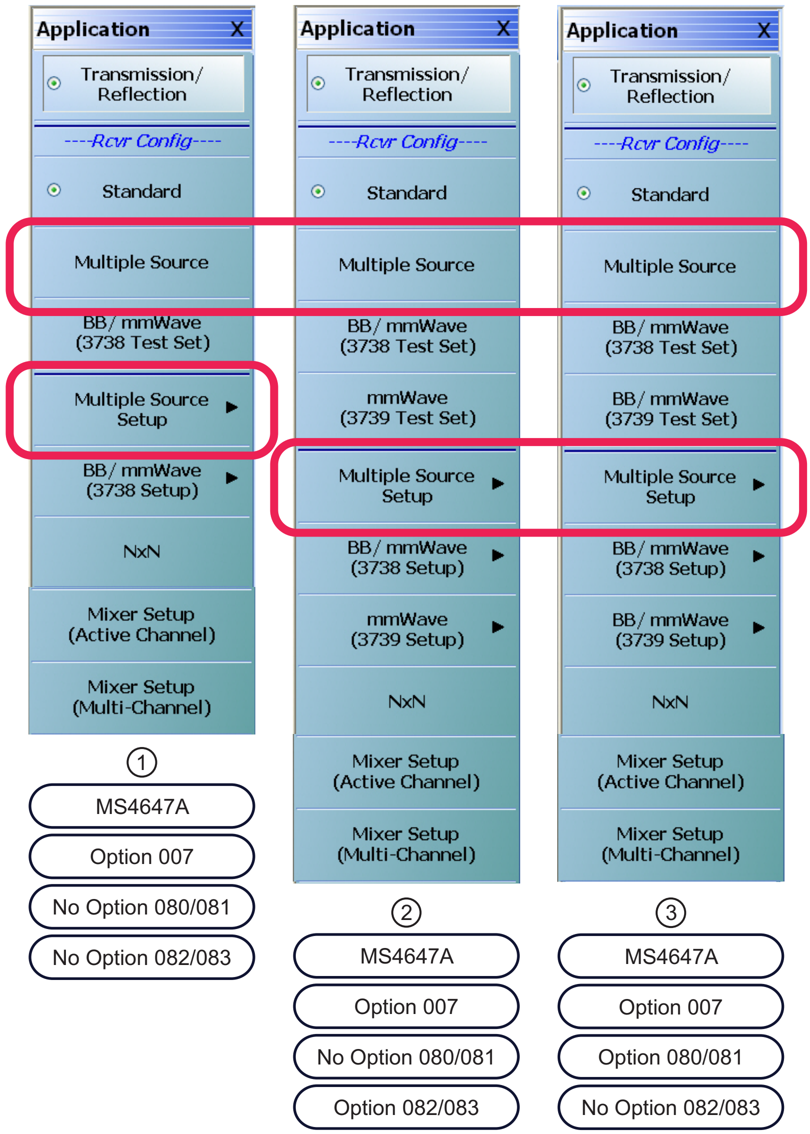
17-2 Introduction

This section discusses the interface and how to configure the instrument and the hardware for generic measurements. The MULTIPLE SOURCE menu selections are available from the primary APPLICATION menu. The APPLICATION menu variants for MS4642A, MS4644A, and MS4645A are shown in Figure 17-1 below. The menu variants for MS4647A VNAs are shown in Figure 17-2, "APPLICATION Menu – Multiple Source Selections – MS4647A" on page 17-3 below.



1. APPLICATION menu default appearance for any VNA when Option 007 Receiver Offset is not installed.
2. APPLICATION menu, Multiple Source button, and Multiple Source Setup button – For MS4642A, 44A, and 45A VNAs when Option 007 Receiver Offset is installed but Option 082/083 is not installed. Option 080/081 is not available for these VNAs.
3. APPLICATION menu, Multiple Source button, and Multiple Source Setup button for model MS4642A, 44A, and 45A VNAs when Option 007 Receiver Offset and Option 082/083 is installed. Option 080/081 is not available for these VNAs.

Figure 17-1. APPLICATION Menu – Multiple Source Selections – MS4642A, MS4644A, and MS4645A



1. APPLICATION menu, Multiple Source button, and Multiple Source Setup button – For MS4647A VNAs when Option 007 Receiver Offset is installed but Option 080/081 or Option 082/083 is not installed. Note that Option 080/081 and Option 082/083 are mutually exclusive.
2. APPLICATION menu, Multiple Source button, and Multiple Source Setup button – For MS4647A VNAs when Option 007 Receiver Offset and Option 082/083 is installed but Option 080/081 is not installed.
3. APPLICATION menu, Multiple Source button, and Multiple Source Setup button – For MS4647A VNAs when Option 007 Receiver Offset and Option 080/081 is installed but Option 082/083 is not installed.

Figure 17-2. APPLICATION Menu – Multiple Source Selections – MS4647A

17-3 Multiple Source Control Set Up

The key concepts to setting up multiple source control are:

Four External Sources for MS4640A VNAs

For MS464A Series VNAs, up to four (4) external sources can be configured.

Frequency Plan Bands

The frequency plan is separated into “bands”. There may be as many as 50 or as few as one. One needs multiple bands ONLY if the relationship between sources and the receiver change in an unusual way at some point in the sweep. Examples:

- A mixer measurement is being setup where the RF and LO are offset by a fixed amount and the IF (which will be sent to the VNA receiver) is constant. Only one band is needed.
- A harmonic converter is being tested where it operates on the 2nd harmonic of the LO up to 10 GHz and the 3rd harmonic beyond that. Two bands are needed here.

Linearly Linked Source Frequencies

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.

Band Start Frequency, Band Stop Frequency, and Runner Variable f

The band start and stop frequencies are in terms of the runner variable f. Thus they may or may not be physical. To reiterate, the choice is usually based on what one wants the X-Axis of the plots to be labeled in terms of (e.g., in terms of the RF frequency or in terms of the IF frequency for a mixer measurement).

MULTIPLE SOURCE Menu

The main multiple source setup menu is shown below in Figure 17-3. The top half of the menu, pertaining to equation editing, will be dealt with first. The special functions of the lower half of the menu will be discussed later.

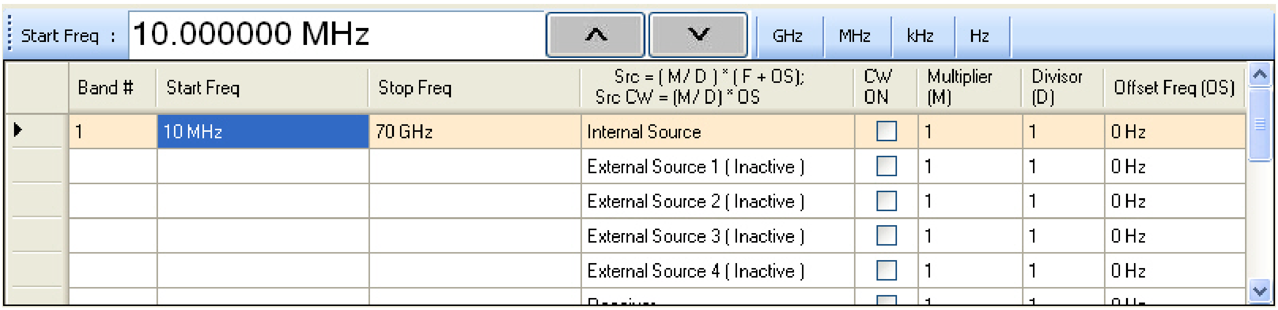
The MULTIPLE SOURCE menu appearance differs slightly depending on the instrument model number, installed options, and band edit state.	• **Multiple Source** and **Phase Inversion** are set to OFF. • Changing **Multiple Source** here also changes the selection on the **APPLICATION** menu. • **External Source Fast Trigger** set to Enabled. • **Phase Inversion** set to OFF.

Figure 17-3. Main MULTIPLE SOURCE Setup Menu

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 on the APPLICATION menu to Standard). When this menu is entered, the MULTIPLE SOURCE tableau will appear in the lower part of the screen (Figure 17-4 below).

Note	The **Done Editing** button in the **Multiple Source** menu MUST be clicked for new values to take effect. Band frequency ranges DO NOT define a required start and stop frequency. These merely set the min and max possible for start and stop. Readjust the desired range for actual measurements on the frequency menu.

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



The MULTIPLE SOURCE tableau dialog appearance differs slightly depending on the instrument model number and installed options.

Figure 17-4. MULTIPLE SOURCE Tableau

Defining a Multiple Source Band

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 frequency for the band.
- A 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:

$$\textit{If CW OFF is selected, then:}$$

$$Src\_X = \frac{M}{D} \cdot (f + OS)$$

$$\textit{If CW ON is selected, then:}$$

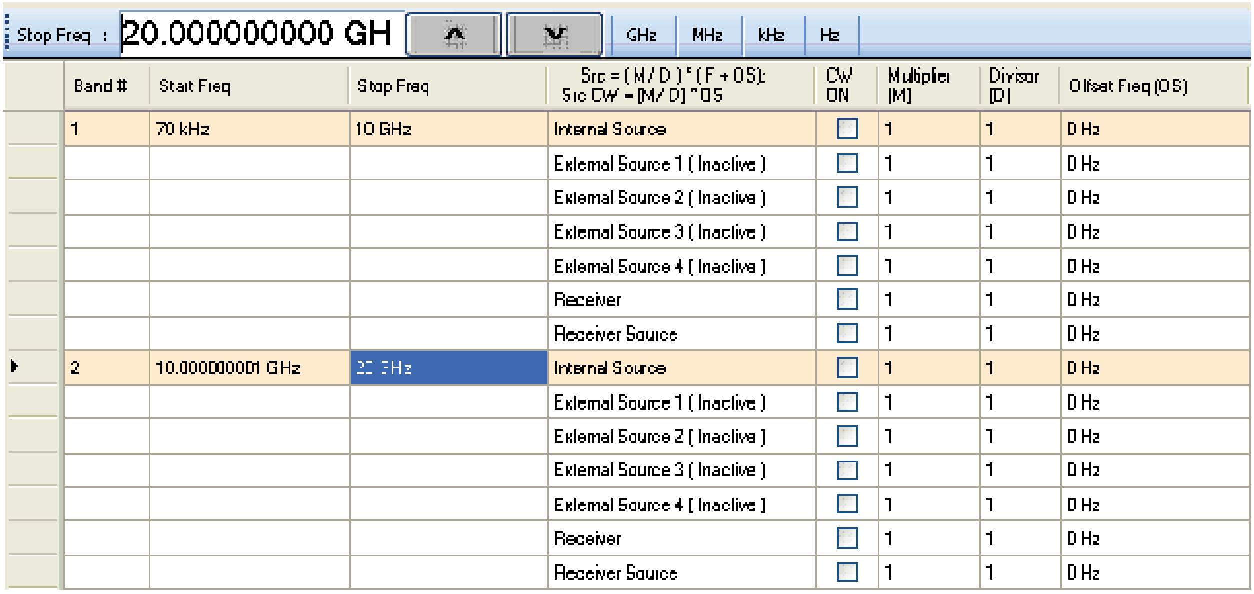
$$Src\_X = \frac{M}{D} \cdot (OS)$$

(Eq. 17-1)

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 17-5. Note that the bands must be contiguous although the sweep range need not be (by using segmented sweep for example).



Band #	Start Freq	Stop Freq	Src = (M / D) * (F + OS); Src CW = [M/ D] * OS	CW ON	Multiplier [M]	Divisor [D]	Offset Freq (OS)
1	70 kHz	10 GHz	Internal Source	☐	1	1	0 Hz
			External Source 1 (Inactive)	☐	1	1	0 Hz
			External Source 2 (Inactive)	☐	1	1	0 Hz
			External Source 3 (Inactive)	☐	1	1	0 Hz
			External Source 4 (Inactive)	☐	1	1	0 Hz
			Receiver	☐	1	1	0 Hz
			Receiver Source	☐	1	1	0 Hz
2	10.000000001 GHz	20 GHz	Internal Source	☐	1	1	0 Hz
			External Source 1 (Inactive)	☐	1	1	0 Hz
			External Source 2 (Inactive)	☐	1	1	0 Hz
			External Source 3 (Inactive)	☐	1	1	0 Hz
			External Source 4 (Inactive)	☐	1	1	0 Hz
			Receiver	☐	1	1	0 Hz
			Receiver Source	☐	1	1	0 Hz

The MULTIPLE SOURCE tableau dialog appearance differs slightly depending on the instrument model number and installed options.

Figure 17-5. MULTIPLE SOURCE Tableau – Two Band Multiple Source Tableau

As soon as values are changed in the table, the Done Editing button shown in Figure 17-3 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.

Note	The **Done Editing** button in the **Multiple Source** menu MUST be clicked for new values to take effect. Band frequency ranges DO NOT define a required start and stop frequency. These merely set the min and max possible for start and stop. Readjust the desired range for actual measurements on the frequency menu.

External Module Control

The EXTERNAL MODULE dialog box is accessed off the primary MULTIPLE SOURCE menu.

MAIN | Application | APPLICATION | Multiple Source Setup | MULTIPLE SOURCE | Ext. Module Control | EXT. MODLE CTRL Dialog Box

This dialog box allows the use of a 3738x or 3739x Test Set and external broadband or millimeter-wave modules. The activation is by band and when turned on, the test set will be informed to activate its modules and use current knowledge of the driving port. This would commonly be used for broadband or mm-Wave measurements when the broadband/mm-Wave mode is too restrictive for the desired measurements. This may happen if different IFs are desired, additional frequency converters are involved in the measurement, or other unusual scenarios. The external IF ports are automatically activated in any of the non-Off modes as are leveling and power control schemes associated with the given test set (see Chapter 16 for more test set information). Only one global mode can be selected per channel but that external module selection can be activated or de-activated on a band-by-band basis.

External Module Ctrl = OFF

External mm-wave or broadband test sets are not being used. The dialog in this state is shown in Figure 17-6. The 3739x test set does not require external synthesizers, so these non-OFF choices will always be available assuming option 08x is present. The 3738 test set does not require additional options, but does require the presence of external synthesizers 1 and 2 on the GPIB bus.

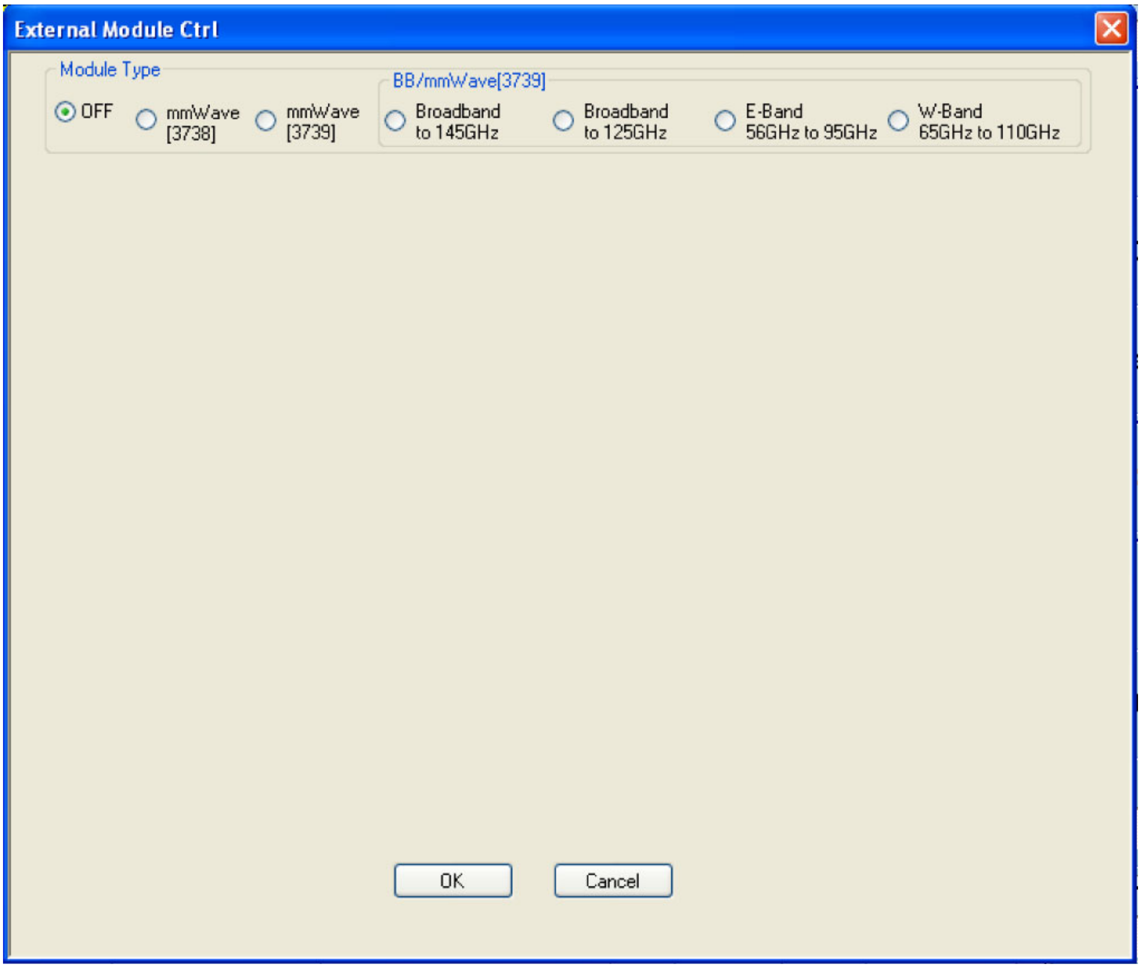


Figure 17-6. The external module control dialog box with off selected is shown here.

External Module Ctrl = mm-wave (3738)

The 3738x test set is being used with conventional OEM mm-wave modules (the ME7828 family of systems). In this case, a check box will be available per-defined band to allow activation of the test set in that band. This option is only available if External Sources 1 and 2 are connected and active. There are no other parameters to select other than to activate or de-activate on a band-by-band basis.

As an example to show how this selection might be used, consider a DUT that is a downconverter taking 250 to 300 GHz down to a fixed IF of 1 GHz. The LO is sub-harmonically driven with an effective multiplier of 18 and will be driven from External Source 3 (EXT. SRC 3). The RF is supplied by an external mm-wave module (WR-03 waveguide in this case), which also has an effective source multiplier of 18, and this will be driven from External Source 1 (EXT. SRC. 1). This external module also has an LO input (x20 effective multiplier) that will be driven from External Source 2 (EXT SRC 2). It is desired to measure both return loss (at the RF) of the DUT as well as its conversion loss. This will require two different multiple source setups since the conversion paths in the VNA are different.

Return Loss Measurement

Connect all external synthesizers and make sure the GPIB addresses match, and that 10 MHz clocks are synchronized (or higher frequency references if those are being used). It is desired that the DUT LO port be driven since that can affect return loss. Since the mm-wave module IF outputs will be used (and routed to the VNA rear panel), the Ext Module Ctrl for BB/mm-Wave must be enabled.

- Band 1: 250-300 GHz
- Int Src (Internal Source) = 1/1(CW 3 GHz)
- We are not using the internal source so it is just parked.
- Ext Src1 (External Source) = 1/18(f +0)
- Ext Src2 = 1/20(f+12.35 MHz)
- The system IF (rear panel) is 12.35 MHz.
- Ext Src3 = 1/18(f+ 1 GHz)
- Rcvr (Receiver) = 1/1(CW 2 GHz)
- We are not using the internal LO so this is just parked.

Conversion Loss Measurement

In this case, Ext Module Ctrl must be OFF since we will not be using the rear panel IFs. Note that this also disables the test set so some care is required with RF signal cabling.

- Band 1: 250 to 300 GHz
- Int Src = 1/1(CW 3 GHz)
- We are not using the internal source so it is just parked.
- Ext Src1 = 1/18(f +0)
- Ext Src2 = 1/1 (CW 2 GHz)
- The external mm-wave module LO is not being used.
- Ext Src3 = 1/18(f+ 1 GHz)
- Rcvr = 1/1(CW 1 GHz)
- The DUT IF is routed to a port or receiver loop so it can be converted

External Module Ctrl = mm-wave (3739)

The mm-wave (3739) selection also assumes the use of OEM mm-wave modules, but with the 3739x test set. Details on some applicable modules, from a hardware perspective, are discussed in Chapter 16. Any multiplied transceivers can be used here as long as the frequency and power plans are consistent with the VectorStar system with the 3739x test set. The test set offers additional power control options and assumes the use of the internal VNA sources so there are some additional selection options as suggested by Figure 17-7.

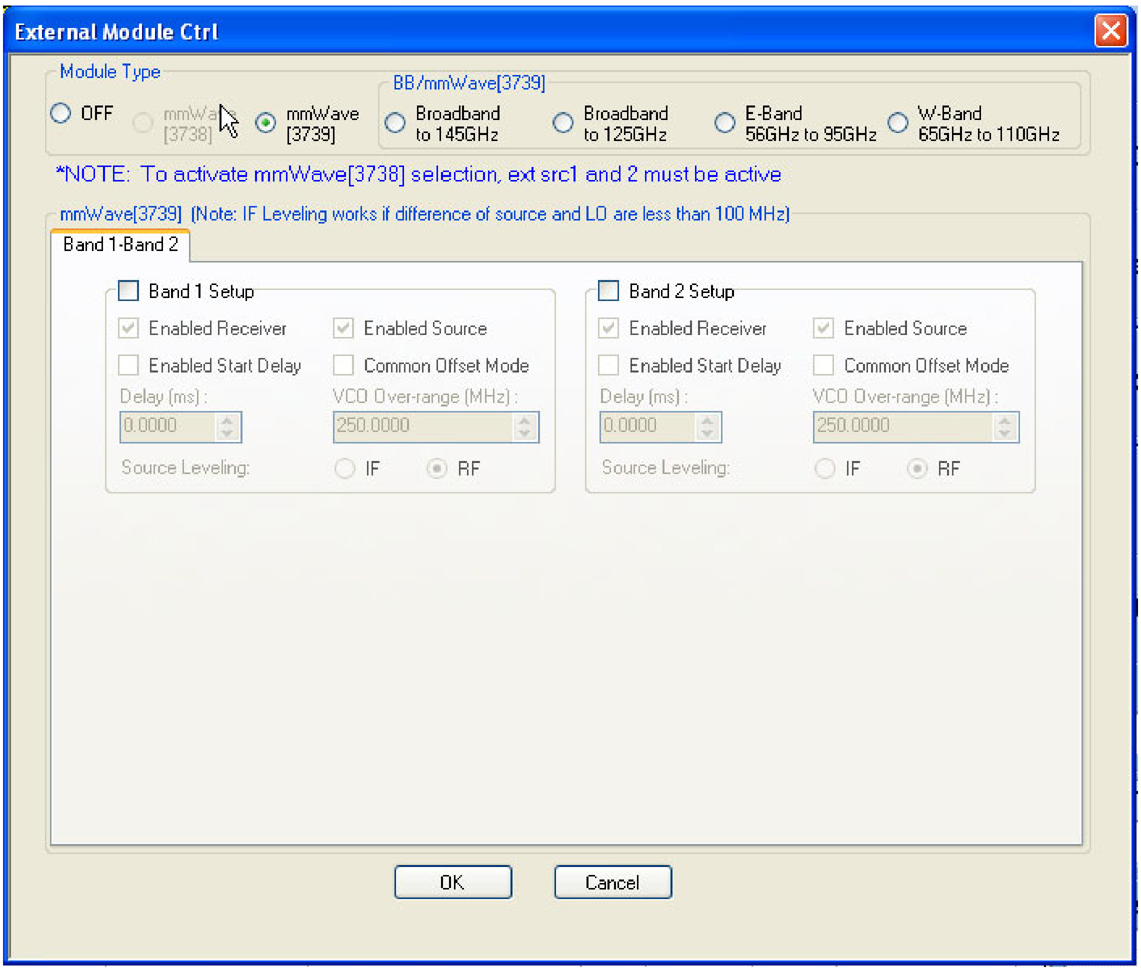


Figure 17-7. The external module control dialog is shown as configured for a single active band of mm-wave (3739).

The selection choices per band are described below:

- **Enabled Receiver:** Use the receiver in the remote modules. Above this breakpoint, the VNA system LO will be set appropriately in terms of frequency and power, the test set configured, and the VNA's rear panel IFs will be activated.
- **Enabled Source:** Use the source multipliers in the remote modules. When enabled the VNA synthesizers will be set appropriately, the test set configured as needed, and ALC leveling prepared (see below).
- **Enabled Start Delay:** This enables a fixed delay at the beginning of the band. This could be useful for certain slow settling DUT measurements or for very low power levels.
- **Common Offset Mode:** At higher multiples (generally for modules running over 300 GHz), it may be desired to improve source correlation to reduce trace noise. This can be done with the Common Offset mode bit (and it is automatically done in the 3739 mm-wave modes discussed in Chapter 16). If the source and receiver frequencies (when reduced to the 2.5-5 GHz range by division) differ by more than about 50 MHz with this bit selected, phase lock errors may occur so this selection is not appropriate for mm-wave mixer measurements but is useful for IMD and other related measurements.

- **VCO Over range:** Normally, the internal VNA multipliers switch at 5, 10, 20, and 40 GHz. In some mm-wave modules operating with high multipliers, it may be desirable to push those switch points out further (up to 5.5, 11, 22, and 44 GHz typical, but not guaranteed). This overrange (expressed in MHz relative to the 5 GHz breakpoint) sets the new breakpoints.
- **Source Leveling:** The leveling choice determines which detection path is used (RF implies the VNA detection on the RF drive path, IF uses the test set detection on a reference IF). Additional cals using the mm-wave ALC subsystem may be required. Generally, IF leveling is only valid if the IF coming from the mm-wave modules is under 100 MHz.

External Module Ctrl= BB/mmWave (3739)

For use with 374x and MA25300A modular components. This right side of the radio button array is for the broadband operation and for banded operation. The selection for BB/mmWave is straightforward. When checked in a given band, the test set will be activated, the VNA's internal transfer switch will be shut down, and the rear panel IF ports on the VNA will be activated. There are at least three choices: broadband, E-band, or W-band. The distinction between these selections is based on the imposed frequency range limits when activated. Broadband allows from the lower instrument limit up to the upper limit of the system (125 GHz or 145 GHz (150 GHz operational) for ME7838A, and ME7838D systems respectively), E band allows 56-95 GHz (under range to 54.000000001 GHz allowed), and W band allows 65 GHz to 110 GHz. For systems loaded with option 080/081, two broadband buttons will be available for 125 GHz or 145 GHz (operational to 150 GHz) situations. The former should be used if 3743x modules are employed and either can be used if MA25300A modules are in use. The dialog in the case of broadband set for two bands is shown in Figure 17-8.

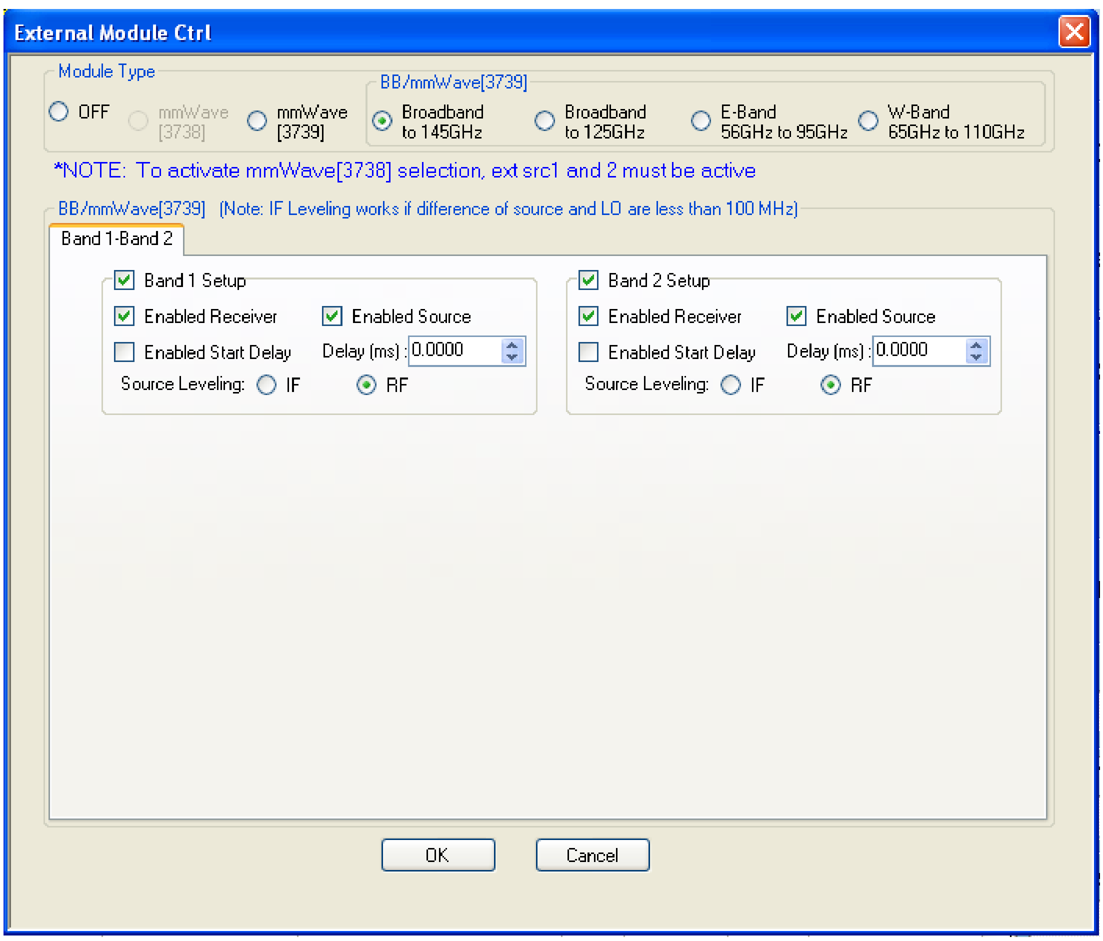
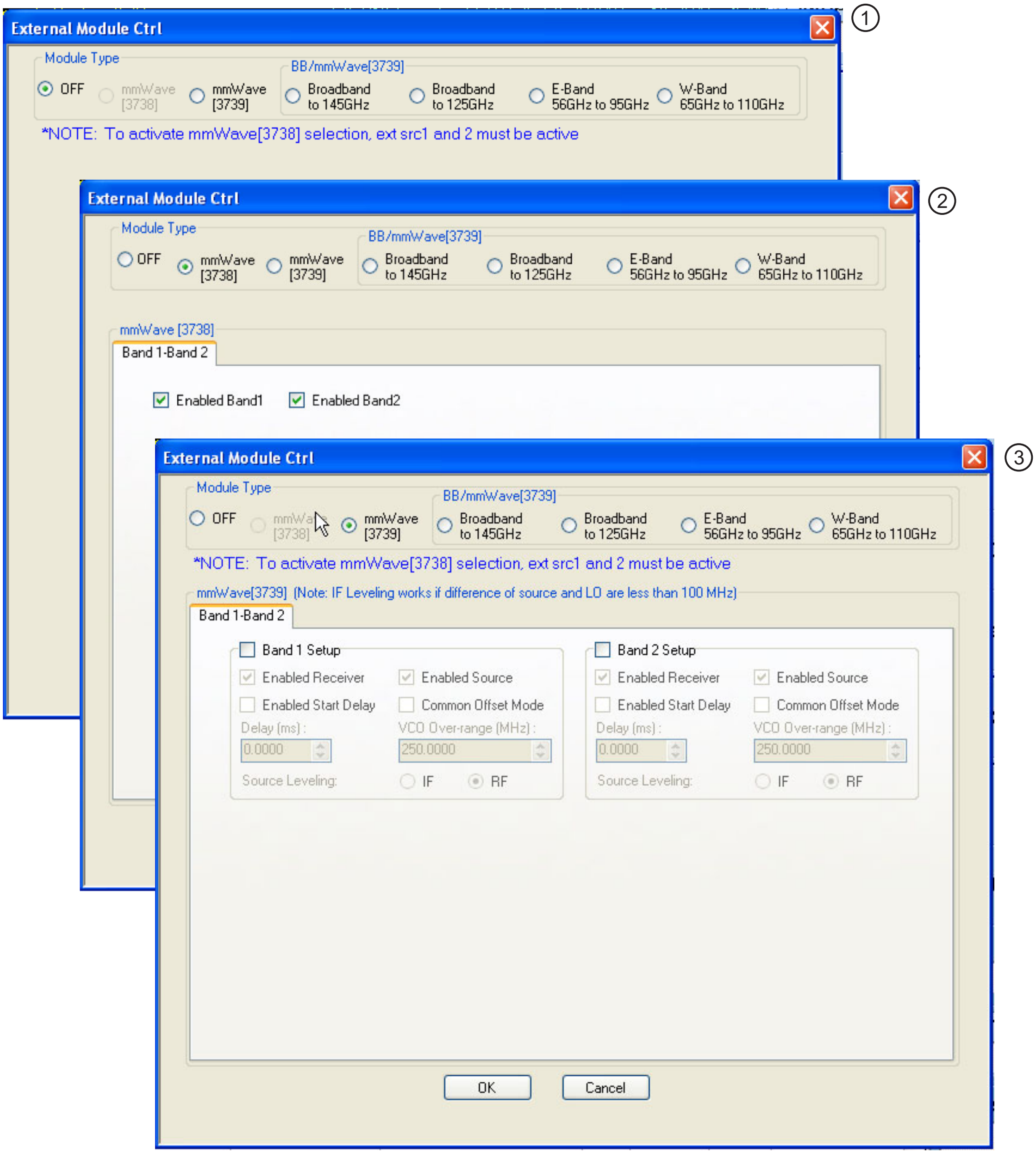


Figure 17-8. The external module control set for broadband (3739x-based) mode is shown here with two bands configured for that mode.

These MA25300A, 3743x, and 3744x modules have independent source and receiver paths that can be selected from the above dialog. The selections can be interpreted as follows:

- **Enabled Receiver:** Use the receiver in the remote modules above the receiver breakpoint (30 GHz). Above this breakpoint, the VNA system LO will be set appropriately in terms of frequency and power, the test set configured, and the VNA's rear panel IFs will be activated.
- **Enabled Source:** Use the source multipliers in the remote modules above the source breakpoints (54 GHz, 80 GHz, and 120 GHz for x2, x3, and x4 respectively for 3743A modules; 54 GHz, 80GHz, and 110 GHz for x2, x3, x6 for MA25300A modules). Above the first breakpoint, the VNA synthesizers will be set appropriately, the test set configured as needed, and ALC leveling prepared (see below). Note that the above and below 54 GHz power control setting apply when this source feature is enabled.
- **Enabled Start Delay:** This enables a fixed delay at the beginning of the band. This could be useful for certain slow settling DUT measurements or for very low power levels.
- **Source Leveling:** The default operation of the modular BB system (when not in multiple source) is to use IF leveling in order to get wide power ranges, but if the source and receiver frequencies are not close enough (or the receiver is not enabled), then an IF is not available for leveling. The leveling defaults to RF in multiple source modular BB and this is recommended unless one knows the IF will be available (up to about 100 MHz) in the module for leveling. Separate ALC calibrations are available for RF and IF leveling and the system will automatically index the correct calibration table.

Figure 17-9 shows the EXTERNAL MODULE CTRL dialog box variants for OFF, mm-Wave 3738, and mm-Wave 3739. In Figure 17-10 on page 17-14, the variants are shown for Broadband, E-Band 56 GHz to 95 GHz, and W-Band 65 GHz to 110 GHz.



1. Dialog box with Module Type OFF selected. 2. Dialog box with Module Type mmWave (3738) selected. Selection boxes enable Band 1 and/or 2.	3. Dialog box with Module Type mmWave (3739) selected. Selection boxes and control fields enable configuration control of Band 1 and/or Band 2.

Figure 17-9. EXTERNAL MODULE CTRL Dialog Box Variants – OFF, mm-Wave 3738, and mm-Wave 3739

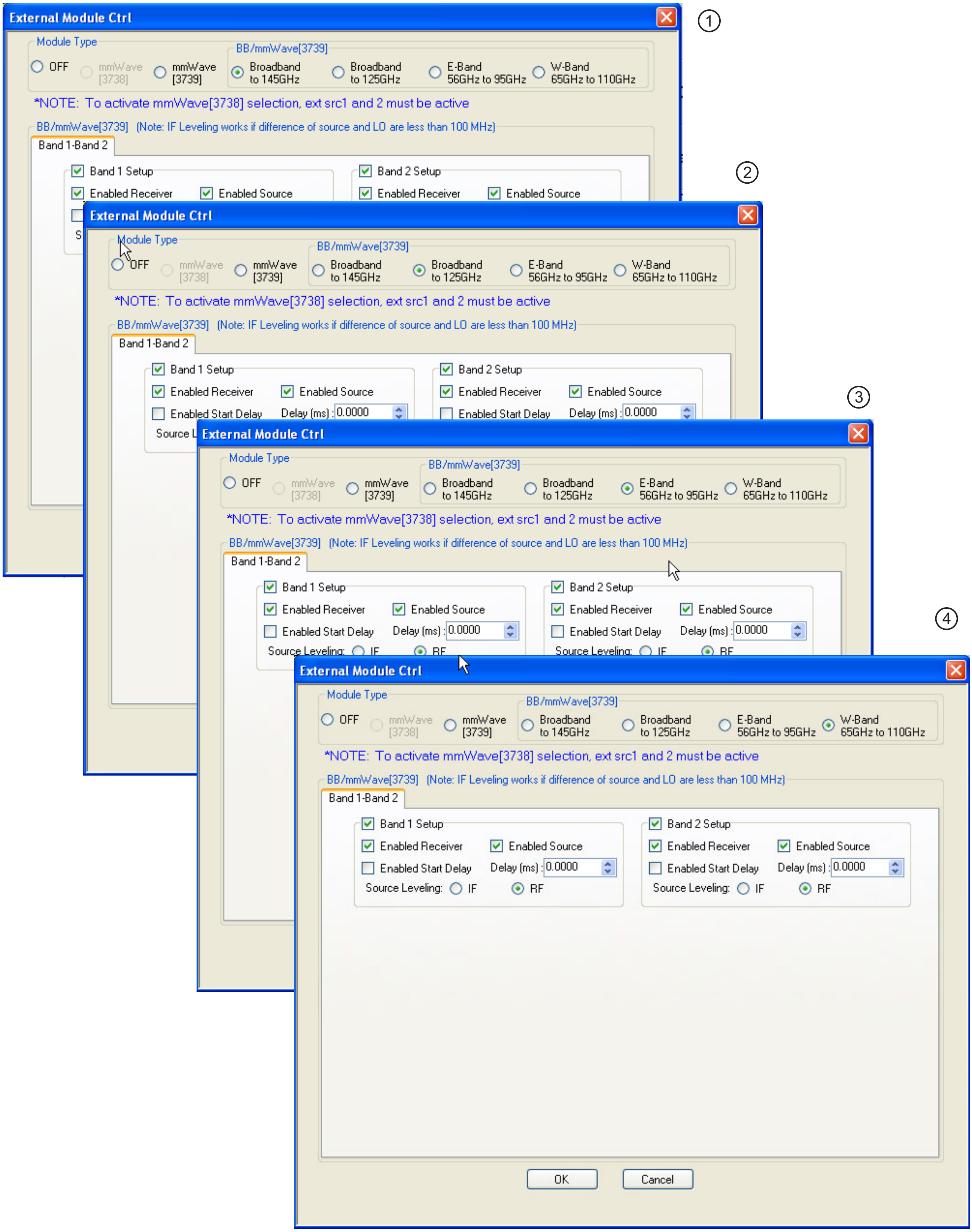
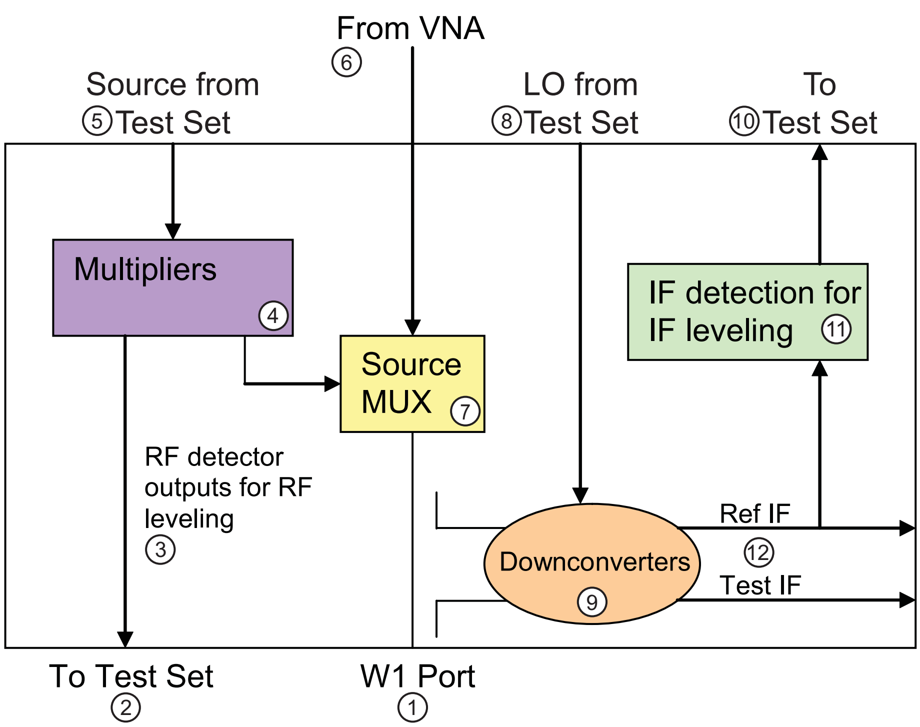


Figure 17-10. EXTERNAL MODULE CTRL Dialog Box – Broadband, E-Band, and W-Band

1. Dialog box with Module Type Broadband to 145 GHz selected. Selection boxes and control fields enable configuration control of Band 1 and/or Band 2. This module type and mode only available with MS4647A VNAs equipped with Option 08x.	3. Dialog box with Module Type E-Band 56 GHz to 95 GHz selected. Selection boxes and control fields enable configuration control of Band 1 and/or Band 2. This module type and mode only available with VNAs equipped with Options 080/081 or 082/083.
2. Dialog box with Module Type Broadband to 125 GHz selected. Selection boxes and control fields enable configuration control of Band 1 and/or Band 2. This module type and mode only available with MS4647A VNAs equipped with Option 080/081.	4. Dialog box with Module Type W-Band 65 GHz to 110 GHz selected. Selection boxes and control fields enable configuration control of Band 1 and/or Band 2. This module type and mode only available with VNAs equipped with Option 080/081 or 082/083.

Figure 17-10. EXTERNAL MODULE CTRL Dialog Box – Broadband, E-Band, and W-Band

The module block diagram below in Figure 17-11 below illustrates where different leveling detection points are located.



1. W1 Test Port	7. Source MUX
2. To Test Set	8. LO from Test Set
3. RF detector outputs for RF Leveling	9. Down converters
4. Multipliers	10. To Test Set
5. Source from Test Set	11. IF Detection for IF Leveling
6. From VNA	12. Reference IF and Test IF

Figure 17-11. 3743X Millimeter-Wave Module – Block Diagram of Leveling Options

Some of these choices can be made clearer with the following measurement examples.

17-4 DUT Measurement Example #1 – Mixer

The DUT is a mixer with:

- a 90 to 100 GHz RF input.
- a 44.5 to 49.5 GHz LO input (with the DUT operating on the second harmonic of this LO input).
- a 1 GHz fixed IF being sent to Port 2 of the VNA.

Setup

A 3743A module will be used to drive the RF port, an external synthesizer (Ext Synth 1) will be used to drive the LO and the DUT output will be sent to Port 2 of the VNA.

- Define band 1: 90-100 GHz
- Int Src = 1/1(f+0)
- Ext Src 1 = 1/2(f-1 GHz)
- Rcvr (Receiver) = CW 1 GHz

Result

External module control activated in 3739-based modes. The source is enabled but the receiver is not. RF leveling should be used. Phase inversion should be activated (see next subsection, “Phase Inversion” on page 17-17 below).

17-5 DUT Measurement Example #2 – Up Converter

The DUT is an up converter with:

- a 1 to 2 GHz input.
- a 76.5 to 77.5 GHz output.
- The LO is fixed at 37.75 GHz and a 2nd harmonic is used.

Setup

Port 1 of the VNA will drive the input of the DUT and the output will be fed to a 3743A module connected to Port 2 of the VNA.

- An external synthesizer (Ext. Synth 2) will provide the LO.
- Define band 1-2 GHz
- Int Src = 1/1(f+0)
- Ext Src 2 = CW 37.75 GHz
- Rcvr = 1/1(f+75.5 GHz)

Result

External module control is activated in 3739-based modes. The receiver is enabled but the source is not. The leveling choice does not matter since the base VNA is providing source drive.

17-6 Phase Inversion

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

- **LO > RF or High-Side Mixing**

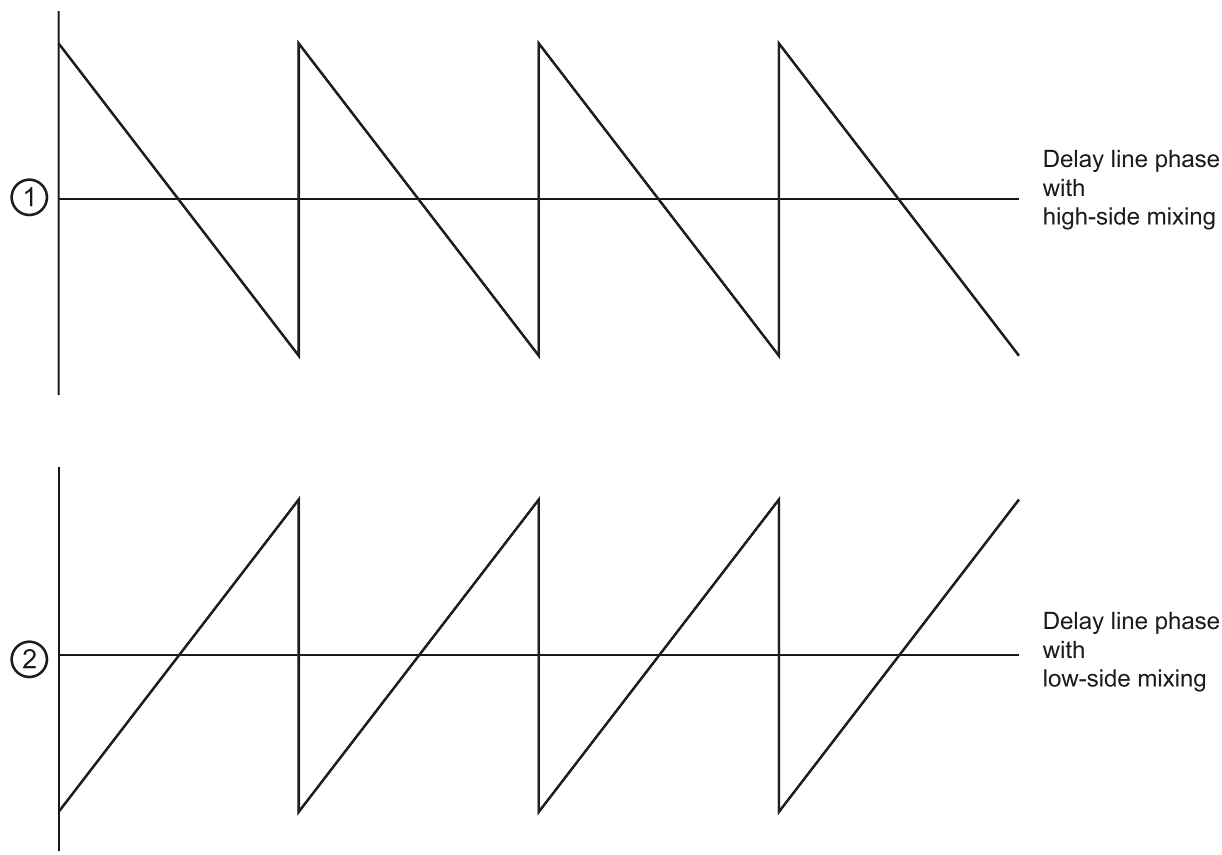
  Here the IF will have the expected phase behavior for the system and phase inversion is not required.

- **LO < RF or 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 on the MULTIPLE SOURCE menu, as shown in Figure 17-3 on page 17-5 above

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 as shown in the 3743X Module Block Diagram in Figure 17-11 on page 17-15 above.



1. Delay line phase with high-side mixing (at top).	2. Delay line phase with low-side mixing (at bottom).

Figure 17-12. Phase Inversion Behavior

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):

$$\varphi = -n \cdot \beta \cdot L$$

(Eq. 17-2)

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.

Receiver Source and Receiver Calibrations

Although receiver calibrations are covered in more detail in another section of this measurement guide, the special use of a multiple source equation should be discussed here.

The receiver calibration is sufficiently general that it may help perform power normalizations even at the plane of an external converter (acting like a pre-receiver). This receiver may be well-characterized at its frequency range (different from the frequency range of the MS4640A Series VNA receiver) but there must be some means of looking up the correct value in that characterization. This is the purpose of the receiver source equation: to act as an index to a receiver calibration that may refer to an unusual reference plane. In most common cases, the receiver source equation is just set equal to the receiver equation. If receiver calibrations are not in use, this equation can be set to any valid frequency.

17-7 Setting Up External Synthesizers

The MS4640A Series VNAs support up to four (4) External Sources.

External Synthesizer Connections

External synthesizers can be used when in multiple source mode. The control connections for a maximally configured multiple source scenario are shown here. All 10 MHz time bases can be linked, but this is not always required depending on the measurement.

It is important to note that the synthesizers are synchronized to the 10 MHz reference of the MS4640A Series VNA 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 at:

- MAIN | System | SYSTEM | Remote Interface | REMOTE INTER. | Ext. Sources | EXT. SRC ADDR.

The EXT. SRC ADDR. menu is shown below in Figure 17-13.

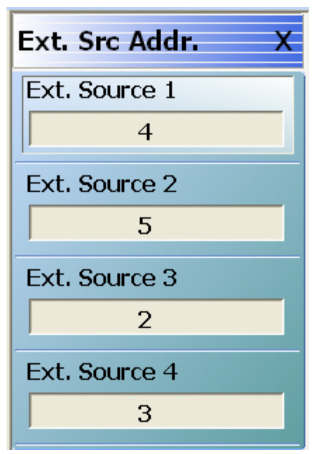


Figure 17-13. EXT. SRC ADDR. (EXTERNAL SOURCE ADDRESS) Menu

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 to see if the State is Active.

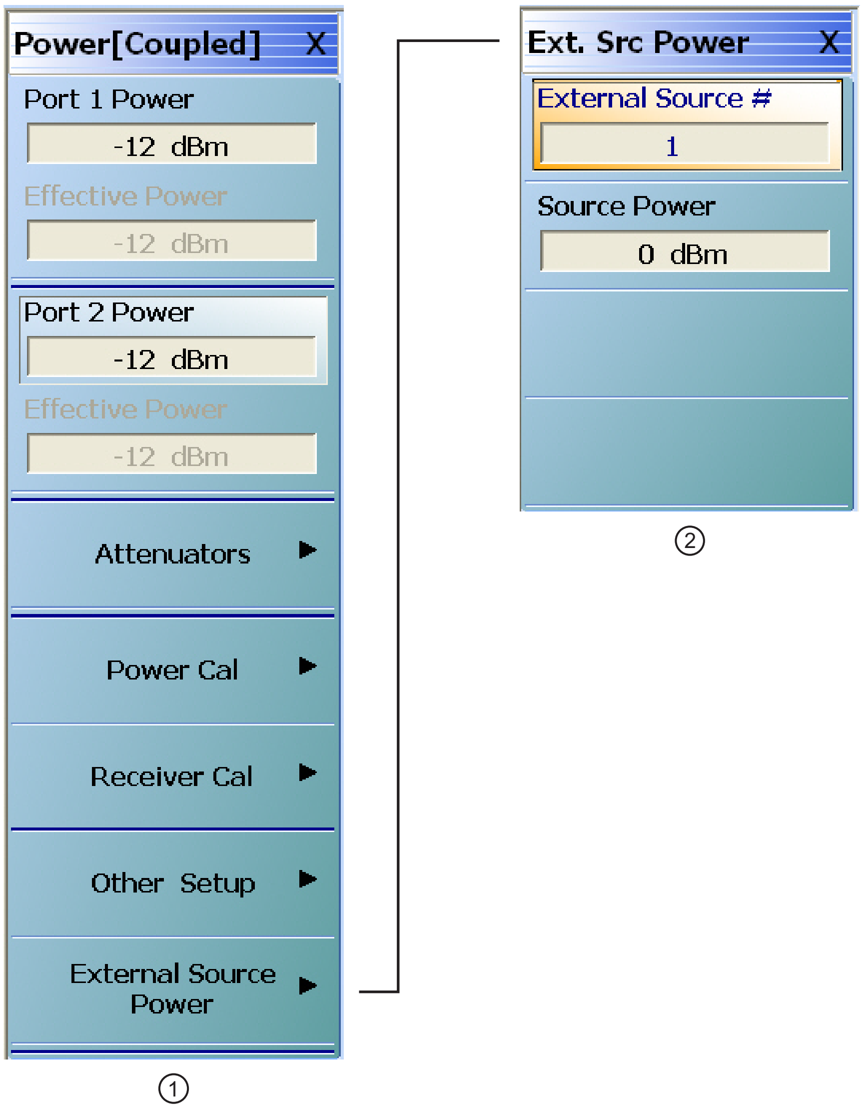
- MAIN | Application | APPLICATION | Multiple Source Setup | MULTIPLE SOURCE
- MAIN | Application | APPLICATION | Multiple Source Setup | MULTIPLE SOURCE | Ext. Src Control | EXT. SRC CONTROL

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 while in broadband or mm-Wave modes, 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.

External Sources Power Level

The power level of external sources is controlled by the External Source Power button on the main POWER menu as shown in the first part (left) of Figure 17-14. This leads to the power entry fields as shown in the second part (right) of Figure 17-14. Again, flatness calibrations may be available with certain firmware versions.



1. POWER [COUPLED] Menu and External Source Power button.	2. EXT. SRC POWER (EXTERNAL SOURCE POWER) Menu with settings for External Source Number and Source Power Level

Figure 17-14. POWER and EXT. SRC POWER Menus

Using the EXTERNAL SOURCE POWER menu, select the source with the top button, then enter the source power with the second button.

External Source Fast Trigger Mode

To enable or disable fast trigger mode when using MG3702xA external synthesizers, on the MULTIPLE SOURCE menu, click on the Ext. Src. Fast Trigger button which will bring up the dialog shown in Figure 17-15. Select the desired mode (ensuring needed cables are connected) and click OK to effect the mode change.

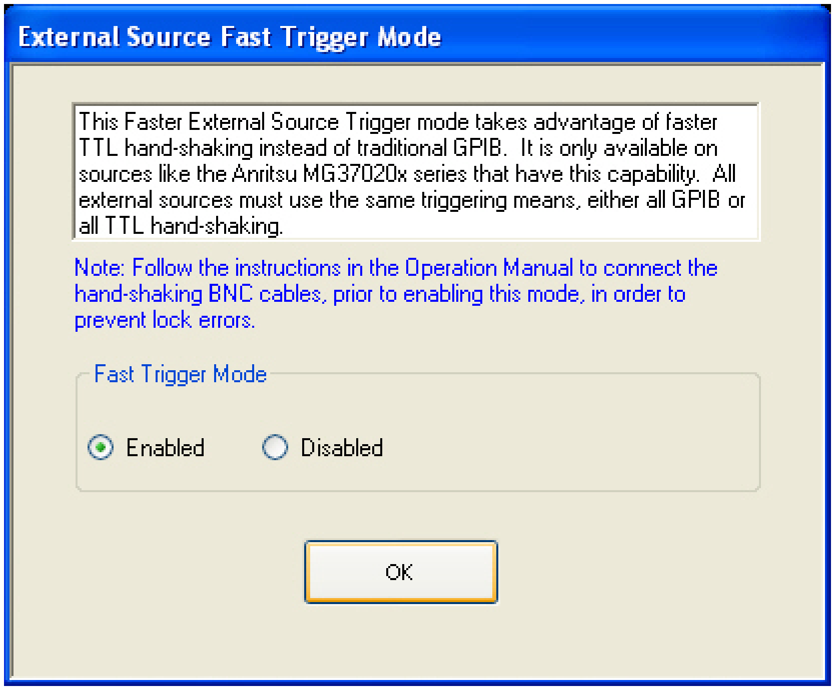


Figure 17-15. EXTERNAL SOURCE FAST TRIGGER MODE Dialog Box

17-8 Multiple Source Hints

So many measurements are possible with the multiple source system that it is hard to provide detailed direction for all of them, but some typical watch-points can be discussed:

- The appearance of the table and the meaning of the band start and stop sometimes cause confusion. The band start and stop do not define the frequencies that you must sweep over, but rather define the range where the given set of equations will be applied. Thus multiple bands can be created with a different equation set for each. When multiple source is ON, the system frequency (i.e., that set on the frequency menu or the segmented sweep screen) must be between the band 1 start frequency (or equal to it) and the last band entered stop frequency (or equal to it). If the Frequency menu range was outside the multiple source range when editing started, when DONE EDITING is hit (or multiple source turned on if it was off), the start and stop frequencies will be coerced to the multiple source band range. One can always sweep any range within the span that has been defined.
- Activation of external synthesizers can sometimes be mysterious and part of this is related to the limitations in constantly polling the GPIB bus. To avoid a slowdown in sweep time, the bus is only polled when entering multiple source or the ext. source submenu (and certain other times related to mm-wave modes). Thus the sources must be connected at their correct addresses (and of course turned on) when the menu is entered in order for it to be visible. If multiple synthesizers were connected and were accidentally set to the same address, it may be necessary to set the addresses correctly and then cycle power on the synthesizers for the bus communication to recover. Also do not forget to connect the 10 MHz references (often the VNA acts as the 10 MHz master, but this is not required).
- When an external synthesizer is under remote control by the VNA, sometimes the display of the synthesizer will still show an old frequency (this depends on firmware revisions and the model of the synthesizer). This may not correspond to where the synthesizer actually has been programmed. That can best be verified with the VNA measurement itself or with a spectrum analyzer. The power readout, if present, will update real time and this is another way to check if control has been established (by changing the entry on the external source submenu of the Power menu).
- Complete control has only been established for the MG3690B (and beyond) and MG37022A synthesizers. Certain older Anritsu and Wiltron synthesizers will work under some frequency plans, but may not always work due to frequency resolution differences.
- On the Ext. Module Control dialog, the maximum VCO overrange defaults to 250 MHz (this is the amount of overrange allowed on the base 2.5-5 GHz VCO, thus at the 20 GHz plane, it translates into 2 GHz), but this amount may not always be available depending on temperature and other variations. If one is using a lot of overrange and lock errors are visible on the message bar, the frequency plan of the setup should be re-arranged to require less overrange.
- When using RF leveling, less control range is available than when using IF leveling (only applies to the 374x modules) due to lower dynamic range detection. The IF leveling only works well when the net IF is less than a few hundred MHz so it can work well for IMD measurements, but not so well for mixer measurements. RF leveling should be used for the latter. Two separate factory ALC calibrations are performed (one using each detector path) so reasonable power control should always be possible.
- The common offset selection (Ext. Module Control dialog) is valuable for high order multiplied measurements as has been discussed, but requires the base receiver and source (referenced to a 5 GHz plane) to be within about 80 MHz of each other. Thus at a 20 GHz max frequency plane, they must be within about 320 MHz. If lock errors are observed, consider unchecking this box.

Chapter 18 — Noise Figure – Option 041

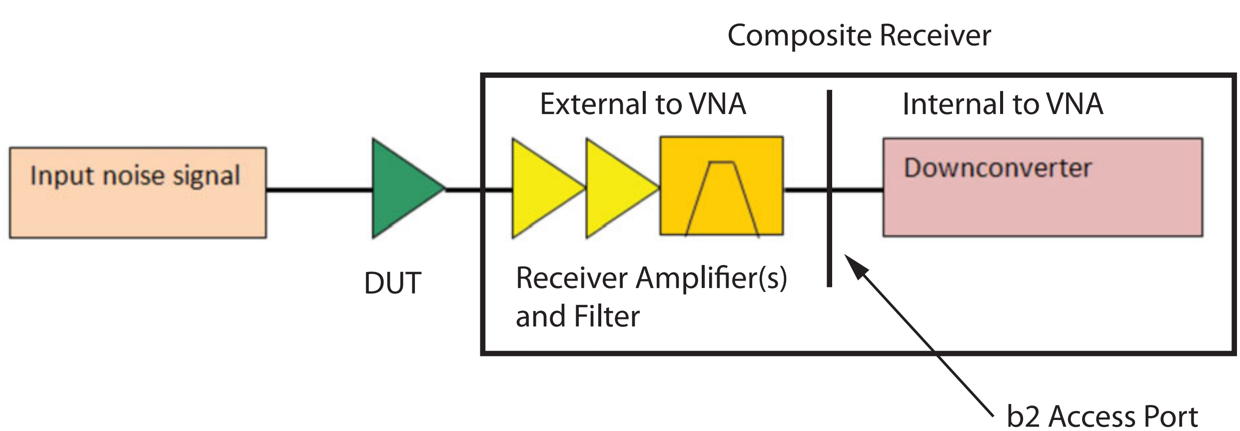
18-1 Chapter Overview

Option 041 provides noise figure measurement capabilities in the MS4640A series VNA family. The intent of this chapter is to explore the physics of the measurement as implemented, offer operational guidance on how to use the option, and to provide hints and tips on how to optimally setup a noise figure measurement.

18-2 Background

In recent years, numerous improvements have been made in noise figure measurements through better algorithmic understanding of the measurements (e.g., [1]-[6]), more sensitive receivers, and simpler methods of processing noise power measurements. This chapter describes one specific set of improvements, based on the cold source measurement technique and related error correction techniques to enhance the noise measurement accuracy.

One particular avenue of noise figure measurements will be discussed here based on a cold source technique and some corrections applied to it. Before beginning with the algorithmic discussion, it may help to briefly look at the measurement hardware. In all cases, the DUT will feed a composite receiver consisting of the main receiver of the VNA augmented with amplification and filtering. The reasons for the extra gain will become clear later in this chapter. The basic structure of the VNA and DUT setup is shown below.



A basic diagram of the noise figure measurement setup is shown here. The MS464XX VNA is represented by the downconverter block and the processing circuitry (not shown) after it.

Figure 18-1. Noise Figure Measurement Basic Setup Diagram

Hot-Cold or Y-Factor Noise Figure Measurement Method

Historically, a popular method for noise figure measurements was termed a hot-cold or Y-factor technique in which a noise source was employed that could produce a low noise output power (cold = N_c) and an elevated one (hot = N_h). This noise source becomes the 'Input Noise Signal' in Figure 18-1.

The ratio of measured noise powers in these two states was termed the Y-factor ($Y = N_h/N_c$) (e.g. [2]) and could lead to a quick calculation of noise figure via the equation (Eq. 18-1) below.

$$F = \frac{\frac{T_h}{T_0} - 1}{Y - 1}$$

Eq. 18-1

Where T_h is the equivalent hot temperature of the noise source and the cold temperature was assumed equal to a temperature of 290 K = T_0 (per IEEE definition).

By making a noise figure measurement of the receiver itself (F_{rcvr}) and of the system ($F_{sys} = F_{DUT}$ + Receiver), it is possible to deconvolve the DUT noise figure with the familiar Friis' equation (Eq. 18-2) below: [1].

$$F_{DUT} = F_{sys} - \frac{F_{rcvr} - 1}{G}$$

Eq. 18-2

Here, the DUT gain G could be measured separately (via S-parameters) or it could be determined from the change in measured noise powers during calibration and measurement. One advantage of the hot-cold noise figure measurement method is that no absolute power calibrations are needed (all based on ratios). This was particularly important in the past when wide dynamic range power measurements over large bandwidths were more difficult. One challenge of this measurement method was the ability to provide a well calibrated noise source.

Because of the signal levels and bandwidths involved, accurate noise source calibration (for T_h) is challenging and normally left to only a few metrology laboratories. In addition to issues in calibrating the noise source, a larger challenge occurred when the match of the noise source changed between the hot and cold states [4]. This could lead to large errors, particularly as the DUT input match worsened. These errors could be partially corrected using a source correction method (e.g., [3]).

Cold Source Noise Figure Measurement Method

The cold source noise figure measurement method was developed to eliminate the requirement for a multi-state noise source, which would the allow the use of a simpler, better controlled noise source (nominally a termination at room temperature). In this case, the noise figure is found from a simpler equation (Eq. 18-3), but it has some subtleties:

$$F = \frac{kT_0B + N}{kT_0BG}$$

Eq. 18-3

Where:

- k is Boltzmann's constant
- N is the noise power added
- G is the gain
- B is the bandwidth

To calculate the noise figure, there are a few key steps to accomplish.

First, an absolute noise power is now required (numerator N), so a means of a receiver power calibration is needed.

- The receiver can be calibrated with a variety of calibrated signal sources including a power-calibrated sinusoidal source or a calibrated noise source. A highly linear receiver allows this use of different signal sources.
- Other methods are possible to determine added noise power including the use of a calibrated hot noise source. Again, the calibrated noise sources would only be utilized for calibration. In both cases, an absolute power reference is being created.

Second, an effective measurement bandwidth (B) is needed. Since measurement bandwidth is largely determined by the digital IF system, B can be pre-calculated. This bandwidth value may also be determined with the absolute power calibration step if a noise signal is used, otherwise it is determined separately.

Third, to isolate the noise figure of the DUT, the noise contributions of the receiver must be taken into account. As with the hot-cold method, a measurement of receiver noise is required with the cold source attached to the receiver input. Taking the receiver noise into account, Eq. 18-3 above can be re-expressed in the form below (Eq. 18-4):

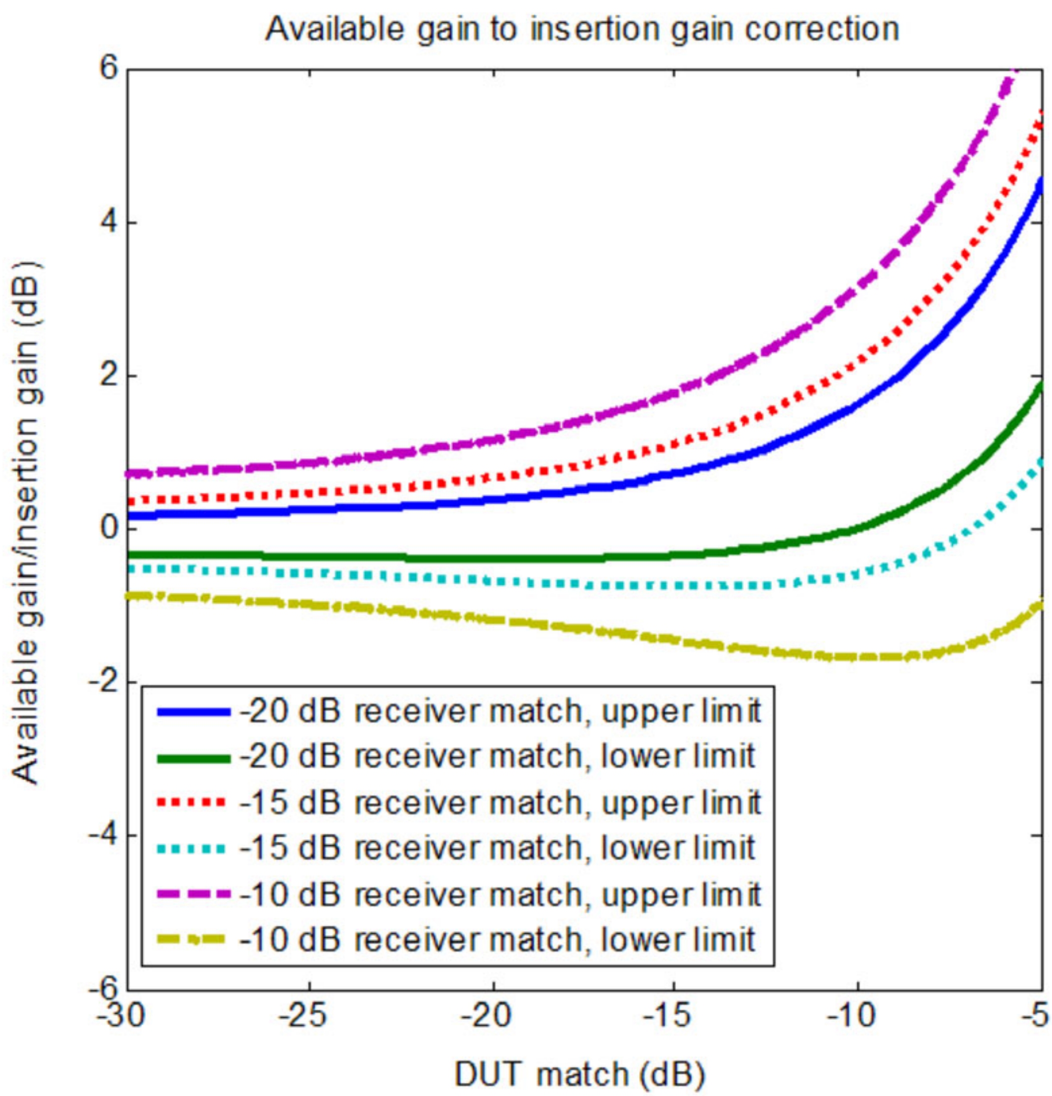
$$F = \frac{1}{G} + \frac{N_{DUT+rcvr} - N_{rcvr}}{kT_0BG}$$

Eq. 18-4

A few things are immediately obvious: errors in gain or the noise power measurement will propagate to noise figure on roughly a dB-for-dB basis (if the gain is sufficiently high at least). These accuracies will be discussed throughout this chapter, but it is worth remembering the approximate dependence.

Measurement Considerations

Of all of these terms, and it is true with hot-cold approaches as well, the term most often misvalued is the DUT gain. As has been discussed many times before (e.g., [3]), the noise figure definition is based on input noise power available to the DUT and output noise power available from the DUT. As a result, it is available gain that is the most appropriate value to use as opposed to insertion gain (which is what was commonly used with Y-factor approaches) or even $|S21|^2$. As the DUT match worsens, the difference between these gain definitions increases. An example plot is shown below, where the DUT input and output matches (assumed symmetric for simplicity) form the x-axis and the receiver match is parameterized. The cold source match is assumed to be -20 dB and the DUT is assumed to have decent isolation ($|S21 \times S12| = 0.1$). Multiple dB differences in gain, and hence in calculated DUT noise figure are possible as the match degrades beyond -10 dB.



The difference between insertion and available gain as a function of match levels is shown here. Since gain strongly affects the noise figure calculation, understanding this difference is important.

Figure 18-2. Differences Between Insertion and Available Gain as Function of Match Levels

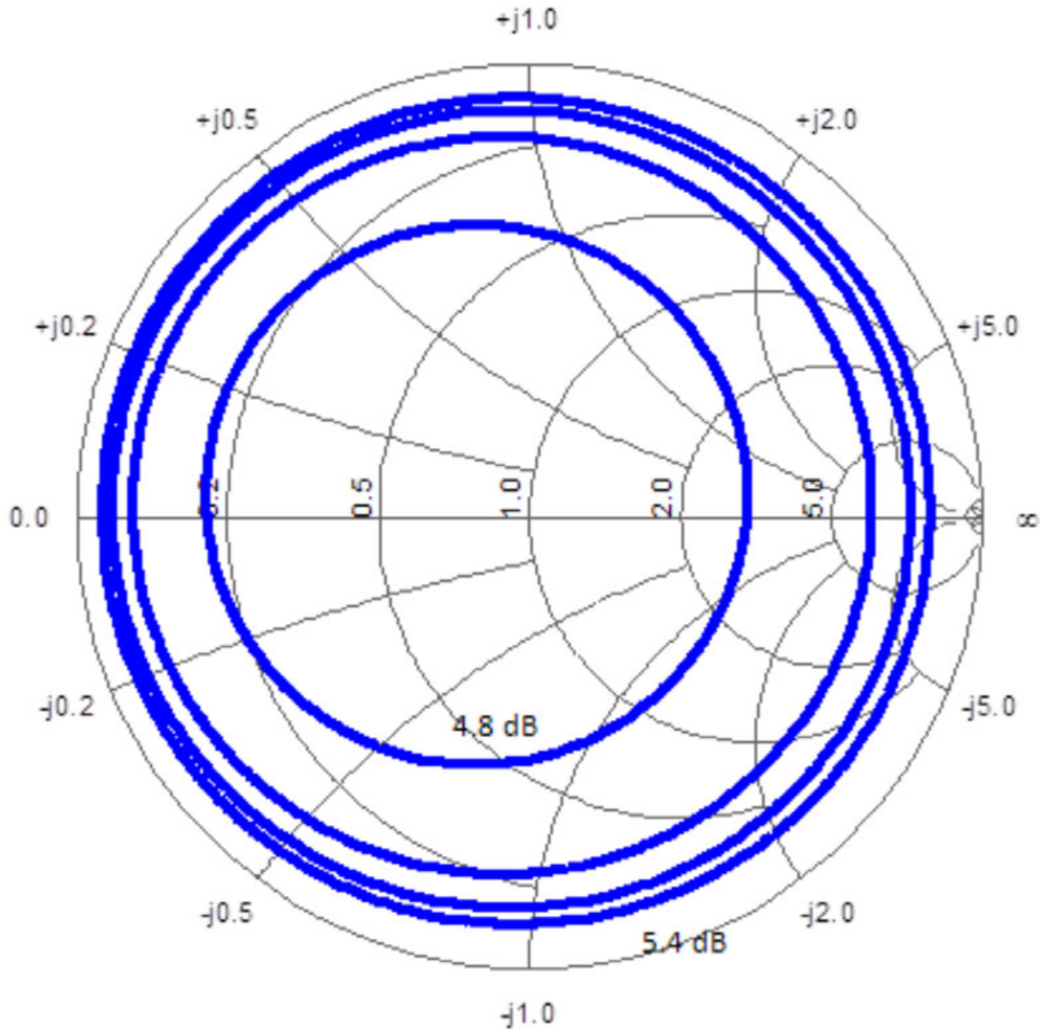
In the case of the cold method (and assuming a quality termination is used on the input), it is primarily the DUT-receiver interaction that causes the difference in gain. From Eq. 18-4, since gain errors map essentially linearly to noise figure errors, using the correct gain term is important even for commonly observed return losses.

Another potential source of errors in the noise figure measurement is the interaction of the receiver with DUT output. If the receiver noise power is strongly affected by the source impedance (i.e., a large R_n in the parlance of noise parameters), then significant errors could be encountered by not accounting for this interaction. This is accomplished by error correcting with the receiver noise parameters. To understand the relationship (e.g., [7]), recall that the noise response of a device (receiver in this case) may usually be characterized by four parameters sometimes represented by F_{min}, R_n, and Γ_{opt} (which is complex hence counting as 2 parameters). F_{min} is the minimum noise figure of the device when presented with an optimum source match (given by Γ_{opt}) and R_n is a sensitivity parameter describing the reaction of noise figure to changes in source match. The net noise figure of the device is given by (in this formalism) (Eq. 18-5):

$$F = F_{min} + \frac{4 \cdot R_n \cdot \left|\Gamma_S - \Gamma_{opt}\right|^2}{Z_0 \cdot (1 - \left|\Gamma_S\right|^2) \cdot \left|1 + \Gamma_{opt}\right|^2}$$

Eq. 18-5

If R_n is small relative to the system impedance Z_0, then the net noise figure is relatively insensitive to changes in the source reflection coefficient Γ_S. Commonly, the effective receiver R_n is small and the dependency is minimal, since the receiver is normally a matched/feedback amplifier with some loss in front of it from cables, switching, and similar parameters. The noise circles of an example, typical receiver structure are shown below at 50 GHz. Even if the DUT output is very poorly matched ($|S22| > -1$ dB), the effective receiver noise figure only changes by ≈ 0.65 dB from F_{min}. Assuming the DUT has ≈ 10 dB of gain and ≈ 2 dB noise figure; this would only add 0.1 dB of uncertainty. If the DUT had ≈ 20 dB of gain and ≈ 2 dB noise figure, this would only add 0.01 dB of uncertainty. With many common receivers, even less sensitivity is displayed although the effect is, of course, a function of which pre-amplifiers are used with that receiver.



The effect on noise figure of varying the impedance seen by an example receiver is shown here. As the parameter R_n gets small (as is the case for many receiver structures), this impedance dependence becomes weak.

Figure 18-3. Variable Impedance Effects on Example Receiver Noise Figure

If further reduction in uncertainty is desirable, it is relatively straightforward to add additional correction by including three additional measurements during the receiver noise calibration step (e.g., [4]). They are measuring the noise power with three reflect standards in addition to the cold noise source. Here one is just drawing on the long history of noise parameter measurement to help with an increase in receiver correction.

Linearity

Another aspect of this measurement that sometimes receives less attention is that of linearity. Since it is a measurement of noise, a common perception is that there could never be anything nonlinear about the measurement process. Several issues do come into play:

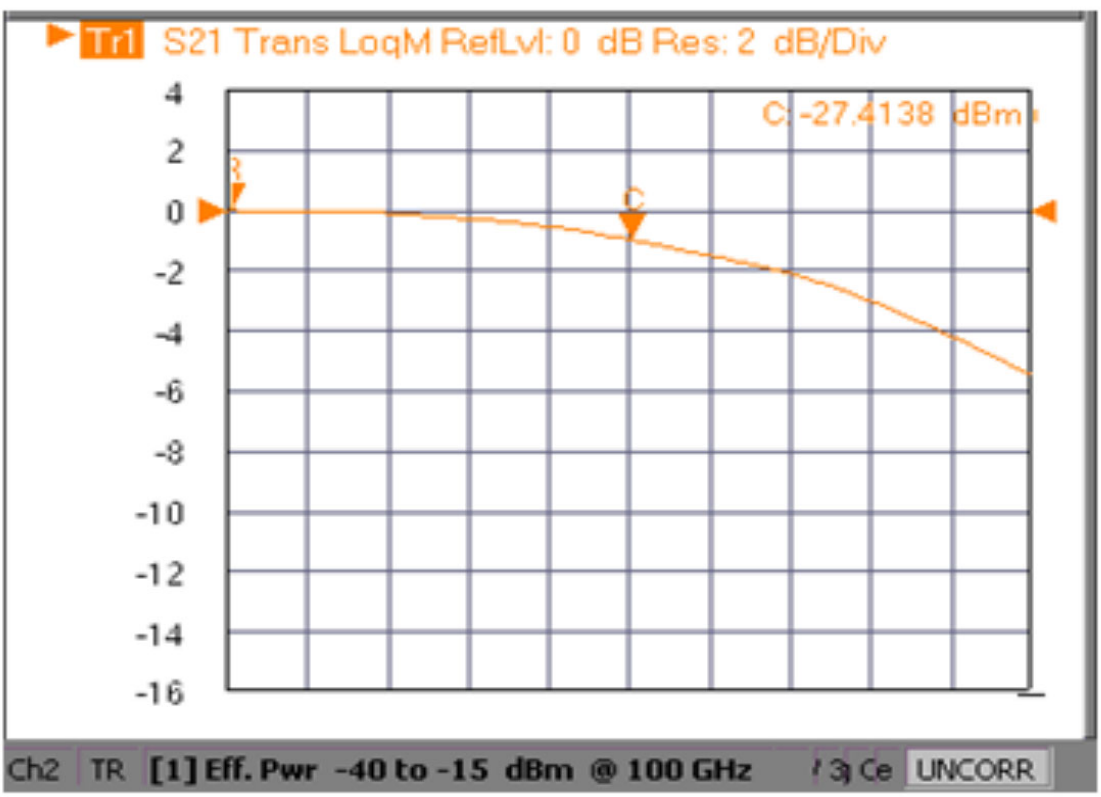
- Since the measurement is over a large bandwidth and the gains of both the receiver and DUT may be large (> 40 dB), the integrated power may be large enough to cause compression either in the amplifiers or in the IF of the instrument.

- Since the DUTs are often small signal LNAs, the power at which the gain was measured must be low enough that the gain result is not compressed. This level may be below –30 dBm for many DUTs.
- The instrument ADCs have low level linearity that must also be respected. This is normally resolved by having enough receiver gain. Receiver gain plays a key role in the uncertainty of the noise figure measurement (see “Uncertainties” on page 18-22 below).

To illustrate the first point, suppose the receiver is composed of a 40 dB gain, 20 GHz broadband amplifier (plus some other components) before the downconverter and suppose the DUT also had about 40 dB gain and about 20 GHz of bandwidth. The input termination (cold noise source) will produce about –174 dBm/Hz noise power at room temperature. The integrated power at the output of the receiver amplifier (integrated over the 20 GHz) could reach +9 dBm (–174 + 80 +103). If the receiver amplifier compressed before this point (or if the downconverter did), then errors would occur. In this particular case, filtering would likely be needed anyway for image rejection (described in sections below) so this may not happen. If compression appears to be a problem, then use less gain in the receiver path could be used.

LNA DUT Compression Behavior

The second point is somewhat obvious, but one may not think to look at the DUT compression behavior if it is an LNA. The VNA default power ranges from –10 dBm to +5 dBm depending on model and options. This power range may not be appropriate for the DUT. By looking at |S21| of the DUT as power is varied or by using the gain compression tools in the power sweep modes (see the relevant sections of this **Measurement Guide** for more information), one can ensure that the DUT gain data is obtained under linear conditions. As an example consider a W-band LNA whose noise figure was of interest. From the plot in Figure 18-4, the DUT is already 1 dB compressed at an input power of ≈ –27.4 dBm at 100 GHz. The gain measurement in this case should be done at –35 dBm or lower.

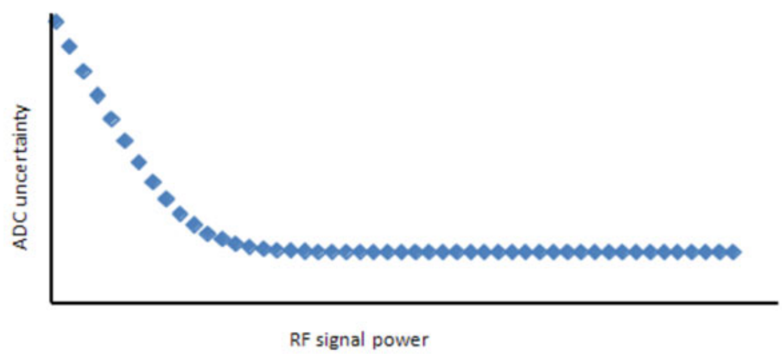


An example LNA power sweep is shown here. Many LNAs compress at very low power levels and it is important that the gain be measured in a linear region for an accurate noise figure result.

Figure 18-4. Example of LNA Power Sweep

Low Level Compression

The third point, related to low level compression, is subtle but true for all analog-to-digital converters (used in every measuring receiver) at some point. In addition to quantization error, integral and differential non-linearities become most obvious at the lower signal levels that are implicit in a noise figure measurement (assuming one avoids the compression conditions described earlier!). In terms of sampling RF power, an ADC uncertainty plot may look something like the figure below. The plot suggests that there is a minimal level of receiver gain necessary to avoid problems from further down the IF chain of the system.



An example analog-to-digital converter uncertainty curve is shown here. At low signal levels, the linearity issues can become more obvious. So, it is important that there be a minimum level of gain earlier in the receiver system to avoid problems in a noise measurement.

Figure 18-5. Example Analog-to-Digital Converter Uncertainty Curve

Noise Power

A key element in Eq. 18-4 above, as yet unaddressed in this document, is the noise power itself. Historically, one way of measuring this quantity is a dedicated noise receiver with a large, variable gain system and appropriate filtering. This can be expensive and cumbersome and the typically wide bandwidths can lead to problems with narrowband devices (if the noise measurement bandwidth is close to the DUT bandwidth, including images, errors can result). Another approach is to use the basic VNA IF system itself, since it is highly linear to extremely low signal levels and has a fairly complete digital filtering system for tailoring the response shape. There may, however, be bias or leakage signal present in the response at these low levels that are not of interest. So in those cases, an RMS-like noise power measurement process is desired. In a non-ratioed channel measurement (usually $b_2/1$), this net RMS noise power can be expressed as (Eq. 18-6):

$$Noise\_power = \frac{\sum_{k=1}^{N} |b_{2,k}|^2}{N} - \left(\frac{\sum_{k=1}^{N} |b_{2,k}|}{N} \right)^2$$

Eq. 18-6

The reader may note the similarity to an equation for variance. Here N is a number of measurements (made at each frequency, termed a ‘number of RMS points’) and is typically a sizeable number so that the effects of the mean (the second term in Eq. 18-6) can be removed even if it is varying slightly with time. The default value of N is 3,000. Smaller numbers can be used for greater measurement speed (at the expense of some data jitter, more on this in the uncertainties section) and larger numbers can be used for some reduction in data jitter. Values of N greater than about 7,000 generally produce little benefit in data jitter reduction.

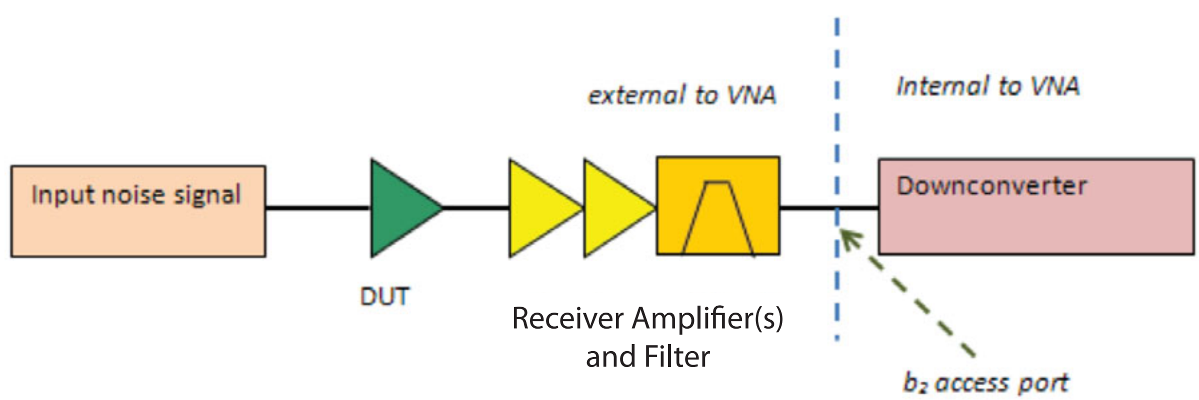
One may also ask how the unratioed parameter, $|b_2|$ in this case, comes to be a proxy for root-power. This comes via the receiver calibration (as is used for mixer, harmonic, IMD, and other measurements), since it transfers the traceable accuracy of the power sensor to the receiver parameter ($|b_2|$). One may rely on the factory ALC calibration to provide the power reference for this calibration. It is more accurate to perform a user power calibration at the frequencies and level of interest prior to the receiver calibration to get the power accuracy roughly to the 0.1 dB level or better. Information on performing the power calibration is elsewhere in the measurement guide and operation manuals. When performing noise figure measurements, they are optimally performed at lower signal levels (e.g., –60 dBm using the internal step attenuators of Options 061/062 or an external attenuator) to stay in roughly the same part of the linearity curve as the noise figure measurement and to improve match. Performing power calibration at low signal levels (e.g. –60 dBm) may not always be practical. A low-level power measurement usually requires a diode-based power sensor, which are not readily available at frequencies above 50 GHz. At higher frequencies, a thermal sensor may be required for power calibration, which typically have a lower power measurement of ≈30 dBm.

18-3 Composite Receiver Component Selection

A number of comments were made in the previous section about the receiver requirements in terms of gain, filtering, linearity and other behaviors. Since these are custom components selected for many measurements, it is important to present a way of assessing a given measurement problem and how to assemble the user provided portions of the composite receiver system.

By slightly modifying the diagram in Figure 18-1, one can see the delineation of system and user components in Figure 18-6. The downconverter is accessed through a port associated with the b_2 loop (this avoids the loss associated with the coupler on Port 2 and helps improve uncertainties). The port itself can be used if the DUT + external gain is high enough (usually over 60 dB).

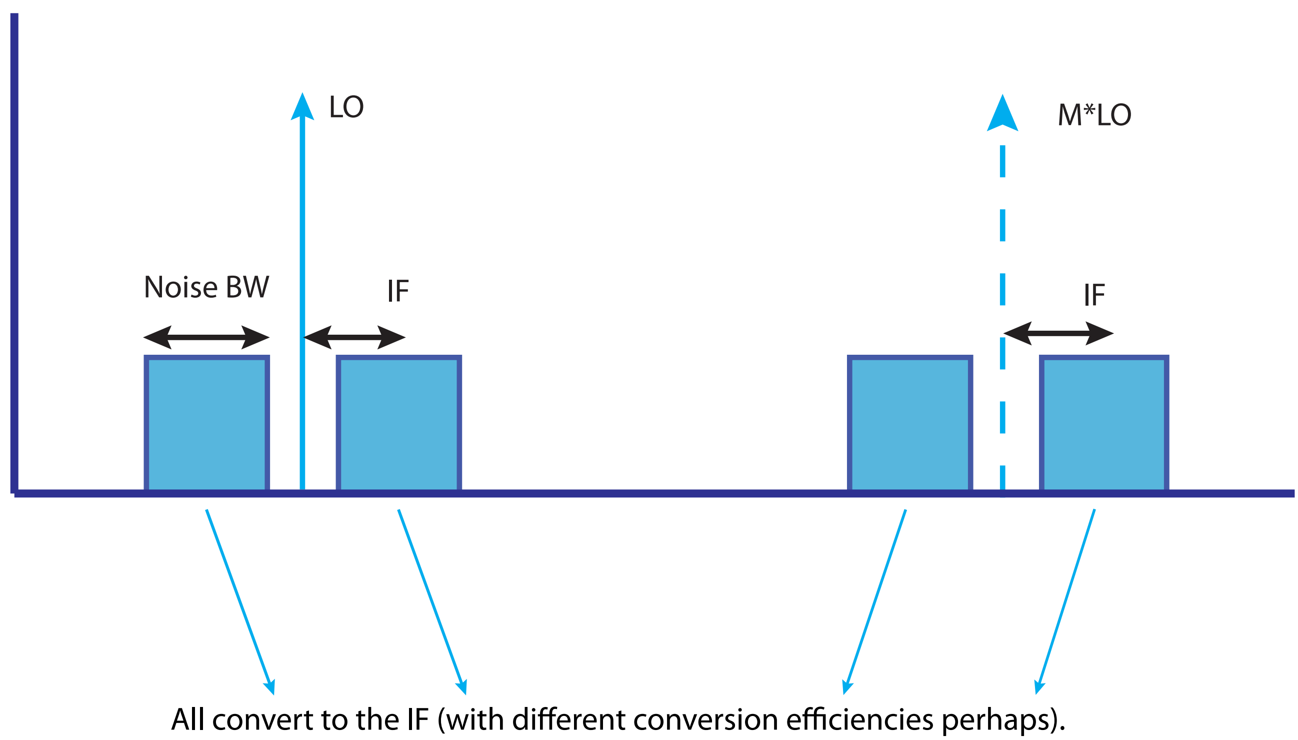
The receiver amplifiers are used to reduce the effective receiver noise figure which can dramatically improve uncertainties as will be shown in a later section. The required gain is somewhat dependent on the DUT but 40 dB of gain is a reasonable starting point. Multiple physical amplifiers can be used. The noise figure itself is generally not as critical but less than 5 dB or so is generally desirable. The lower the DUT noise figure, the more important the receiver amplifier noise figure becomes. This will become clearer in the uncertainties section.



A modified block diagram is shown here to illustrate locations better.

Figure 18-6. Modified Block Diagram for Locations

A filter is shown in above in Figure 18-1 and Figure 18-6 and 6 and this is for several reasons. As mentioned earlier, if the gain blocks are very broadband, some filtering can help prevent inadvertent receiver compression. Perhaps more importantly, the filter helps prevent image responses of the receiver from complicating the noise figure measurement. To understand this, recall that any downconverter has responses for at least some harmonics of the LO (commonly 3rd, 5th, 7th… for balanced mixers and all harmonics for some structures). Thus noise energy at an IF offset from these LO harmonics will also convert to the system IF and be included in the noise power computation. This effect becomes more pronounced when the desired product is already a harmonic of the basic LO and subharmonic components (which may have more favorable conversion efficiencies) can play a role. The general concept is illustrated below in Figure 18-7.



A spectral diagram is shown here is illustrate how harmonic conversion in the downconverter can add noise sidebands to the result that may be unintentional. Filtering as part of the receiver chain can reduce this issue.

Figure 18-7. Spectral Diagram for Harmonic Conversion in the Downconverter

By having a filter in the receiver chain to isolate the LO harmonic of interest, the other multiples can be effectively removed. As an example, suppose measurements are being run over 5 to 10 GHz which happens to be the fundamental LO component. By having a low pass filter in the chain with a corner of about 10 GHz, higher order terms can be removed.

Depending on the roll-off rate of the filter, it may be necessary to split that octave into two bands (e.g., 5 to 8 GHz and 8 to 10 GHz). This decision would be based on the DUT bandwidth as well as the filter behavior: if the DUT is already rolling off at 10 GHz, then a fairly weak stop band filter would be ok but if the DUT gain is fairly flat to much higher frequencies, then a very sharp stop band filter is suggested or the band should be split as mentioned.

For higher frequency measurements, it is useful to recognize that the fundamental LO range is still 5-10 GHz with the normal harmonics being used of 1, 2, 4, and 8 (adding 9 and 11 for ME7838A operation to 110 GHz). The filtering should be designed to remove the other harmonic responses. Recall that the MS464XX has a system breakpoint at 2.5 GHz (lower frequency loops are on the rear panel, higher frequency loops are on the front panel) but this is a natural filtering breakpoint as well. When operating at frequencies lower than a few hundred MHz, additional filtering may be desired (if the DUT has substantial gain to much higher frequencies) to remove effects of the 3rd harmonic and 5th harmonic responses of the low band converter.

From Figure 18-7, one may question the two noise sidebands centered around the LO signal. Since the VNA input is not preselected, noise energy at an IF offset either above or below the LO will be included. The basic IF frequency is 12.35 MHz so the measurement will effectively be an average over approximately a 25 MHz region. Additional filtering can be employed in narrowband applications where this bandwidth is an issue.

18-4 Measurement Setup and Procedure

Noise Figure Measurement Procedure

The noise figure measurement process consists of a few relatively straightforward steps

1. Measurement of DUT gain or S-parameters (over an appropriate frequency range and at an appropriate power level as discussed before)
2. Perform an optional user power calibration over the frequencies of interest to optimize receiver calibration accuracy
3. Physical configuration for the noise measurement (discussed in the previous section)
4. Basic setup (frequency range, number of points, type of device)
5. Receiver calibration (transferring the traceable power accuracy to the receiver)
6. Noise calibration (measurement of the receiver noise power so it can be removed from the calculations)
7. DUT measurement

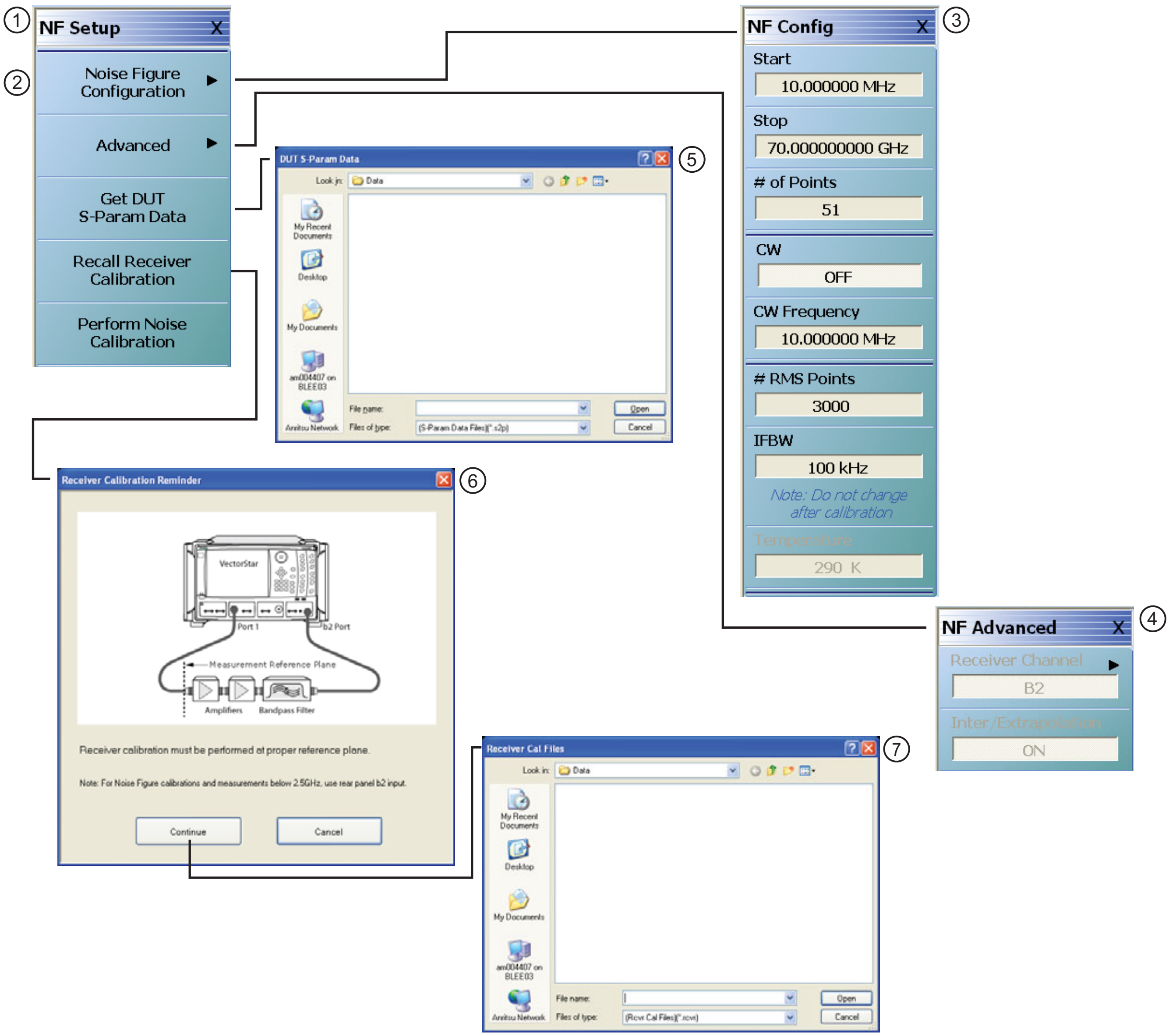
The first three items have already been discussed. A few more details are in order on the gain/S-parameter measurement comment.

Gain/S-Parameter Data

The gain/S-parameter data should be acquired on a frequency range containing the desired noise figure frequency range. The same frequency points need not be used (although that may be desired if the gain changes rapidly with frequency) as interpolation will be invoked. Extrapolation will also be used if needed but this is not advised for accuracy reasons.

S-parameters should be saved in the S2P file format and they will be loaded in the noise figure application. A full 12-Term calibration is advised for optimal accuracy and to enable the use of the more correct available gain terms but data from normalization-only calibrations will also be accepted.

The basic setup steps mentioned in line 4 are illustrated in the menus of Figure 18-8 below.



1. NF SETUP menu.	5. DUT S-PARAM (S-Parameter) dialog box.
2. Noise Figure Configuration button selected.	6. RECEIVER CALIBRATION REMINDER dialog box.
3. NF CONFIG (NF Configuration) menu.	7. RECALL RECEIVER CAL FILES dialog box. Provides access to previously saved receiver calibration RCVR files.
4. NF ADVANCED menu.	

Figure 18-8. Noise Figure Menu Set

Note	When the instrument changes the VNA application mode from Transmission/Reflection to Noise Figure, the instrument resets to the default settings for that mode. The default Noise Figure trace condition is a single trace and Noise Figure (LogMag) response. The default Transmission/Reflection condition is four traces, S11 (Smith Chart), S12 (LogMag + Phase), S21 (LogMag + Phase), and S22 (Smith Chart) responses.

Most of the setup parameters are self-explanatory. Some of the more noise-specific items

- **Number of RMS Points:**

  The number of measurements used in the noise power computation.

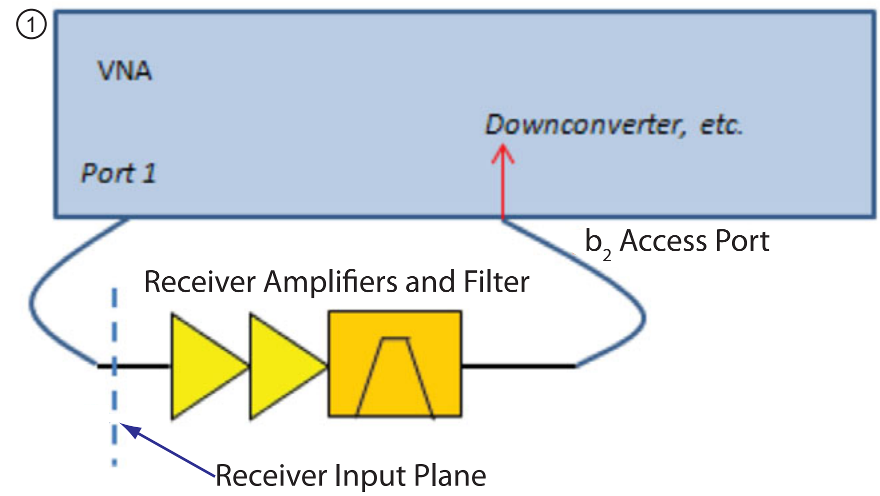
- **Temperature**:

  This is nominally the temperature of the cold termination used during the measurements and defaults to 290 K. The IEEE definition specifies this temperature which may be different from the physical termination temperature. For reference:

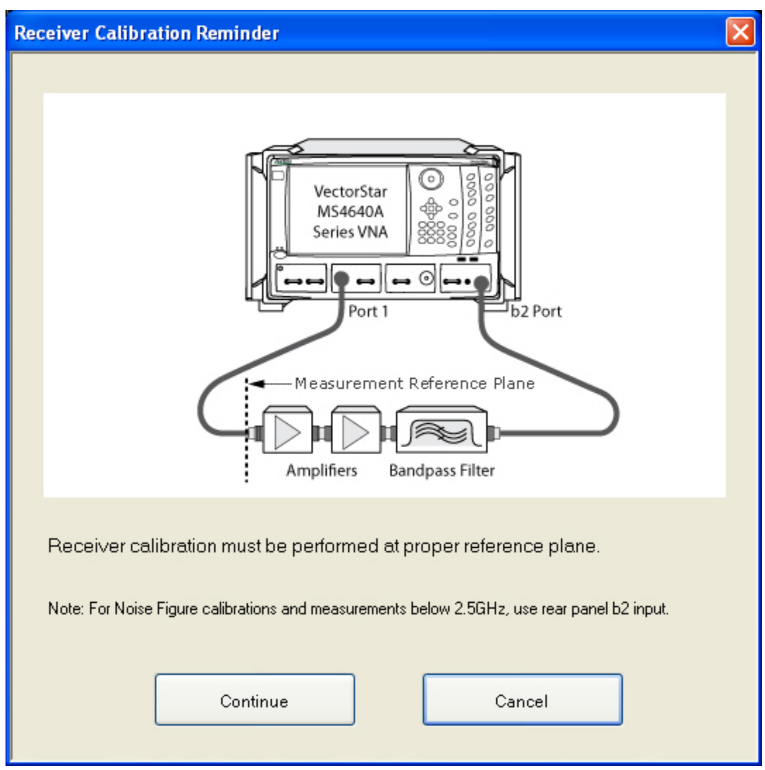
  - 290 K = 17 °C (62.6 °F)
  - 0 K = −273.15 °C (−459.67 °F)

The receiver calibration in step 5 is performed by simply connecting a cable from the source (usually Port 1) to the receiver input plane as suggested in Figure 18-9. The power calibration discussed earlier and in line 2 should ideally be performed at the end of this cable. The receiver calibration, as discussed elsewhere in this document, measures the receiver parameter and forces it to match the calibrated power level. Uncertainty addition may come at this point due to mismatch between the source and receiver and due to any residual nonlinearity in the receiver. These points will be discussed in more detail in the uncertainties section.

1



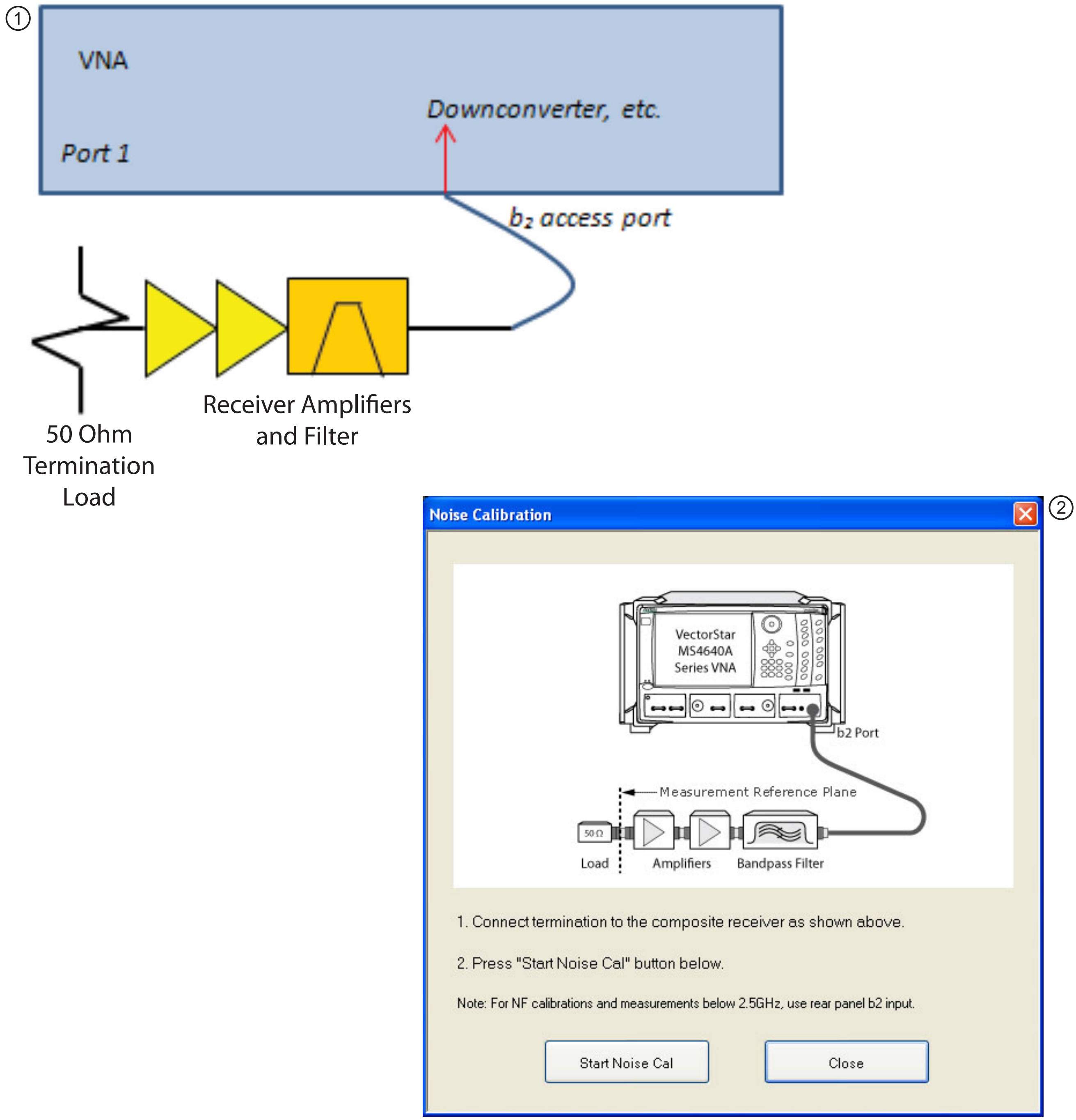
2



1. The receiver calibration (step 5) is illustrated here as a schematic view. Note the VNA connections at Port 1 and the b_2 Access Port and also the Receiver Input Plane.	2. The equivalent pictorial view is shows in the RECEIVER CALIBRATION REMINDER dialog box.

Figure 18-9. Noise Calibration Step 5

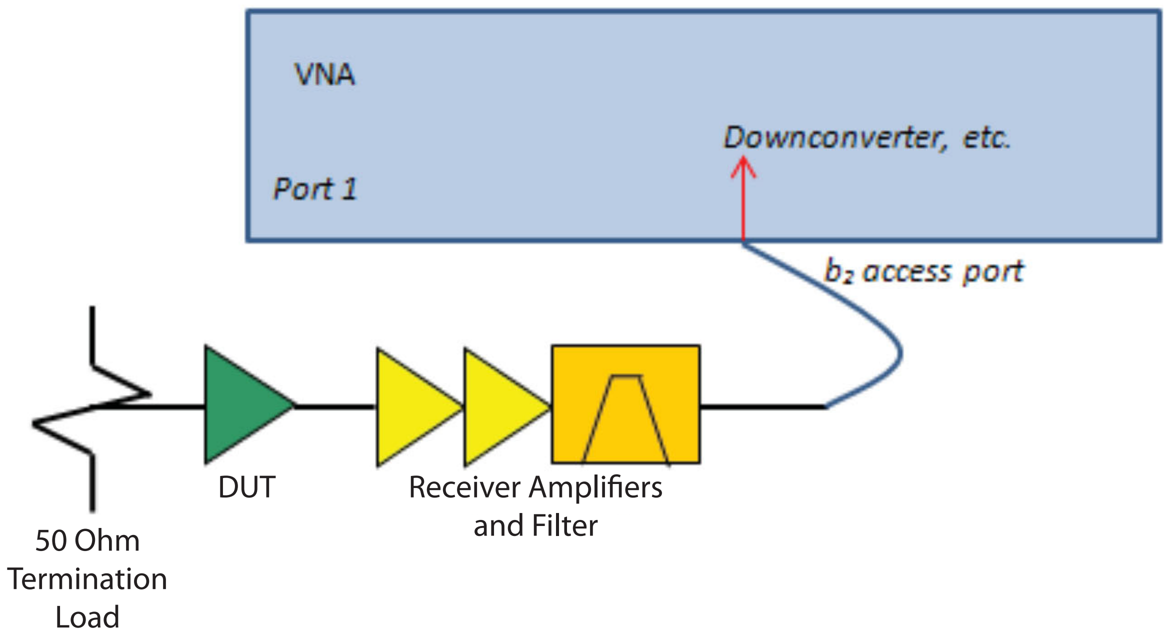
The noise calibration in step 6 is even simpler. Here one simply places the 50 Ohm cold termination on the input to the receiver plane and allows the system to measure noise power. This is illustrated in Figure 18-10. Depending on how many frequency points are used, this may be the most time-consuming of the setup/ calibration steps (allow on the order of 0.2 seconds to 2 seconds per frequency point depending on IFBW, averaging, and number of RMS points). If the frequency range is changed after calibration, interpolation and extrapolation of both the noise calibration data and DUT S-parameter data will be employed. Uncertainties may degrade, particularly if extrapolation is invoked by going outside the original frequency range of either step.



1. The noise calibration (step 6) is shown here as a schematic view.	2. The equivalent pictorial view is shows in the NOISE CALIBRATION dialog box.

Figure 18-10. Noise Calibration Step 6

The final step is the measurement of the DUT itself and this is equally simple. The output of the DUT is connected to the receiver input plane and the cold noise source with a typical termination load of 50 Ohms is connected to the DUT input. This step is shown in Figure 18-11.



The final step, that of measuring the DUT (here illustrated as an amplifier), is shown here. Note the 50 Ohm Termination Load attached to the DUT.

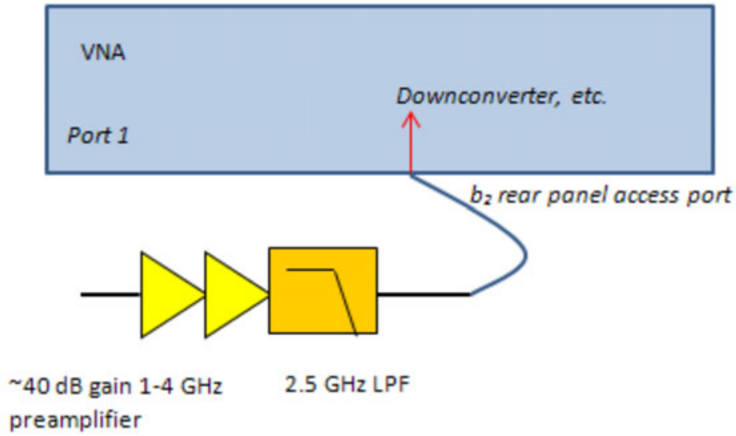
Figure 18-11. Amplifier DUT Final Measurement Step

Measurement Example

To integrate all of these concepts, let us consider an example measurement.

- DUT 1.7 to 2.4 GHz
- With an average gain of 12 dB
- A nominal noise figure of 0.8 dB.

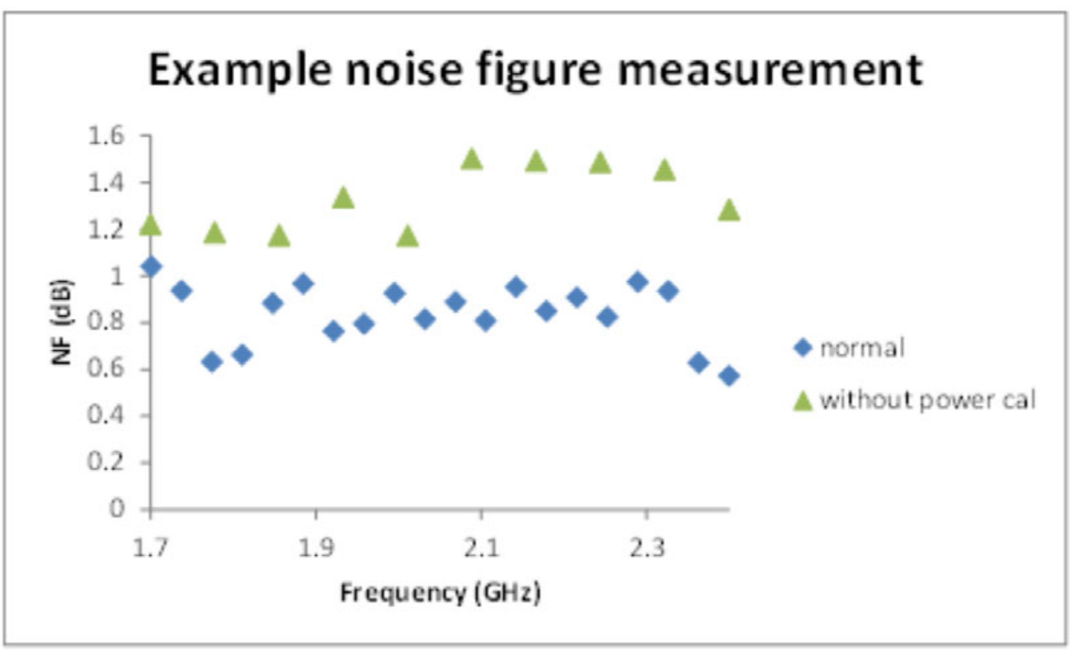
This is a challenging measurement in some sense in that the noise figure is relatively low and the gain is not very high. We will proceed with an IF Bandwidth of 1 kHz and 3000 RMS points and no averaging. The receiver structure is annotated in Figure 18-12. The compression point of this structure is about –10 dBm which should easily avoid linearity issues. The power calibration and receiver calibration will be performed at –60 dBm. The input match of the preamplifier structure was better than –20 dB and the noise parameter R_n was small enough that a 0 dB source match only results in a 0.1 dB receiver noise figure deflection. Since all frequencies are below 2.5 GHz, the rear panel b_2 access port is used.



The example measurement receiver structure is shown here.

Figure 18-12. Example of Measurement Receiver Structure

Because the noise figure is low, accuracy throughout the receiver calibration step is important since those errors will propagate roughly on a dB-for-dB basis. Since the basic ALC factory calibration has a nominal uncertainty of 0.5 dB to 1 dB, using this in lieu of a user power calibration could have a significant impact on this measurement. The difference in results is shown in Figure 18-13.



The example measurement is shown here with and without a power calibration preceding the receiver calibration.

Figure 18-13. Receiver Calibration Example with and without a Power Calibration

For another example, a mixer will be considered. In this case, the DUT has a fixed IF of 70 MHz and an RF range of 2 GHz to 2.5 GHz (and the LO is below the RF). The mixer setup dialogs discussed earlier make this setup straightforward. The conversion gain of the DUT is approximately 10 dB. The basic measurement parameters are the same as in the previous example. A different low pass filter is used to avoid LO leakage corrupting the receiver response (the DUT in this case is already well-filtered but it is reasonable practice). A preamplifier with a 10 MHz low end was used for this setup.

18-5 Receiver Cal Offset

The receiver cal offset is a file that can be used to modify the receiver calibration used in noise figure measurements when it is known that there are some power discrepancies within that receiver calibration.

Examples of this situation include:

- The only power calibration that could be performed was at a higher level than that where the receiver calibration was performed and one wishes to correct for the frequency response of a pad/attenuator (or other means of power reduction) used for the receiver cal.
- The source used for the receiver calibration had some harmonic content that could cause inaccurate power readings relative to the receiver calibration readings. Knowledge of these harmonic levels can be used for a correction.
- There are other known inaccuracies with the power calibration (due to fixturing, bandwidth, etc.) that one wishes to correct for.

A common scenario for using this function is in mm-wave noise figure measurements when high dynamic range power sensors are not available (bullet 1 above) and a factory receiver calibration of the mm-wave module is available to help. This case will be covered in detail at the end of the section.

The receiver cal offset process simply involves loading a file. The menu button to load the file is shown in Figure 18-14 on page 18-21. Once a file is loaded, a check box appears and the correction then can be turned off and on (also shown in Figure 18-14).

The file format is a standard text file (.txt) and is the result of a Save Data operation with a single trace enabled in Log Mag display format.

The response parameter is $b_{2/1}$ in this case but can be anything appropriate (usually will be $b_{2/1}$ or S_{21}) to describe the response. The data in this file should represent the power error incurred when doing the receiver calibration: a value > 0 dB means the actual power was higher than the system detected during the receiver cal and a value < 0 dB means the actual power was lower than the system detected.

A segment of an example .txt file is shown below. This is the file format used for the receiver cal offset correction. The response parameter can be anything but will most commonly be S_{21} or $b_{2/1}$.

```
MS4647A
!10/23/2012.12:32:31.PM
!CHANNEL.1
!TR.MEASUREMENT
!RF.CORRECTION.OFF
!AVERAGING.OFF
!IF.BANDWIDTH: 10HZ
!NUMBER.OF.TRACES: 1
!TRACE:       TRACE.1
!PARAMETER:   B2/1
!PORT:        PORT1
!GRAPH:       LOGMAG
!SMOOTHING:   OFF
!TIMEDOMAIN:  OFF
!SWEEPTYPE: FREQ.SWEEP(Linear)
PNTFREQ1.GHZLOGMAG1
180.001000000-8.735106E+000
280.150995000-6.820481E+000
380.300990000-6.195999E+000
480.450985000-6.687141E+000
580.600980000-6.155944E+000
680.750975000-6.188873E+000
780.900970000-6.445963E+000
881.050965000-6.779163E+000
981.200960000-6.733072E+000
1081.350955000-6.922758E+000
1181.500950000-7.044048E+000
1281.650945000-7.252111E+000
1381.800940000-6.779829E+000
1481.950935000-7.133829E+000
1582.100930000-7.282691E+000
1682.250925000-7.258348E+000
1782.400920000-7.333891E+000
1882.550915000-7.438091E+000
1982.700910000-7.777820E+000
2082.850905000-7.632741E+000
2183.000900000-7.665494E+000
```

Examples

1. An uncompensated adapter with 1 dB of loss was used for the receiver calibration but was not present during the power calibration. The power seen by the receiver was 1 dB lower than what the power calibration is reporting.

In this case the values in the file will all be around −1 dB. This can be measured with a simple S-parameter measurement of the adapter (using adapter removal or reciprocal techniques as necessary if the connections required are not mateable).

2. Another example is in mm-wave systems where power sensors that operate at the desired levels for the receiver calibration (which may be −50 dBm or lower) are rare.

If measurements are performed with the 3744A-Rx direct receiver module, there is a correction path available. This module is usually supplied with a factory receiver calibration file that one can use to back-propagate accuracy to the source power so that when one performs the 'real' receiver calibration for noise figure (with a pre-amplifier/filter assembly attached), the correct receiver calibration values can be obtained indirectly.

Creating the Receiver Cal Offset File

1. Connect the desired source reference plane to the 3744A-Rx module at the target power level (−60 dBm for this example).
2. Load the provided factory receiver calibration file.
3. Set the frequency range to the one desired for the noise figure measurement (with an adequate number of points) and set the display for single trace, $b_{2/1} | P_1$, log mag.
4. Set the reference plane magnitude to correct for the intended power level (60 dBm in this case) as shown in Figure 18-14 on page 18-21 below. The resulting data then represents an error from the ideal power level and helps to describe the actual source power in a nominal bandwidth of interest.
5. Save the resulting data as a .txt file. This step creates the receiver cal offset file for the measurement.
6. Connect the rest of the assembly for the noise figure measurement (pre-amplifiers and filters normally) between the 3744A-Rx module and the source reference plane leaving the power setting the same.
7. Perform the receiver calibration on this setup and save the results as a text file.
8. Load the receiver calibration file from step 5 and the receiver cal offset file from step 7 when performing the noise figure calibration and measurement.
9. Load the DUT S-parameters and perform the noise calibration.

.

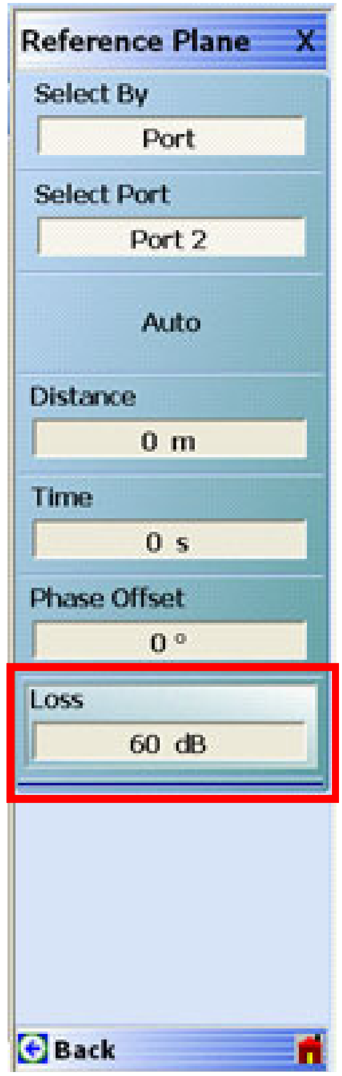


Figure 18-14. The reference plane adjustment for the measurement is shown outlined in red.

18-6 Uncertainties

As has been alluded to in the previous sections, many factors affect noise figure uncertainty and an understanding of their impacts and interactions can be important in setting up and performing a high accuracy noise figure measurement. The purpose of this subsection is to explore these effects and to produce a more realistic picture of the uncertainties one can expect and how to improve them.

Looking back at the noise figure equation (Eq. 18-4 above), one can recast it to show how component uncertainties affect the result. In Eq. 18-6 above, the Δ terms represent deviations that may occur during the measurement or the calibration. Not all possible deviations are included here but rather only those that are most dominant practically are shown.

$$\tilde{F} = \frac{1}{G + \Delta G} + \frac{(N_{DUT+rcvr} + \Delta N_{DUT+rcvr} - N_{rcvr} - \Delta N_{rcvr}) \cdot (1 + \Delta R)}{kT_0 B(G + \Delta G)}$$

Eq. 18-7

The Gain variance is perhaps the easiest to understand. Gain errors can arise in the usual s-parameter uncertainty context (or the equivalent for a frequency converting device) and this uncertainty is usually what is included. Errors due to linearity faults or other structural measurement problems are generally assumed to be taken care of by the user.

The other potential terms relate to the measurement of noise power and those are split into two groups: those common to both DUT measurement and calibration noise measurement (represented by ΔR) and those unique to the individual noise measurements (the two ΔN terms). All of these have several sub-terms.

- **ΔR**

  Terms related to the user power calibration (power sensor accuracy and mismatch) and to the receiver calibration (match of the receiver, match of the source, linearity and noise floor).

- **ΔN**

  Match interactions (termination with the receiver, termination with the DUT, DUT with the receiver), power measurement linearity, jitter.

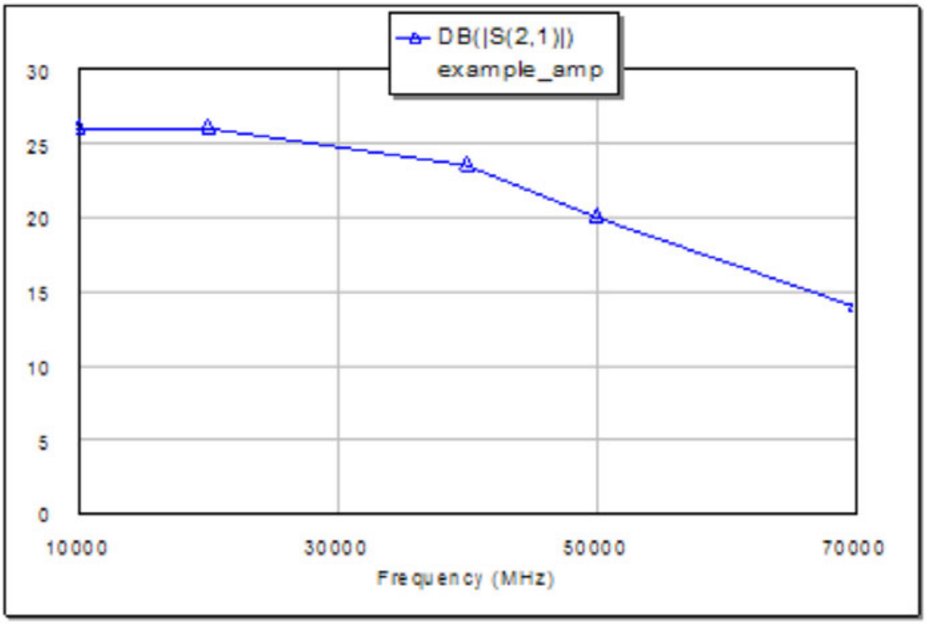
These terms in turn have many dependencies on DUT S-parameters/gain, DUT noise figure, receiver noise floor, receiver linearity, source match, absolute signal levels, power sensor characteristics, etc. Because so many variables are involved, an uncertainty calculator has been created to help in analyzing some of the scenarios. A Monte Carlo approach is used since many of the variables have random distributions (particularly in phase) so a statistical analysis of the uncertainty may be more practically useful and is increasingly accepted as a preferred approach (e.g., [8]).

A few general observations can be made:

- The better matched the DUT and the receiver, all else held constant, the lower the uncertainties
- The higher the DUT gain and receiver gain (up until the point of linearity issues), the better the absolute (in dB) uncertainties
- Lower IFBWs and higher RMS point counts help (in terms of jitter) but only up to a point
- In terms of DUT parameters, the worst-case scenario is a poorly matched, low gain, low noise figure device. The best-case scenario is a well-matched, high gain device.

To understand the parameter space and to illustrate some of the computation options that are available, we will run through some examples.

Consider an example amplifier with the following gain profile:



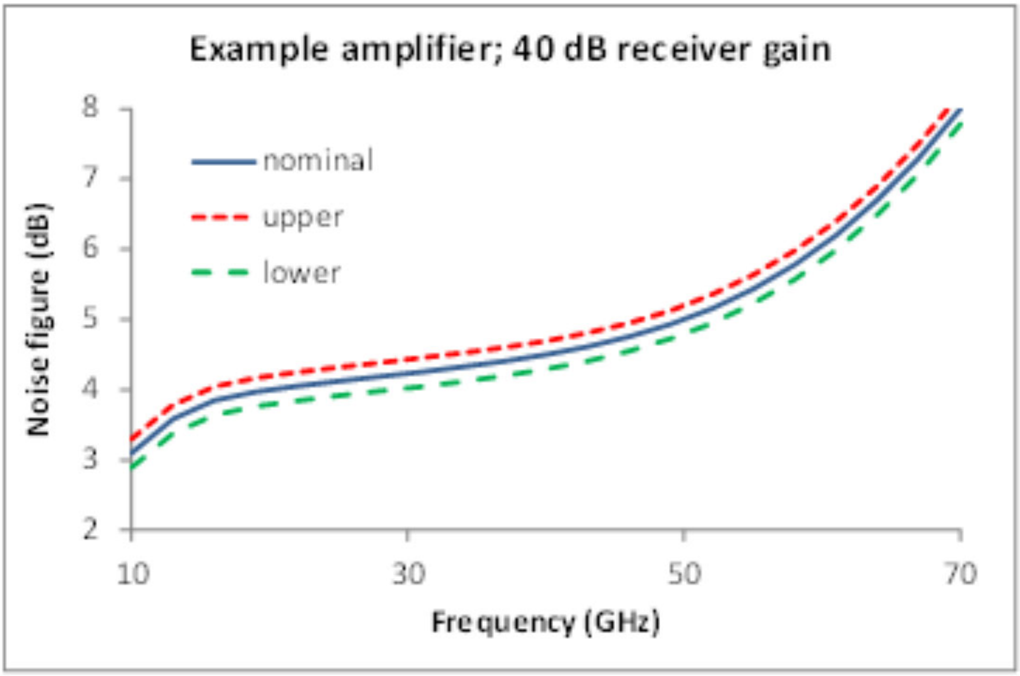
The |S21| behavior with frequency for the example amplifier is shown here.

Figure 18-15. Behavior of |S21| with Example Amplifier

The DUT noise figure ranges from 3 dB at 10 GHz to 8 dB at 70 GHz with a frequency dependence that will be shown shortly. Consider the following example parameters:

- Starting IF Bandwidth: 1 kHz
- Averages: 1
- Number of RMS points: 3,000
- Temperature: 290 K
- Termination match: –30 dB
- Power sensor accuracy: 0.1 dB
- Power sensor match: –20 dB
- Source match: –20 dB
- Receiver match: –20 dB
- Receiver P1dB: 0 dBm
- Receiver calibration power level: –60 dBm
- Starting receiver gain: 40 dB

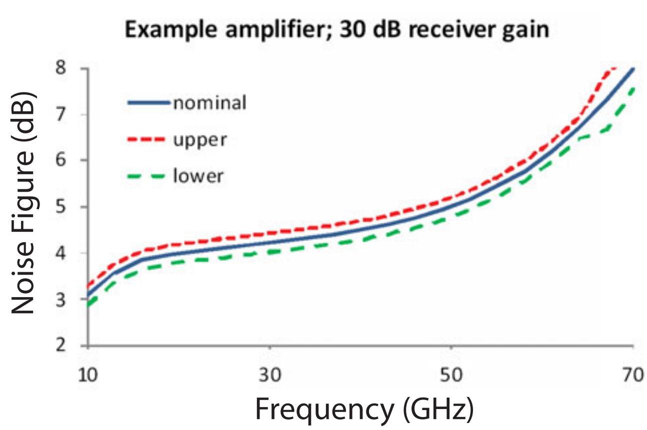
The first plot in Figure 18-16 shows the nominal DUT noise figure (solid line) and the upper and lower 95% uncertainty bounds if the receiver gain is 40 dB.



Example uncertainties are shown for the case of receiver gain = 40dB.

Figure 18-16. Uncertainties for 40 dB Receiver Gain

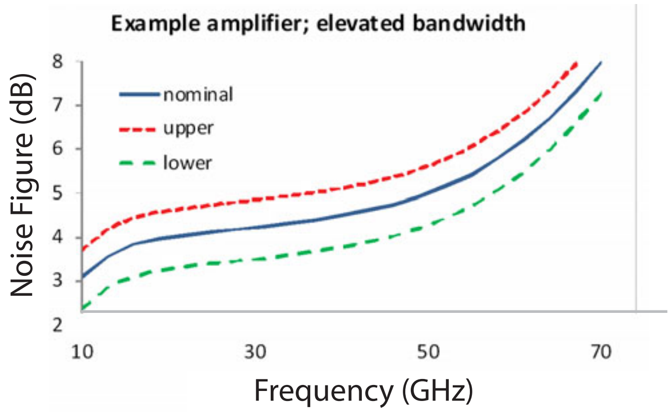
Next the receiver gain is reduced. Note that there is little change except at the higher frequencies where the DUT gain is low. This is a general concept that the DUT gain + receiver gain is a normative parameter.



The uncertainties for the same measurement as in Figure 18-16 above are shown here except the receiver gain has been reduced.

Figure 18-17. Uncertainties with Reduced Receiver Gain

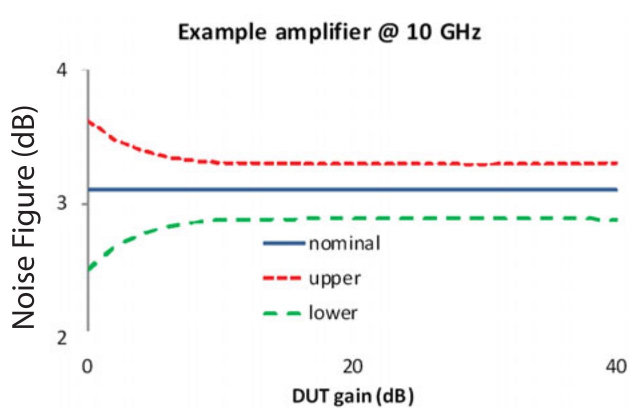
Next, let us return the receiver gain to 40 dB but increase the measurement bandwidth to 30 kHz. This increases the data jitter and the net uncertainty.



The uncertainties are shown here for the case of Figure 18-16 above except the IF bandwidth has been increased.

Figure 18-18. Uncertainties with Increased IF Bandwidth

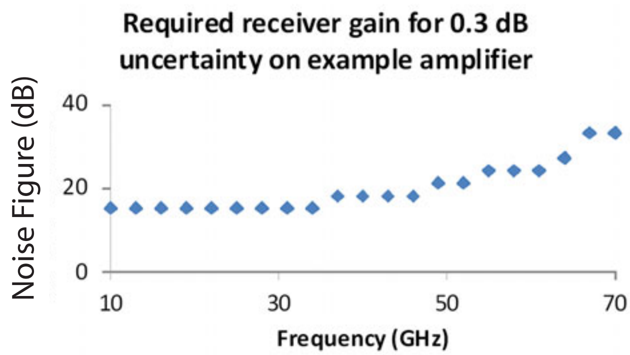
We can also look at a different independent variable. In Figure 18-19, the receiver gain and IF Bandwidth have been returned to their starting values but we will plot versus DUT gain for a single frequency (10 GHz). As might have been surmised from the Figure 18-15 discussion, if the gain gets low enough (in concert with receiver gain), the uncertainty will increase.



A plot of uncertainty as a function of DUT gain is shown here for the parameters discussed in this section at a fixed frequency.

Figure 18-19. Uncertainty as a Function of DUT Gain Plot

Finally, one may want to know the receiver gain for a given level of uncertainty. This is plotted in Figure 18-20 for our example amplifier (using nominal parameters) but with a 0.3 dB desired uncertainty. There is a step-like quality to the plot since the possible receiver gains are parameterized in ~2 dB steps for simplicity. As might be expected, as the DUT gain drops at higher frequencies (and noise floors increase in the VNA slightly), additional receiver gain is needed to hold the uncertainty constant.



A plot of required receiver gain for a given level of uncertainty for the example amplifier is shown here.

Figure 18-20. Required Receiver Gain Plot

18-7 Noise Figure Uncertainty Calculator

The VectorStar Noise Figure Uncertainty Calculator is a standalone program used to provide the user a tool for easily determining measurement uncertainty while using the VectorStar VNA Option 041 – Noise Figure. The calculator can be used for non-frequency converting active devices, such as amplifiers. The uncertainty calculator takes into account the five primary parameters of the system configuration:

- Receiver parameters
- DUT parameters
- Power measurement parameters
- Source parameters
- Cold source temperature

In addition, the calculator is helpful in determining the optimum measurement setup for achieving a desired measurement uncertainty target.

Installation

The calculator is installed on the VectorStar instrument desktop and can also operate on an external Windows PC as a standalone executable that is launched from the Program Menu or the desktop Icon shown below.

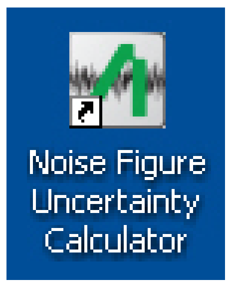


Figure 18-21. Desktop Icon in Windows for Noise Figure Uncertainty Calculator

To start the standalone Noise Figure Uncertainty Calculator installation on a local PC, select the Setup_XXXX.exe file (where the XXXX provides the calculator revision) and follow the installation dialogs.

Best practices recommend pinning the calculator to the Start Menu and to also create a short-cut on the desktop.

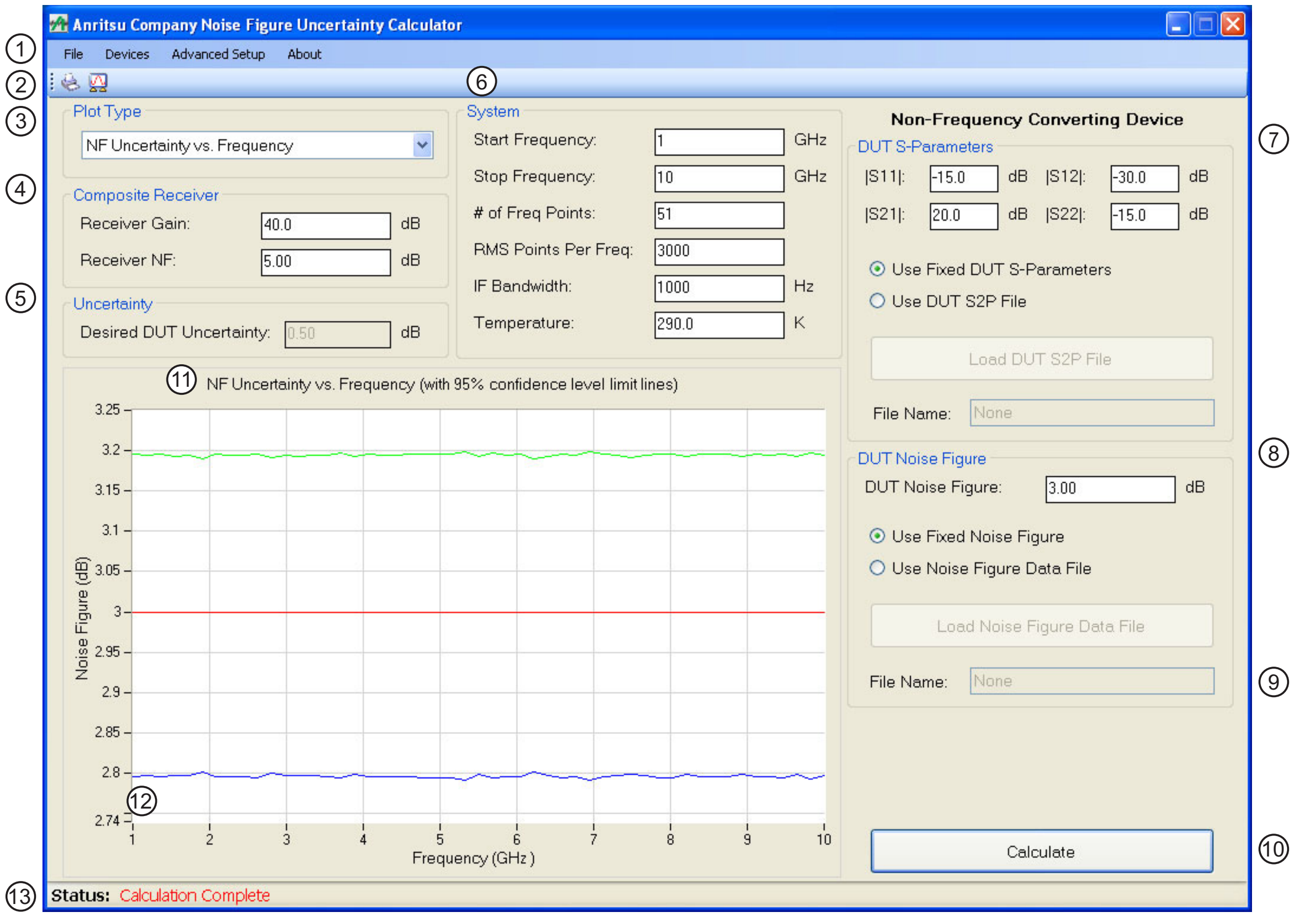
For more information, refer to the Installation Guide contained in the InstallationGuide.txt file which is provided with the Uncertainty Calculator download package.

User Interface

The program user interface provides editable fields for the most common noise figure measurement test setup variable parameters, such as composite receiver and DUT information. When the Calculate button is pressed, the input is used to determine the overall measurement uncertainty. Conversely, a desired DUT uncertainty value can be input and the calculator will provide a display of required receiver performance (gain and noise figure) for a given DUT performance.

The Advanced Setup menu provides the ability for further modification of the measurement parameters and additional input such as receiver, source, and power sensor match.

The figure below shows the various user configuration and calculation controls. A detailed control description is in the section following.



1. Menu Bar selections for File, Devices, Advanced Setup, and About – Selection displays a drop-down menu or sub-dialog.
2. Icon Bar functions – Selection toggles between:
   - Print Window dialog
   - Markers - Activates user movable plot markers.
3. Plot Type – Select displays pull-down menu for:
   - NF Uncertainty vs. Frequency
   - NF Uncertainty vs. Gain
   - Receiver Gain vs. Frequency
4. Composite Receiver Configuration Area
5. Uncertainty Configuration Area
6. System Configuration Area
7. DUT S-Parameters Area – Start of the Non-Frequency Converting device type controls.
8. DUT Noise Figure Area
9. Noise Figure Data File Name – If Use Noise Figure Data File is selected, file name appears here. A standard VectorStar TXT format file is required.
10. Calculate execute button
11. Graph Display Title – Determined by the selection in Plot Type.
12. Display Graph – Axis labels and range determined by user settings. Graph values change when Calculate button is selected.
13. Status Message – Shows calculator status such as “Calculation Complete” or “Calculation in Process”

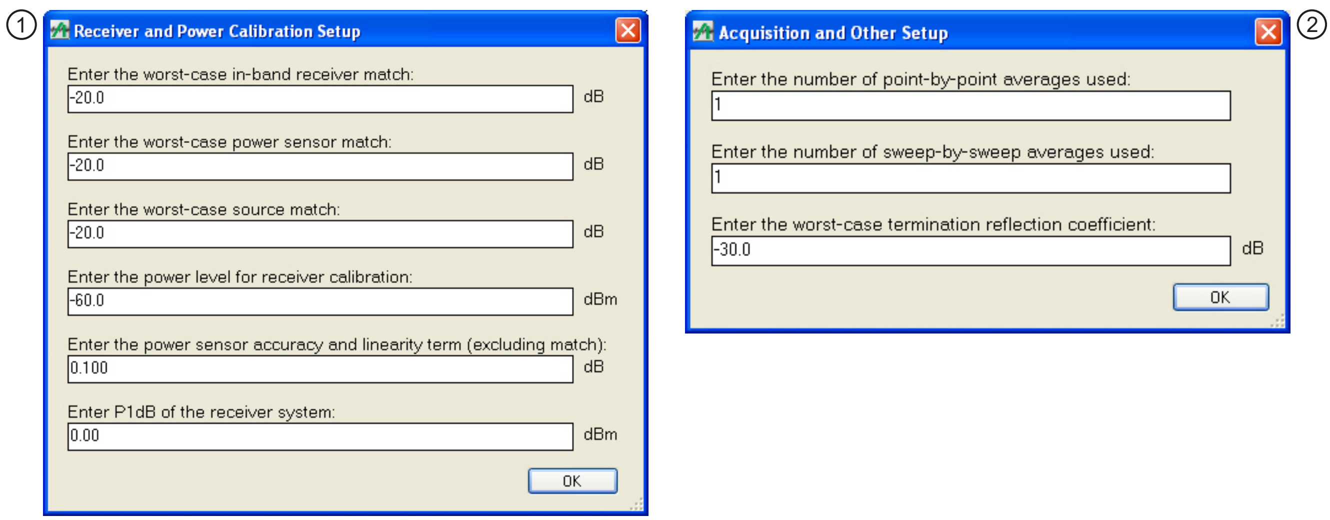
Figure 18-22. UNCERTAINTY CALCULATOR Dialog Box

Uncertainty Calculator Controls

The uncertainty calculator provides user interface (UI) controls in a Menu Bar, an Icon Bar, and in several dialog box areas.

Menu Bar Controls

- **File** – Drop-down menu provides selections for:
    - Save Uncertainties – Saves the calculated uncertainty data as a TXT file.
    - Print Window – Displays the standard print dialog for available printers.
    - Save Window – Saves the current Uncertainty Calculator UI display as a PNG file.
    - Preset – Clears the current user-defined configuration and resets all values to their default state.
    - Exit
- **Devices** – Allows selection of device type as:
    - Non-Frequency Converting – Select also configures the right side controls as Non-Frequency Converting Devices.
- **Advanced Setup** – Allows selection of advanced setup in sub-dialog boxes as:
    - Receiver and Power Calibration Setup – Select displays the same named sub-dialog box as shown in the side of Figure 18-23 below.
    - Acquisition and Other Setup – Select displays the same named sub-dialog box as shown in the right side of Figure 18-23 below.



1. Receiver and Calibration Setup – Provides input fields for:
    - Worse-Case In-Band Receiver Match dB
    - Worse-Case Power Sensor Match dB
    - Worse-Case Source Match dB
    - Power Level for Receiver Calibration dBm
    - Power Sensor Accuracy and Linearity Term dB
    - Receiver System P1dB dBm
2. Acquisition and Other Setup – Provides input fields for:
    - Number of Point-By-Point Averages Used
    - Number of Sweep-by-Sweep Averages Used
    - Worse-Case Termination Reflection Coefficient dB

Figure 18-23. Advanced Setup Sub-Dialog Boxes

- **About** – Displays a sub-dialog box that provides version number and location of additional sources of information as shown below in Figure 18-24.

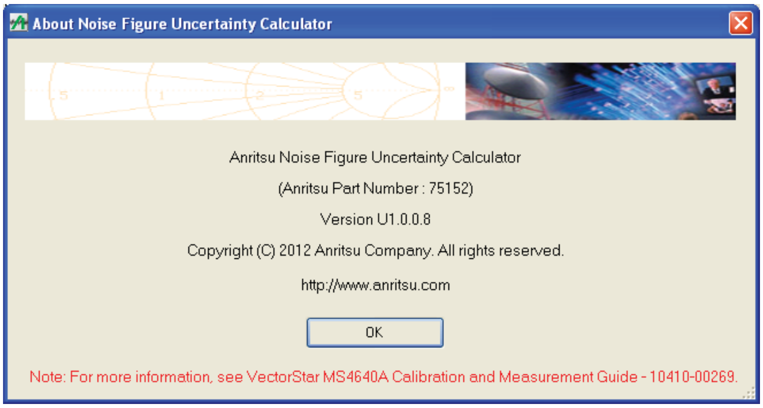


Figure 18-24. About Noise Figure Uncertainty Calculator Dialog Box

Icon Bar Controls

The Icon Bar provides two controls for fast access to print and marker functions:

- Print Icon – Select opens the Print Window dialog box to the default local or network printer. The output is sized to fit on standard A4/8.5 in × 11 in letter-sized paper.
- Marker Icon – Select toggles the plot marker on. The second selection toggles the markers off. If markers are moved and then turned off, turning them back on restores their previous positions.

Dialog Box Controls

These control descriptions are organized by the dialog box area name. Where noted, some controls are only present when the appropriate converting mode is selected.

Plot Type Area

A pull-down menu provides selection between:

- NF Uncertainty vs. Frequency – Display NF uncertainty as a function of frequency.
- NF Uncertainty vs. Gain – Display NF uncertainty as a function of DUT gain.
- Receiver Gain vs. Frequency – For a desired DUT NF uncertainty.

The plot type selection updates the label on the display graph after a calculation is performed.

Composite Receiver Area

Provides input configuration of the VNA plus additional user supplied components:

- Receiver Gain – Provides an input field for gain in dB. Typically used with multiple physical external amplifiers. Receiver Gain is unavailable if Receiver Gain vs. Frequency is selected in Plot Type.
- Receiver NF – Provides an input field for noise figure in dB. Typically dominated by the noise figure of the amplifier closest to DUT.

Uncertainty Area

Provides input of the Desired DUT Uncertainty in dB. Only available if the **Plot Type** above is set to Receiver Gain vs. Frequency.

System Area

Provides input configuration of the relevant VNA parameters:

- Start Frequency GHz
- Stop Frequency GHz – Stop Frequency must be greater than the Start Frequency.

- # of Freq Points – Number of Frequency Points between the Start and Stop Frequencies. Must be 2 points or greater.
- RMS Points Per Freq – Root Mean Square Points Per Frequency Point. Sets the number of measurement points to be used for each frequency points. For example, if the default of 51 frequency points is used with the default of 3,000 RMS Points, there will be 153,000 total measurements (51 × 3,000) used in the noise power computation.
- IF Bandwidth Hz – Should be the same as that used in the receiver calibration.
- Temperature K – Nominal temperature of the cold termination, defaults to 290K (17 °C, 62.6 °F), specified by the IEEE definition.

DUT S-Parameters Area

This control area is present if the Menu Bar | Devices parameter above is set to Non-Frequency Converting. Select allows the user to select between entering fixed data or using a previously loaded DUT S2P file.

- Use Fixed DUT S-Parameters – Select allows the user to define and apply fixed S-parameters located in the fields immediately above for: S11, S12, S21, and S22.
- Use DUT S2P File – Select allows the user to load a previously stored S2P DUT file. If selected, the Load DUT S2P File button and the File Name field become available. Select the button and navigate to the previously stored S2P file. When complete, the loaded file name appears in the File Name field.

DUT Noise Figure Area

This control area is present if the Menu Bar | Devices parameter above is set to Non-Frequency Converting. Select allows the user to select between entering fixed data or loading measured data.

- Use Fixed Noise Figure Data – Select allows the user to define and apply a fixed DUT Noise Figure value defined in the field immediately above.
- Use Noise Figure Data File – Select allows the use to load a previously stored noise figure data file in standard VectorStar TXT format. If selected, the Load Noise Figure Data File button and the File Name field become available. Select the button and navigate to the previously stored data file. When complete, the loaded file name appears in the File Name field.

Calculate Button

Select starts the calculation after all parameters are entered. The status message at the bottom changes to Calculation in Progress. The button name changes to Abort where selection stops the calculation and returns the status to Calculation Complete. Once the calculation is complete, the display graphs and axis labels are updated and the status changes to Calculation Complete.

Typical Uncertainty Calculator Use Procedure

1. Select plot type. The plot type selection activates the required fields and controls.
2. Setup system and input device parameters.
3. Plot uncertainties by selecting the Calculate button.
4. If uncertainty improvements are needed, modify the IFBW and # of RMS Points to verify that the current receiver gain and noise figure are adequate for the desired measurement uncertainty.
5. If further improvement is needed, adjust the gain of the receiver to determine if adding additional preamps will reach the objective.
6. Alternatively, enter the desired uncertainty and compute the required receiver parameters.
7. As required, activate and place markers at frequencies of interest.
   - On the Icon Bar, select the Marker icon.
   - A marker is available for each displayed trace.
   - Drag the marker to the position of interest and read off the axis values.
8. As required, print display graph as a PNG file.
9. As required, save uncertainty output as a TXT or CSV file.

18-8 Conclusions

The noise figure application has been discussed in this section in terms of its algorithm, a comparison to other approaches, the setup requirements and options, and the associated uncertainties. By considering the setup needs and how they interact with the uncertainties, successful and accurate measurements are considerably more likely.

18-9 References

1. H. T. Friis, "Noise figure of radio receivers," *Proc. IRE*, vol. 32, Jul. 1944, pp. 419-422.
2. –, "Noise Figure", Anritsu Application Note 11410-00210, Aug. 2000.
3. D. Vondran, "Noise figure measurement: corrections related to match and gain," *Microwave Journal*, Mar. 1999, pp. 22-38.
4. N. Otegi, J. M. Collantes, and M. Sayed, "Cold-source measurements for noise figure calculation in spectrum analyzers," *67th ARFTG Conf. Dig.*, Jun. 2006, pp. 223-228.
5. N. Otegi, J. M. Collantes, and M. Sayed, "Receiver noise calibration for vector network analyzer," *76th ARFTG Conf. Dig.*, Dec. 2010, pp. 1-5.
6. J. M. Collantes, R. D. Pollard, and M. Sayed, "Effects of DUT mismatch on the noise figure characterization: A comparative analysis of two Y-factor techniques," *IEEE Trans. Instr. And Meas.*, vol. 51, Dec. 2002, pp. 1150-1156.
7. L. Escotte, R. Plana, and J. Graffeuil, "Evaluation of noise parameter extraction methods," *IEEE Trans. Micr. Theory Tech.*, vol. 41, Mar 1993, pp. 382-387.
8. –, "Supplement 1 to the "Guide to the expression of uncertainty in measurement" — Propagation of distributions using a Monte Carlo method", Joint Committee for Guides in Metrology, 2008.

Chapter 19 — Mixer Setup and Measurement

19-1 Chapter Overview

In contrast to the fully general multiple source control approach (see Chapter 17, “Multiple Source Control (Option 007)”) and the algorithm-specific NxN approach (see Chapter 20, “NxN Application”), the mixer wizard and (guided) mixer setup approach help to setup common mixer measurements with a simplified, yet still accurate, calibration methodology. The prime objective of the guided mixer setup is to help configure the frequency plan of the measurement using easier to understand diagrams. The mixer wizard goes a step further and helps configure measurement channels to handle any of a suite of possible mixer measurements and to list the required calibration steps. Both of these tools are coupled with a mixer calibration menu system that enables both scalar and vector corrected measurements.

19-2 Mixer Theory

The literature on mixer theory is extensive and many topics will not be covered here. The interested reader is referred to, for example, S. A. Maas, ***Microwave Mixers***, Artech House, 1993 and references therein for a complete treatment.

The central purpose is the translation from one frequency (at the input) to another in an additive (or subtractive) fashion (at the output). As an aside, this chapter and the instrument will generally use the terms ‘input’ and ‘output’ so the names do not have to keep changing depending on the type of conversion. The software will allow labeling of ports as IF and RF (and allow them to be changed) as will be seen later.

In the simplest sense, the mixer can be viewed as a perfect multiplier so if the input is some sinusoid with frequency ω_{in} and the Local Oscillator (LO) port has some sinusoid with frequency ω_{LO}, then the output signal is given by Equation 19-1 below, (ignoring any constant phase terms, it is mainly frequencies we are interested in at the moment).

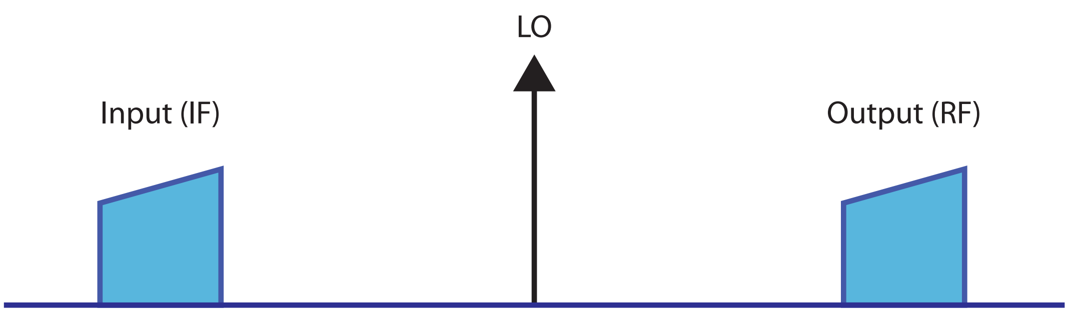
$$Output = A \cdot \cos(\omega_{in}t) \cdot B \cdot \cos(\omega_{LO}t) = \frac{AB}{2}[\sin((\omega_{in}+\omega_{LO})t) + \sin((\omega_{in}-\omega_{LO})t)]$$

(Eq. 19-1)

Also, the conversion distortions (magnitude and phase) of the mixer itself are not in the above equation. The important point is that sum and difference frequencies are created. Other higher order terms are also created in practice that will be discussed later.

Up Conversion

One case is when the sum term is of interest, this is called *up conversion* and typically the input is labeled as the IF in this case. This is the least complicated case and there is little ambiguity with the signals unless ω_{LO} is very small relative to ω_{in} (not common). The spectra are illustrated in Figure 19-1.



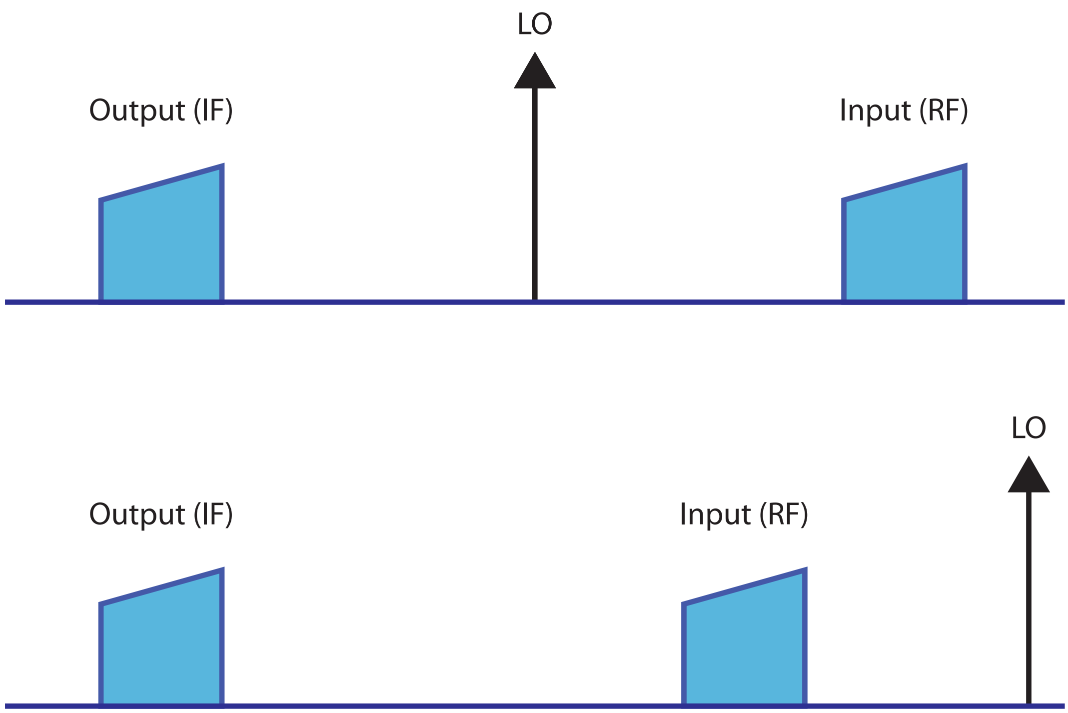
The spectra of signals in an up conversion case are shown here. The LO is normally greater than the input but this is not a requirement

Figure 19-1. Up Conversion Signal Spectra

Down Conversion

The difference frequency case (down conversion) can be more complicated in that now the relationship of the input frequency range to the LO makes a difference in the behavior (due to a sign flip in Equation 19-1). If the input frequency range is greater than the LO (Figure 19-2), then there is no inversion while if the LO is greater than the input, there is an inversion. One could argue that the signs in Equation 19-1 could be re-arranged arbitrarily but the key point is if there is a minus sign before the input frequency. If there is, then the output sweep will be in an inverse direction from the input sweep and there is a phase conjugation.

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 instrument software will generally use the latter terminology.



The spectra of signals in down conversion cases are shown here. The LO position relative to the input affects the behavior. The spectra picture on top is of a low-side LO or USB case while the spectra picture on the bottom is of a high-side LO or LSB case

Figure 19-2. Down Conversion Signal Spectra

One may ask about the negative frequency implications in Equation 19-1 of the LSB case but the sign simply flows out of the sinusoid and inverts the phase. As far as the instrument is concerned, it takes the absolute value of the computed frequency before programming the hardware, which is just what the equation is telling it to do.

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. The real embodiment of Equation 19-1 is more like that shown in Equation 19-2 below:

$$X = A \cdot \cos(\omega_{in} t) + B \cdot \cos(\omega_{LO} t)$$

$$Output = a_0 + a_1 X + a_2 X^2 + \ldots$$

(Eq. 19-2)

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 M $\omega_{in} \pm$ N ω_{in}. The measurement of these spurs is also possible with the MS464XX and will be discussed towards the end of this chapter.

As might be suggested by Equation 19-2, one could conceivably use a harmonic of the LO to do the heavy lifting of conversion. That is, one could intentionally use the 1 by N 'spur' for the conversion. This is indeed done, particularly for higher frequency and mm-wave applications where creating a sufficiently low noise fundamental LO is either too difficult or too expensive. Harmonic mixers and samplers (or subharmonic mixers which is confusing but equivalent terminology usually) are handled by the multiple source control system described in another chapter.

Another terminology problem is that of mixers vs. converters vs. frequency conversion devices. There is some lack of consistency in the industry but often a converter is a mixer with some additional functionality (gain blocks, switching, etc.). A frequency conversion device can be a mixer but is also sometimes use to denote a multiplier. This chapter is concerned with those devices that translate frequency in an additive or subtractive fashion but with additional gain or linear networks allowed. We will thus use the terms mixer and converter somewhat interchangeably. Multipliers are also covered by the very general multiple source control section in another chapter.

19-3 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 chapter.

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.

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 default has an input of RF and an output of IF but these can be reversed. The arrow directions in the diagram 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.

Isolation

This is transmission through the mixer (input->output, output->input, LO->output or LO->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.

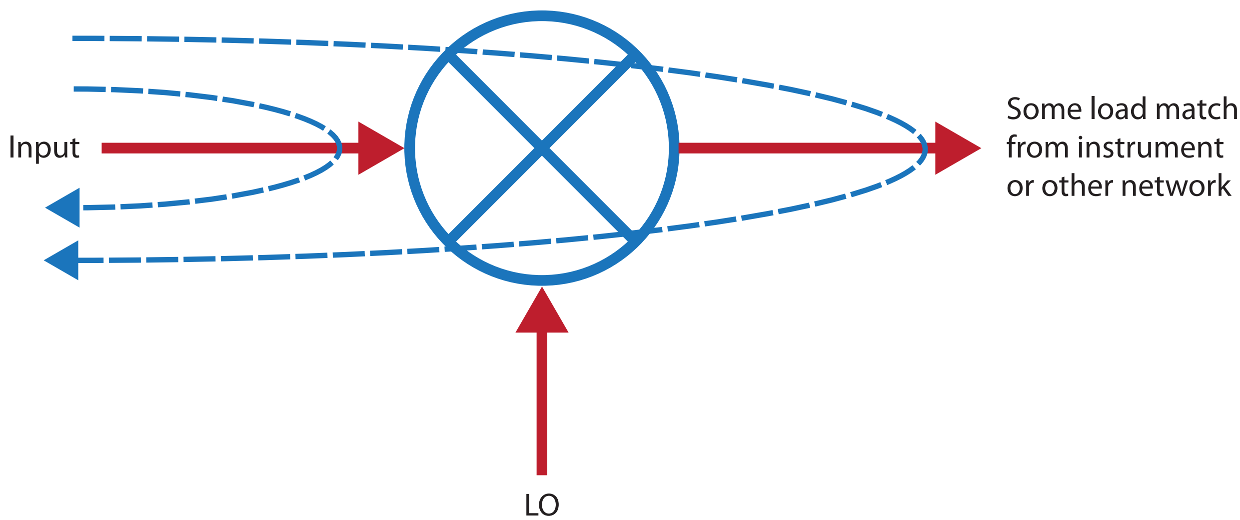
Conversion Gain/Loss

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. The NxN technique discussed in the next chapter is another method for getting at conversion gain/loss vectorially.

19-4 Mixer Measurements

As was suggested in the previous section, there are many different ways of making mixer measurements and many different calibration approaches. The purpose of this section is to explore some of the options and how they might perform under various circumstances.

Some of the mixer measurements described in the previous section (match and isolation) are essentially simple S-parameter measurements that have been discussed previously in this guide. The match measurements 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 lead be some load match dependencies and some confusion in the meaning of the practical match of the mixer (see Figure 19-3).



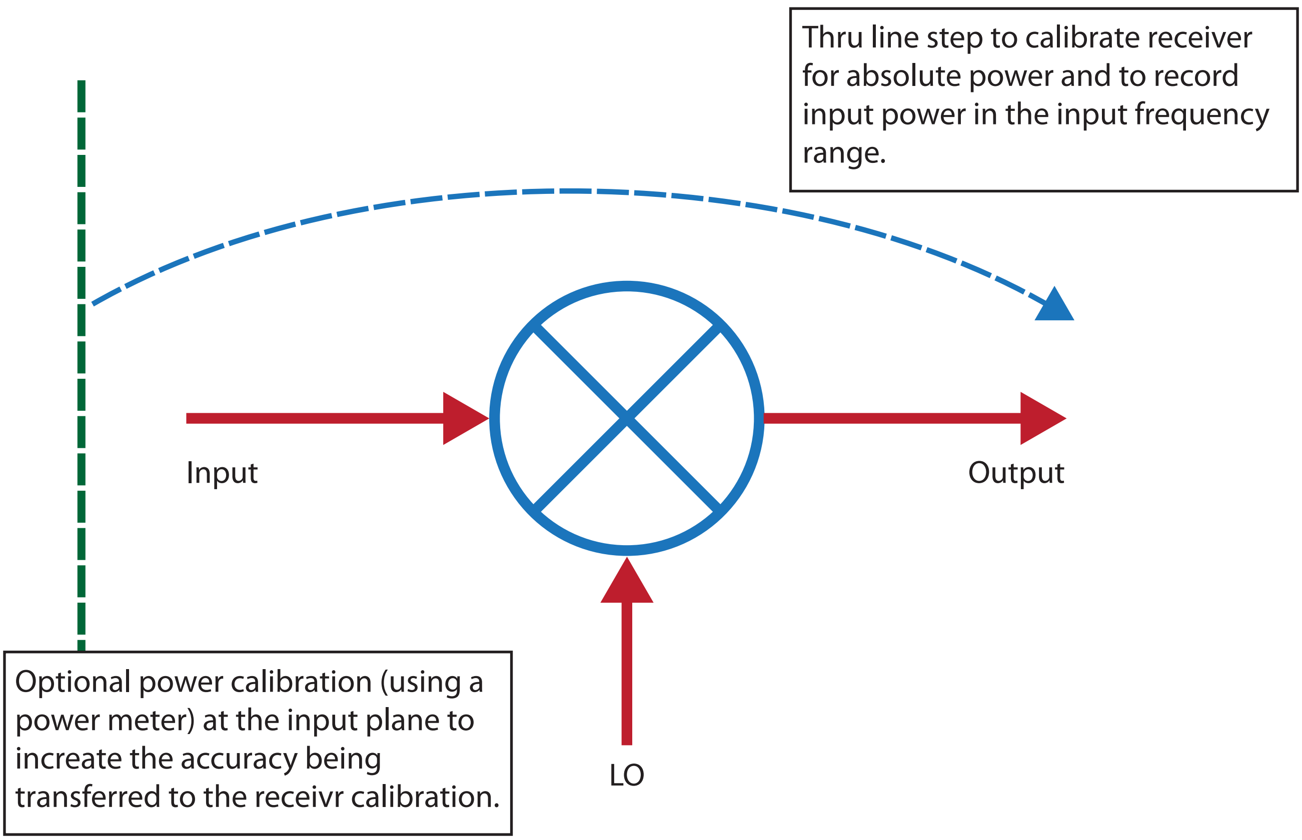
An illustration of the dynamics of the actual match of a mixer is shown here. If the isolation of the mixer is poor and the load match at the input frequencies is poor, multiple reflections can make the actual match of the mixer (in system) worse than one might expect. This can also have implication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

Figure 19-3. Actual Match Dynamics

The newer measurement is really that of conversion gain/loss although it has been touched on in the Multiple Source Control chapter. The concept as discussed above is power transfer from input to output but since the frequencies are different, a classical ratioed S-parameter is not possible (a1 is at the input frequency and b2 is at the output frequency). There are several ways to handle this.

Normalization

This is a scalaresque approach where the receiver is calibrated for absolute power and the input power is calibrated absolutely. This allows one to measure the power received at the output and calculate conversion loss/gain based on knowledge of the input power. This is using the VNAs narrowband receiver so one is not also measuring spurs and leakage that one may be doing with power meter techniques and is hence more accurate than those approaches. Match is, however, neglected and can reduce accuracy. The ports can be heavily padded to reduce any match-related error. Also, group delay of the DUT is unavailable with this method but it is the simplest approach and may be most practical in mm-wave frequencies or in complex media. The measurement is illustrated in Figure 19-4.

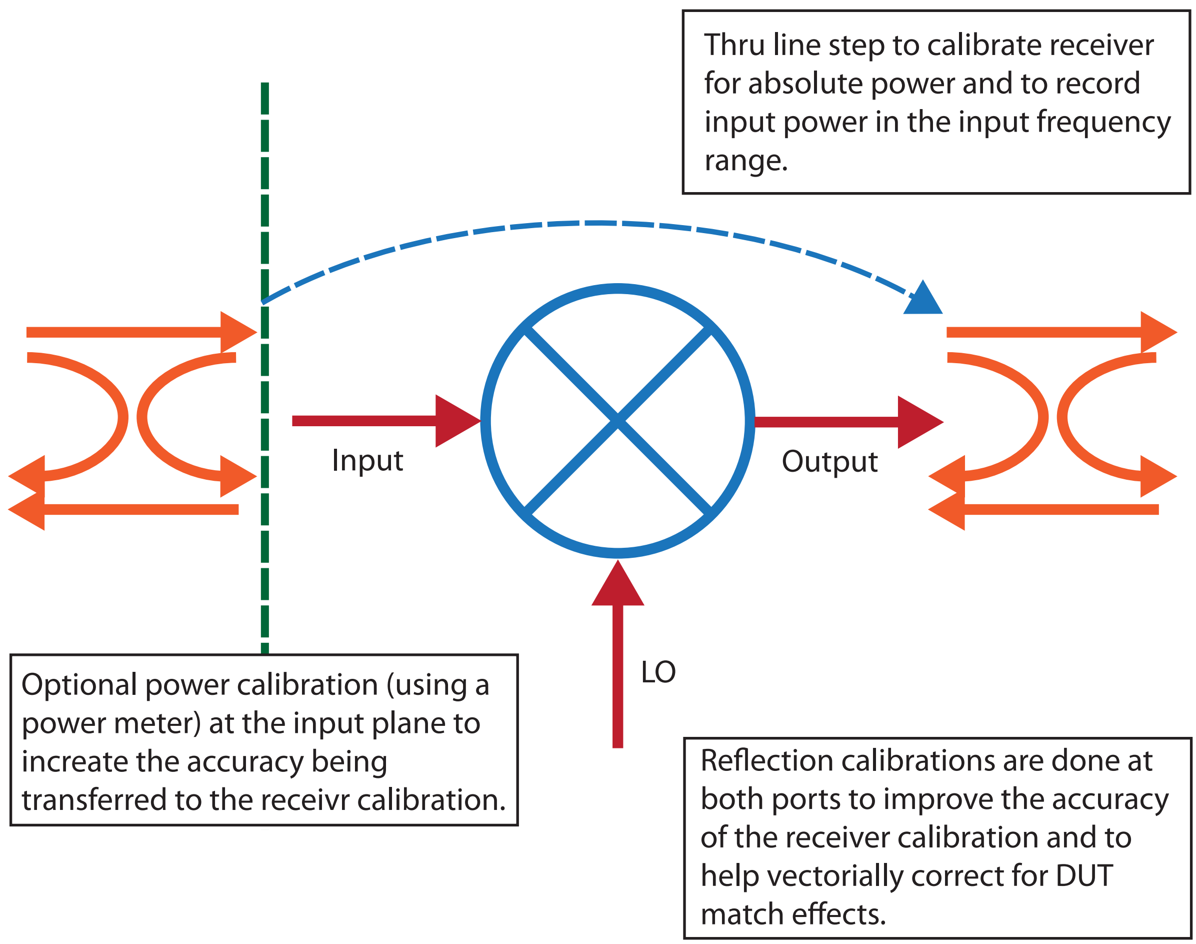


The normalization method of conversion loss/gain measurements is shown here. A thru line is used to establish the input power to the DUT (at the input frequencies) and to calibrate the receiver for absolute power (at the output frequencies). Match is neglected and padding of the ports (prior to calibration) is sometimes done to reduce mismatch effects of a poorly matched DUT.

Figure 19-4. Normalization Method of Conversion Loss/Gain

Enhanced Match

This calibration approach combines power normalization with vector match correction to make a vector method that is still relatively simple to execute and provides better accuracy. The concept is illustrated in Figure 19-5 and relies on multiple one port calibrations in multiple frequency ranges per port (input and output ranges) to correct for DUT match interaction with the ports and for port match interaction during calibration steps. The accuracy is better than that of straight normalization at the expense of some additional calibration steps. Group delay information is also not available with this method.

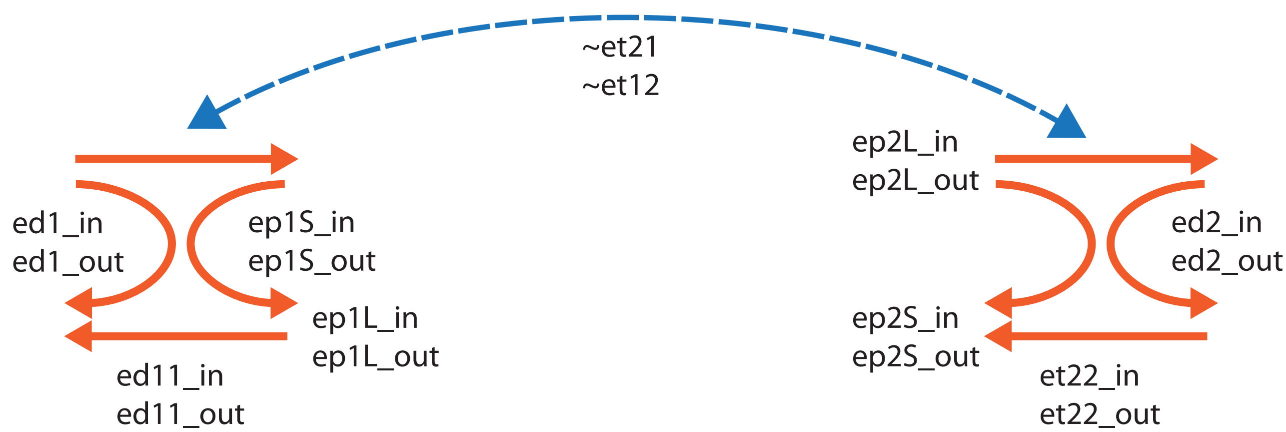


The enhanced match calibration is shown here. The ports are corrected for mismatch at both input and output frequencies so that match effects during both the DUT measurement and during the calibration steps can be corrected vectorially.

Figure 19-5. Enhanced Match Calibration

The principles of the enhanced match calibration are essentially the same as for the regular S-parameter calibrations covered earlier in this document. There are the obvious disparate frequency ranges involved and some assumptions are implicit that are worth discussing. The error boxes for the present problem are illustrated in Figure 19-6. The reflectometer terms have the frequency range explicit in their names. The transmission terms have the frequency conversion implicit in their definition (with a ~ to denote a variance from the usual S-parameter meaning in that now it applies to unratioed conversion).

The receiver calibration is corrected for the interaction of the input port source match and the receiving port load match (ports 1 and 2 in this description although that is not a requirement). This reflection term is of the form (1-ep1S*ep2L) and is done for both input and output frequencies. For the DUT correction, similar terms apply for the interaction of DUT S22 and ep2L_out and the interaction of DUT S11 and ep1S_in. As the isolation terms are included, this correction gets more complex but the form of the terms is similar. Since only fundamental mixing terms are included, this correction can never be complete so the accuracy will be best when the device is operating more linearly (obvious on many levels), when isolation is high, and when the DUT is more unilateral (i.e., does not convert in both directions well).



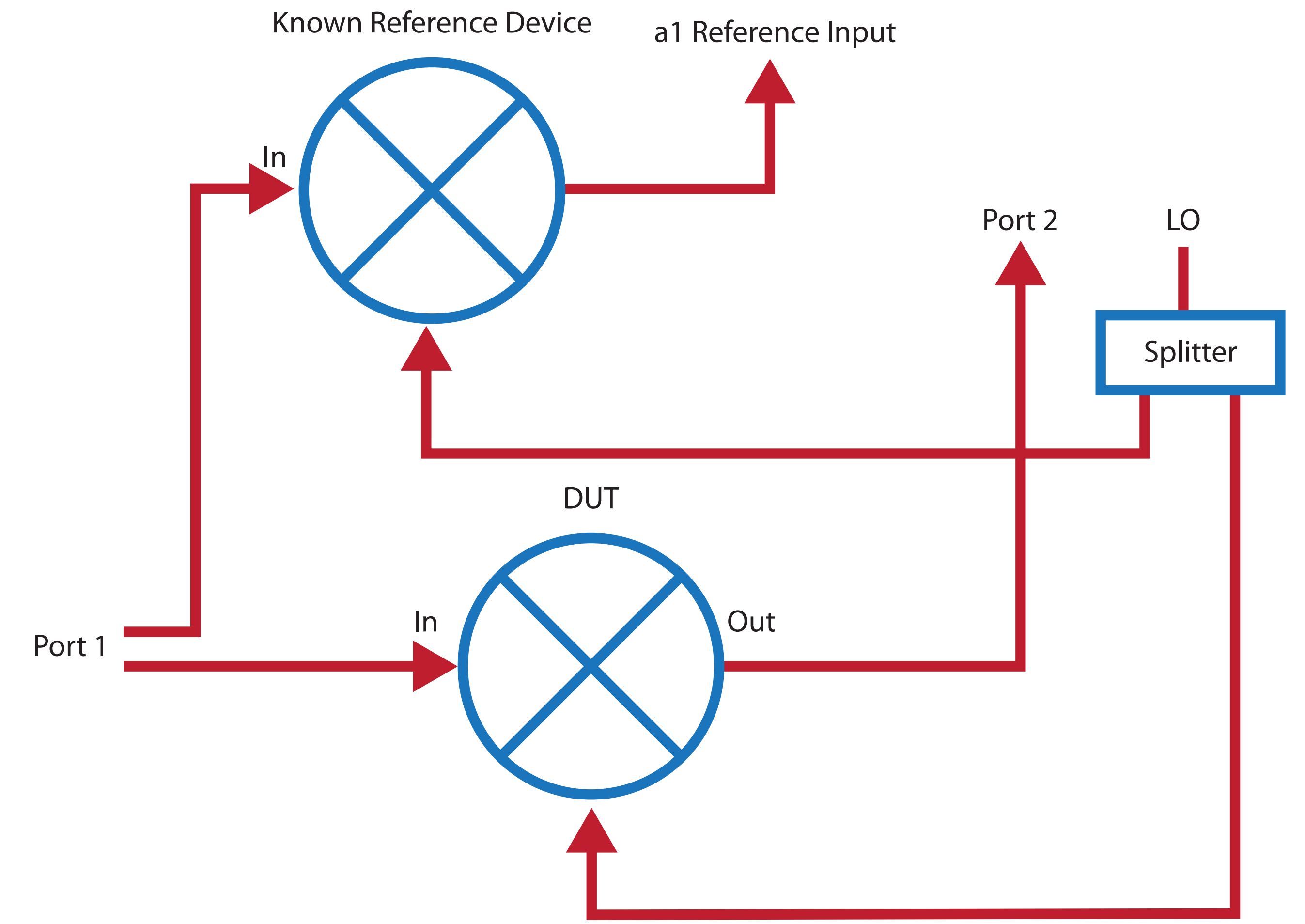
The error boxes for the enhanced match correction are shown here. Port 1 is used as the input and Port 2 as the output in this figure but that is not a requirement.

Figure 19-6. Error Boxes for Enhanced Match Correction

Reference Mixer

One way to get back to a ratioed measurement is to also place a converter in the reference channel (a1 often). This requires one of the loop options (051/061/062) but allows for a S21 (or similar) measurement to be made on a mixer and hence allow group delay extraction. The simplest approach is to use a very broadband (relative to the DUT) mixer that is well-padded to act as the reference mixer so the correction for its effects is a simple normalization. The concept is shown in Figure 19-7.

The reference mixer sequence is not explicitly supported in the wizard setup systems but is compatible with it. The reference mixer must obviously support at least the frequency plan of the DUT but ideally is very broadband. The LO is shown as split in Figure 19-7 but another synthesizer (as long as it is locked to the same timebase as the instrument) can also be used. Indeed, a harmonic mixer with a different multiplier can be used as the reference but multiple source control will generally be needed for this effort (see Chapter 17, “Multiple Source Control (Option 007)”).



The reference mixer approach is shown here. The port definitions can be changed as before.

Figure 19-7. Reference Mixer Approach

Embedding/De-embedding

A more complex approach is to characterize the reference mixer and then to de-embed its effects using the embedding/de-embedding engine discussed in a previous chapter. The parameters of this mixer can be found using the NxN method (see the next chapter) or using network extraction (Type B discussed elsewhere in this guide).

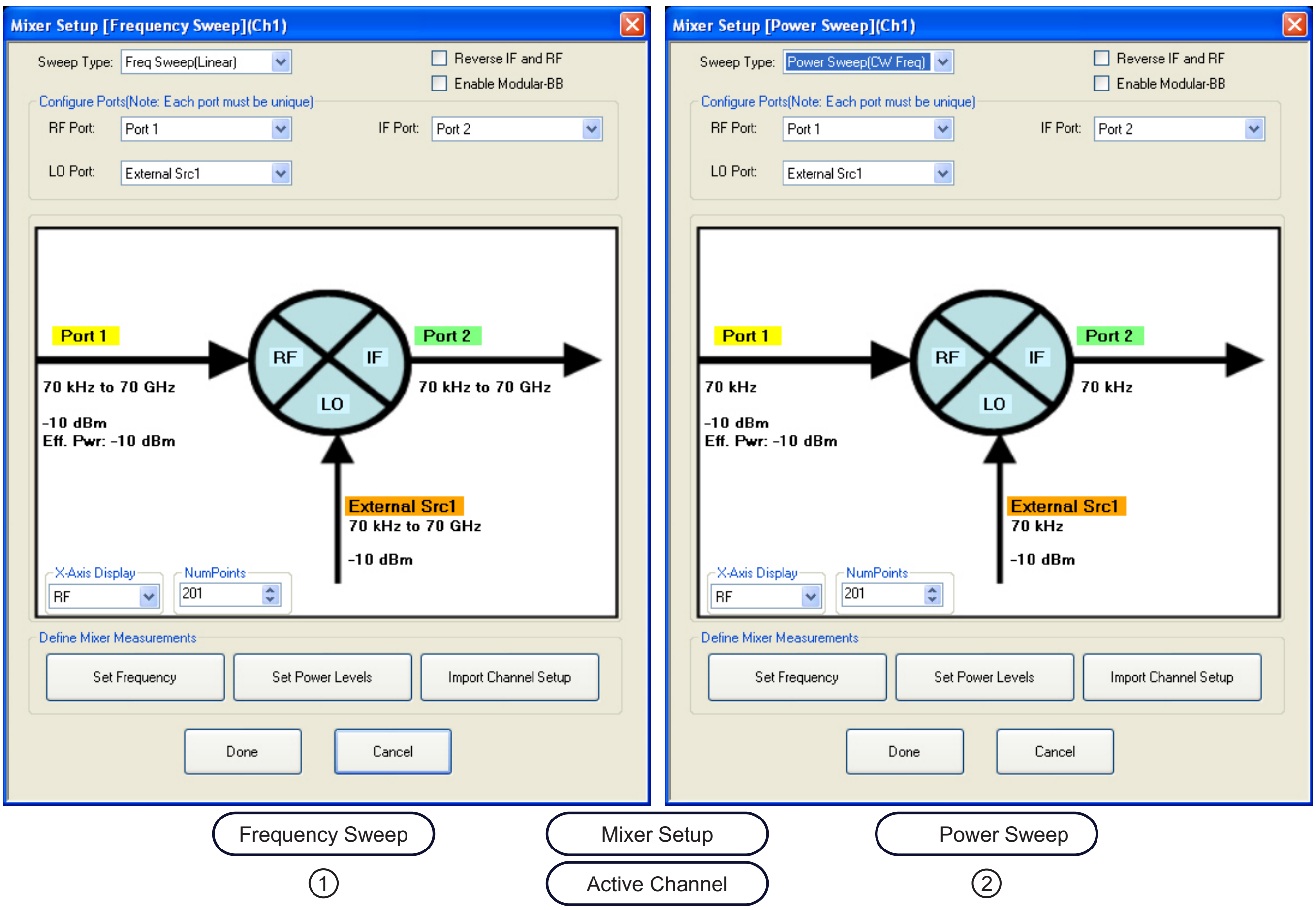
NxN

A fourth method, also recreating a ratioed measurement, is termed NxN and is discussed in more detail in the next chapter. The idea here is to use a characterized mixer to reconvert the DUT output frequency back to the input. This does not require a loop option but does require some care in handling the image and match at the interface between the DUT and the characterized mixer (usually with a simple filter and pads). Accuracy is approximately the same as with the previous two methods.

19-5 Active Channel Mixer Guided Setup Controls

The guided setup and wizard sections of the application menu are split into two parts: one that only sets up the active channel and acts more as a guide (will be discussed now) and a multi-channel wizard that helps one configure multiple measurements in a more organized fashion (to be discussed later in this chapter). Details on the controls themselves are covered in the operations and user interface manuals. The purpose here is to discuss how the controls relate to the mixer measurement concepts discussed previously.

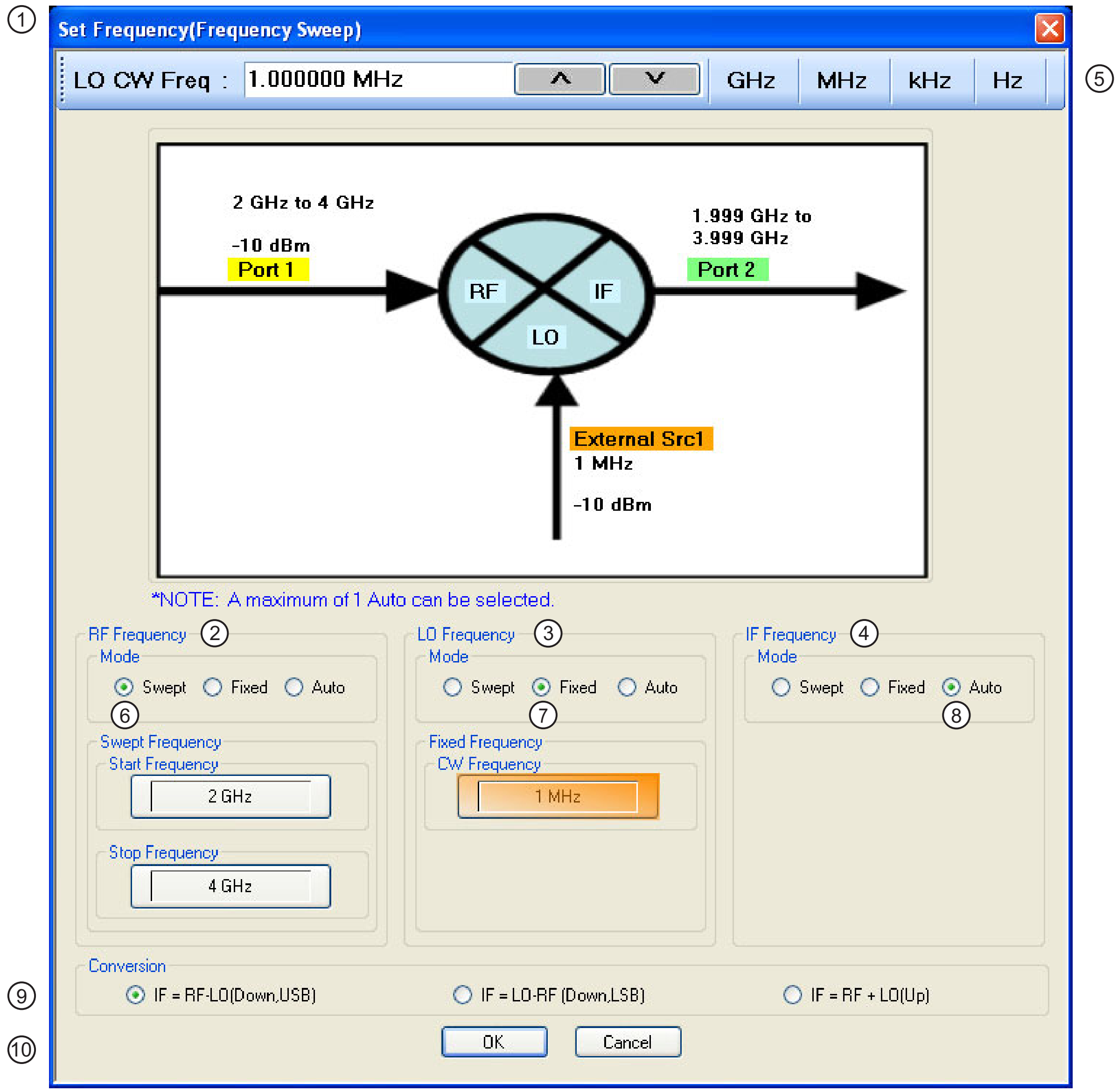
The basic setup screens for this active channel method are shown in Figure 19-8. The IF and RF ports can be assigned to different VNA physical ports as has been discussed and the IF/RF labeling can be swapped (see the check box near the top). Both frequency sweeps (of input and LO possibly) and power sweeps are supported and are chosen from a pull-down menu. Also part of the input/output duality is how the x-axis of the plots are labeled and this is handled by the pull-down in the lower left part of the dialog. In the case of a fixed output frequency or a fixed input frequency, labeling the x-axis with the fixed variable is usually not helpful.



1. On left, MIXER SETUP (FREQUENCY SWEEP).	2. On right, MIXER SETUP (POWER SWEEP).

Figure 19-8. Mixer Setup Dialogs

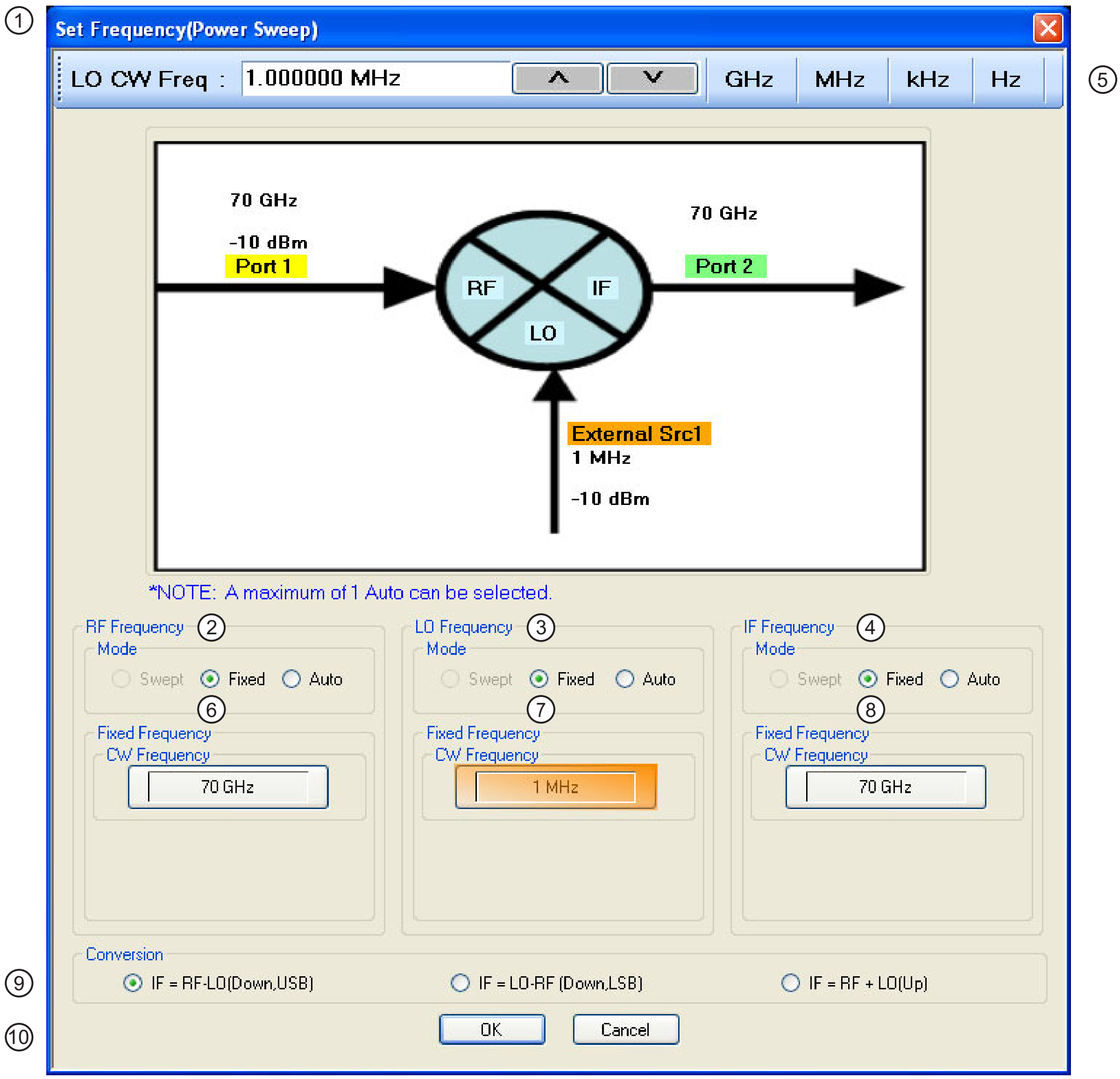
The frequency ranges (including the possibility of reverse sweeps) are shown in the dialog and are setup using a sub-dialog as shown in Figure 19-9. The conversion direction and sideband choices discussed previously are handled here and there are many permutations possible. The conversion direction is selected from the radio buttons at the bottom and note the two downconversion selections discussed previously (USB and LSB). Input, output, or LO may be fixed (generally only one of them) and an Auto selection may be used to let the system calculate the frequencies for one of the ports. It is, of course, possible, for an invalid frequency combination to be entered (out of range of the hardware) but this will be scanned for when the OK button is selected.



1. SET FREQUENCY (FREQUENCY SWEEP) Wizard Dialog Box.
2. RF Frequency mode and value area.
3. LO Frequency mode and value area.
4. IF Frequency mode and value area.
5. Frequency input field toolbar. The label changes depending whether RF, IF, or LO are selected.
6. Mode set as Swept. Any combination of the RF, IF, and LO ports can be set as Swept. When selected, Start and Stop Frequency fields appear.
7. Mode set as Fixed. Any combination of the RF, IF, and LO ports can be set as Fixed. When selected, a CW Frequency field appears.
8. Mode set as Auto. Only one of the three ports can be set as Auto. If selected, the instrument determines the frequency settings based on the other two values and the Conversion type setting.
9. Conversion setting. Changes based on whether RF is input or output.
10. Dialog box control buttons.

Figure 19-9. Frequency Setup Dialog for Frequency-Sweep Case

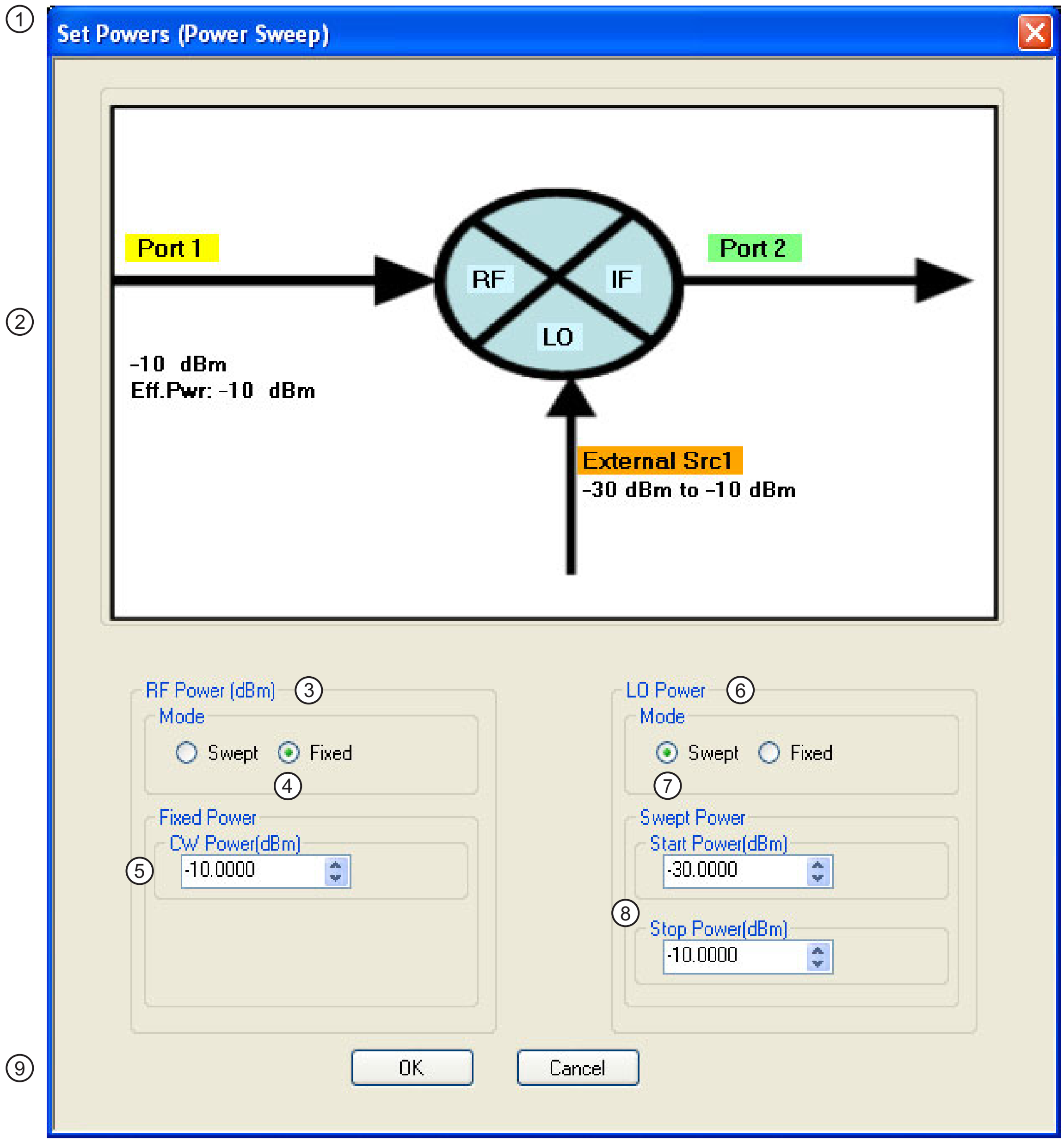
In the case of a power sweep, all of the frequencies must be CW so the frequency selection dialog simplifies as shown in Figure 19-10. The same sideband and conversion choices apply; there is just no frequency sweeping involved in this measurement setup.



1. SET FREQUENCY (POWER SWEEP) Dialog Box.
2. RF Frequency mode and value area.
3. LO Frequency mode and value area.
4. IF Frequency mode and value area.
5. Frequency input field toolbar. The label changes depending whether RF, IF, or LO are selected.
6. RF Mode setting can only be Fixed or Auto. Only one mixer port can be Auto. If fixed, RF CW frequency is input in field below.
7. LO Mode setting can only be Fixed or Auto. Only one mixer port can be Auto. LO CW frequency is input in field below.
8. IF Mode setting can only be Fixed or Auto. Only one mixer port can be Auto. IF CW frequency is input in field below.
9. Conversion setting. Changes based on whether RF is input or output. If RF is input, equations show conversion calculations for IF. If IF is input, equations show conversion calculations for RF.
10. Dialog box control buttons.

Figure 19-10. Frequency Setup Dialog for Power Sweep Case

Correspondingly, the power setup is now more detailed as suggested by Figure 19-11. There are no conversion complications but there could be simultaneous sweeping of power on input and LO (not commonly done but possible). The swept power input is often done to look at gain compression of the DUT while LO power sweeps are often employed to look at the saturability of the LO path. The latter can be important since it has many linearity implications depending on the DUT technology.



1. SET POWERS (POWER SWEEP) Wizard Dialog Box	6. LO Power controls
2. Mixer Schematic – Port assignments and power levels are updated automatically.	7. Mode set as Swept with option of Fixed.
3. RF Power (dBm) controls.	8. Swept start and stop power input fields.
4. RF Power Mode set as Fixed with option of Swept.	9. Dialog box control buttons.
5. RF Power CW Power input field	

Figure 19-11. Power Setup Dialog for the Power Sweep Case

19-6 Using the Active Channel Guided Setup

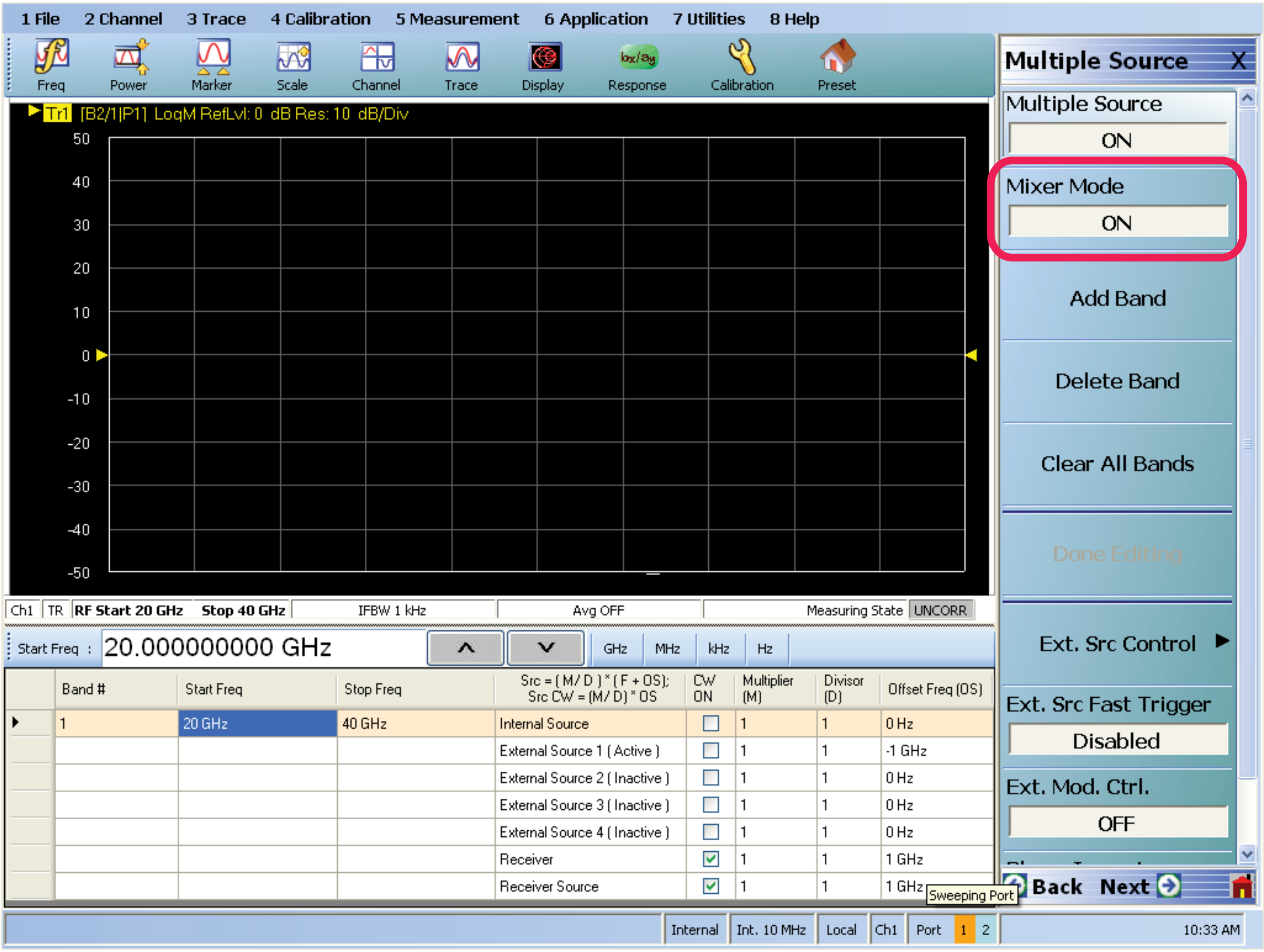
The general procedure for using the guided setup is relatively simple:

1. If a previously used mixer setup exists that is of interest, it may be imported first.
2. Decide on the type of sweep needed (frequency or power)
3. Decide on the frequency plan for the DUT addressing the following parameters as required:
    - What are the Input, LO and Output Frequencies.
    - Which mixer ports are swept and which are fixed.
    - If downconversion is used, is it USB (upper side band) or LSB (lower side band).
    - What are the power levels.
4. Decide on the number of points needed and what X-Axis labeling is desired (input or output frequency in the case of a frequency sweep)
5. Enter the guided setup dialog and input the desired parameters. Auto can be used to help with the frequency entry.
6. Exit the dialog by selecting the OK button. If not successful (i.e., the error checking of your entries indicated a problem), return and fix the errors. When successful, proceed to configure your desired measurements.

Note that when one successfully leaves the dialog, the channel will be setup in converting mode (sourcing at the input frequency and the receiver tuned to the output). If one wishes to perform some non-converting measurements, proceed to multiple source control and put the receiver and source equations where desired. In the dialog of Figure 19-12, if one wanted to measure input match or input-to-output isolation, change the receiver and receiver source equations to 1/1(f+0 GHz).

After using the guided setup, one may find that one wants to change or optimize some settings. One can always return to the dialog and try again. For more advanced modifications, one can also proceed to the multiple source dialog (see Chapter 17, "Multiple Source Control (Option 007)") and edit all of the equations manually. This multiple source system is automatically populated with the mixer settings when one leaves the guided setup so one can perform more extensive modifications later. This includes the possibility of changing to a harmonic converter or a multiple conversion setup. As shown in Figure 19-12, a button labeled Mixer Mode has been added to the screens shown in Chapter 17, "Multiple Source Control (Option 007)". This mode enables the extra mixer calibration options available on the calibration menus and the linkage to the guided setup and wizard dialogs.

The reader may have noticed the Enable Modular BB check box in the setup dialog. This check box enables the internal frequency plans for use with the MA25300A or 3743x mm-wave modules for extended frequency range. Generally, this enables the VNA source and receivers to reach 125 GHz (requires opt 08X, the 3739X test set, and the appropriate mm-wave modules). The same setup controls apply.



The multiple source screen after a successful guided mixer setup execution is shown here. Note the Mixer Mode button which is not present in traditional multiple source control modes.

Figure 19-12. Multiple Source Screen After Successful Guided Mixer Setup

19-7 Typical Required/Recommended Active Channel Mixer Calibrations

The required calibrations are dependent on what measurements are going to be completed. Since the active channel setup is somewhat less of a guided approach than is the full mixer wizard (to be discussed in a later section), the guidance in this section will be at something of a macro level. All but the power calibrations and traditional receiver calibrations are located in the main Calibration menu system.

For Mixer Port Return Loss

A full 1 Port calibration is normally used. The calibration must exist over the runner frequency range for this mode and is often done in standard mode. It can be in the form of a full 2 Port calibration to capture isolation terms.

For Isolation

A transmission frequency response calibration can be used or it can be combined with return loss measurements in a full 2 Port cal.

For Conversion Loss

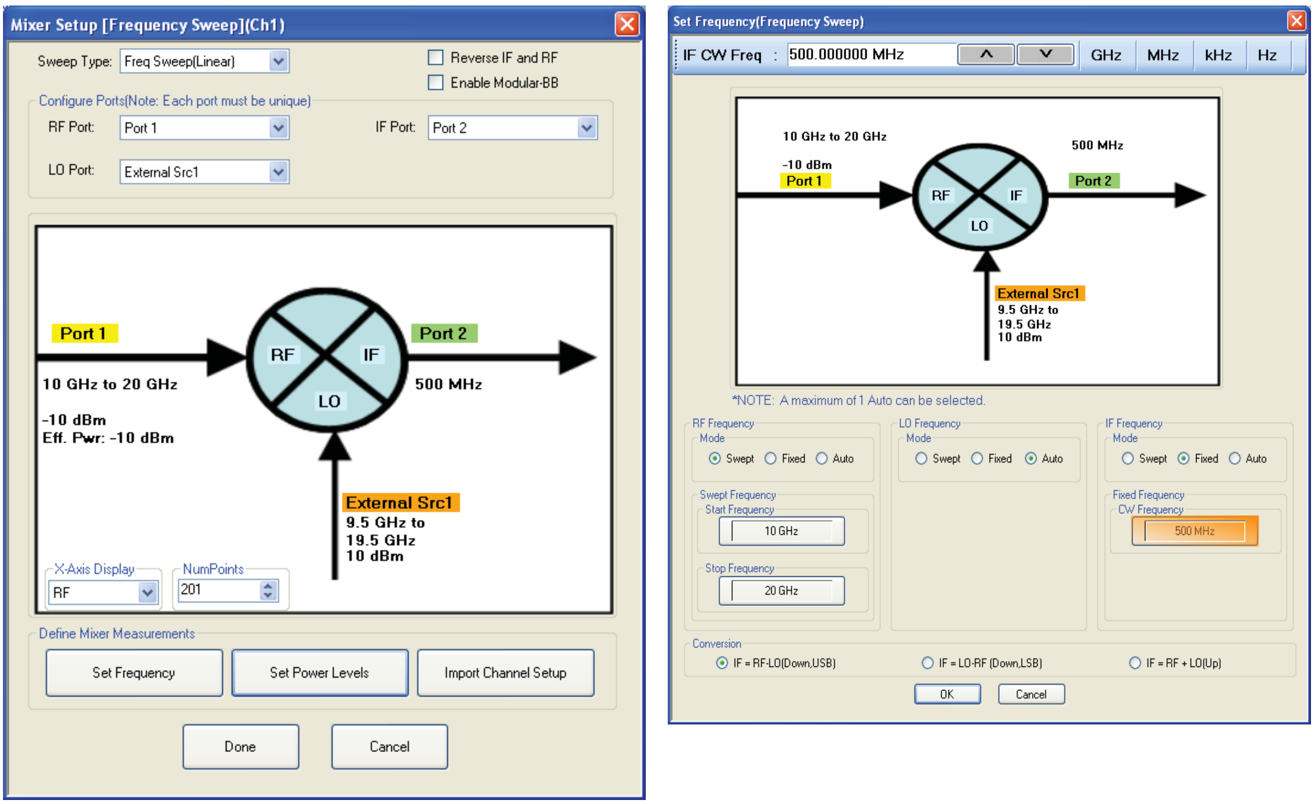
As has been discussed, a normalization-cased calibration or an enhanced match calibration can be used. The latter provides a higher level of correction and provides return loss data as well at the expense of additional calibration steps.

For Power Calibration

A power calibration is also often recommended for conversion loss situations in that it can improve the accuracy of the receiver calibration that is embedded in both types of conversion loss calibrations. The power calibrations are discussed in separate chapters but use a power meter to more accurately establish an absolute power level at a given reference plane (e.g., at the end of a cable where the DUT will be connected).

19-8 Procedure for a Typical Single Channel Mixer Measurement

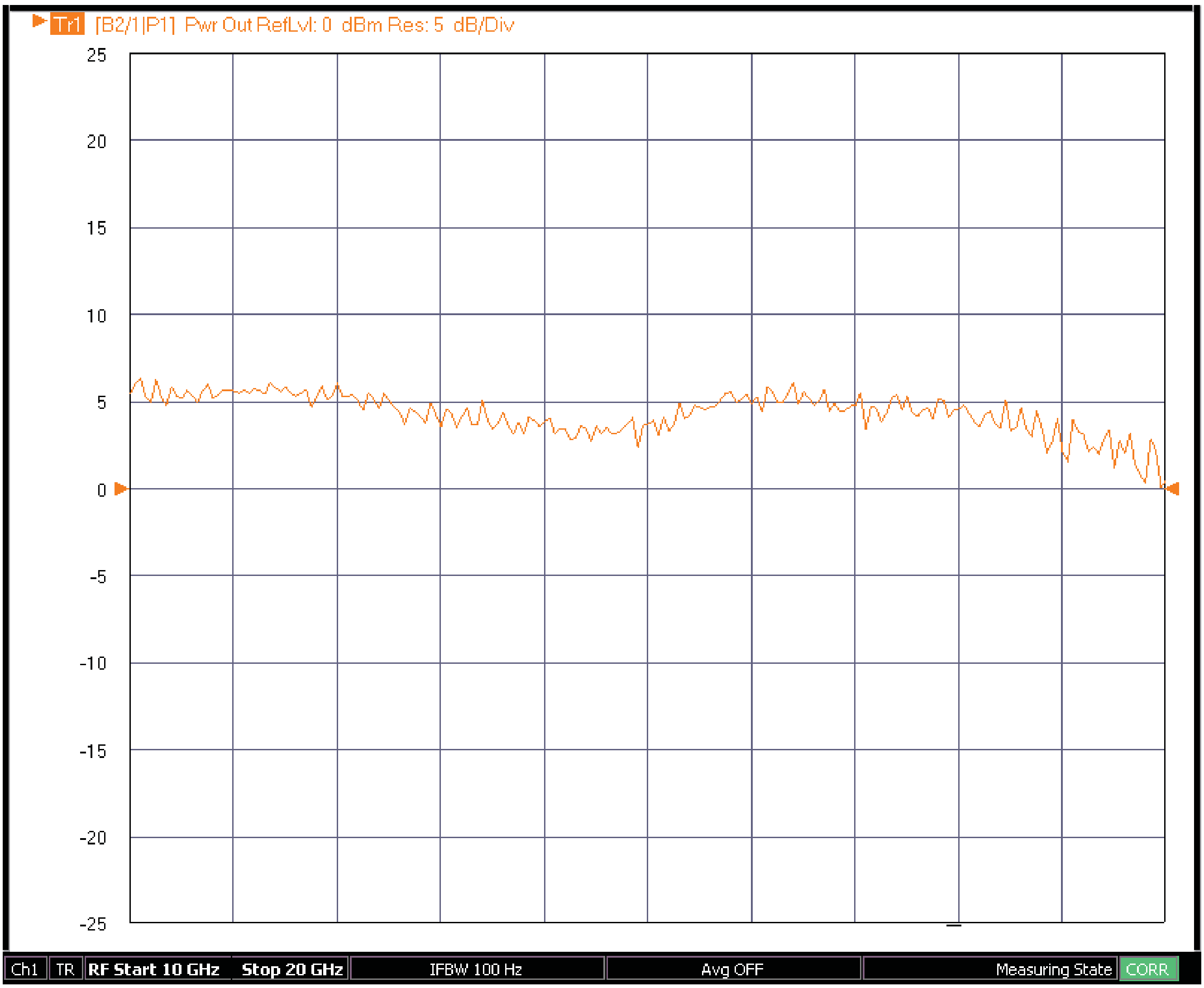
Consider that one wishes to make a conversion loss measurement of a DUT with a 10 to 20 GHz input range, a fixed 0.5 GHz output and a low-side LO. External synthesizer 1 will be used as the LO (and it is on the GPIB address of 4 which is default for external synth 1) and it has been connected to the GPIB and the 10 MHz reference out of the VNA and turned on. The LO power is to be +10 dBm and the input power is to be -10 dBm. The setup dialogs for this scenario are shown in Figure 19-13. Here we used the 'auto' function on the LO entry to simplify things. Note the selection of the conversion direction on the frequency setup. Once the Done button is selected on the main dialog, the setup will be verified and the system placed into a converting mode where the source at port 1 is sweeping over 10 to 20 GHz and the receiver is fixed at 0.5 GHz.



An example setup is shown here for a 10 to 20 GHz downconverter with a fixed IF of 0.5 GHz. The LO range will be calculated to be 9.5 to 19.5 GHz and programmed into an external synthesizer.

Figure 19-13. Example Setup for 10 to 20 GHz Downconverter

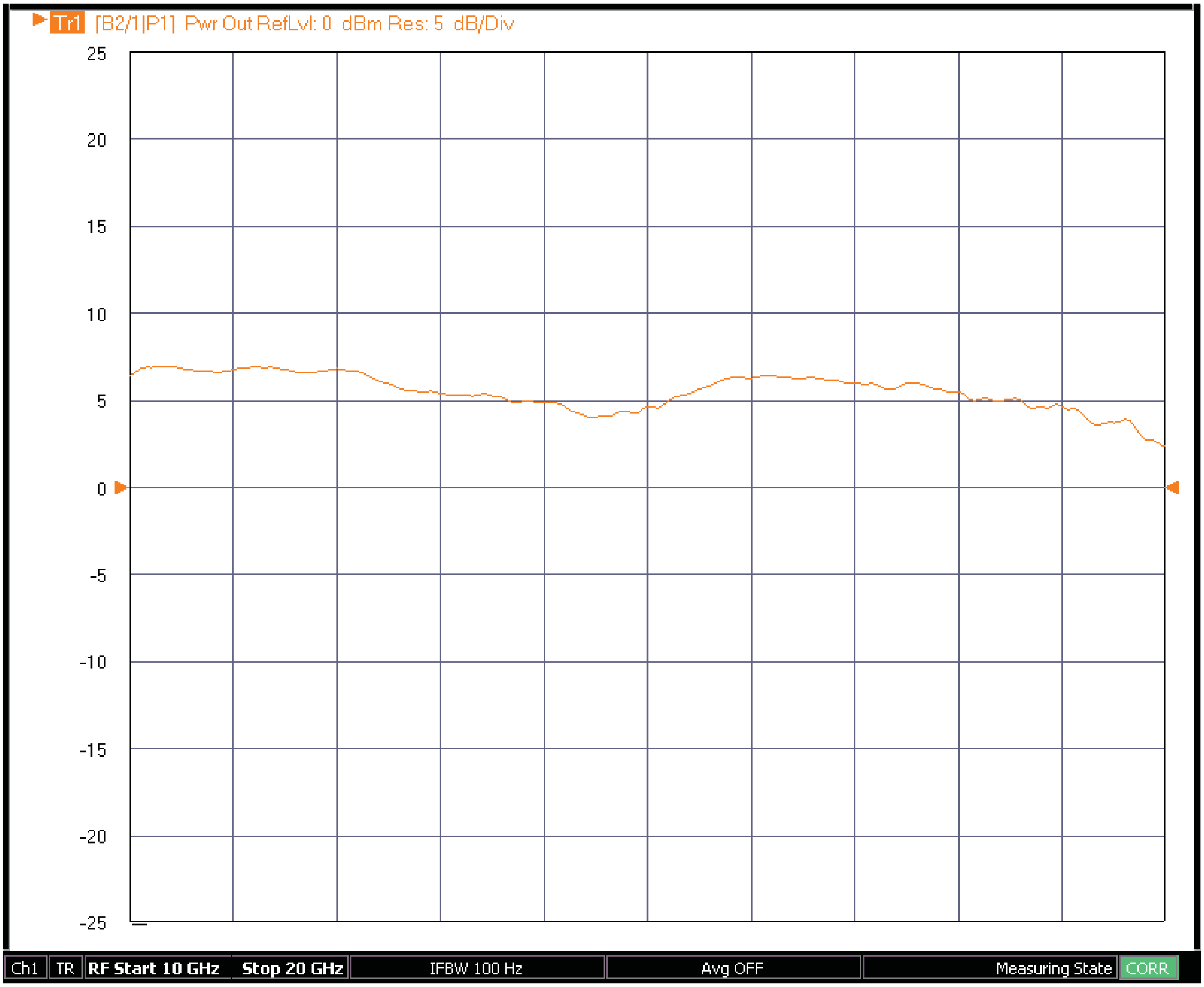
The next step would normally be to go to the calibration menu and select either a normalization or an enhanced match calibration for this conversion loss measurement. During the normalization calibration, only a thru line connection is needed as discussed earlier. The measurement result for this case is shown in Figure 19-14. No port padding was used and the DUT was not particularly well-matched so there is some ripple.



An example conversion gain measurement is shown here using the setup of Figure 19-13 above and a normalization-based calibration.

Figure 19-14. Example Conversion Gain Measurement with Normalization-Based Calibration

An enhanced-match calibration was also performed on this setup and the measurement results are shown in Figure 19-15. A standard manual OSL calibration kit in the K connector (3652X) was used for the reflectometer calibration steps. The measurements were not identical due to some bias changes on the DUT but the reduction in ripple is apparent.



An example conversion gain measurement is shown here using the setup of Figure 19-13 and an enhanced match calibration.

Figure 19-15. Example Conversion Gain Measurement with Enhanced Match Calibration

19-9 Multiple Channel Mixer Wizard Controls

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 19-16. In addition to some of the controls discussed previously 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 setup at once but the results from different groups will only be meaningful if the DUT is connected correctly

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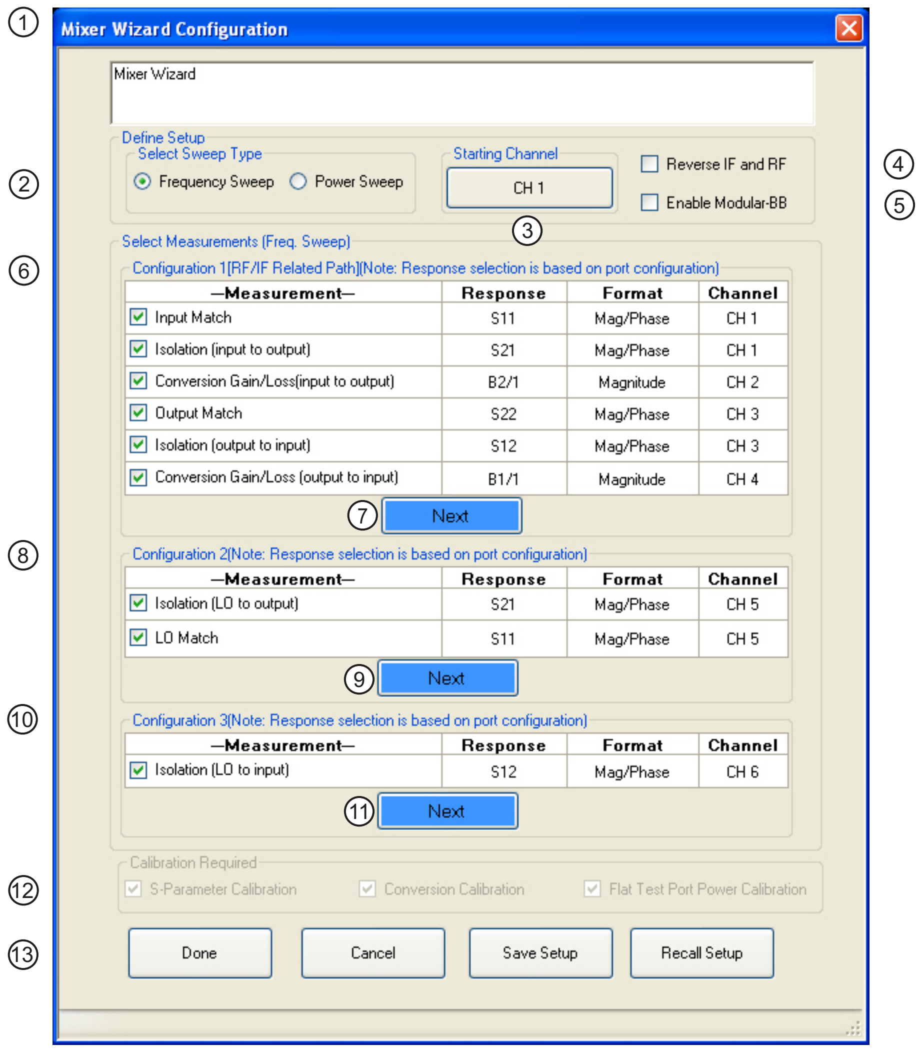


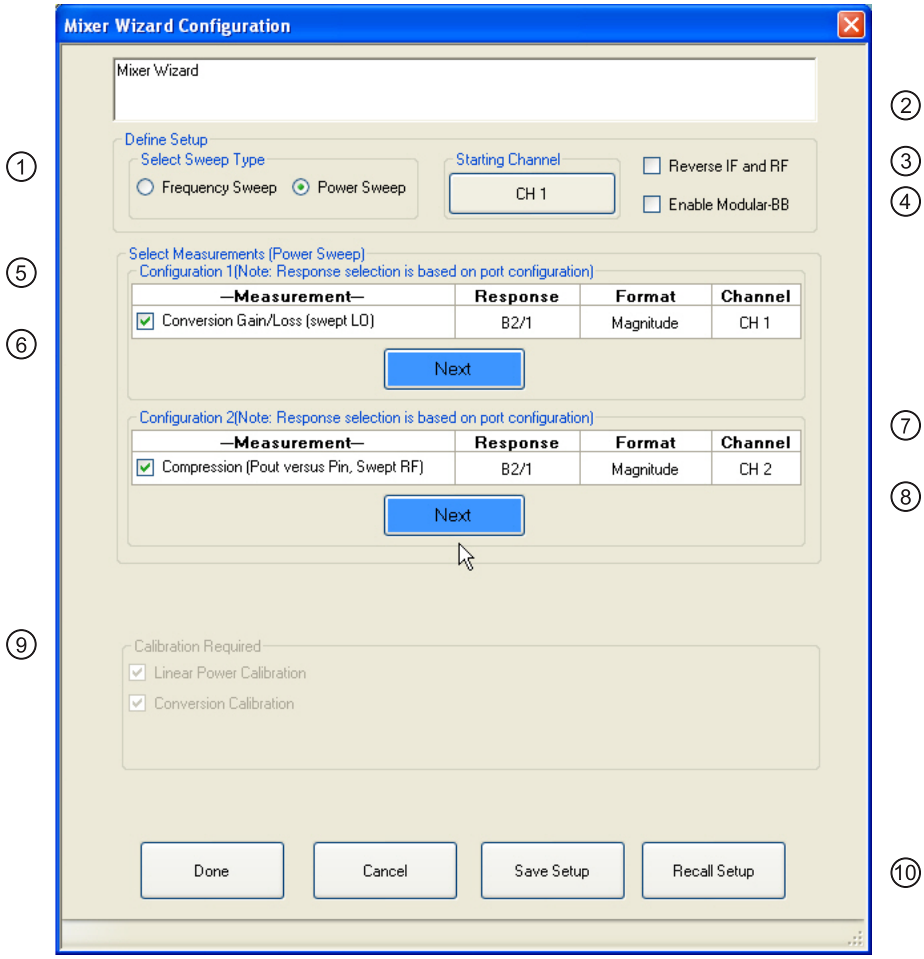
1. MIXER WIZARD CONFIGURATION (FREQUENCY SWEEP) Dialog Box
2. Select Sweep Type as Frequency Sweep or Power Sweep.
3. Channel Start Selection
4. Reverse IF and RF – Default is RF as input and IF as output. Toggles to RF as output and IF as input.
5. Enable Modular-BB – Only for MS4647A VNAs with Option 080/081 BB/m-Wave System.
6. Configuration 1 – Conversion Gain/Loss Swept LO – RF/IF Related Path – Select any combination of measurements. Channels are automatically assigned based on Starting Channel.
7. Next Button – Links to Configuration 1 Dialogs to configure mixer and VNA ports, external sources, frequency, and power levels.
8. Configuration 2 – Compression Pout versus Pin Swept RF – Select any combination of measurements. Channels are automatically assigned.
9. Next Button – Links to Configuration 2 Dialogs to configure mixer and VNA ports, external sources, frequency, and power levels.
10. Configuration 3 – Isolation – LO to Input Available Measurement
11. Next Button – Links to Configuration 3 Dialogs to configure mixer and VNA ports, frequency, and power.
12. Calibration Required Area
13. Dialog Controls

Figure 19-16. Main Wizard Setup Dialog for Frequency Sweep Case

All of the measurements shown have been discussed previously 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 and will not be repeated here. Minor differences can be analyzed in the operating manual or the UI guide. For the power sweep case, the choices are more limited and are shown in Figure 19-17. As had been discussed previously, 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.



1. Select Sweep Type	6. Next button to Configuration 1 dialogs
2. Select Starting Channel	7. Configuration 2 Measurements for Compression Pout versus Pin Swept RF.
3. Reverse RF and IF – Standard is RF is input and IF output. Reverse is RF as output and IF as input.	8. Next button to Configuration 2 dialogs.
4. Enable Modular Broadband.	9. Calibration Required Area display.
5. Configuration 1 Measurements for Conversion Gain/ Loss Swept LO.	10. Dialog control buttons.

Figure 19-17. Main Wizard Setup for Power Sweep Case

19-10 Using the Multiple Channel Mixer Wizard

The procedure for using the wizard is essentially the same as that discussed in "Using the Active Channel Guided Setup" on page 19-14 above for the single channel guided setup except now, one may want to more carefully list the needed measurements so that they can be selected in the dialog. Once the setup is complete, the wizard will issue a list of recommended calibrations for the various channels that can then be executed. Once those are complete, the channels will complete all requested measurements (for a given DUT connection setup).

19-11 Typical Required/Recommended Multi-Channel Mixer Calibrations

The types of calibrations were already discussed in section 18-7 and in earlier sections. The multi-channel wizard will provide a dialog indicating suggested calibrations based on the measurement requested (see Figure 19-18). In this case, input match, input-to-output isolation, input-to-output conversion gain/loss and output match were requested.

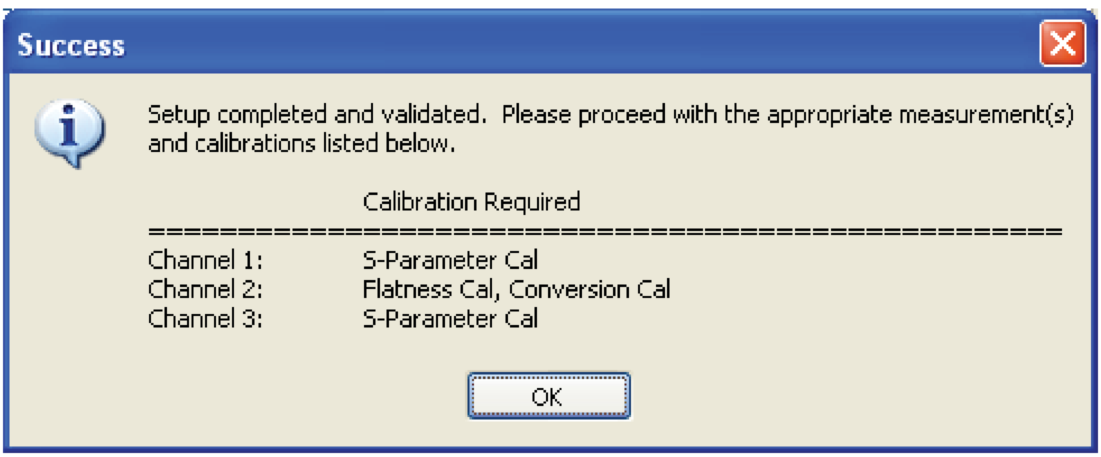


Figure 19-18. Example Listing of Recommended Mixer Calibrations

19-12 Procedure for a Typical Multiple Channel Mixer Measurement

We will extend the example of Section 18-8 now to include additional measurements. The setup parameters are the same as before except now we will request input match, output match, forward conversion loss, and input-to-output isolation. The measurement results are shown in Figure 19-19.

- **Channel 1:**

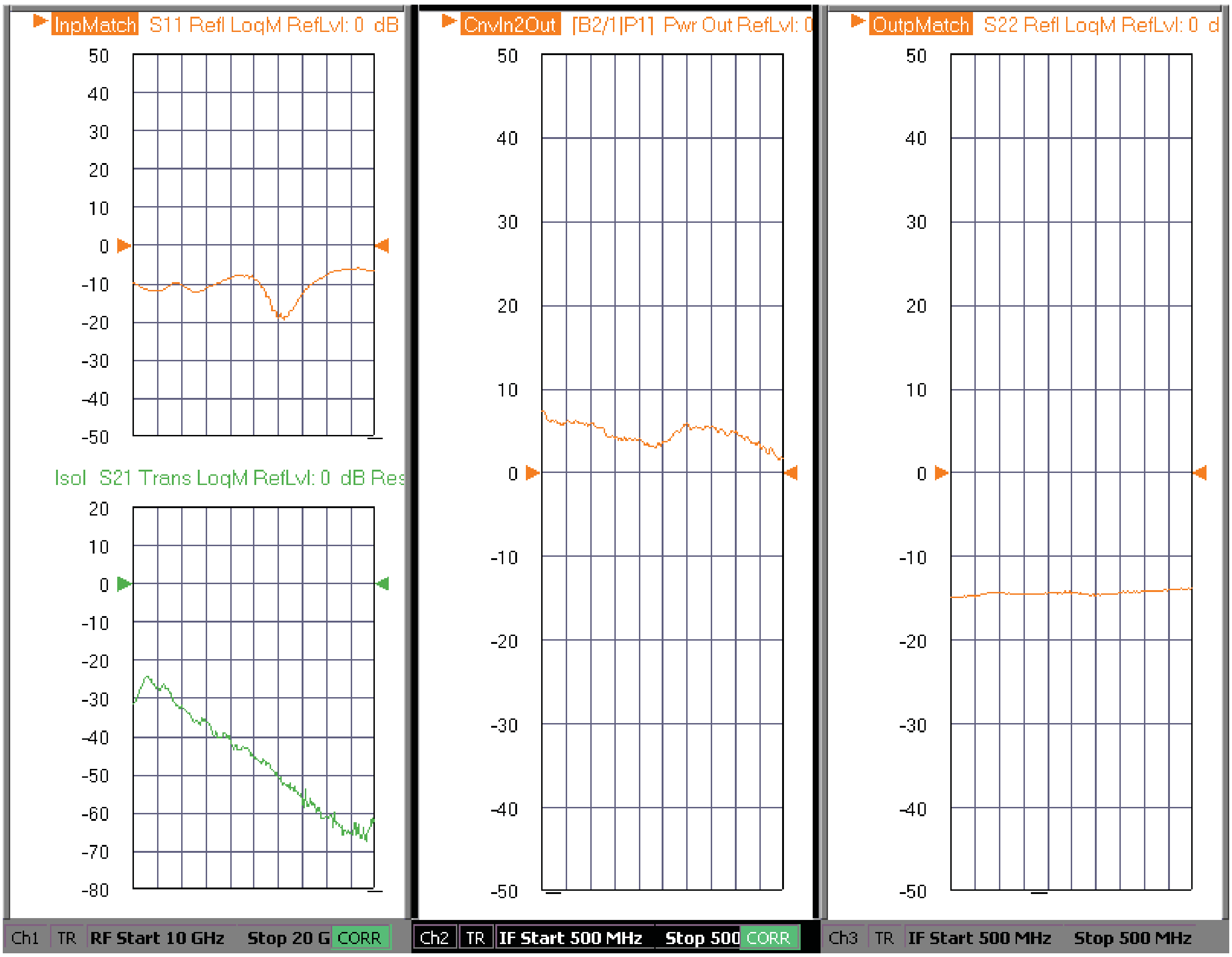
  Sweeping both source and receiver 10 to 20 GHz to measure input match and input-to-output isolation

- **Channel 2:**

  Sweeping the source 10-20 GHz with the receiver fixed at 0.5 GHz to measure conversion loss (actually more is going on here since an enhanced match calibration was used so this channel also measures DUT input and output match behind-the-scenes).

- **Channel 3:**

  CW measurement at 0.5 GHz to get the output match. Note that although the source and receiver are CW during this measurement, the LO is sweeping so one does see a variation over the sweep. Since the LO sweep range is known to be 9.5 to 19.5 GHz (or one can plot with this x-axis), the correlation can be studied.



The three channels of measurement results for our example are shown here.

Figure 19-19. Three Channel Measurement Results

19-13 Tips, Techniques, and Best Practices

This section contains some general hints on successful mixer measurements along with some tips on how to conduct ancillary measurements like coarse spur analysis.

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.

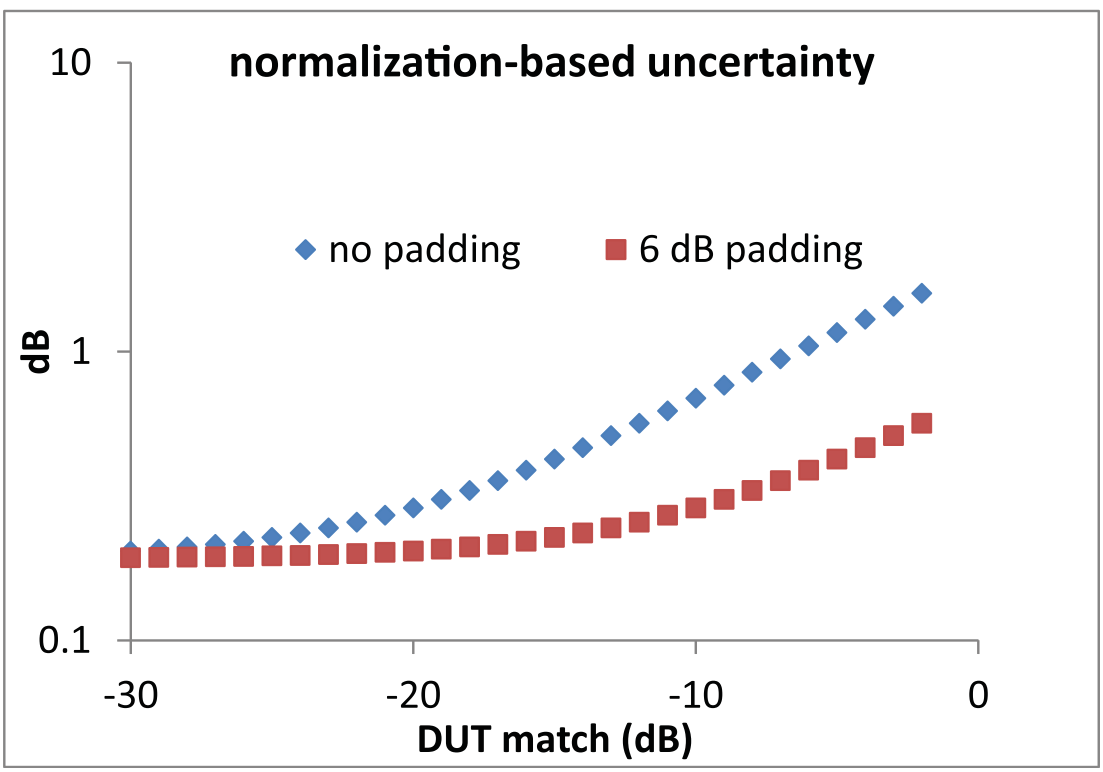
- Knowing all of the required measurements in advance can help speed up the setup when using the multi-channel wizard
- For complex conversion scenarios (harmonic or subharmonic conversion, multiple LOs and multiple stages, etc.), the multiple source control system see Chapter 17, “Multiple Source Control (Option 007)” gives very flexible control of the internal sources and up to 4 external synthesizers.
- 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.

Dealing with Uncertainty Terms

On the subject of uncertainties, the one new measurement (conversion gain/loss) 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

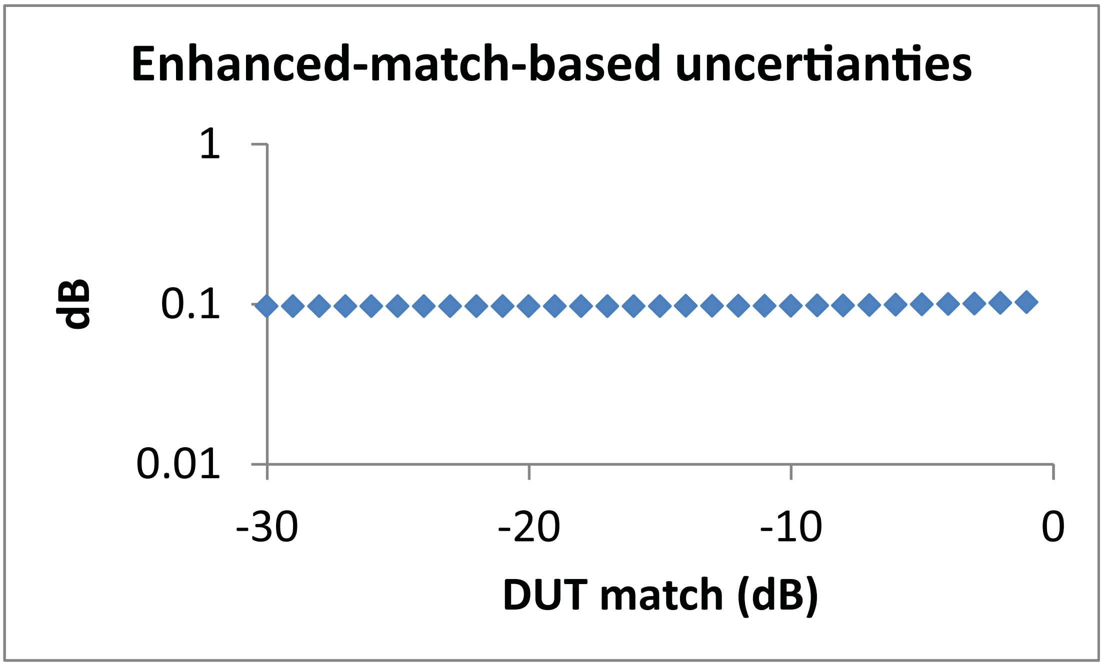
Assuming nearly optimal typical numbers for the other terms, an estimate of total uncertainty on conversion loss vs. DUT match (assumed symmetric and unilateral) is plotted in Figure 19-20 with and without some modest (6 dB) port padding. As might be expected, the worse the DUT match, the greater the value of the port padding.



An estimate of normalization-based conversion gain/loss uncertainty versus DUT match is plotted here

Figure 19-20. Normalization-Based Uncertainty

With the enhanced match calibration, the receiver calibration and DUT interaction uncertainties can reduce dramatically. The residual errors are based on a common SOLT calibration and the same unilateral assumptions as before are employed to simplify the calculation. The results are shown in Figure 19-21. The scales are changed and no padding was assumed. The result is largely match-invariant assuming the surrounding calibration was adequate.



An estimate of enhanced-match based uncertainties vs. DUT match are plotted here under the assumptions stated in the text.

Figure 19-21. Enhanced-Match Based Uncertainties

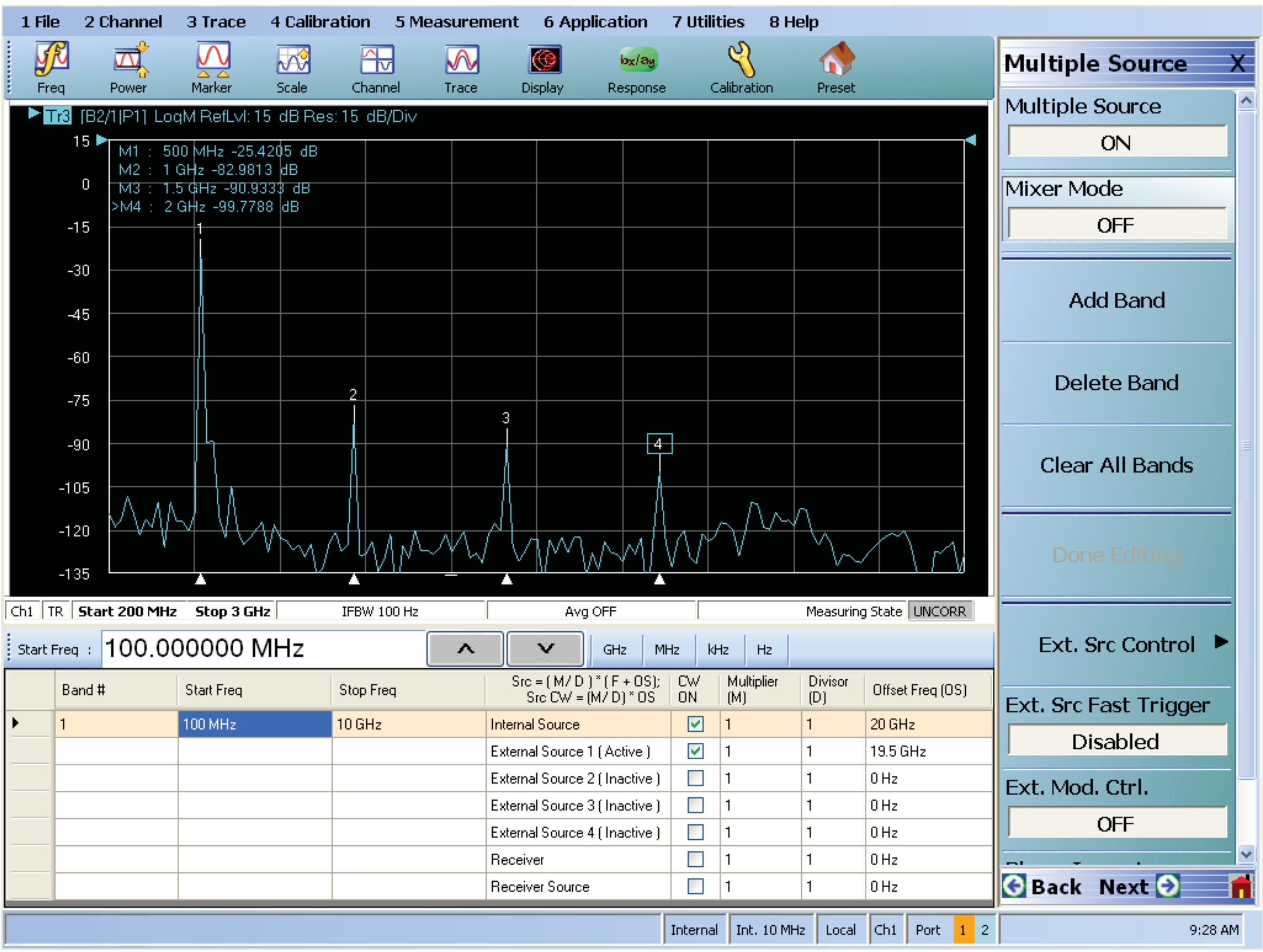
19-14 Final Topics

Final topics for this chapter are some ancillary measurements.

Spurs

The MS464XX can be used as a spectrum monitor to scan for spurious products of the mixer. This is most easily done with multiple source control (see Chapter 17, "Multiple Source Control (Option 007)") with the input source and LO usually set to some CW frequencies and the receiver allowed to sweep over a range of interest to look for spurious products on the LO. The unratioed test channel is often used as a monitor and a receiver calibration can be applied to get an absolute signal level for those spurious products. An example setup is shown in Figure 19-22 where the source is parked at 20 GHz and LO at 19.5GHz. The desired IF is 0.5 GHz but we can sweep over a wider range to look for products and the result is shown in the figure as well.

In this particular case (and with the sweep resolution used here), the dominant spurs are all harmonics of the IF. Using the previous nomenclature, they are of the form N × (Input – LO) and they are all at least 55 dB below the desired IF. With a different sweep range and point density, other spurs might have been found so it does help to work out the frequency plan in advance where likely spurs might reside.



A multiple source setup to look for spurious products on an example DUT is shown here. The plot shows the products measured,

Figure 19-22. Multiple Source Setup – Search for Spurious Products

One does have to exercise some caution in interpreting these results since the VNA receiver is not pre-selected and there may be internally generated spurs as well. In addition, the internal converters have an image located (usually) 24.7 MHz above the programmed frequency (at certain frequencies below 50 MHz, the offset is slightly larger). It usually pays to back calculate the product orders to see if they make sense for the DUT's frequency plan.

IMD

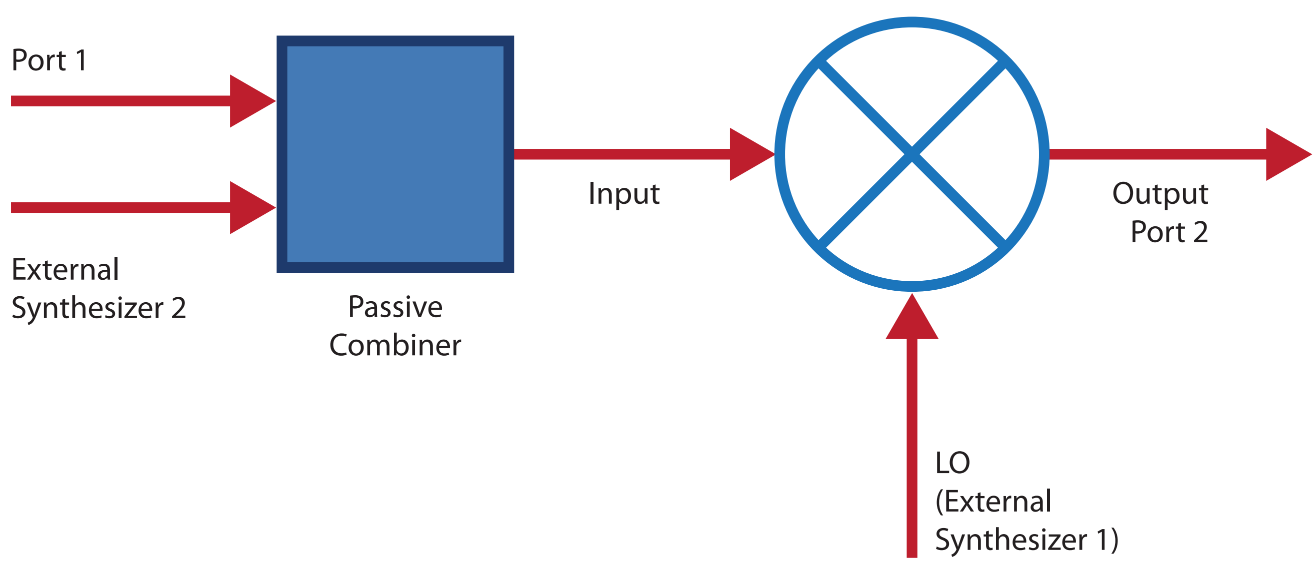
Using multiple source control again and two external synthesizers, it is quite easy to configure an IMD measurement. The measurement concept is covered in more detail elsewhere but the basic idea is to apply two closely spaced sinusoids to the input of the DUT (at frequency f1 and f2) and examine the third order products at the output as shown in Equation 19-3 below:

$$|\mathrm{LO} \pm (2 \times f_2 - f_1)|$$
$$|\mathrm{LO} \pm (2 \times f_1 - f_2)|$$

(Eq. 19-3)

The setup is shown in Figure 19-23 and the multiple source configuration is shown in Figure 19-24, "Example of Multiple Source Setup For CW Mixer IMD Measurement" on page 19-30 below.

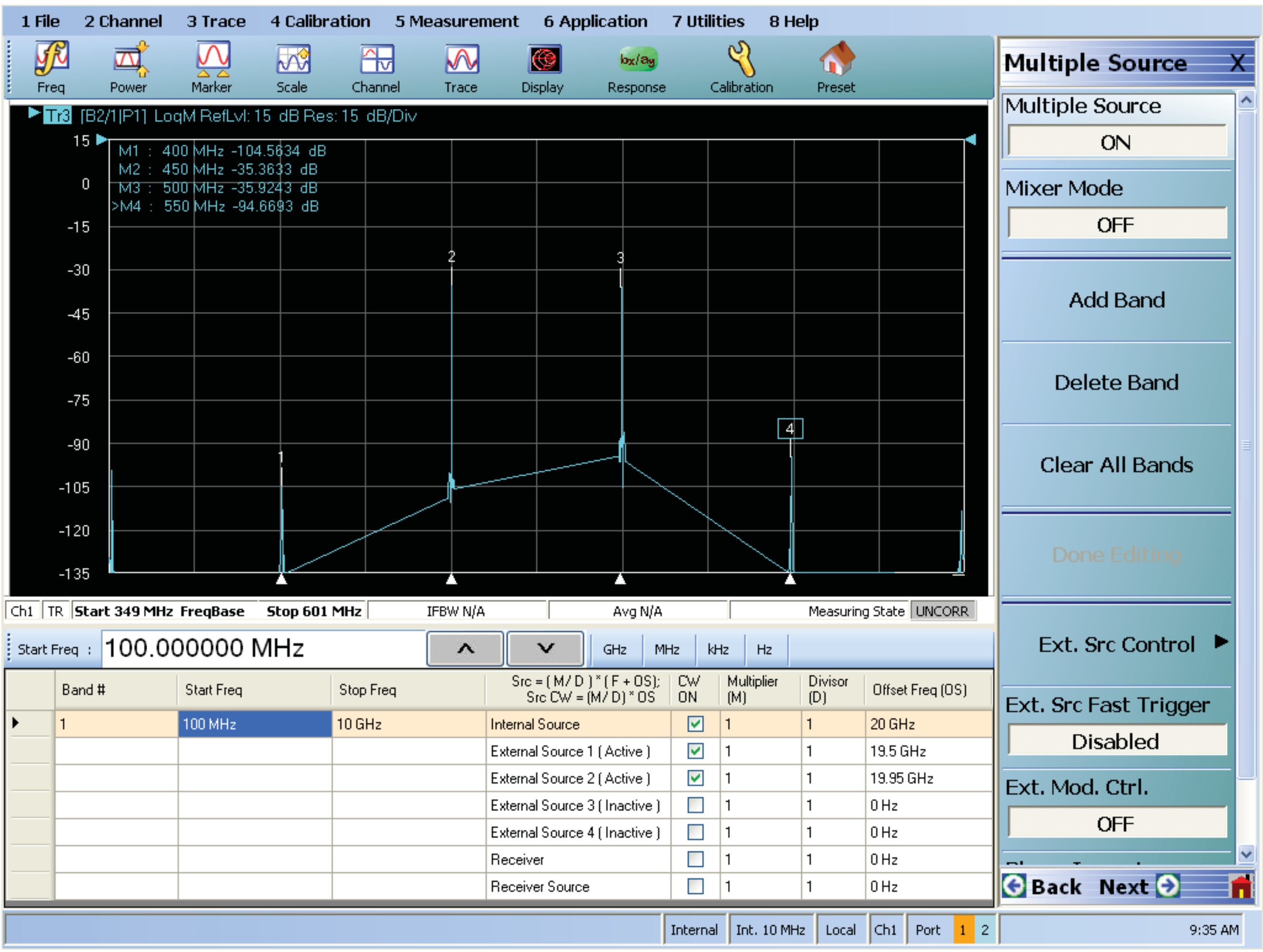
Typically b2/1 is the response variable and the measurement can be constructed to be CW (to look like a spectrum analyzer output) or swept to reveal the IMD product magnitude vs. frequency (in either dBc or dBm terms). The CW-measurement is illustrated in Figure 19-23 below where the sources are kept fixed and the receiver is allowed to move over the range of interest.



A simplified setup for mixer IMD is shown here.

Figure 19-23. Mixer Setup for IMD Measurement

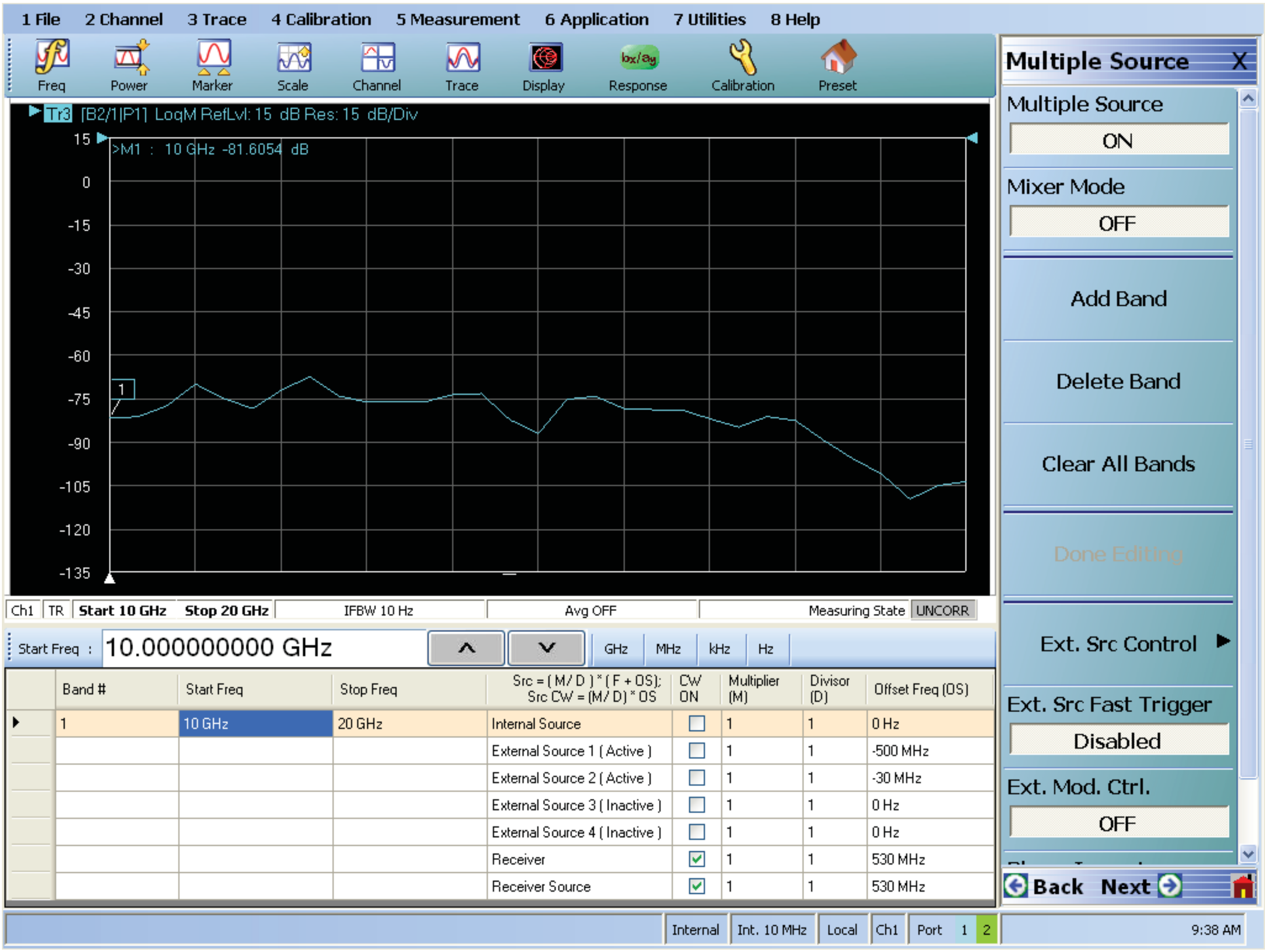
A segmented sweep setup was used in Figure 19-24 with 11 points (spaced by 200 kHz in this case) around the main tones (a 50 MHz tone offset was chosen), the 3rd order products and the 5th order products. This can optimize measurement time by not measuring frequencies that are not of interest and it allows one to measure quickly when at the main tones (large signals) and in a narrower IFBW when measuring the products (since they may be close to the noise floor). External synthesizer 2 was used to create the 2nd tone and its amplitude was adjusted to make the main tone levels approximately equal although other values could be chosen. In this example, the upper and lower products are not symmetric which may be an indication of bias network interaction within the DUT, compressive behavior in parts of the DUT, or other memory effects.



A multiple source setup for an example CW mixer IMD measurement is shown here.

Figure 19-24. Example of Multiple Source Setup For CW Mixer IMD Measurement

The swept measurement is shown in Figure 19-25 where the LO is fixed but the two source-like synthesizers are sweeping along with the receiver. In this case the tone offset was chosen to be 30 MHz. The only practical limit (outside of DUT bandwidth) is that very small offsets may incur a noise penalty and the synthesizer noise skirts start to interact. This normally does not happen until below 1 MHz offset depending on the synthesizers being used. The receiver is kept locked onto the upper IMD product in this case. Here just a receiver calibration was used so the readout is the product in absolute power terms (dBm). By doing a sweep with the receiver at a main tone (470 or 500 MHz in this case) and doing a trace(/)memory normalization, one could then measure the product in relative (dBc) terms.



An example swept mixer IMD measurement is shown here.

Figure 19-25. Example of Swept Mixer IMD Measurement

Chapter 20 — NxN Application

20-1 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 non-coaxial/non-waveguide).

20-2 Introduction

This section provides a brief overview of the NxN method and how the application within the MS4640A Series VNA 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 20-1. Device 2 is required to be reciprocal.

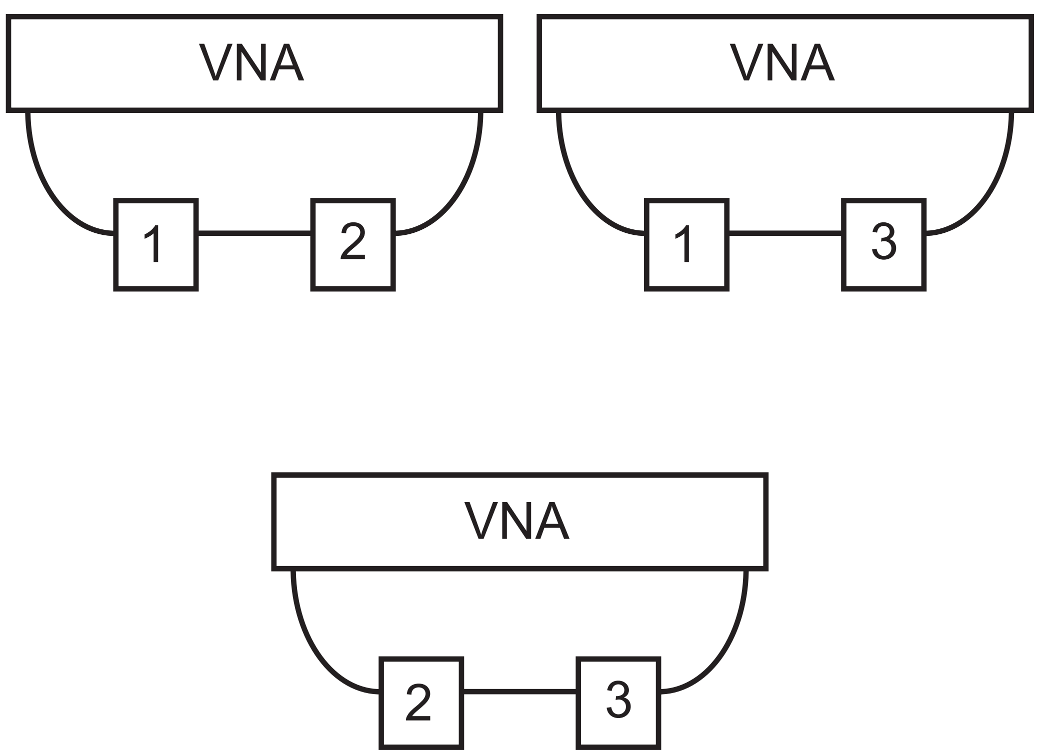


Figure 20-1. NxN Technique Measurements

If the devices are non-translating, few precautions are needed. If the loss of the devices gets high relative to the dynamic range of the VNA (in whatever state it is being used), then accuracy will be degraded. Normally a full 2-Port calibration is performed on the VNA (so that outbound matches can be corrected) but simple normalization calibrations can be adequate. Note that the inner matches cannot be corrected (since no access is available) hence match is not an extracted parameter. Full s2p files will be generated for the devices but S_{11} and S_{22} will be set to zero.

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 20-2. 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.

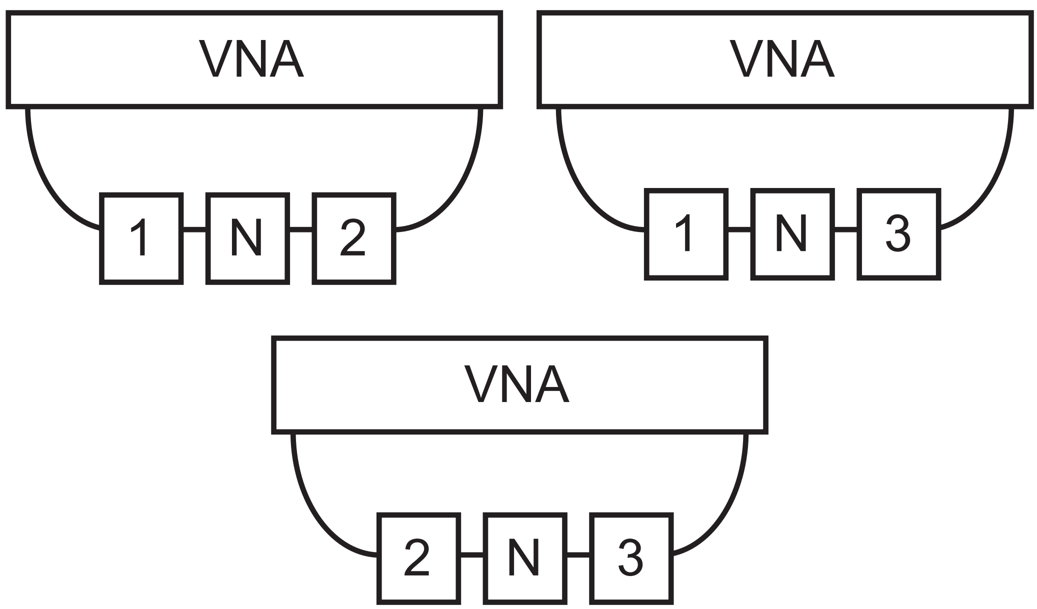


Figure 20-2. NxN Measurement Setup (using an inner network N)

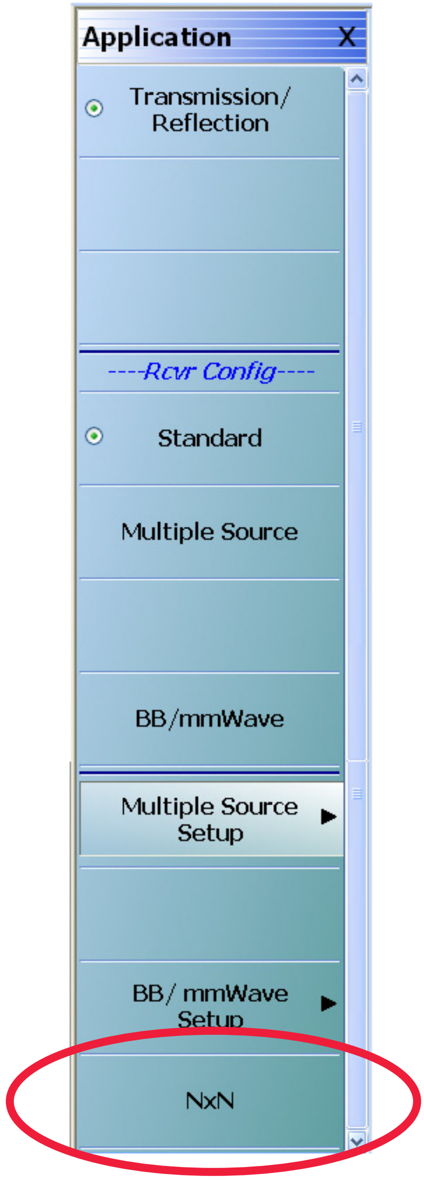
NxN is a popular mixer technique since the VNA sees the same input and output frequencies. Thus normal calibrations can be used, no frequency offsets are needed and there are no reference complications. The first device in each pair will be used as an up converter or down converter and the second device 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 20-2) 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.

20-3 Using the NxN Application

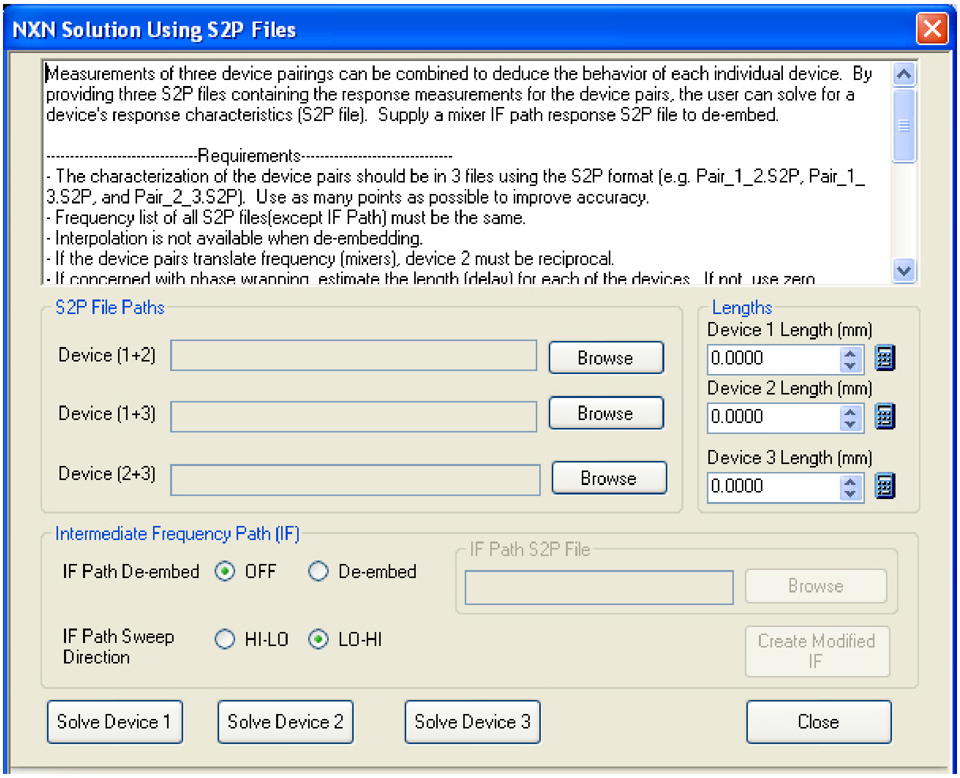
The NxN application is started from the APPLICATION menu as shown in Figure 20-3.



The APPLICATION menu appearance varies depending on the instrument model and installed options. See Figure 17-1, "APPLICATION Menu – Multiple Source Selections – MS4642A, MS4644A, and MS4645A" on page 17-2 for detailed menu appearance.

Figure 20-3. APPLICATION Menu - NXN Control Button

Selecting the NxN button will open the main NxN dialog as shown in Figure 20-4. The measurements shown in Figure 20-1 or Figure 20-2 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.



Main NXN Solution Using S2P Files Dialog

Figure 20-4. NXN SOLUTION USING S2P FILES Dialog Box

If the scheme of Figure 20-2 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 the information for one device 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.

Chapter 21 — Miscellaneous Features

21-1 Chapter Overview

This chapter provides information on other features available on the VectorStar MS4640A Series VNAs including frequency blanking.

21-2 Frequency Blanking

Frequency Blanking is typically used in secure environments to prevent frequency information from being displayed on the analyzer. When frequency blanking is activated, the display of all frequency information is changed from real value to “XXXX.”

Procedure

1. In normal operation, the frequency information is displayed at the bottom of the display area, and frequency values are displayed for each active marker.
   - Figure 21-1 shows a typical display with frequency information displayed for all markers.
   - At the bottom of the display area, not shown here, additional start and stop frequency information is displayed.

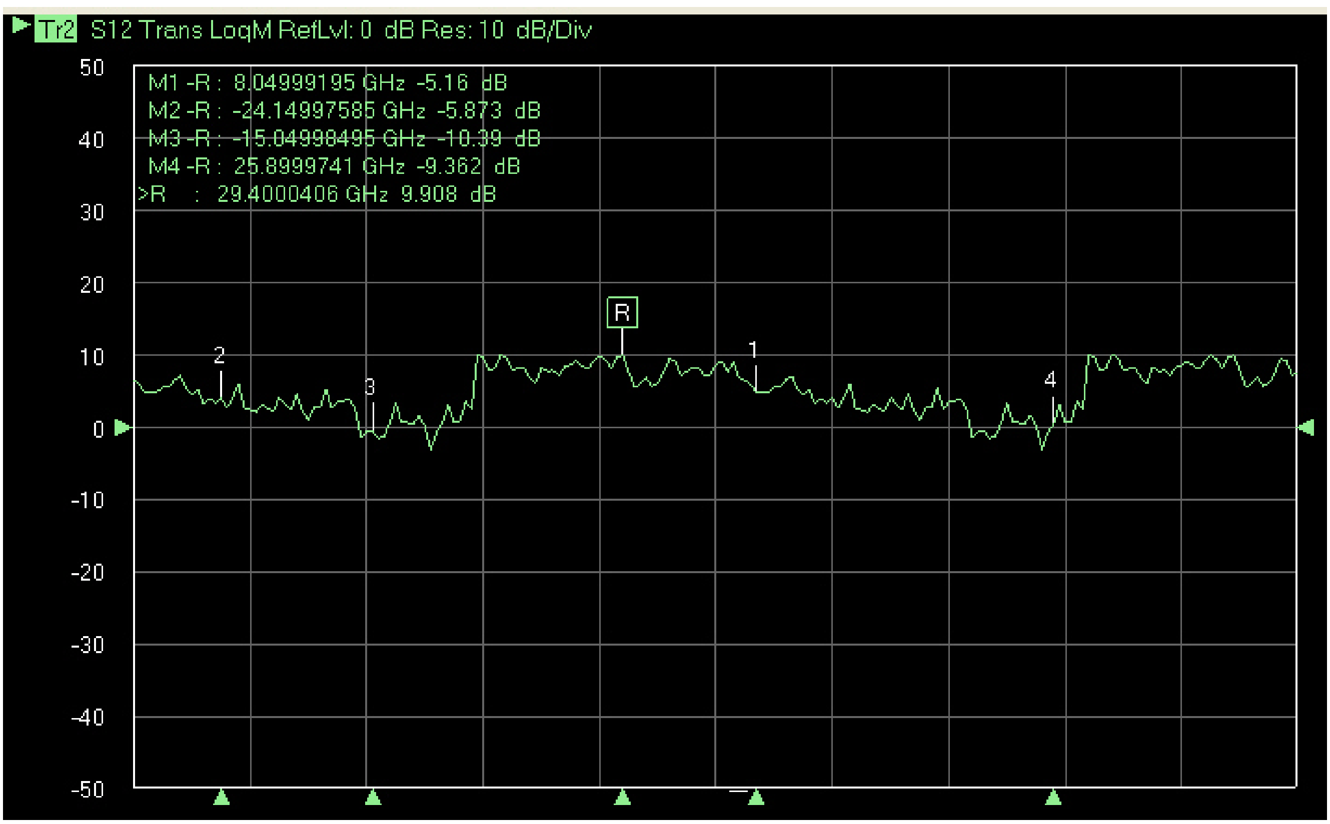


Figure 21-1. Typical Display Graph with Markers and Frequency Blanking Off)

2. A best practices recommendation is to save the current instrument setup configuration to a preset file.

- On the top menu bar, select File | Save and assign a unique name for the CAL file.
- Click Save.

3. To activate frequency blanking, from the Main Menu, select:

- System button | System menu | Utility button | Utility menu | Frequency Blanking toggle button.

4. Click the Frequency Blanking button to toggle the frequency display to Off.

- All frequency information is replaced with "XXXX".
- The Frequency Blanking button is now unavailable.

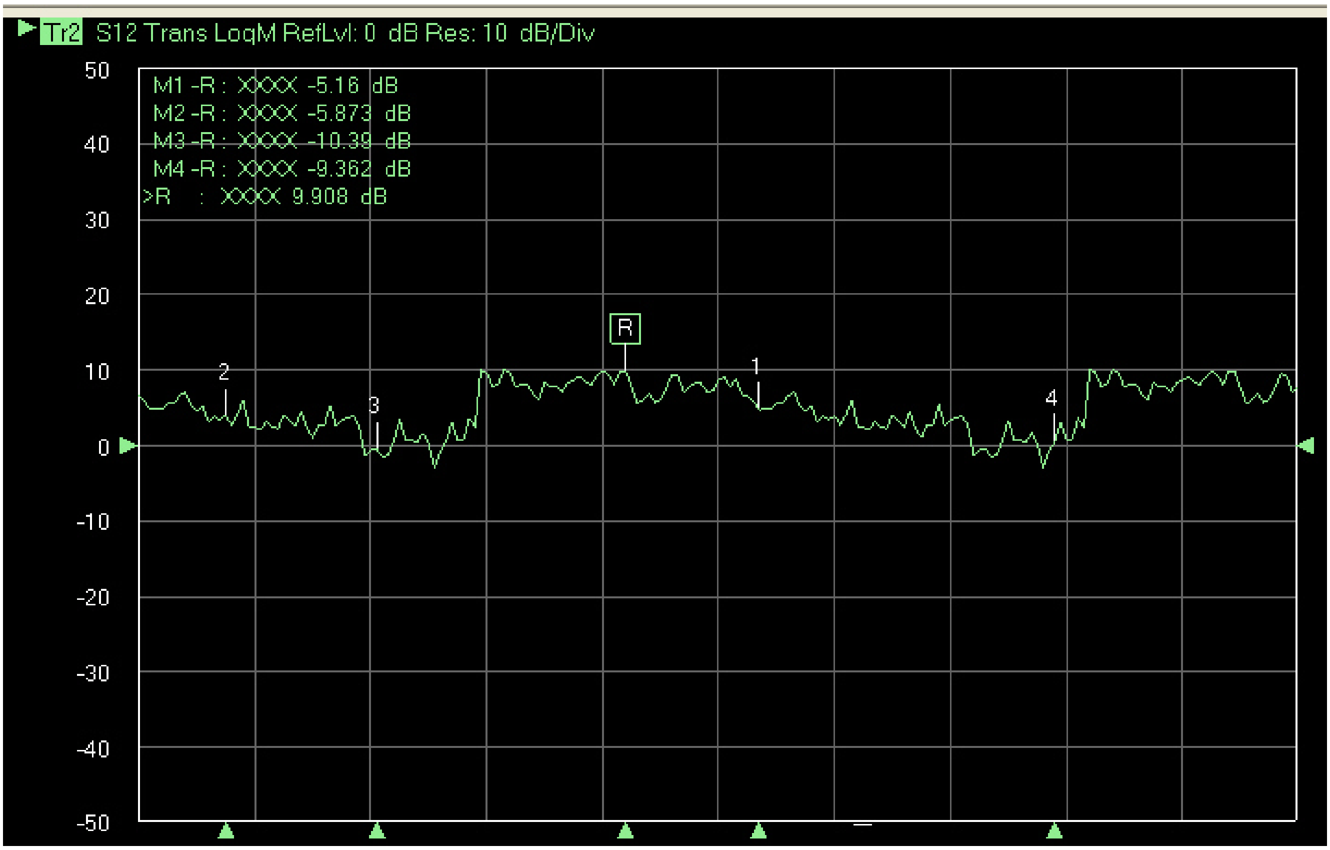


Figure 21-2. Typical Display Graph with Markers and Frequency Blanking On

5. To restore frequency information and set Frequency Blanking to Off, click the Preset icon on the icon toolbar.

- The instrument returns to its last saved preset configuration.

Chapter 22 — Multiport Measurements

22-1 Introduction to Multiport

The MN4690B Series Test Set, in conjunction with a MS4640A Series VNA, allows multiport measurements in an integrated context. The test set consists of a set of test couplers along with appropriate switching to use the source and receivers of the base VNA. The 1- to 4-Port measurements with this arrangement can satisfy many applications

- Balanced/differential device measurements
- Balanced to unbalanced device measurements (including baluns and other hybrids)
- General 3- and 4-Port microwave devices (such as splitters, hybrids, circulators, couplers, or distribution networks)
- Multiple measurements of one and two port devices for a fast, manufacturing test setup

The purpose of this chapter is to introduce the measurement setup (VNA + test set), some basic multiport S-parameter definitions, and how many of the measurement steps discussed earlier in this guide are generalized for the multiport scenario.

22-2 VectorStar VNA and Multiport Test Set

The VectorStar MN4694B Multiport Test Set provides coverage from 10 MHz (70 kHz if supported by the VNA) to 40 GHz and can be paired with the following VNAs equipped with K Connector Test Ports:

- MS4642A or MS4644A VNAs

The VectorStar MN4697B Multiport Test Set provides coverage from 10 MHz to 70 GHz and can be paired with the following VNAs equipped with V Connector Test Ports:

- MS4645A or MS4647A VNAs

Below, Figure 22-1 shows a VectorStar MN4697B 10 MHz (70 kHz if supported by the VNA) to 70 GHz Test Set paired with a MS4647A VNA.

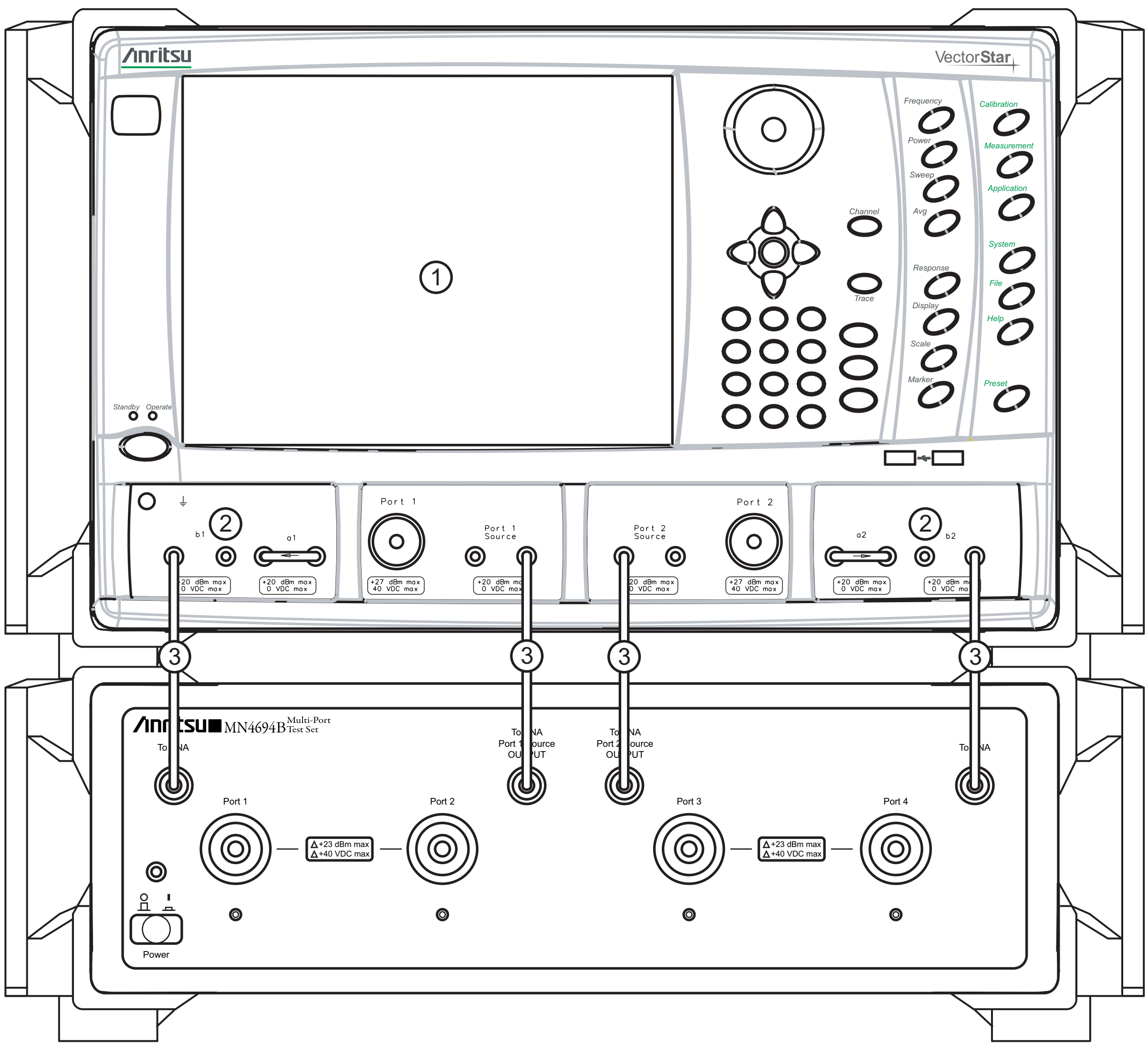
VectorStar MS4647A VNA, 10 MHz to 70 GHz, V Test Port Connectors (on top).	VectorStar MN4697B Multiport Test Set, 10 MHz to 70 GHz, V Test Port Connectors (on bottom).

Figure 22-1. VectorStar MN4697B Multiport Test Set and MS4647A Vector Network Analyzer

Cabling Connections

The front and rear panel setup configurations and system block diagrams are shown in the three figures below (Figure 22-2, Figure 22-3, and Figure 22-4). RF cables are required to link the source drive as well as the receivers. The receive path is split into two parts with some cabling on the rear panel and some on the front panel. Consult the following documents for detailed installation and cabling instructions:

- **VectorStar MN4690B Series Multiport VNA System Technical Data Sheet – 11410-00528**
- **VectorStar MN4690B Series Multiport Test Set Installation Guide – 10410-00288**
- **VectorStar MN4690B Series Multiport Test Set Quick Start Guide – 10410-00290**.



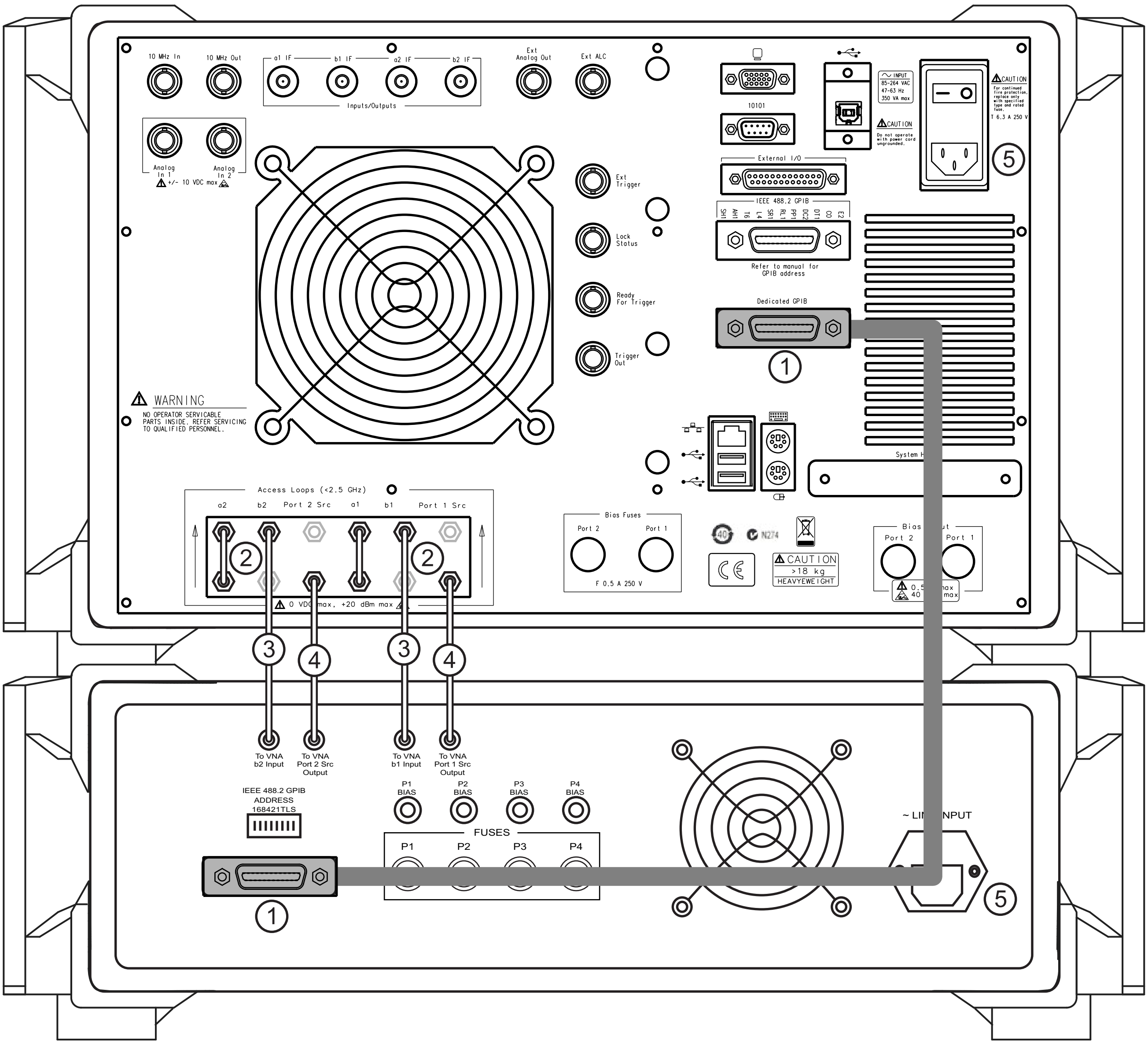
1.Install the VectorStar VNA on top of MN4690B Series Multiport Test Set.

2. Remove the VNA **b1** and **b2 test loops.**

3. Install four (4) provided RF (K m-m or V m-m) cables between the following port pairs:

- **To VNA b1** output port to VNA **b1** input port
- **To VNA Port 1 Source Output** port to VNA **Port 1 Source** output port
- **To VNA Port 2 Source Output** port to VNA **Port 2 Source** output port
- **To VNA b2** output port to VNA **b2** input port

Figure 22-2. MS4640A Series VNA and MN4690B Multiport Test Set Front Panel Interconnections



1. Connect GPIB cable between the Test Set **IEEE 488.2 GPIB** and the VNA **Dedicated GPIB** connectors.

2. Disconnect and set aside the four SMA (m-m) loops from VNA ports **Port 1 Src**, **b1**, **Port 2 Src**, and **b2**.

3. Connect two RF (SMA m-m) cables between the following port pairs:

- **To VNA b1 INPUT** output port to VNA **b1** input port.
- **To VNA b2 INPUT** output port to the VNA **b2** input port.

4. Connect two RF (SMA m-m) cables between the following port pairs:

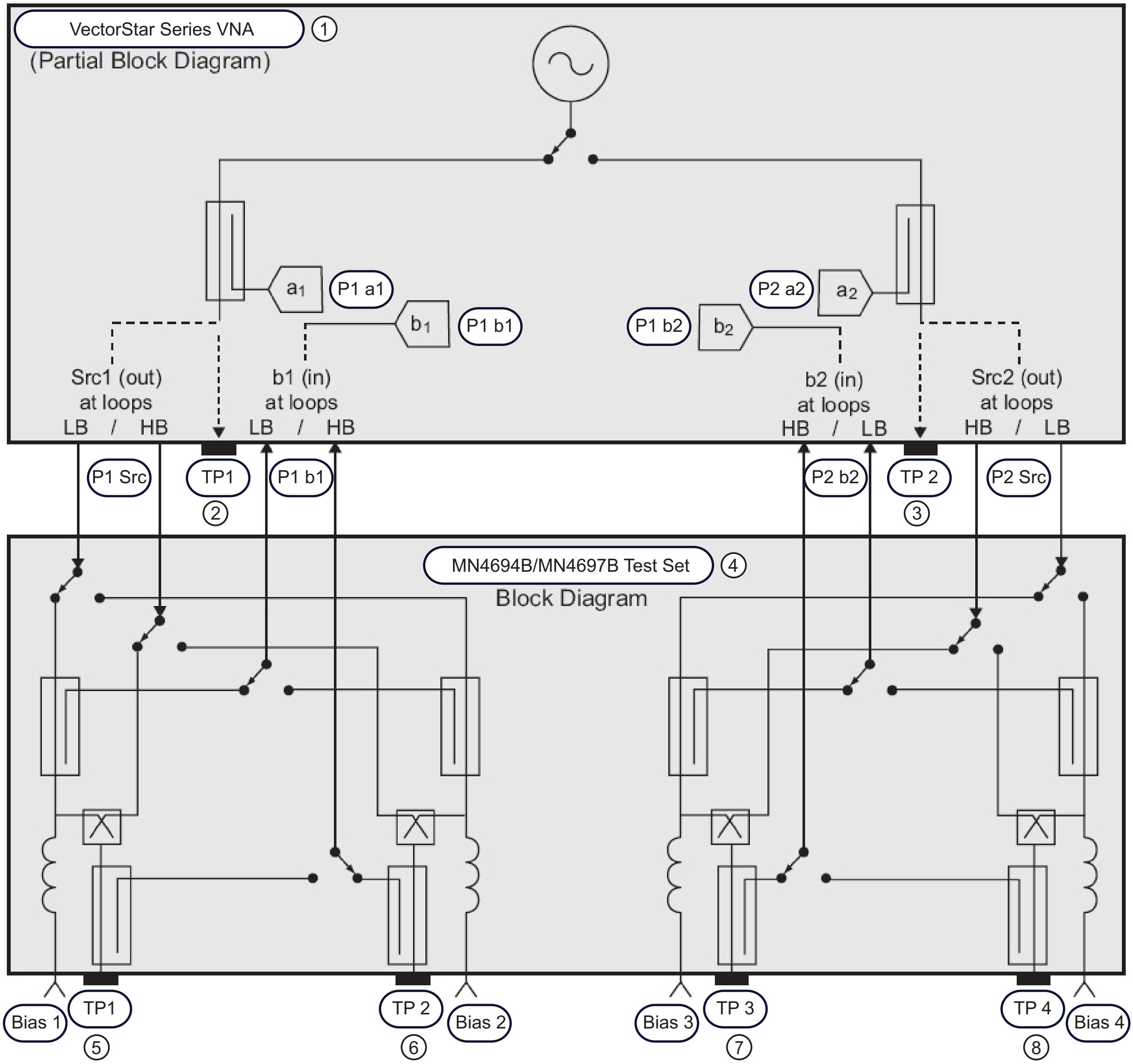
- **To VNA Port 1 Src OUTPUT** output port to VNA **Port 1 Src** output port.
- **To VNA Port 2 Src OUTPUT** output port to VNA **Port 2 Src** output port.

5. Connect AC Power Cords to the Test Set and VNA and then to AC Mains.

Figure 22-3. MS4640A Series VNA to MN4690B Multiport Test Set Rear Panel Connections

Architecture Block Diagram

Many architectures are possible (e.g., [1]) but this one was chosen for optimal high frequency performance.



The two VNA ports and the two test receivers are multiplexed to the four user ports for these measurements. The switches are of high isolation, low insertion loss, and high speed to allow for good performance even at 70 GHz.

1. VectorStar Series VNA
2. VNA Test Port 1, Port 1 Source, Port 1 a1, Port 1 b1
3. VNA Test Port 2, Port 1 a2, Port 2 b2
4. MN4692B/MN4697B Test Set
5. Test Set Port 1 and Bias Port 1
6. Test Set Port 2 and Bias Port 2
7. Test Set Port 3 and Bias Port 3
8. Test Set Port 4 and Bias Port 4

Figure 22-4. MN4690B Series Test Set Internal Block Diagram

Note	The VNA application must be started ***AFTER*** the Test Set is connected and powered up. If the VNA application is started before the Test Set, the VNA will remain in 2-Port mode and the 4-Port functions will not be available. If this happens, exit the VNA application by selecting **MENU BAR | File | Exit** and then in the dialog box, confirm the exit. The VNA application closes to the Windows desktop. For MS4640A Series VNAs only, if returning to 100,000 point mode, restart the VNA application by selecting: **Start | All Programs | VectorStar_100K | VectorStar**. For MS4640A Series VNAs, if returning to 25,000 point mode, restart the VNA application by selecting: **Start | All Programs | VectorStar | VectorStar**.

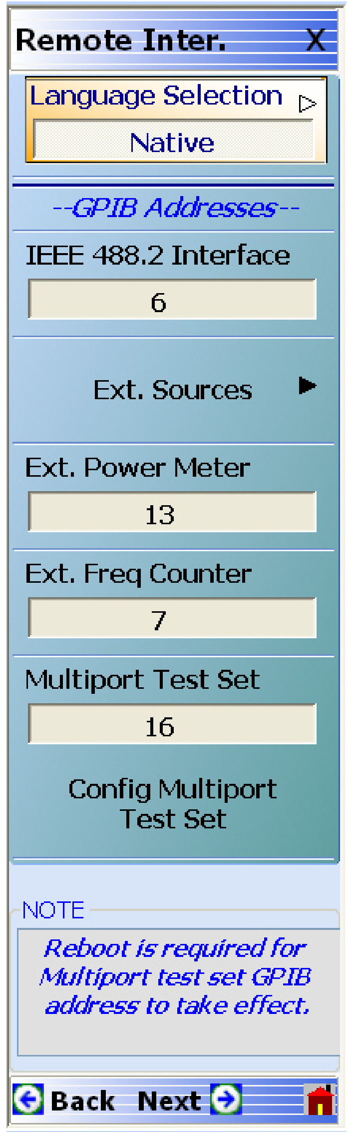
Changing Test Set GPIB Addresses

The MN4690B Series Test Set GPIB address must match the GPIB address set on the VNA (described immediately below) and is set by rear panel Dual-In-Line package switches (DIP-switches). The factory-default Test Set GPIB address is 16 (**Switch 1** ON and all other **switches** OFF) which matches the default VNA address setting. Consult the **VectorStar MN4690B Series Test Set Installation Guide – 10410-00288** for additional information on DIP Switch Settings.

Changing VNA Addresses for the Test Set

The default VNA GPIB address for the MN4690B Series Test Set is GPIB 16 and must match the address set on the Test Set rear panel DIP switches. To change the GPIB address on the VNA, navigate to the REMOTE INTER. (REMOTE INTERFACE) menu shown below (Figure 22-5) and select the Multiport Test Set button. Set the same GPIB address as set at the Test Set rear panel.

- MAIN | System | SYSTEM | Remote Interface | REMOTE INTER. | Multiport Test Set



The **REMOTE INTERFACE** menu contains the **External Test Set/Multiport Test Set** button which accesses the addressing and configuration dialog.

Figure 22-5. REMOTE INTER. (REMOTE INTERFACE) Menu

Power Up Sequence

When the VNA application starts, the GPIB bus is polled for the presence of the Test Set. If the test set is detected, the VNA enters multiport mode and the response, calibration, and certain other menus switch to those shown in this section. If the test set is not detected, the VNA application remains in the 2-Port mode discussed in earlier chapters.

Blocking Test Set Combinations

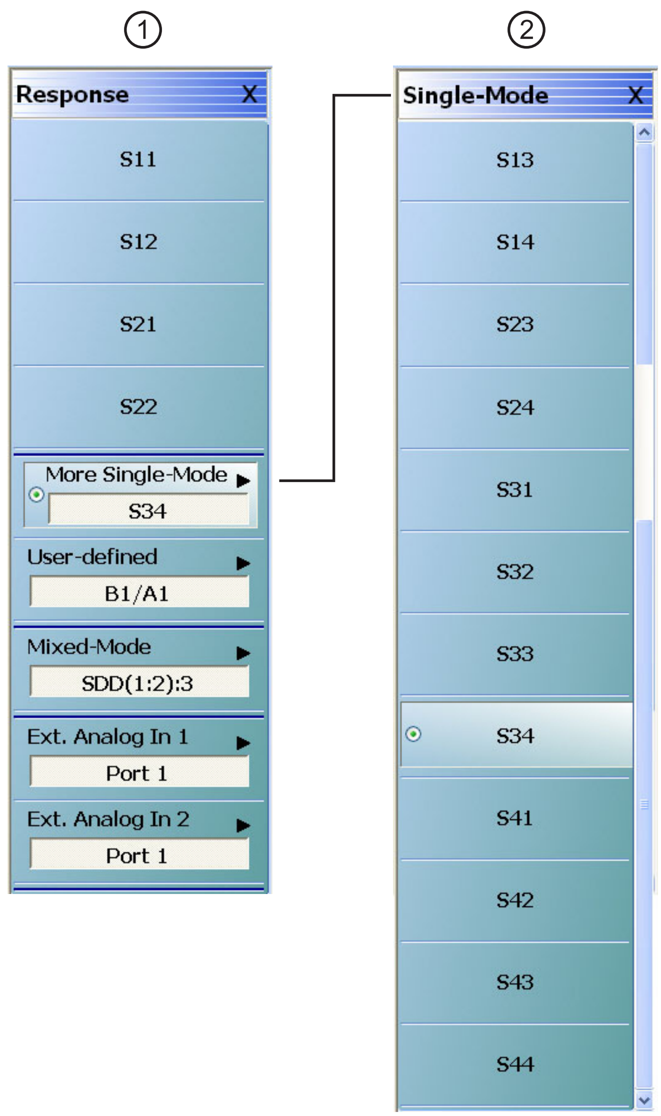
One may note that not every VNA port can be connected to every test set port (termed a blocking test set). All 16 4-Port S-parameters can be easily measured but not with an arbitrary setup. The VNA application handles all of these tasks automatically so this detail is normally invisible to the user. It does, however, have some impact on measurement time since there is a limitation on how many parameters can be measured during a sweep with a single switch configuration (for example, S_{11} and S_{21} at the 4-Port plane cannot be measured simultaneously). In those situations when multiple switch configurations are required, the VNA application will automatically handle those tasks.

22-3 Conventional (Single-Ended) S- and User-Defined Parameters

As might be expected, there are 16 possible S-parameters when measuring a 4-Port device as suggested by the defining Equation 22-1.

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} \tag{22-1}$$

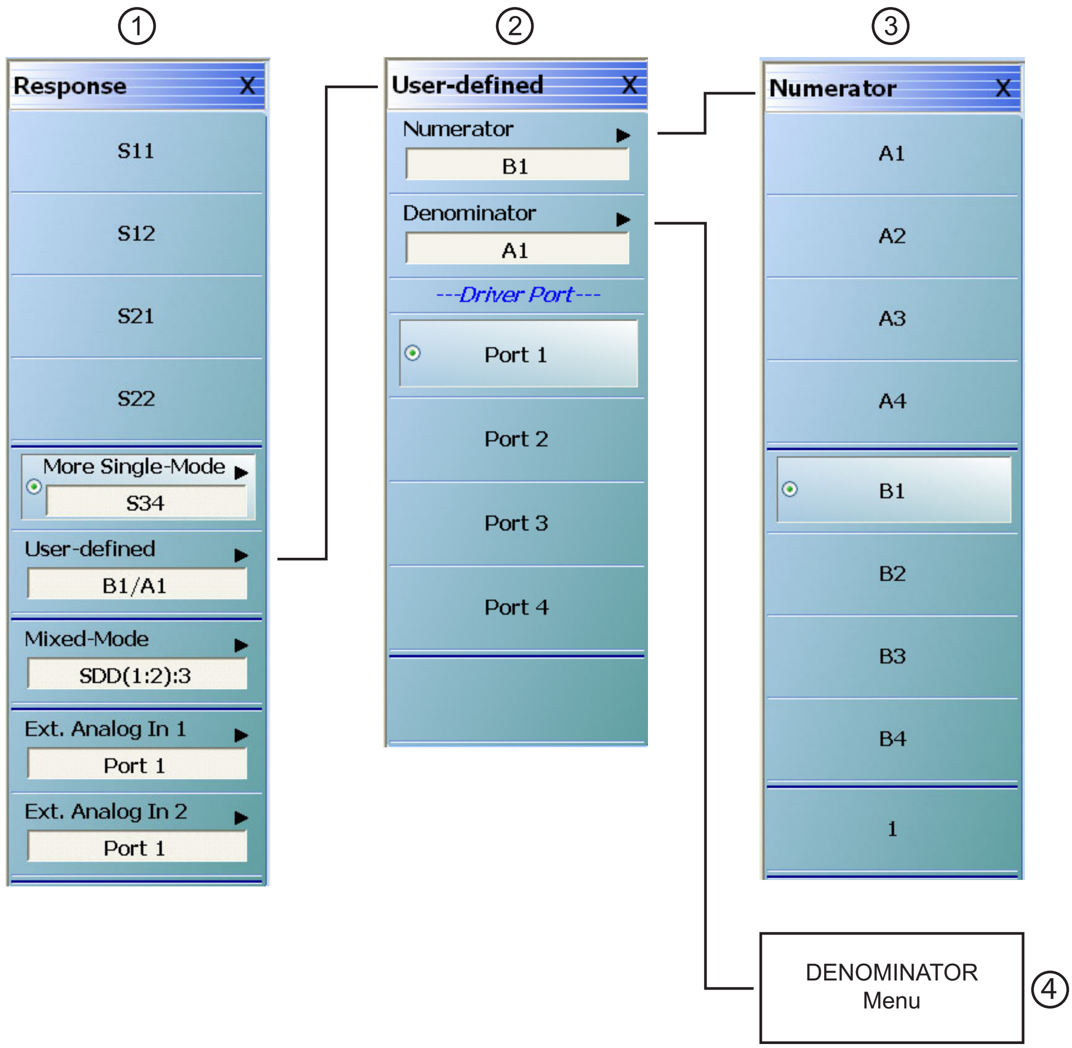
The primary RESPONSE menu and the SINGLE-MODE selection menu for the other standard S-parameters are shown below (Figure 22-6). Note that the parameters after the first four 2-Port S-parameters are contained on a submenu. All of the parameters are available regardless the calibration in place so obviously some parameters could be uncorrected depending on the calibration. The term “single-ended” is used here to denote conventional S-parameters. This is in contrast to “mixed mode” parameters which are explained in the next section. As in the two port system, the External Analog In selections are available and function the same as before.



1. The top-level 4-Port version of the **RESPONSE** menu is shown here. Buttons provide access to S-Parameters for S11, S12, S21, and S22. The **More Single-Mode** button displays the **SINGLE-MODE** sublevel menu.	2. The **SINGLE-MODE** menu provides S-Parameter selection from S13 to S44. The menu representation here is elongated, on an actual system there will be a scroll bar and not all parameters will be visible at once.

Figure 22-6. RESPONSE and SINGLE-MODE Menus

The expected user-defined parameters can be selected as suggested by the menus below (Figure 22-7). Note that any of the four ports may be defined as the driver (or sourcing) port. The allowed numerator and denominator values for user-defined are a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4,and 1 as suggested by the figure. Note that only the NUMERATOR menu is shown here for simplicity, the DENOMINATOR menu has the same selections.



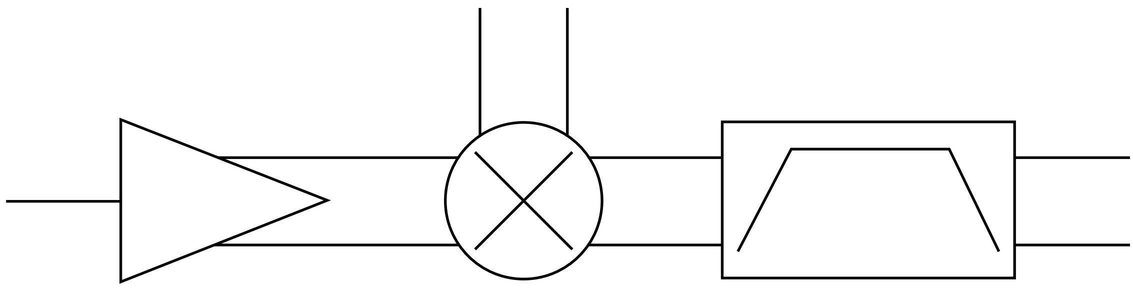
1. The 4-Port version of the **RESPONSE** menu and the submenus linking from the **User-Defined** button. 2. On the lower level of the **USER-DEFINED** response submenu (at center), any one of the four ports may be sourcing RF power as the “driver” port. On the upper level of the **USER-DEFINED** menu, selections are made for the numerator and denominator values of user-defined parameter.	3. The **NUMERATOR** menu (at upper right) menu for user-defined parameters is a submenu to the **USER-DEFINED** menu. 4. The equivalent **DENOMINATOR** menu (at lower right) is not shown.

Figure 22-7. RESPONSE, USER-DEFINED, and NUMERATOR Menus

When a channel is constructed of many traces measuring these parameters, the system will determine the optimal sweep combination to get at all of the required measurements as discussed earlier. The measurement time can be difficult to predict since there are a large number of possible combinations and the test set is partially blocking. Considering again the block diagram of Figure 22-4, $S1x$ and $S2x$ cannot be measured simultaneously nor can $S3x$ and $S4x$. When those pairs (or equivalent b_i measurements) are present in a given channel, extra switching and time will be required. The switching was kept simplified to maintain low insertion loss in the test set at the higher microwave frequencies.

22-4 Mixed-Mode Parameters

The reader will have noted another submenu in the response category that describes mixed-mode parameters. One is likely familiar with the concept of a differential amplifier and the general concepts of differential and common-mode signals [2] as suggested by Figure 22-8. It is clear that it may be useful to represent S-parameter data in a form corresponding to differential drive/reception (and similarly for common-mode). Such a formulation has been developed in the past (e.g., [1]-[4]). The purpose of this section is to describe and define this representation, provide some hints on data interpretation along with explaining how to setup the desired responses.

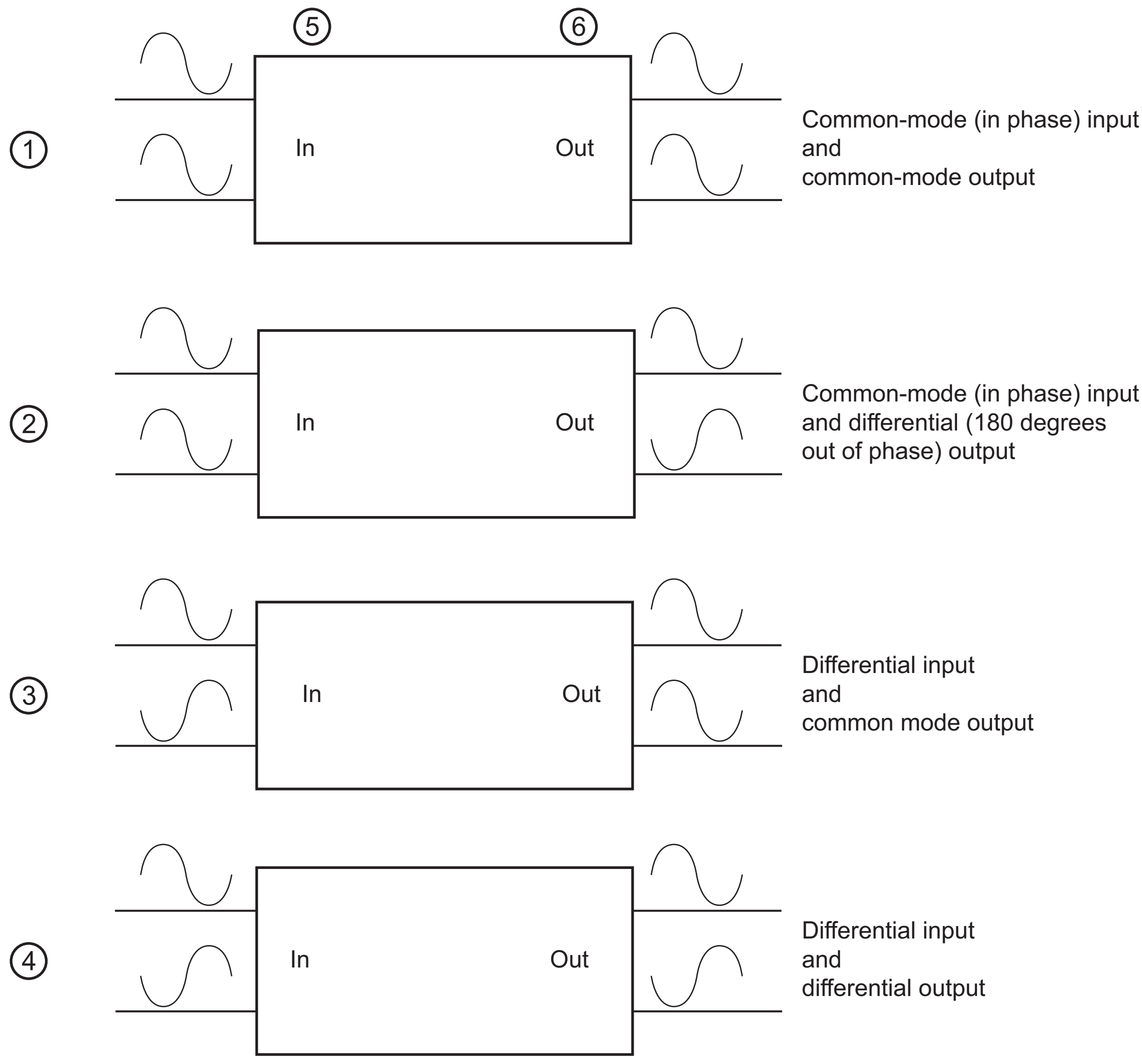


A portion of a common communications circuit is shown here where a number of components are driven differentially. It is of obvious interest to characterize these parts in terms of differential and common mode signals.

Figure 22-8. Characterizing Differentially Driven Components

The concept here is one of a pair of ports being driven at a time, either in-phase (common mode drive) or 180 degrees out of phase (differential drive). Similarly, we are interested in the received signal in a port pair context: what is the common-mode (in-phase) signal received and what is the differential signal received. In contrast to the single-ended drive and single-ended receive types of parameters are conventionally used, these parameters represent a transformation of the data.

This combined signal drive concept can also be explained pictorially. Each pair (either 1-2 or 3-4) can be driven either in phase (common mode drive) or 180 degrees out of phase (differential drive). For the transformation, it is convenient to group together single ended ports 1 and 2 together as the new Port 1 (which can be driven differentially, common-mode, or some combination). Similarly, single ended Ports 3 and 4 will be grouped as the new Port 2 (same idea: differential, common-mode, or combination). Thus the new basis is to think of a port pair as being driven in phase or 180 degrees out of phase (instead of thinking of each port of the pair being driven individually). The new input and output bases are illustrated below (Figure 22-9). The reader may recognize this as a simple shift in basis, which can be thought of as a 45 degree rotation.



The new basis for analyzing mixed-mode S-parameters are shown here. With the physical ports considered as pairs, one can analyze in terms of common-mode and differential drive and common-mode and differential output. 1. Common-mode (in phase) input and common-mode output.	2. Common-mode (in phase) input and differential (180 degrees out-of-phase) output. 3. Differential input and common-mode output. 4. Differential input and differential output. 5. Input Side (at left). 6. Output Side (at right)

Figure 22-9. Analyzing Mixed-Mode S-Parameters

A common question is whether these ports need to be driven with pure differential and common-mode signals or whether the same result can be achieved by mathematical superposition of single-ended signals. With certain assumptions on linearity, the answer is yes and the derivation will be presented next. The only practical requirement is that the bulk of any strong non-linearity be after the first differential stage or that there is reasonable common-mode to differential isolation (e.g., [5]-[6]) which is true for many devices even when gain compression is being measured.

The next step is to construct S-parameters for this type of input/output. The possible incident waveforms can be deduced from Figure 22-9 above:

- differential on the new Port 1
- common-mode on Port 1
- differential on Port 2
- common-mode on Port 2

The output waves will have the some structure which leads to the S-parameter matrix structure depicted in Eq. 22-2.

$$\begin{bmatrix} b_{d1} \\ b_{d2} \\ b_{c1} \\ b_{c2} \end{bmatrix} = \begin{bmatrix} S_{d1d1} & S_{d1d2} & S_{d1c1} & S_{d1c2} \\ S_{d2d1} & S_{d2d2} & S_{d2c1} & S_{d2c2} \\ S_{c1d1} & S_{c1d2} & S_{c1c1} & S_{c1c2} \\ S_{c2d1} & S_{c2d2} & S_{c2c1} & S_{c2c2} \end{bmatrix} \begin{bmatrix} a_{d1} \\ a_{d2} \\ a_{c1} \\ a_{c2} \end{bmatrix} = \begin{bmatrix} S_{dd} & S_{dc} \\ S_{cd} & S_{cc} \end{bmatrix} \begin{bmatrix} a_{d1} \\ a_{d2} \\ a_{c1} \\ a_{c2} \end{bmatrix} \tag{22-2}$$

Here the four S blocks in the square matrix to the right are actually submatrices [2]. S_{dd} corresponds to the four purely differential S-parameters while S_{cc} corresponds to the four purely common-mode parameters. The other two quadrants cover the mode-conversion terms. These are expanded in the center part of Eq. 2. The matrix equation can be interpreted as expressing an output wave b_i in terms of the four possible input waves a_{d1}, a_{d2}, a_{c1}, and a_{c2}. An example of one of these sub-equations is shown below.

$$b_{d1} = S_{d1d1}a_{d1} + S_{d1d2}a_{d2} + S_{d1c1}a_{c1} + S_{d1c2}a_{c2} \tag{22-3}$$

It is straightforward to write the relationships between the single-ended incident and reflected waves and the new balanced versions. To simplify the presentation, the next set of equations will assume port pair 1 is composed of physical ports 1 and 2 while port pair 2 is composed of physical ports 3 and 4. We will show a means of generalizing this construction later. The difference and sum choices are obvious for differential and common-mode waves, respectively, and all else that is needed is a normalization factor to keep power levels equivalent.

$$
\begin{aligned}
a_{d1} &= \frac{1}{\sqrt{2}}(a_1 - a_2) \\
a_{c1} &= \frac{1}{\sqrt{2}}(a_1 + a_2) \\
a_{d2} &= \frac{1}{\sqrt{2}}(a_3 - a_4) \\
a_{c2} &= \frac{1}{\sqrt{2}}(a_3 + a_4) \\
b_{d1} &= \frac{1}{\sqrt{2}}(b_1 - b_2) \\
b_{c1} &= \frac{1}{\sqrt{2}}(b_1 + b_2) \\
b_{d2} &= \frac{1}{\sqrt{2}}(b_3 - b_4) \\
b_{c2} &= \frac{1}{\sqrt{2}}(b_3 + b_4)
\end{aligned}
\tag{22-4}
$$

This linear combination of single-ended wave functions makes the transformation particularly transparent. One can define a simple transformation matrix to operate on single ended S-parameters to produce the mixed-mode S-parameters that are shown below. The parameters are grouped by the quadrants labeled in Eq. 22-2.

The differential-to-differential terms:.

$$
\begin{aligned}
S_{d1d1} &= \frac{1}{2}(S_{11} - S_{21} - S_{12} + S_{22}) \\
S_{d1d2} &= \frac{1}{2}(S_{13} - S_{23} - S_{14} + S_{24}) \\
S_{d2d1} &= \frac{1}{2}(S_{31} - S_{41} - S_{32} + S_{42}) \\
S_{d2d2} &= \frac{1}{2}(S_{33} - S_{43} - S_{34} + S_{44})
\end{aligned}
\tag{22-5}
$$

The common mode-to-common mode terms:

$$S_{c1c1} = \frac{1}{2}\left(S_{11} + S_{21} + S_{12} + S_{22}\right)$$
$$S_{c1c2} = \frac{1}{2}\left(S_{13} + S_{23} + S_{14} + S_{24}\right)$$
$$S_{c2c1} = \frac{1}{2}\left(S_{31} + S_{41} + S_{32} + S_{42}\right)$$
$$S_{c2c2} = \frac{1}{2}\left(S_{33} + S_{43} + S_{34} + S_{44}\right) \quad \text{(22-6)}$$

The common mode-to-differential terms:

$$S_{d1c1} = \frac{1}{2}\left(S_{11} - S_{21} + S_{12} - S_{22}\right)$$
$$S_{d1c2} = \frac{1}{2}\left(S_{13} - S_{23} + S_{14} - S_{24}\right)$$
$$S_{d2c1} = \frac{1}{2}\left(S_{31} - S_{41} + S_{32} - S_{42}\right)$$
$$S_{d2c2} = \frac{1}{2}\left(S_{33} - S_{43} + S_{34} - S_{44}\right) \quad \text{(22-7)}$$

and the differential-to-common mode terms:

$$S_{c1d1} = \frac{1}{2}\left(S_{11} + S_{21} - S_{12} - S_{22}\right)$$
$$S_{c1d2} = \frac{1}{2}\left(S_{13} + S_{23} - S_{14} - S_{24}\right)$$
$$S_{c2d1} = \frac{1}{2}\left(S_{31} + S_{41} - S_{32} - S_{42}\right)$$
$$S_{c2d2} = \frac{1}{2}\left(S_{33} + S_{43} - S_{34} - S_{44}\right) \quad \text{(22-8)}$$

The simple linear relationship between the parameters should be evident. Just to reinforce the interpretation of these parameters: S_{d2d1} is the differential output from composite port 2 (the old ports 3 and 4) ratioed against a differential drive into composite port 1 (the old ports 1 and 2). Similarly S_{c2c2} would be the common-mode reflection off of composite port 2 ratioed against the common-mode signal applied to composite port 2.

MIXED MODE Dialog Box

The dialog for selecting a mixed mode parameter in this sense is shown in Figure 22-10.

- MAIN | Response | RESPONSE | Mixed-Mode | MIXED MODE Dialog Box

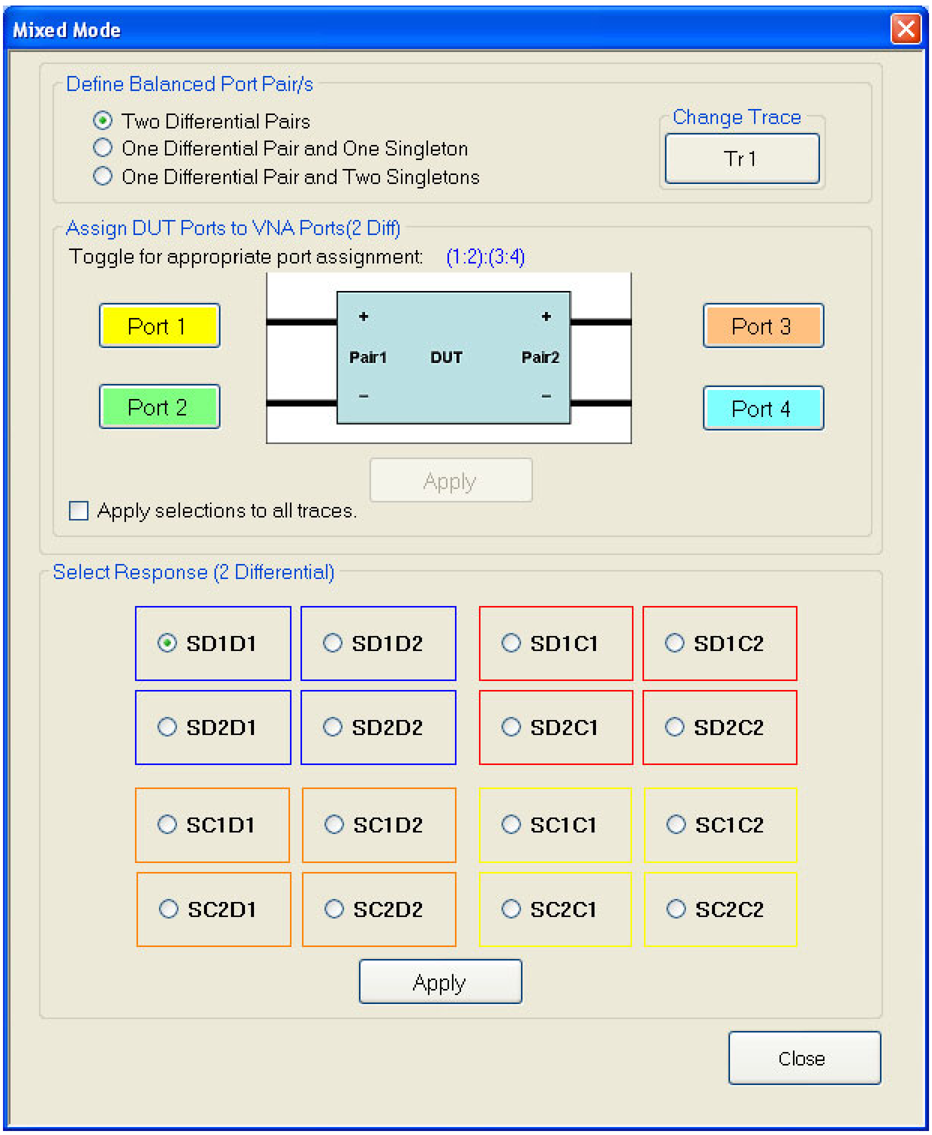
Aside from selecting among the 16 parameters described above, there is also the matter of defining the port pairs. This is accomplished in the middle part of the dialog and note that there is a polarity sense assigned to the pairing (determines the sign of the differential signals). When displaying the parameters, this port assignment must also be conveyed and is done with the following symbolism:

- (A:B):(C:D) (where A, B, C, and D are unique port numbers from {1,2,3,4})

Here, the first port pair is A-B (with A assigned the positive polarity) and the second port pair is C-D (with C assigned the positive polarity).

For example:

- (1:2):(3:4) The first port pair is measured from 1 to 2 and the second port pair is measured from 3 to 4.
- (1:2):(4:3) The first port pair is measured from 1 to 2 and the second port pair is measured from 4 to 3.



The dialog for selecting mixed-mode parameters, configured for two differential pairs, is shown here. The instrument defaults to the SD1D1 response.

Figure 22-10. MIXED MODE Two Differential Pairs Dialog Box

The 3-Port version of these mixed-mode parameters is a straightforward simplification. Port X will remain single ended while ports Y and Z will form a balanced port pair. Following the analysis path from before:

$$\begin{bmatrix} b_x \\ b_d \\ b_c \end{bmatrix} = \begin{bmatrix} S_{xx} & S_{xd} & S_{xc} \\ S_{dx} & S_{dd} & S_{dc} \\ S_{cx} & S_{cd} & S_{cc} \end{bmatrix} \begin{bmatrix} a_x \\ a_d \\ a_c \end{bmatrix} \tag{22-9}$$

$$\begin{aligned} a_d &= \frac{1}{\sqrt{2}}(a_y - a_z) \\ a_c &= \frac{1}{\sqrt{2}}(a_y + a_z) \\ b_d &= \frac{1}{\sqrt{2}}(b_y - b_z) \\ b_c &= \frac{1}{\sqrt{2}}(b_y + b_z) \end{aligned} \tag{22-10}$$

$$\begin{aligned} S_{xd} &= \frac{1}{\sqrt{2}}(S_{xy} - S_{xz}) \\ S_{xc} &= \frac{1}{\sqrt{2}}(S_{xy} + S_{xz}) \\ S_{dx} &= \frac{1}{\sqrt{2}}(S_{yx} - S_{zx}) \\ S_{cx} &= \frac{1}{\sqrt{2}}(S_{yx} + S_{zx}) \\ S_{dd} &= \frac{1}{2}(S_{yy} - S_{yz} - S_{zy} - S_{zz}) \\ S_{cc} &= \frac{1}{2}(S_{yy} + S_{yz} + S_{zy} + S_{zz}) \\ S_{dc} &= \frac{1}{2}(S_{yy} + S_{yz} - S_{zy} - S_{zz}) \\ S_{cd} &= \frac{1}{2}(S_{yy} - S_{yz} + S_{zy} - S_{zz}) \end{aligned} \tag{22-11}$$

In Equation Group 11 (Eq. 22-11, the subscript *x* remains since that port is defined solely as a single-ended port.

The three port configuration is termed a differential pair and a singleton and the dialog for selecting this type of parameter is shown in Figure 22-11. Note that one can define this parameter class even if a 4-Port calibration is applied; it is a matter of port assignment. As with the dual differential case, the ports must be assigned with polarity in mind.

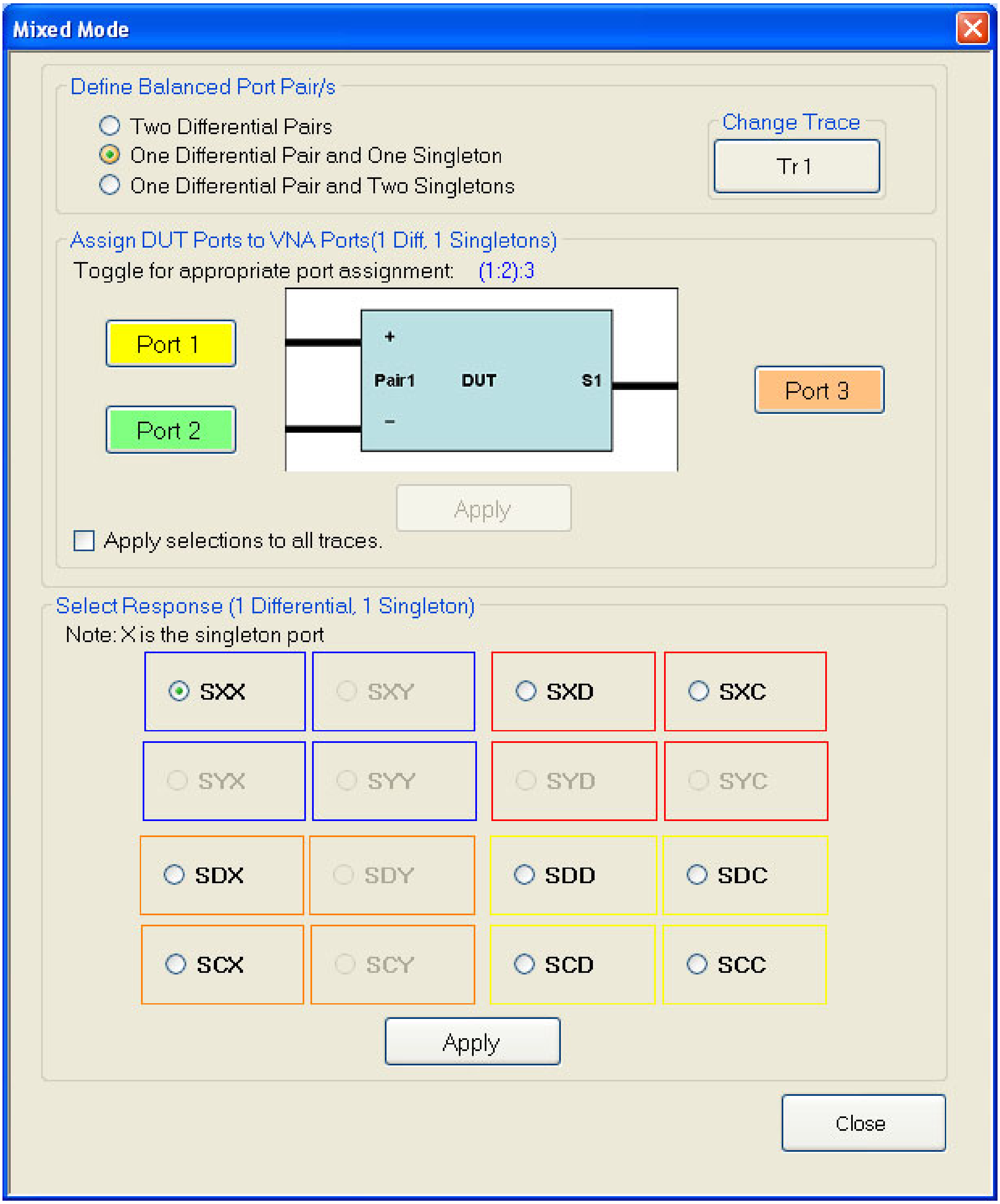


Figure 22-11. MIXED MODE One Differential Pair and One Singleton Dialog Box

For the situation in the figure above (Figure 22-11), there will be a different annotation on the graph legends to denote how the ports are configured but it is similar to the two-differential-pair format discussed earlier. (1:2):3 denotes that the differential pair is measured from Port 1 to Port 2 and Port 3 is the singleton.

Certain 4-Port devices are configured as one differential pair plus two single-ended ports. The parameters can then be configured in a one differential pair and two singleton format. The mixed mode definitions are identical to those presented above for the 1 singleton case. Now there is just a different possible free port number running around in the definition and 16 parameters are again possible. This selection structure is shown below(Figure 22-12).

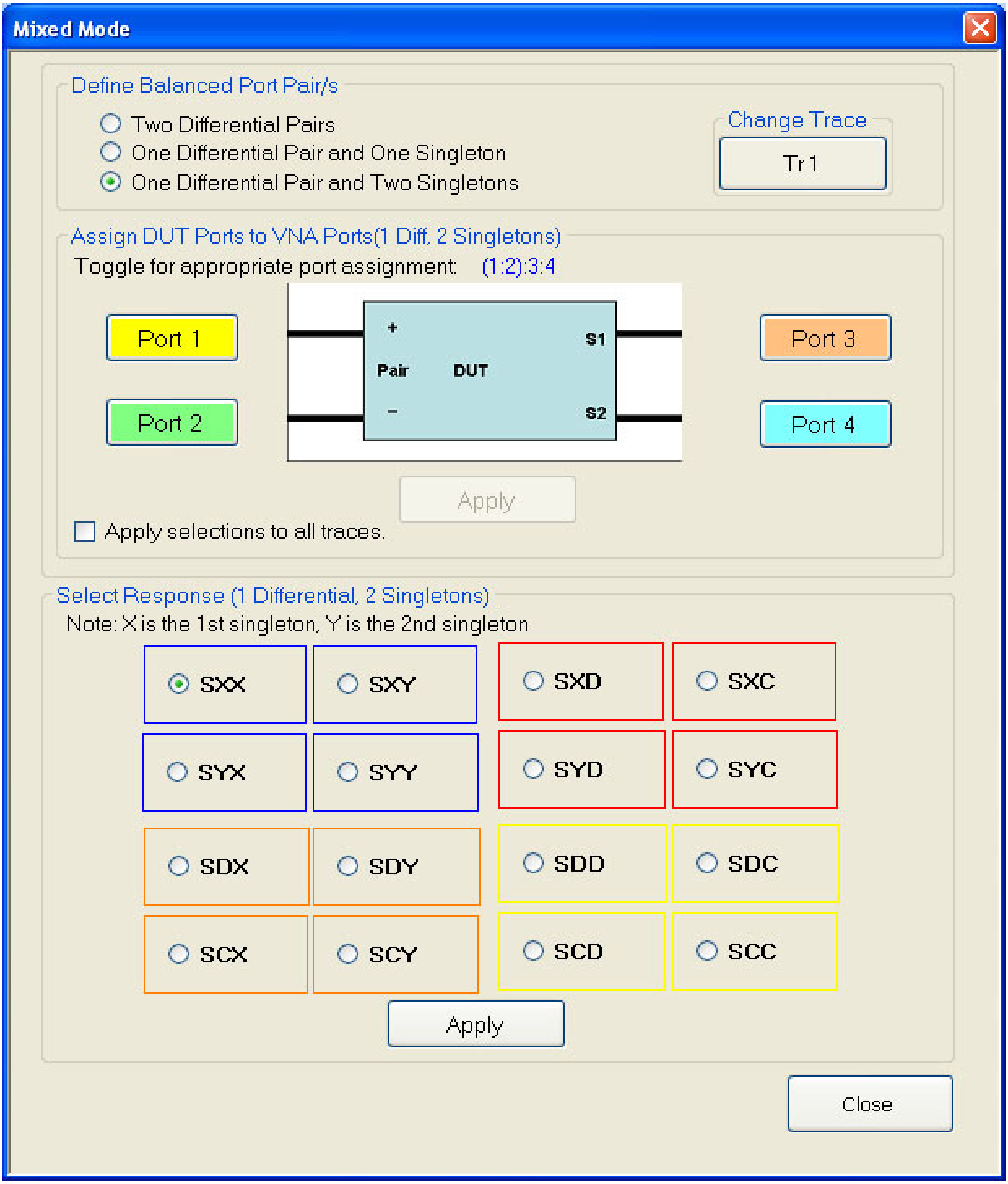


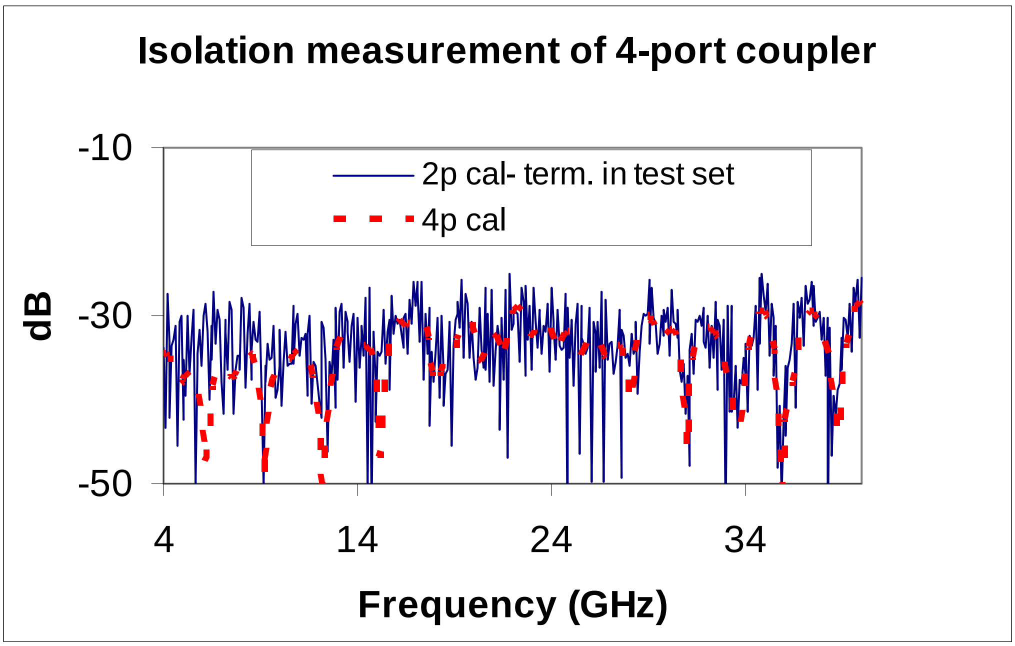
Figure 22-12. MIXED MODE One Differential Pair and Two Single-Ended Ports Dialog Box

On the graph legends, a format like (1:4):2:3 will be used to denote the port configuration. In this example, the differential pair is measured from Port 1 to Port 4, Port 2 is the first singleton and Port 3 is the second singleton.

22-5 Calibrations

In earlier chapters, a considerable amount of detail on various calibration algorithms and calibration types has been covered. The 3- and 4-Port variants of these calibrations are different from their 2-Port relations in fairly straightforward ways. The purpose of this subsection is to show where the differences are and how these calibrations can be properly configured.

A logical starting point is to ask what is different between measuring, say S_{41}, using a 4-Port calibration versus measuring it with a 2-Port calibration while properly terminating Ports 2 and 3. The quick answer is nothing, assuming the terminations are of good quality and one does not care about measurement time when measuring many parameters (while one swaps terminations around to get all of the S-parameters). If one just connected Ports 2 and 3 of the DUT to VNA ports, the results would probably not be as good since the raw broadband return loss of a VNA port is usually not better than 15 dB. To illustrate this concept, consider the measurement of isolation of a 4-Port coupler (S_{41} in the previous discussion). If a full four port calibration is performed, the dotted line in Figure 22-13 is obtained. If instead only a 2-Port cal is performed and the other coupler ports are left terminated in the test set (seeing the raw match of those ports), then the solid line of Figure 22-13 is obtained. The error here could be on the order of 10 dB at the –30 dB level.



An example showing the measurement improvement of a full four port calibration over a partially terminated two port calibration is shown here.

Figure 22-13. Measurement Improvement for Full 4-Port Calibration

By performing a full 3- or 4-Port calibration, the effective return loss of those other ports is improved to that of the residual load match (typically 30-50 dB depending on the calibration algorithm and components used) thus improving the measurement result. Thus overall measurement time and accuracy are the usual drivers for considering 3- and 4-Port calibrations.

The first step in understanding these calibrations is to look at the complete error model for N ports. As is apparent from the figure below (Figure 22-14), it is a straightforward extension of the 2-Port error model covered in Chapter 1, “Calibration Overview”. The directivity and match terms are basically functions of the port itself so one must just add these terms for the additional ports.

Tracking

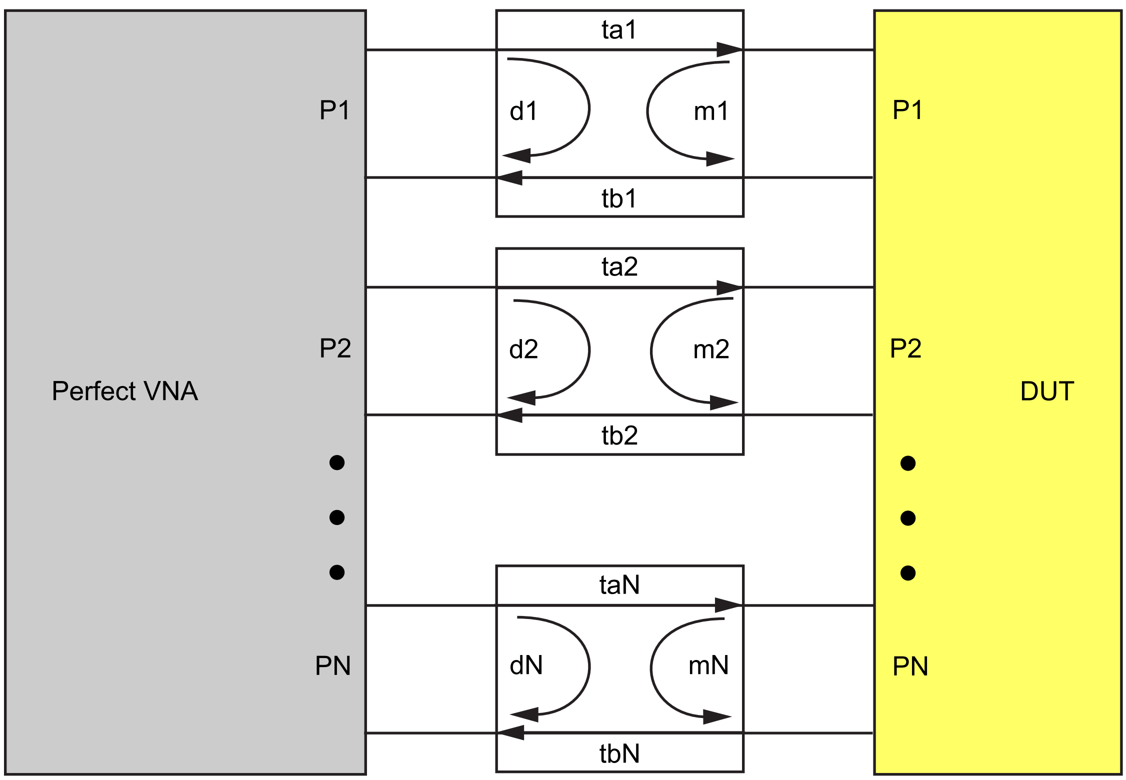
Tracking is again broken down into reflection tracking (the frequency response on a reflection measurement) and transmission tracking (the frequency response on a transmission measurement). Reflection tracking then also is a port property and can be assigned for each additional port. Transmission tracking is a property of a pair of ports (the correction to get a through line to measure S_{ij}=1 after other port errors have been handled) hence this term must be assigned for every permutation of two ports.

Isolation

Finally isolation is usually also considered the property of a pair of ports so the same permutation will be required. The last statement is not entirely valid if isolation is dependent on DUT impedances and is normally reserved to correct for isolation deep in the instrument. This distinction will be ignored for now since the isolation step is optional.

New Error Model

Thus we have a fairly straightforward new error model as shown below (Figure 22-14). As before, the pair of lines (in the diagram) per port is to help delineate incident and reflected waves. The reflection tracking for port q can be thought of as the product of taq and tbq; the transmission tracking from port k to port l can be thought of as the product of tak and tbl (no new information is being added, it is just being redistributed).

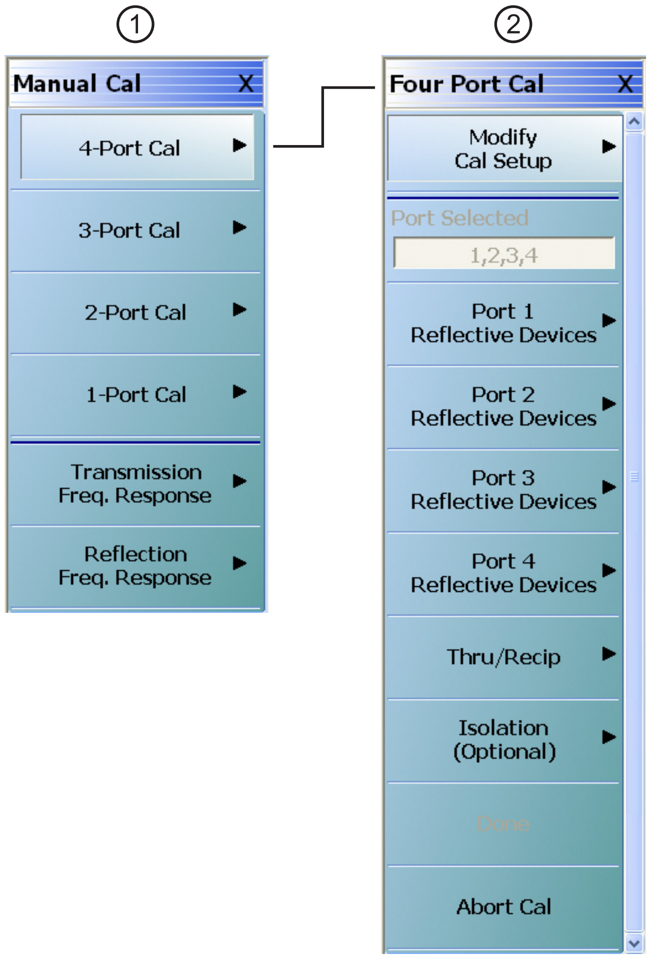


An N-Port error model is shown here. Directivity, match and reflection tracking can be assigned on a per-port basis while transmission tracking can be assigned on a pair-of-ports basis. Isolation is also nominally assigned on a pair-of-ports basis but that does have problems (isolation is often ignored practically).

Figure 22-14. N-Port Error Model

Menus

As might be expected, the main calibration menu will have a selection based on the type of calibration (full or nearly so versus frequency-response) and the number of ports. The MANUAL CAL menu below (at #1 left in Figure 22-15) provides the selection path to the FOUR-PORT CAL menu (at #2 below). This menu is the calibration execution menu for a 4-Port calibration (defined standards call.



1. The **MANUAL CAL** menu (at left) provides access to all multiport calibration modes. The **4-Port Cal** button provides access to the **FOUR PORT CAL** procedure menu for a 4-Port VNA.	2. The **FOUR PORT CAL** calibration execution menu (at right) for a 4-Port calibration (defined-standards calibration).

Figure 22-15. MANUAL CAL (MANUAL CALIBRATION) and FOUR PORT CAL Menus

The menus for the lower port count defined-standards calibrations follow in a predictable fashion. On the FOUR PORT CAL menu (at 2 right in Figure 22-15 above), the second field from the top, a read-only box, will indicate which ports are in play for the current calibration. The details on selecting these ports will be presented later.

Transmission Tracking

The key complication of multiport calibrations lies in the handling of transmission tracking. Since the reflection and transmission tracking terms overlap, they are not entirely independent. The following is the relationship that one can pull directly off of Figure 22-14, "N-Port Error Model" on page 22-21:

$$etkn \cdot etnl = etnn \cdot etkl$$

(22-12)

To see how this is used, consider the redundant through line problem (as in previous chapters, we will use the term "through" to denote any fully defined transmission line whether it be of zero length or not). Suppose we have connected throughs between Ports 1-2, 1-3 and 1-4 sequentially. Presumably the first three term types (directivity, source match and reflection tracking) have been computed for all four ports. The through connects allow us to compute all of the load match terms and all transmission tracking terms except for *et32, et23, et24, et42, et34* and *et43*. These last tracking terms can be found with the following forms of Eq. 22-12 (above) shown below in Eq. 22-13:

$$\begin{aligned} et43 &= \frac{et41 \cdot et13}{et11} \qquad (k = 4, l = 3, n = 1) \\ et32 &= \frac{et31 \cdot et12}{et11} \qquad (k = 3, l = 2, n = 1) \\ etc. \end{aligned}$$

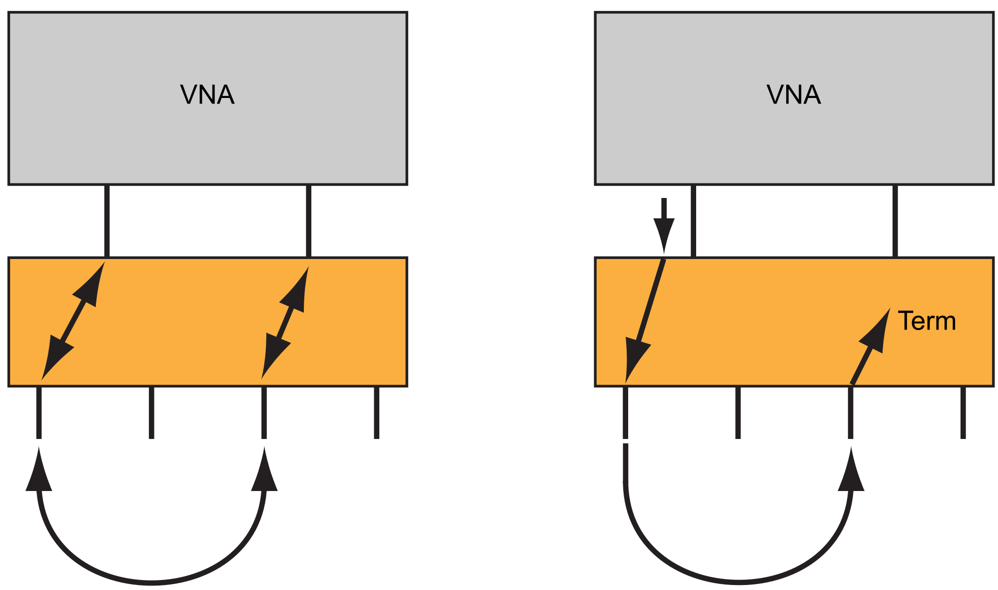
(22-13)

This process is termed the use of redundancy since the reflect measurements and the through measurements do overlap to a certain degree. Thus, one does not need to connect all six (6) possible through lines in a 4-Port calibration or all three (3) possible through lines in a 3-Port calibration. The basic requirement is that all ports be "connected" in some way with a line. Now, additional throughs can always be used and can improve accuracy of the tracking terms by a certain amount (to be discussed). There are many cases, however, where it is difficult to construct a high quality line between ports (orthogonally positioned wafer process for example) and the use of redundancy will produce a better result than trying to use a poor through during the calibration. Similar analyses are used for all calibration types so the user will see considerable flexibility in how the throughs/lines are defined.

Load Match

A related topic is load match (primarily for defined-standards calibrations) since it can generally be computed in multiple different ways since multiple throughs are involved. The guiding principle is the first-in rule: the first through measured will be used to compute the load match for the ports involved, the second through will be used for its ports but it will not overwrite earlier computed load matches, and so on. This allows the user to optimize load match performance by measuring the highest quality throughs first.

A consistent load match is guaranteed by generally using the test set terminations to form the reference load for all transmission measurements. When the linkage to the VNA termination is required (for reciprocal calibrations and for the LRL/LRM families), the final load matches are transformed to the test set termination in order to guarantee consistency. This concept is shown below (Figure 22-16). Thus whenever a transmission parameter is measured, a unique load match is always defined and the corrections are self-consistent.



The concept of load match plane translation is shown here. Although the connection (shown on the left) may be needed for LRL/LRM and SOLR-like calibrations, the reference plane for load match will always be translated to the test set termination (as shown on the right).

Figure 22-16. Load Match Plane Translation

Setting Up the Defined Standards Calibration

The next topic is that of setting up the defined standards calibration. Consider the dialog shown below (Figure 22-17) that is used for setting up a 4-Port calibration using the SOLT/R algorithm.

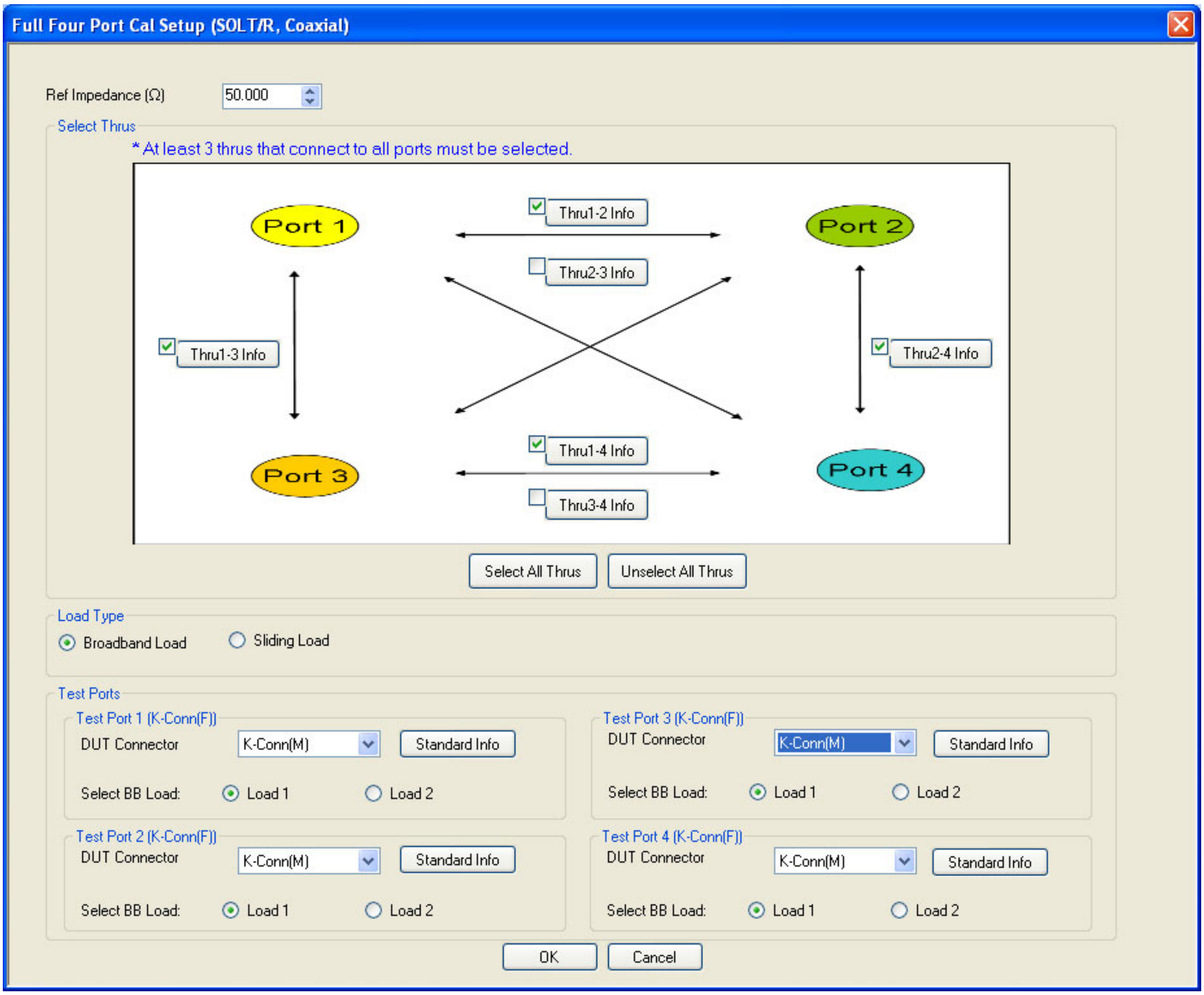
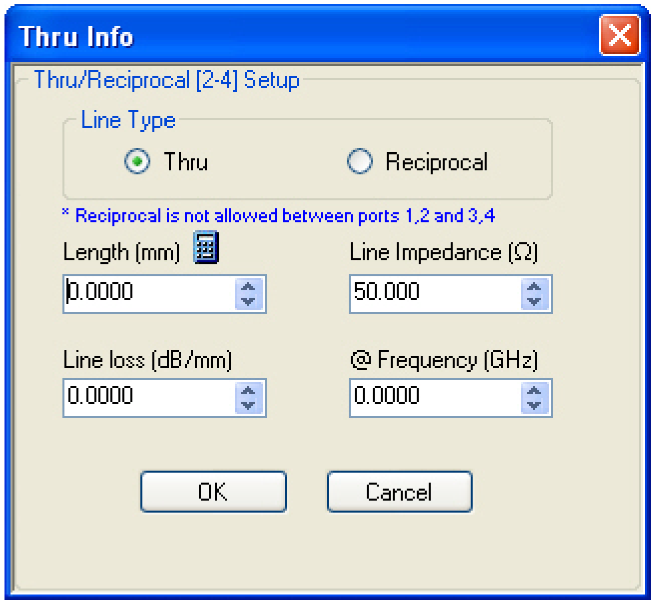


Figure 22-17. FULL FOUR PORT CAL SETUP Dialog Box - SOLT/R - Coaxial

Selecting Possible Throughs

As might be expected, there are the usual items for selecting the port connector types, the type of load (broadband or sliding) and the reference impedance. What is somewhat different is the through selection tableau. The six possible throughs are shown, each having a button allowing the definition of that line as shown below (Figure 22-18). As discussed earlier, at least three throughs must be selected such that all ports are "connected."

- Allowed:
  - 1-2, 1-3, and 1-4
  - 1-3, 2-4, and 1-4
  - Etc.
- Not allowed (without adding more lines):
  - 1-2, 1-3, and 2-3 (port 4 is not "connected")

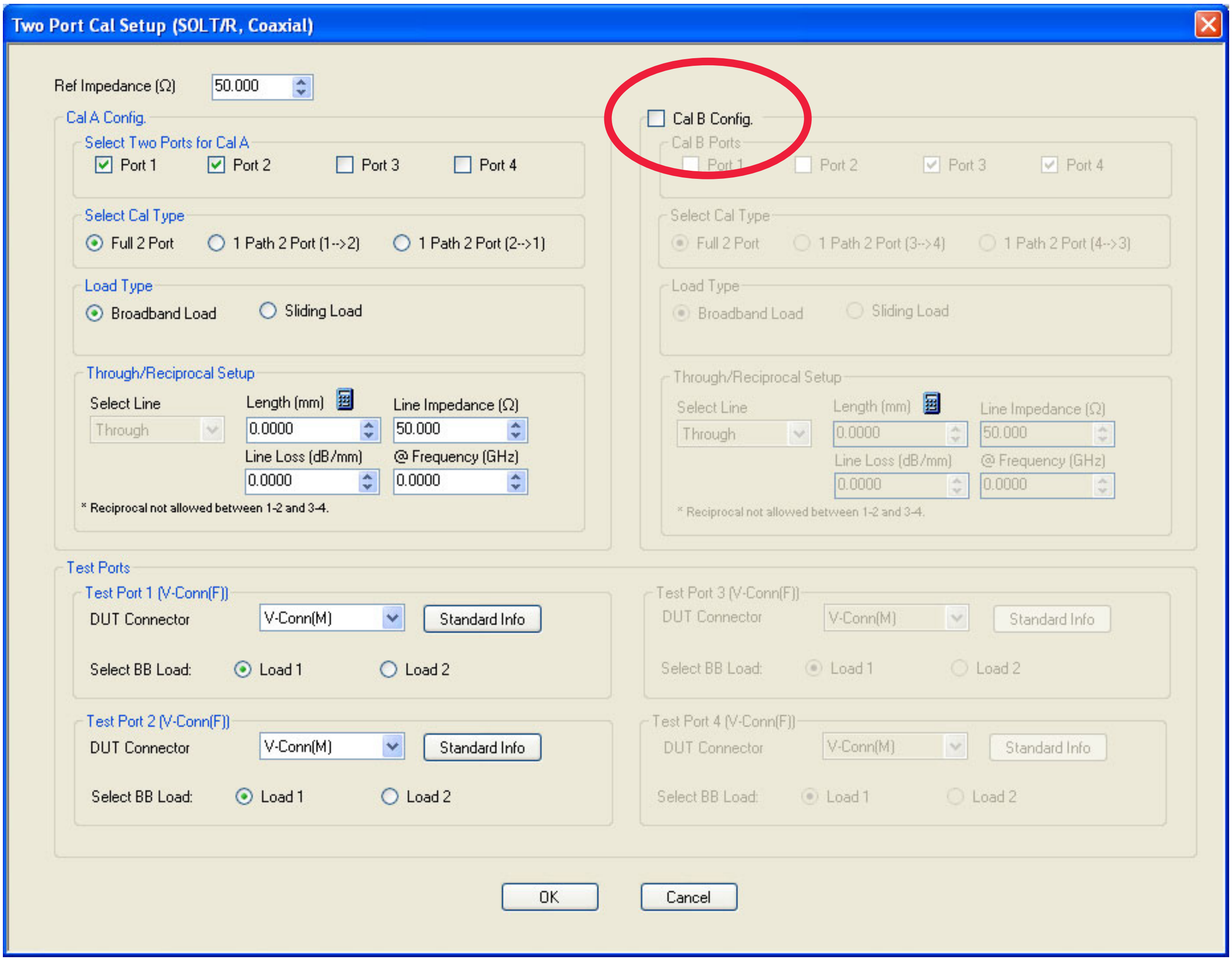


Typical through line configuration in the THRU INFO dialog box for the defined-standards calibrations.

Figure 22-18. THRU INFO Dialog Box

As suggested by the figure above (Figure 22-18), each of the selections may be defined as a "through" or as a "reciprocal" as discussed in earlier chapters. From the point-of-view of "connectedness", these designations are equivalent. As discussed in an earlier chapter, however, there is some accuracy degradation (particularly with regard to load match) that can be compounded if all lines are reciprocals. This point is discussed in more detail in the uncertainty section.

The three port calibration is analogous and the menus are covered in the operation guide. One port (to include reflection response calibrations) and two port calibrations are a little different in that multiple calibrations are allowed. Since it is a four port instrument, the user is allowed to perform two 2-Port calibrations or up to four 1-Port calibrations simultaneously. The two port calibration setup dialog is shown below (Figure 22-19) to illustrate the option of another calibration (Cal B in this dialog).

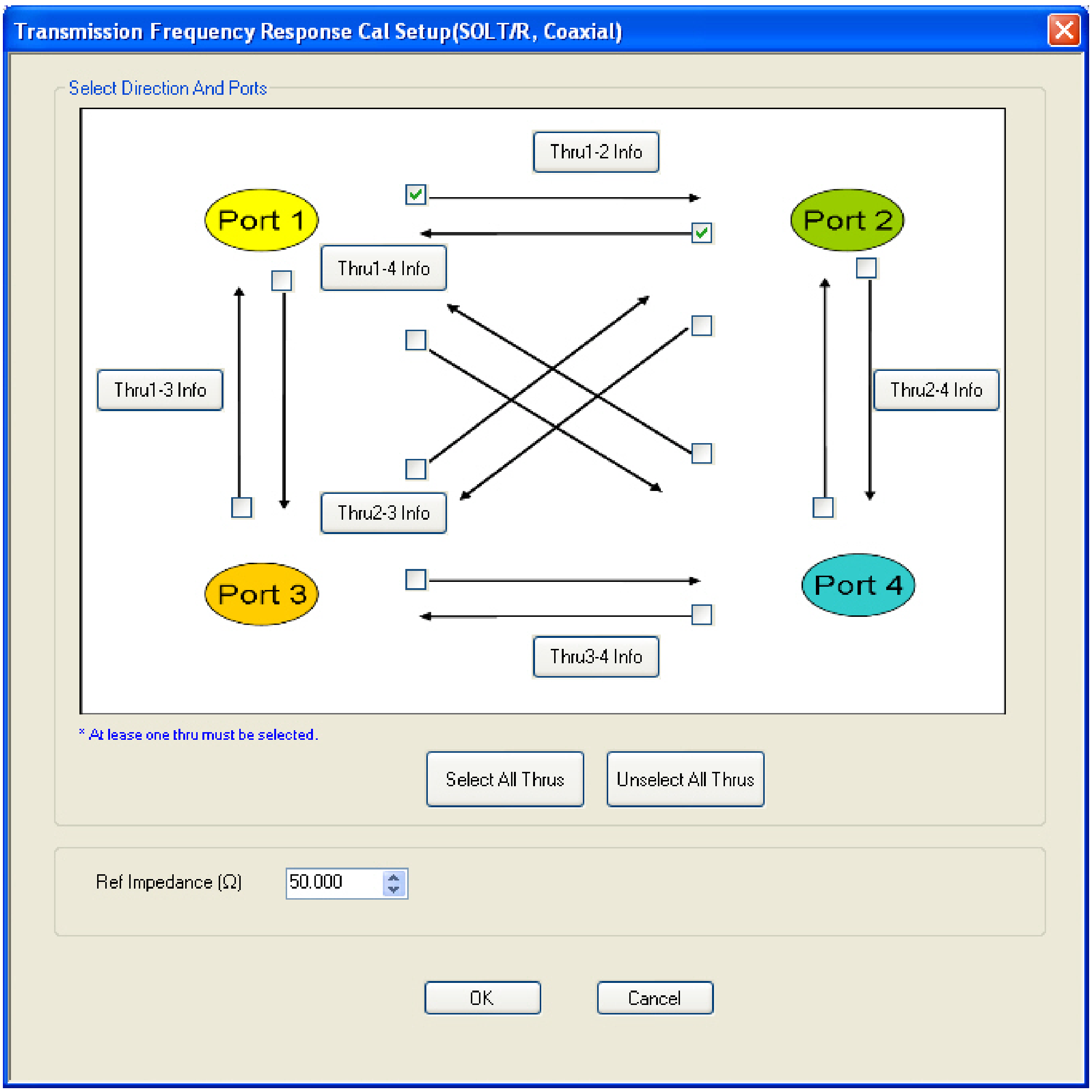


Typical calibration setup for a 2-Port calibration with selections of SOLT/R, Coaxial, and Cal B Not Selected. The two-port modify setup (SOLT/R) dialog is shown here to illustrate the multiple calibration functionality.

Figure 22-19. TWO PORT CAL SETUP (SOLT/R, COAXIAL) Dialog Box

If Cal B is activated from the check box, then the other two ports (not defined under Cal A) can be used to form an independent calibration. Port overlap is not allowed in order to avoid error-term self-consistency issues.

Transmission frequency response calibrations generalize as one might expect since there are now 12 transmission S-parameters potentially available to normalize. The dialog is shown below (Figure 22-20). As with the full calibrations, the throughs may be defined independently although the reciprocal choice is not available in this case. Note that unlike through selections in the full calibrations, the directions can be independently selected in this case. As is the case with two port systems, it is allowed to normalize, say, S_{21} but not S_{12}. In the full calibration case, both directions are always required.



The transmission frequency response modify setup dialog is shown here for a 4-Port system.

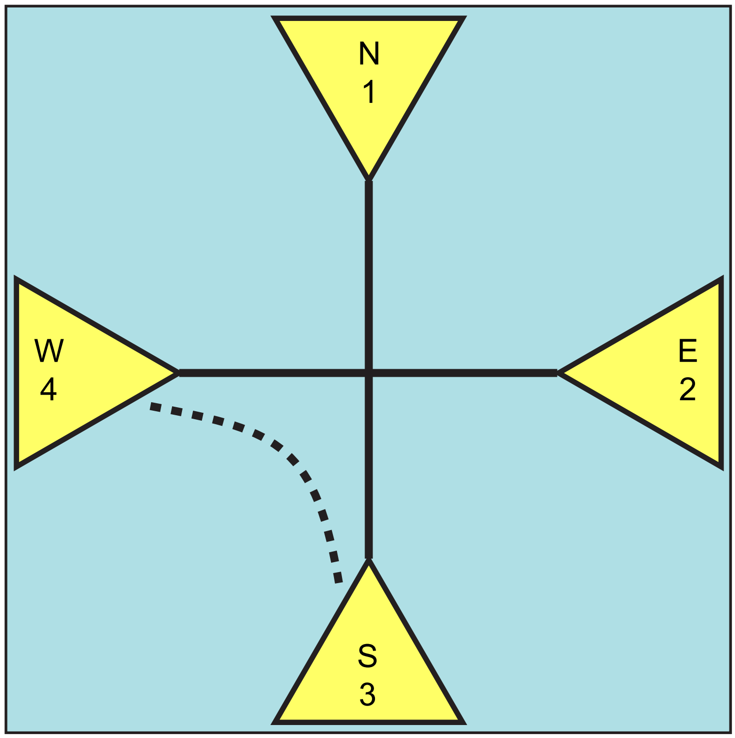
Figure 22-20. TRANSMISSION FREQUENCY RESPONSE CAL SETUP Dialog Box - SOLT/R - Coaxial

The above dialogs and setup requirements are completely analogous for SSLT/R and SSST/R algorithms. The LRL/LRM family, however, is somewhat different.

LRL/LRM Calibrations

In this implementation LRL/LRM family, there is a basic structure that is fundamentally 2-Port like in nature. As such, the 4-Port LRL/LRM calibration will be defined as a pair of basic 2-Port calibrations linked together by one or more through measurements (to complete the path linkage as for defined-standards calibrations). This can have an additional benefit in certain cases since it allows the hybridization of reciprocal and defined-through approaches (on the additional paths) with LRL/LRM approaches on the base paths.

A situation where this is useful is shown in the figure below (Figure 22-21) where orthogonal on-wafer probes are being used. It is relatively easier to define good transmission lines on the horizontal and vertical paths (1-3 and 2-4) but less so, at least for higher frequencies, on the other paths (bends in the required lines causing radiation or otherwise leading to reflections). Such a problem is a good candidate for hybridization.

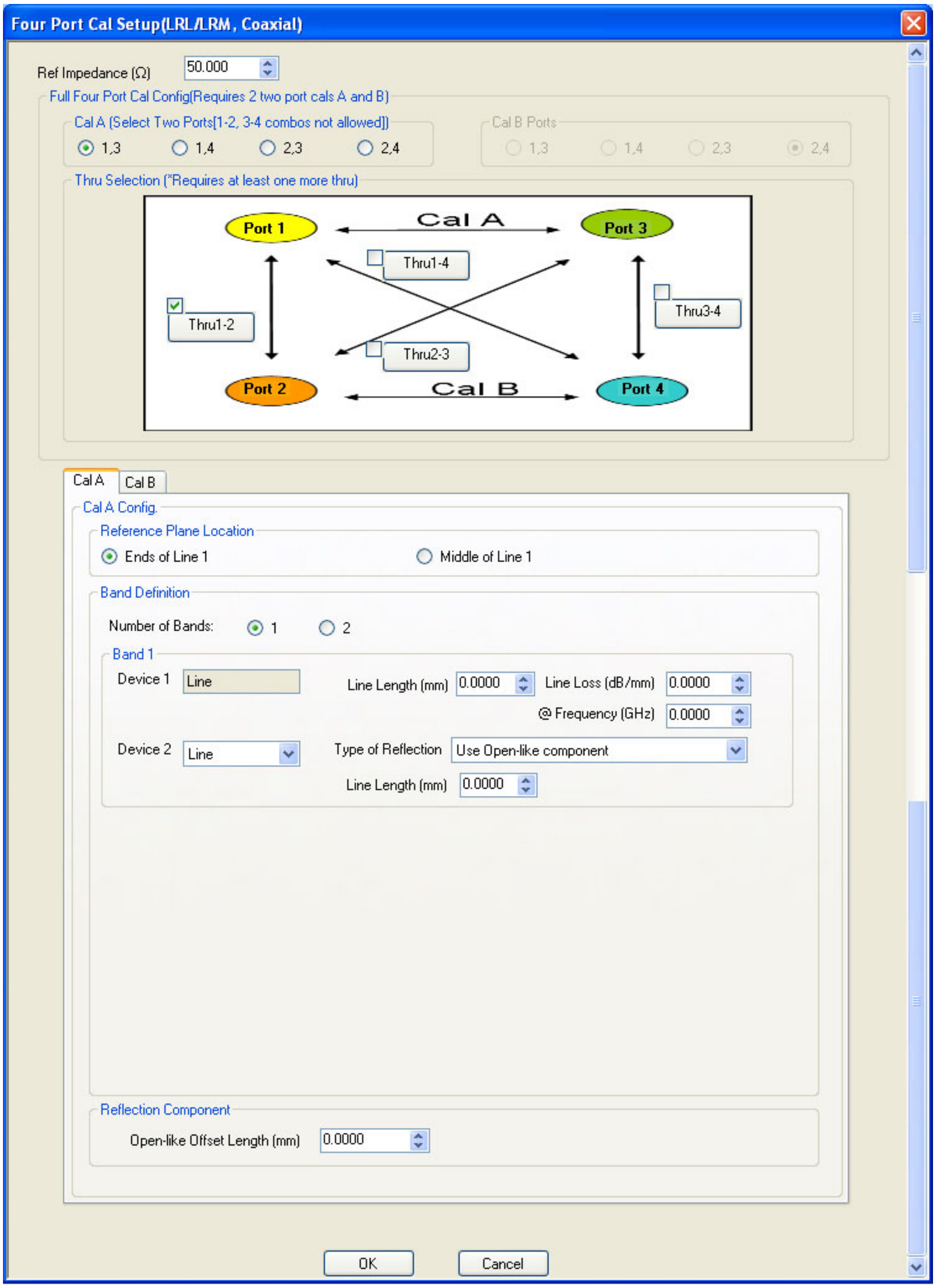


An on-wafer configuration where some line paths are more likely to be of higher quality than others. The solid lines will generally not be an issue but a transmission path illustrated by the dotted line (S-W) may be electromagnetically compromised at higher frequencies.

Figure 22-21. On-Wafer Line Path Quality

4-Port LRL/LRM Calibrations

The configuration dialog for 4-Port LRL/LRM calibrations is shown in the figure below (Figure 22-22). Note how the primary LRL/LRM ports are defined and how additional information may be required for the continuation lines. The two 2-Port calibrations are defined on the two tabs labeled Cal A and Cal B. Each tab alone looks the same as the two port LRL/LRM calibrations discussed in earlier chapters. Note that on the actual display all of the information may not be visible and a scroll bar may be required.

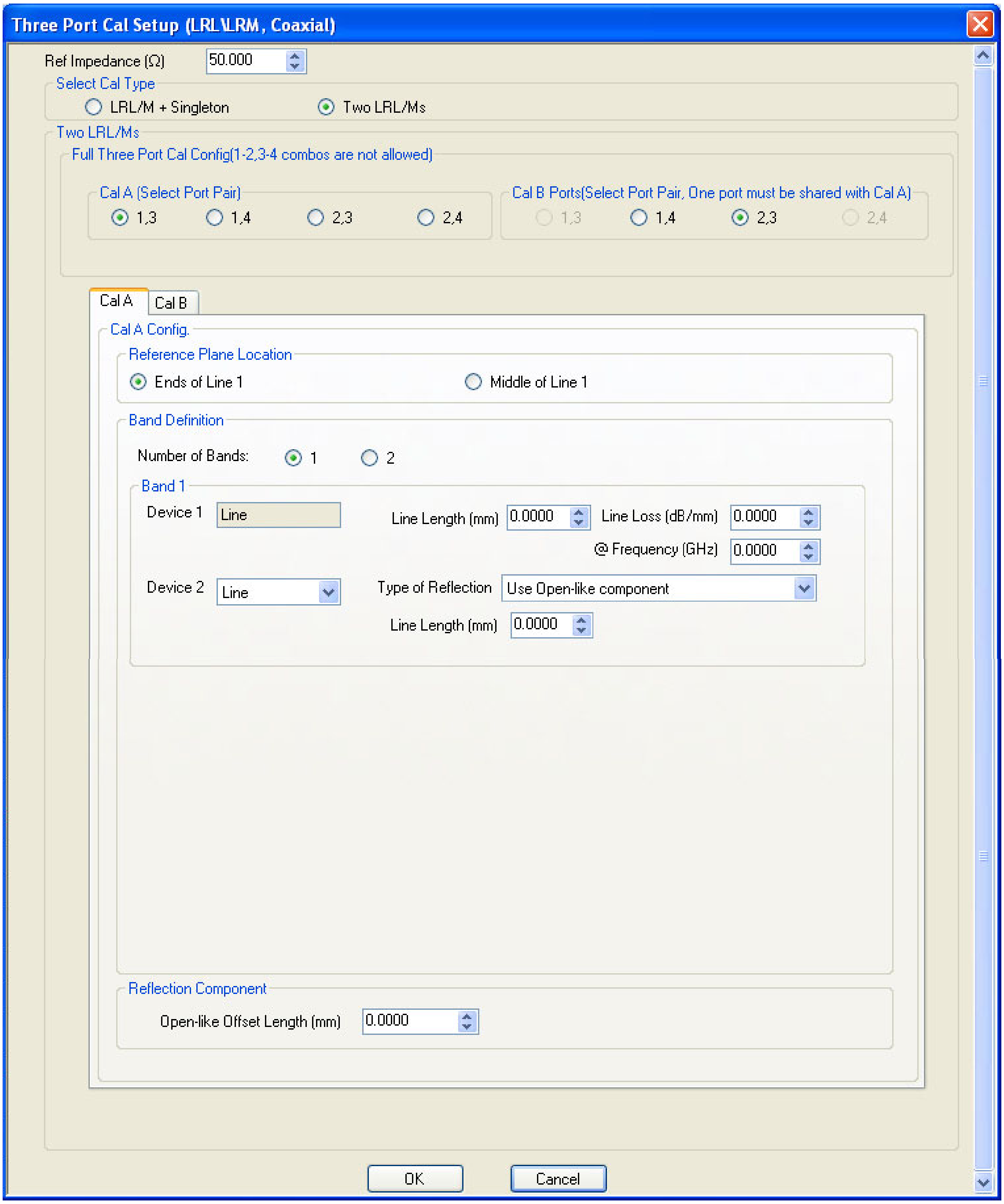


The modify calibration dialog for 4-Port LRL/LRM calibrations is shown here.

Figure 22-22. FOUR PORT CAL SETUP (LRL/LRM, COAXIAL) Dialog Box

Three Port LRL/LRM Calibration

Much like the 4-Port LRL/LRM calibration, the 3-Port version is constructed from a pair of 2-Port LRL/LRM calibrations (unlike the defined-standards approaches). Obviously there is going to be port overlap. The first calibration will define the port reflectometer parameters on the overlap port. The modify calibration dialog for this situation is shown below (Figure 22-23).



The modify calibration dialog for the three port LRL/LRM calibration is shown here for the case of a single LRL/LRM step plus a single through line completion step.

Figure 22-23. THREE PORT CAL SETUP (LRL/LRM, COAXIAL) Dialog Box - Two LRL/Ms - Cal A Tab

The 2-Port calibration situation for LRL/LRM is similar to that shown for the defined-standards case: it is allowed to perform two of these calibrations in parallel. Aside from the additional definition required, the approach is the same as discussed in an earlier chapter.

This 3-Port calibration can also be constructed from a single 2-Port LRL/LRM cal together with a singleton definition. This version is shown below (Figure 22-24). The single LRL/LRM cal must be defined as usual and the one or two extra thrus must also be defined as before.

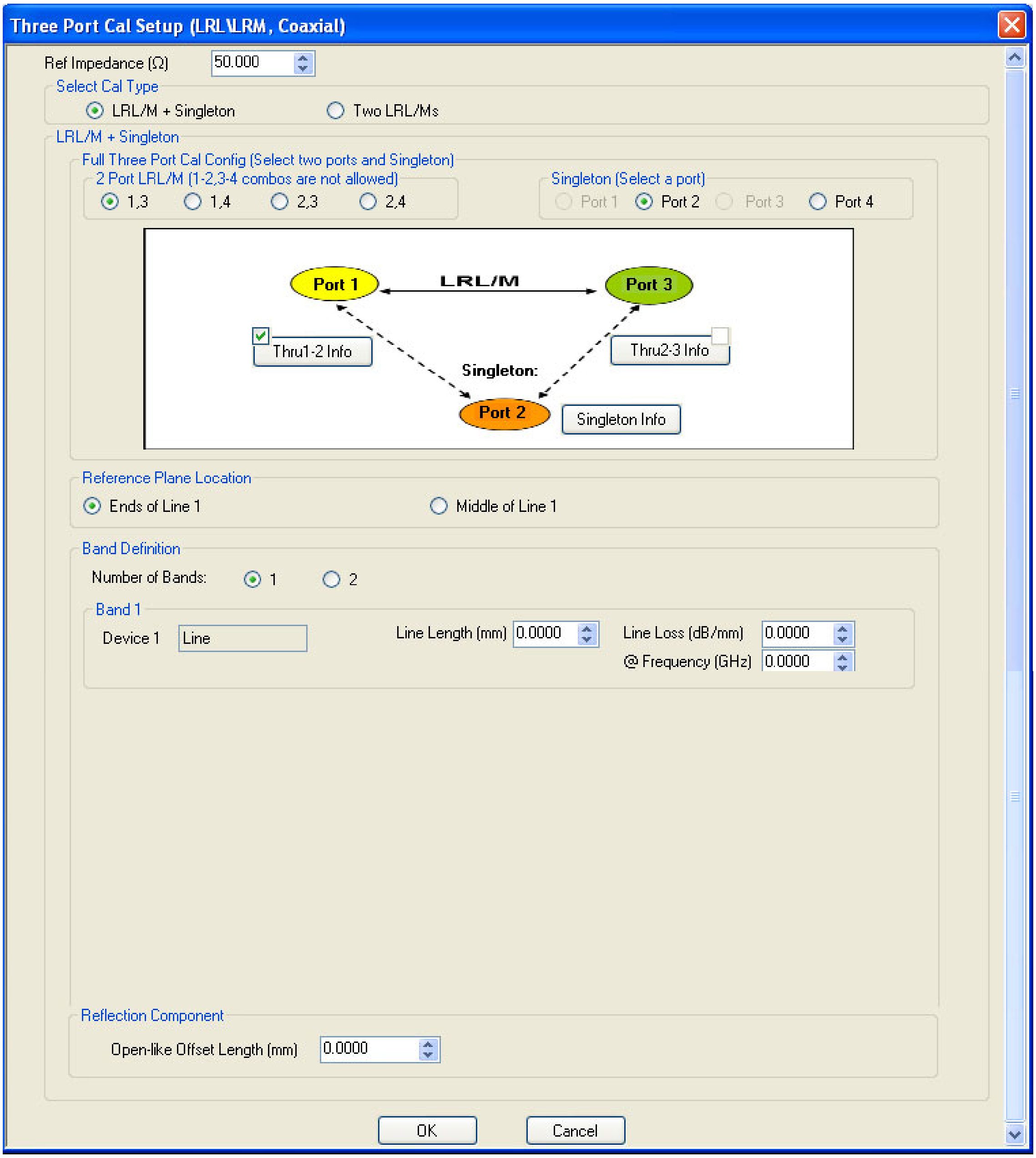


Figure 22-24. THREE PORT CAL SETUP (LRL/LRM, COAXIAL) Dialog Box - LRL/M + Singleton

In addition, a single defined standard must be measured at the singleton port defined under the Singleton Info button as shown below (Figure 22-25). The standard is allowed to be an open or a short and the usual offset plus inductance or capacitance polynomials are supported. The measurement of this additional standard allows one to distinguish between load match and source match at the singleton port. Note that in this case, the connections to the singleton port must be thrus (reciprocals are not allowed). The interconnect is used to derive the singleton ports reflectometer behavior so that additional restriction is required.

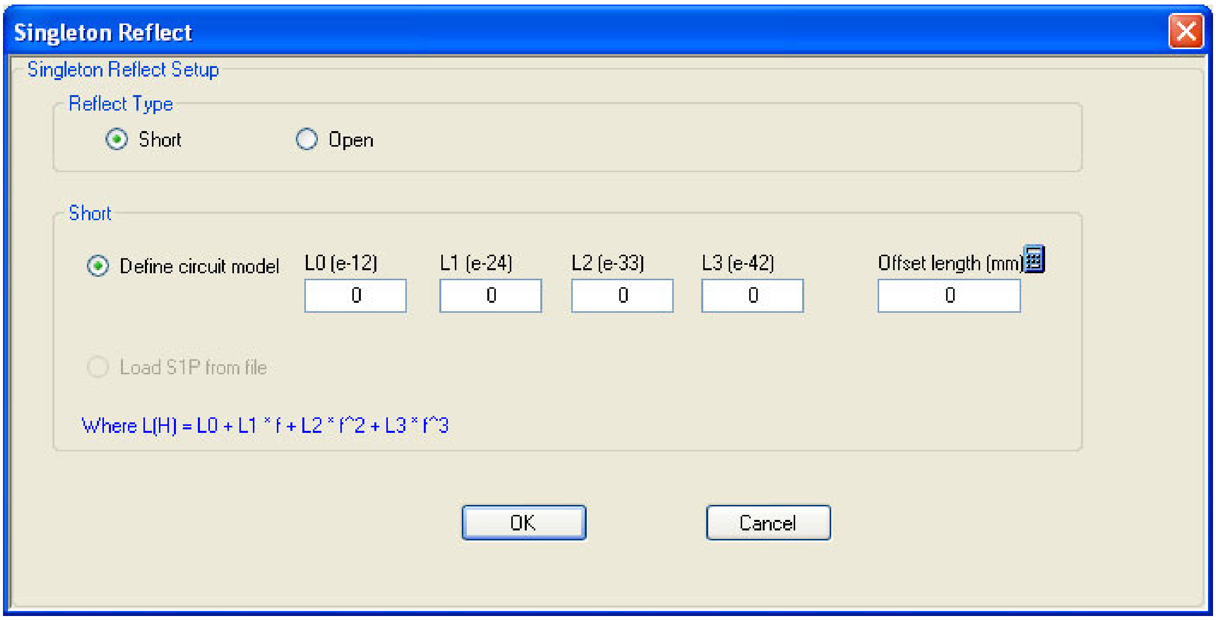


Figure 22-25. SINGLETON REFLECT Dialog Box

The calibration steps are a bit different for this type of calibration and the step menu is shown below (Figure 22-26). The extra singleton button reflects the asymmetric nature of the information required from this port.

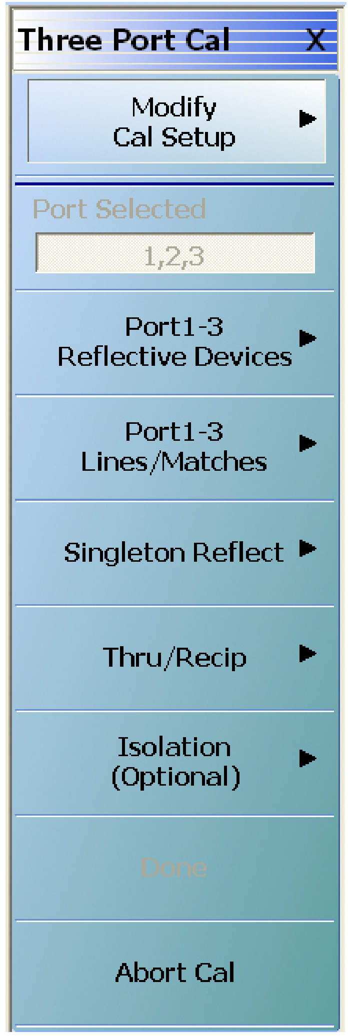
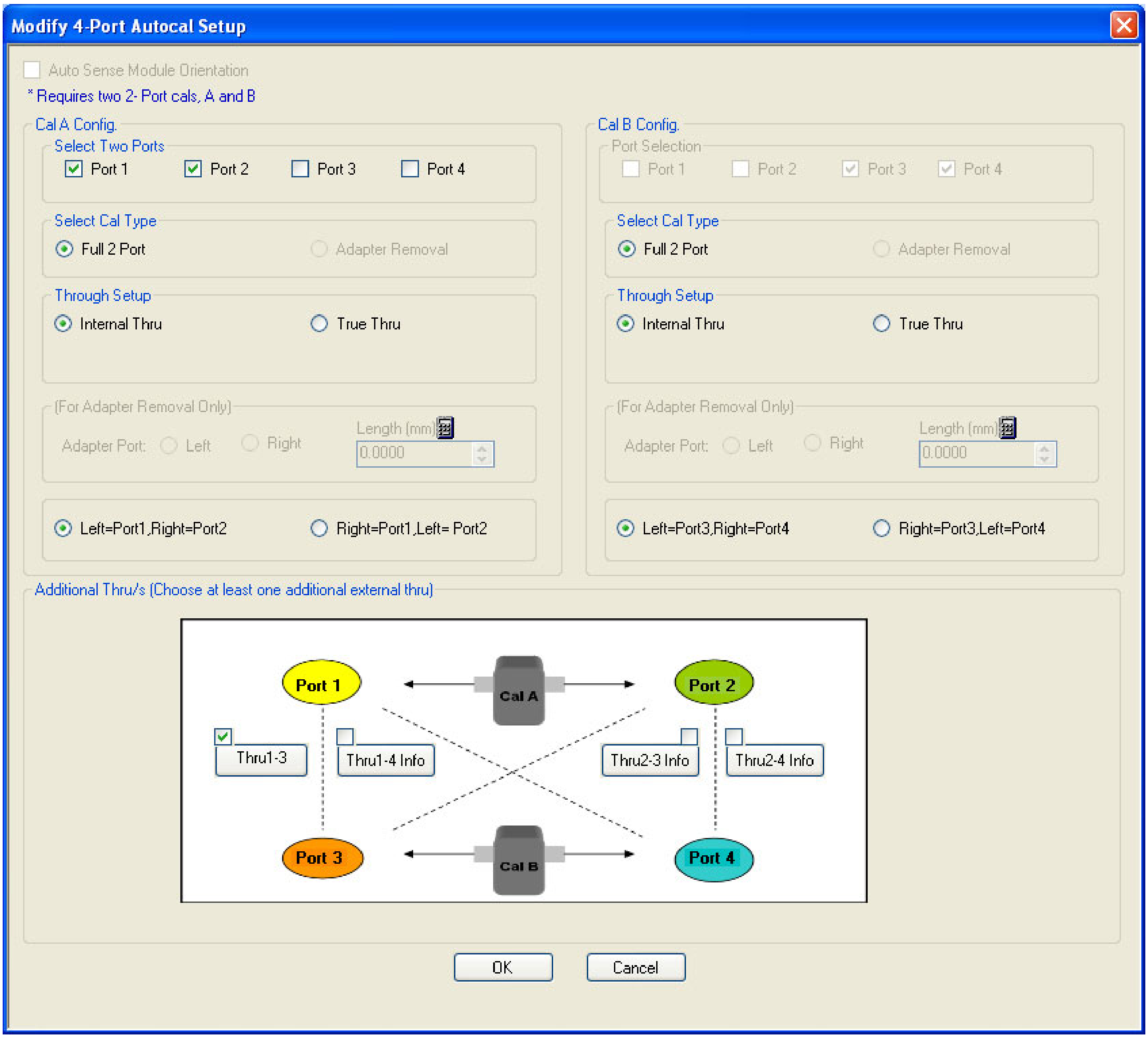


Figure 22-26. THREE PORT CAL Menu - LRL/LRM - Coax - One LRL/M + Singleton

22-6 AutoCal Calibrations

The last main calibration category is that of AutoCal. As only 2-Port AutoCal exists with this release, the AutoCal may be used to perform a pair of 2-Port calibrations followed by a minimum of one additional line connection in order to complete the error model. As with the manual calibrations, additional throughs may be used to improve on the redundant transmission tracking calculations. The usual AutoCal options discussed in above in Chapter 2, “AutoCal Procedures” are still available. The modify setup dialog is shown below (Figure 22-27).

Note	A three-port automatic calibration is not available in release 1.3.0.

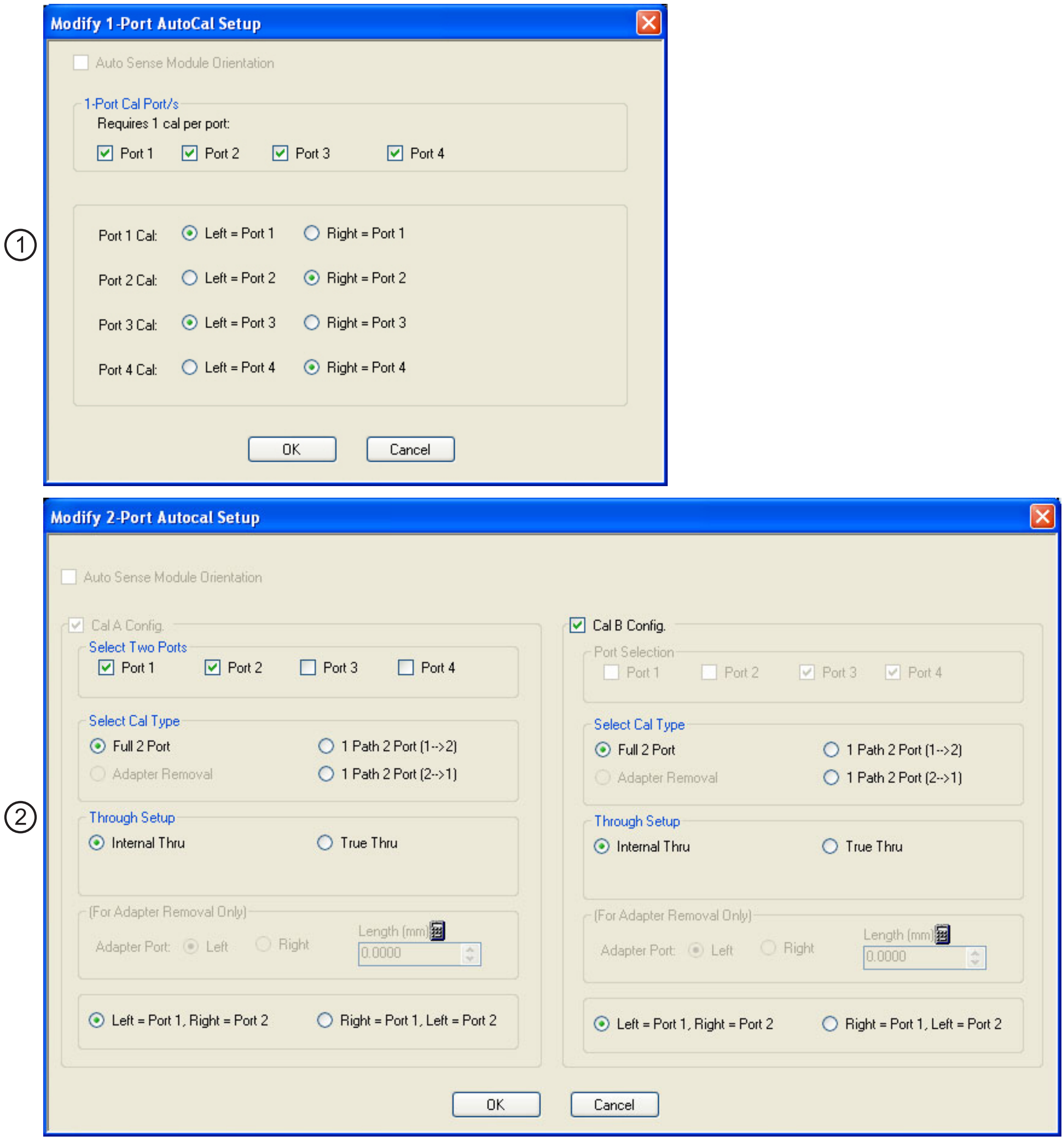


The setup dialog and menu for 4-Port AutoCal are shown here with Thru 1-3 selected.

Figure 22-27. MODIFY 4-PORT AUTOCAL SETUP Dialog Box

Note that the port assignment for Cal B (the second of the AutoCal connections as shown in the figure at upper right) is uniquely defined once the first cal (Cal A) is defined. There is flexibility on how internal/true throughs are allocated and on the use of adapter removal between these calibration steps.

At least one additional, physical through line is required to complete this 4-Port calibration and these selections are shown as a diagram at the bottom of the dialog box (for example, the Thru1-2 or Thru2-4 buttons). It is also allowed to use true throughs during the AutoCal step so it is conceivable there could be anywhere from one to six physical through connections involved depending on how the calibration is configured. A pair of unlinked 2-Port calibrations based on AutoCal (like that for the other algorithmic approaches) is also possible as shown below (Figure 22-28). The obvious extension continues to include up to four unlinked 1-Port calibrations.



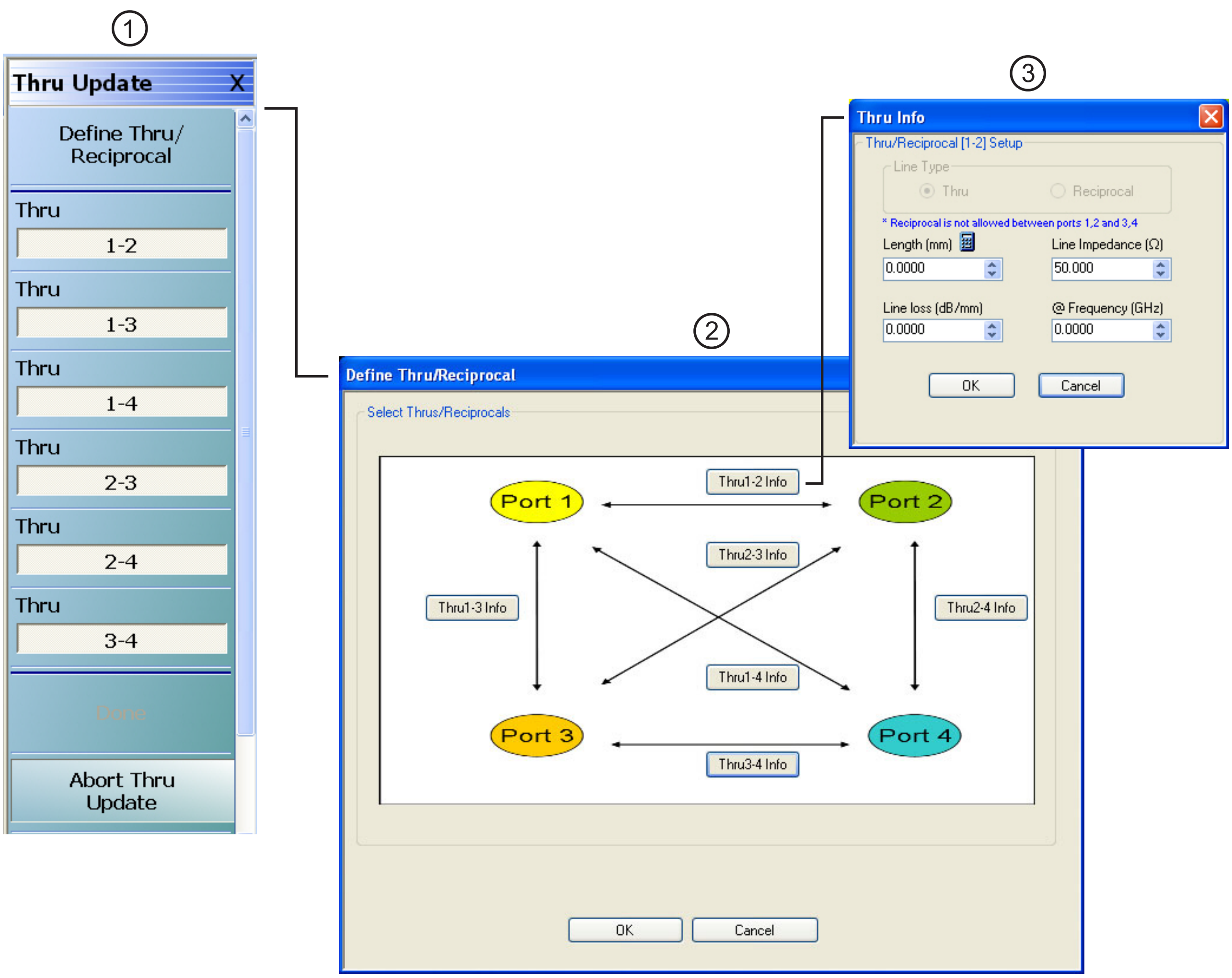
1. The **MODIFY 1-PORT AUTOCAL SETUP** dialog box (at top) for automatic calibrations using the 4-Port system.	2. The similar **MODIFY 2-PORT AUTOCAL SETUP** dialog box (at bottom).

Figure 22-28. MODIFY AUTOCAL SETUP Dialog Boxes

Port assignments and, where appropriate, the internal/true through selections remain flexible. In the two port case, AutoCal adapter removal is still allowed on either calibration if two are selected.

Thru Update

Thru update would, as might be expected, have acquired additional flexibility in the 4-Port system. The menu and related configuration dialogs is shown below (Figure 22-29), with the six possible throughs which, again, may be independently defined. Any number of throughs may be selected in the update but note that only the transmission tracking and load match terms connected to the through selected will be updated. That is, any redundantly-related terms that may have been derived during the original calibration will not be recomputed. As with the base calibrations, the first-in rule applies. If the first through selected is between Ports A and B, the load matches for Ports A and B will be computed there. If the second through selected is between Ports A and C, only the load match for Port C will be computed with that line (since that for Port A was already found). Thus the higher quality (in terms of match and knowledge about the loss) throughs should be measured first.



1. The **THRU UPDATE** menu (at left) is shown here along with the related configuration dialog boxes. 2. The **DEFINE THRU/RECIPROCAL** dialog (at center) allows each through to be defined in turn.	3. A typical **THRU INFO** dialog box (Thru/Reciprocal 1-2 shown at right) configures each required through. Many of the through definition concepts here have been discussed previously.

Figure 22-29. THRU UPDATE Menu and Related Configuration Dialog Boxes

22-7 Uncertainty

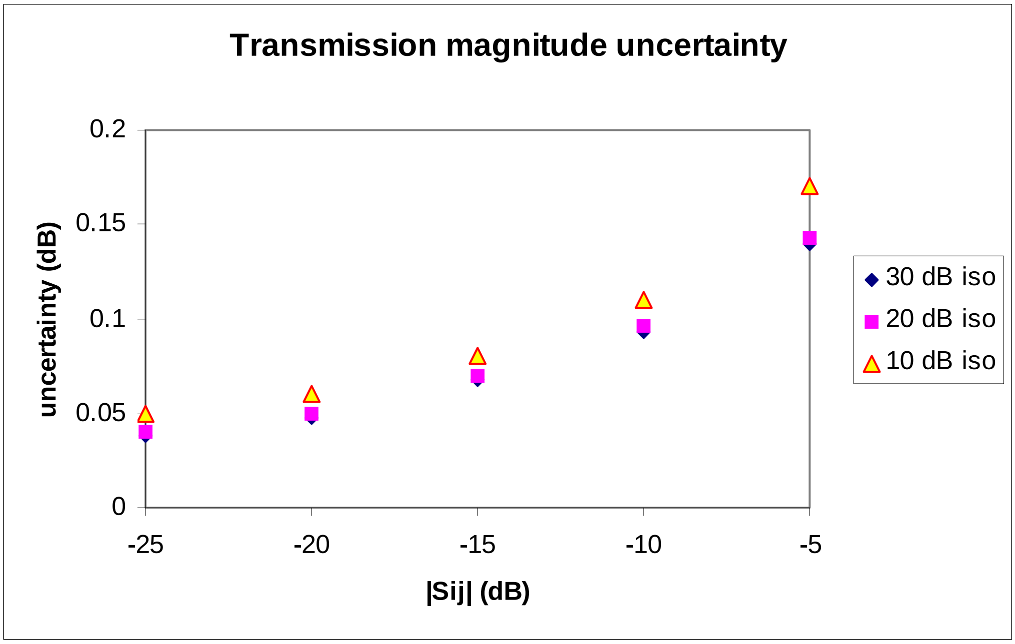
The uncertainties in the 4-Port measurement itself are straightforward extensions of those derived from the two port model. Associated with each port are residuals due to source and load match, directivity, and reflection tracking. Between every pair of ports is a residual due to transmission tracking. Other terms due to isolation and repeatability are often ignored in the analysis. The only real difference from a two port model is that there are multiple load match terms and each is dependent on path isolation (e.g., [7], section III. A). From the point of view of classical error models, one can simulate these effects with an elevated effective load match in many cases.

As an example, consider the measurement of S11. The primary factors affecting this measurement (ignoring noise floor and compression effects) will be residual directivity errors ($\Delta ed1$), source match errors ($\Delta ep1S$), reflection tracking ($\Delta et11$) and load match ($\Delta epnL$). This simplified analysis also ignores multiple reflections between a series of ports since they will be at most 2nd order effects.

$$err \approx \Delta ed1 + S_{11} \cdot \Delta et11 + S_{11}{}^{2} \cdot \Delta ep1S + S_{21}S_{12} \cdot \Delta ep2L + S_{31}S_{13} \cdot \Delta ep3L + S_{41}S_{14} \cdot \Delta ep4L \quad (22\text{-}14)$$

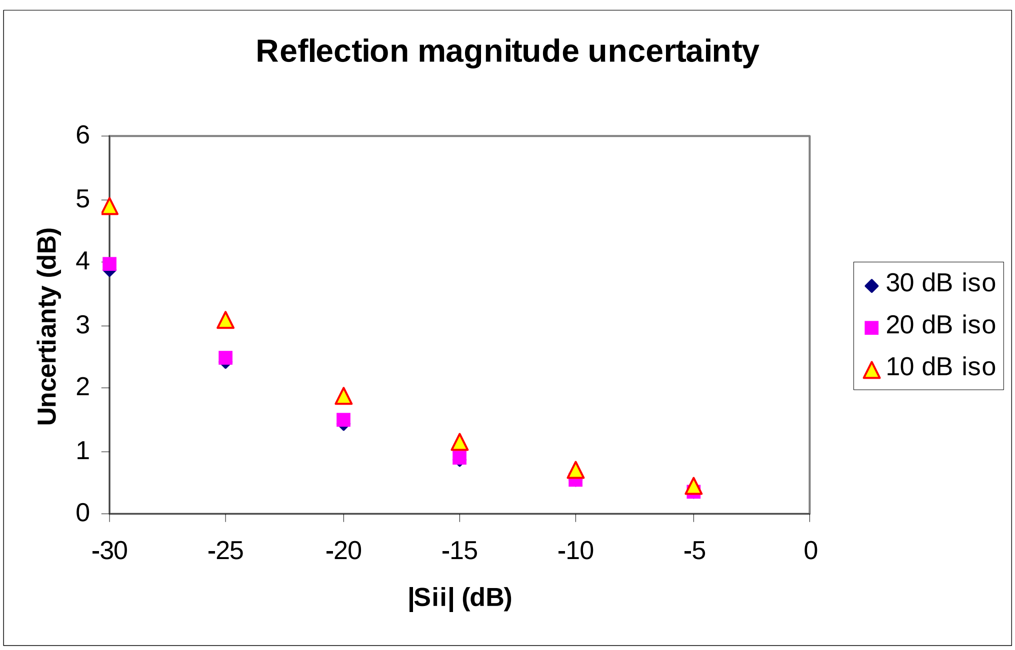
Clearly if some of the transmission terms are small, the load match quality becomes less important as observed before. Some curves are shown below (Figure 22-30 and Figure 22-31) to illustrate this dependence on isolation. These are based on calibration residuals characteristic of a reasonably high quality calibration but the main intent of the curves is to display tendencies. The transmission curve of Figure 22-30 shows little effect until the isolation gets to between 10 and 20 dB. The greatest impact will be for devices of low insertion loss (right side of the curve) as might be expected.

The reflection curves of Figure 22-31 show a similar qualitative dependency on isolation and a worsening of the relative effect as the desired return loss gets larger. Combining the two figures, it is clear that the worst case scenario is a low insertion loss, high return loss path with poor isolation to the remaining ports. This makes intuitive sense since this situation provides a maximum number of interfering standing waves within the device.



The dependence of transmission magnitude uncertainty on the loss in the desired path and the isolation to the other ports is shown here.

Figure 22-30. Transmission Magnitude Uncertainty



The dependence of reflection magnitude uncertainty on the reflection at the desired port and the isolation to the other ports is shown here.

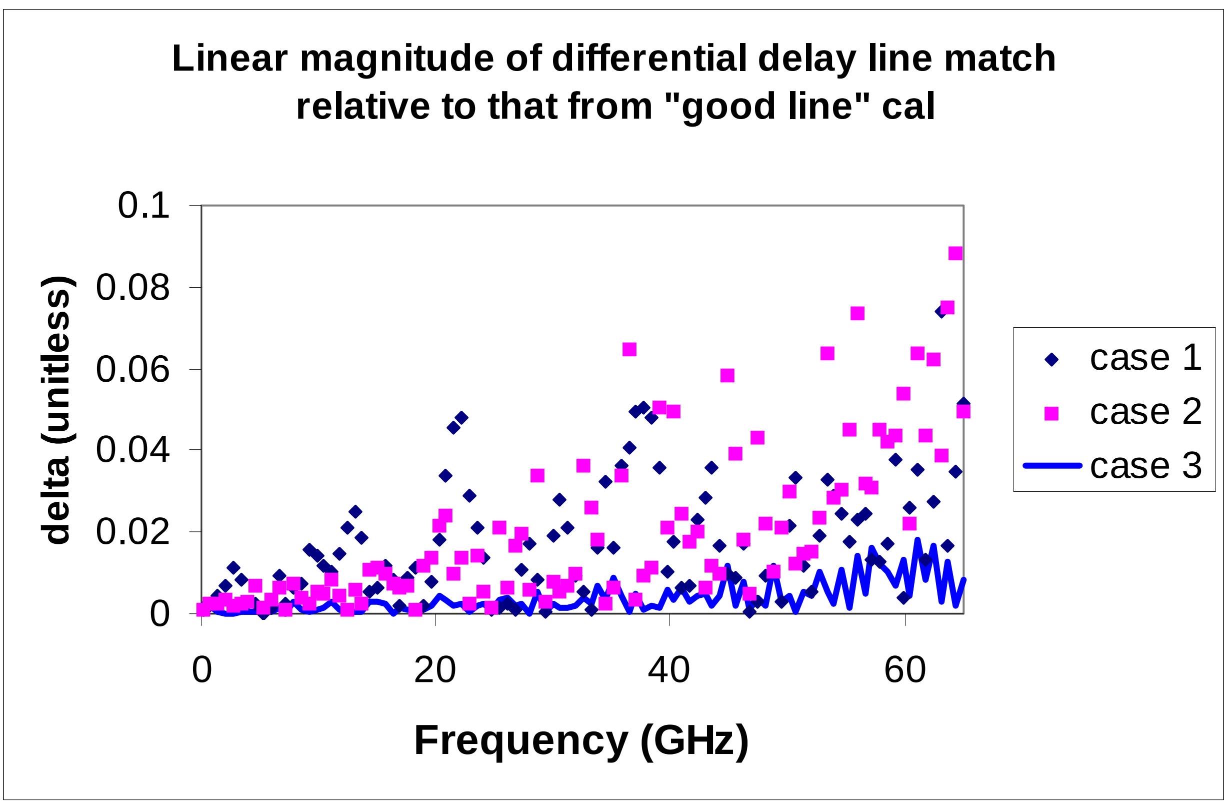
Figure 22-31. Reflection Magnitude Uncertainty

The exact configuration of the through selections will have some impact on uncertainty as well. If one uses redundancy heavily, some of the previous calibration results (which have there own uncertainty) are used to compute other transmission tracking terms (thus elevating their uncertainties). Thus there is something of an uncertainty penalty in taking advantage of redundancy to reduce calibration time. Depending on the nature of the available throughs between some ports (electromagnetically questionable), however, there may be even more of a penalty in trying to use all of the throughs if they are of low quality. If the calibration is of reasonably high quality, the transmission tracking penalty in using redundancy will normally not exceed a few hundredths of a dB but each calibration situation can be different.

The heavy use of reciprocals in lieu of throughs can also affect uncertainties since the accuracy on load match acquisition is lower using reciprocals. Again, trying to treat the networks as throughs may make it even worse so there is an additional trade-off in play. If the reciprocal loss is under 5-10 dB and its return loss is better than about 10 dB, the uncertainty penalty will be small except for measurements of very low loss, high return loss devices (which if they existed, why were not they used as the reciprocals?).

The plot below (Figure 22-32) illustrates some of these complex trade-offs. The DUT in all cases is a differential delay line and we are interested in measuring its return loss. There are two high quality throughs available during the cal (return loss >30 dB) but the other available lines have a 15 dB return loss. The error relative to the correct return loss (in linear units) is being plotted.

- **Case 1 (not done)** – Use the poor line to establish load match and treat it as a through.
- **Case 2 (can be done)** – Use the good lines to get load match but treat the poor line a s a through to get the remaining transmission tracking terms
- **Case 3 (preferred)**: Treat the poor line as a reciprocal.



An example of the effects of through and reciprocal selection on measurement uncertainties is shown here.

Figure 22-32. Measurement Uncertainties for Through and Reciprocal Selection

In this case, using a reciprocal gives a far better result than trying to force a “through” utilization.

Uncertainty of Derived Mixed-Mode S-Parameters

Uncertainty of derived mixed-mode S-parameters is another issue of interest. Since the mixed mode terms are simple linear combinations of the normal S-parameters, the uncertainty in a mixed-mode parameter is easy to compute:

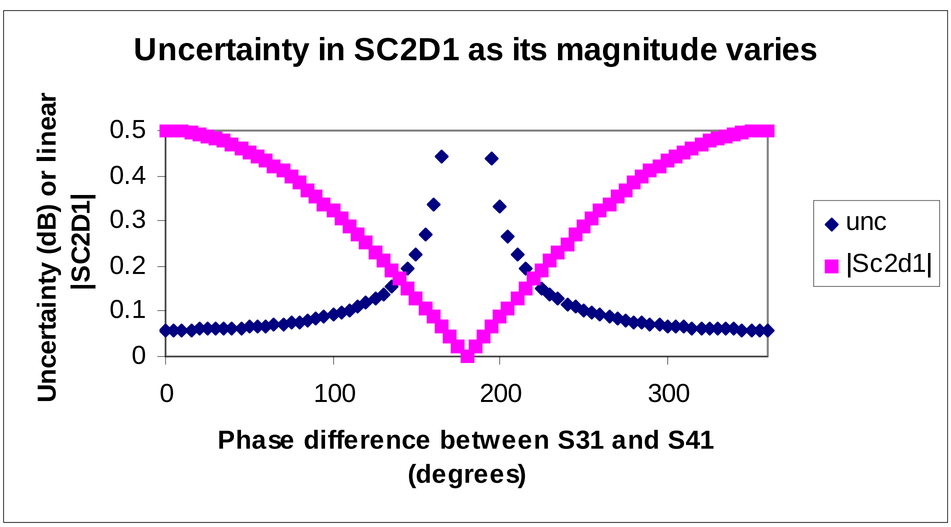
$$S_{c2d1} = \frac{1}{2}(S_{31} + S_{41} - S_{32} - S_{42})$$

(22-15)

$$\frac{\Delta S_{c2d1}}{S_{c2d1}} \le \frac{|\Delta S_{31}| + |\Delta S_{41}| + |\Delta S_{32}| + |\Delta S_{42}|}{S_{31} + S_{41} - S_{32} - S_{42}}$$

(22-16)

Where linear absolute magnitudes can be used for a worst case computation. The caveat here is that this is in linear terms while uncertainties are often more useful in a log form. This has a surprising effect for some parameters. As an example, consider the case where the single-ended uncertainties are fixed at 0.03 dB, S_{32} and S_{42} are zero and S_{31} and S_{41} are allowed to vary. For the purposes of an example, the magnitude of S_{31} and S_{41} will be fixed at 0.5 and the phase will be allowed to vary. As one can see below (Figure 22-33), when the phase of the single ended parameters is such that $|S_{C2D1}|$ is small, the uncertainty (in dB terms) explodes. This follows from Eq. 22-10 since the numerator is largely fixed but the denominator can get small.



The uncertainty (in dB) in a mixed-mode parameter is a strong function of the magnitude of that parameter because of how they are computed.

Figure 22-33. SC2D1 Uncertainty in SC2D1

Since the desired quantity (S_{c2d1} in this case) is very small, the relative uncertainty can be quite high. This is somewhat intuitive since the computation is subtracting nearly equal numbers. The user is therefore cautioned that cal stability will be extremely critical on the smaller mixed mode parameters and the uncertainties will be relatively high. The biggest source of problems will often be cable changes with flexure or connector repeatability.

22-8 Hybrid Calibrations

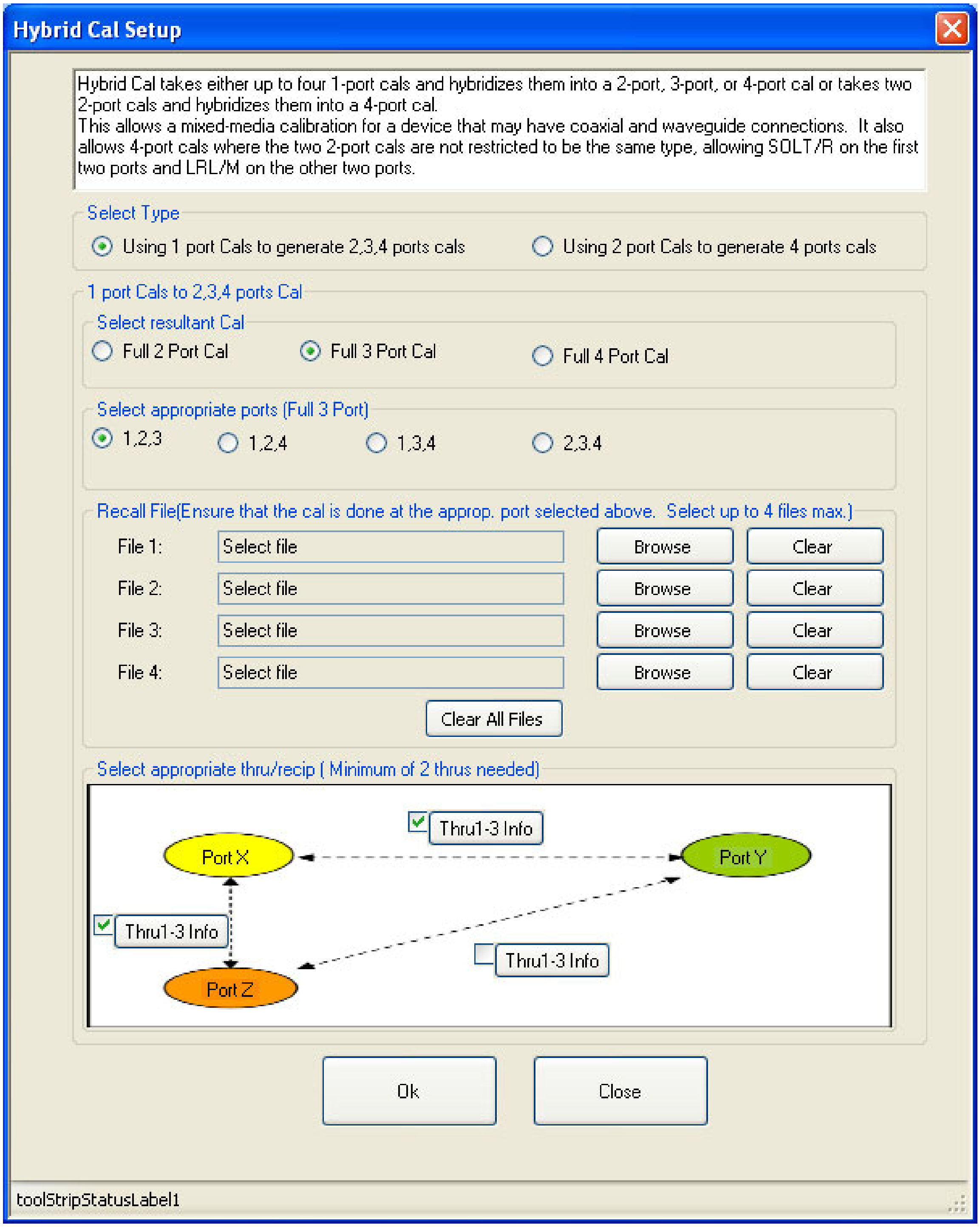
The concept of hybrid calibrations was introduced in Chapter 9, "Other Calibration Procedures" in the "Hybrid Calibrations" section for the 2-Port VNA but it takes on more importance in the multiport case. This is largely because of the geometrical complications in a multiport setup (particularly on-wafer or fixtured) that demand more flexibility in cal algorithm selection.

There are two main subcategories in the multiport case: the combination of 1-Port calibrations and the combination of 2-Port calibrations. In both subcategories, the frequency lists used in the constituent calibrations must be the same.

Combination of 1-Port Calibrations

The first subcategory is illustrated in the dialog below (Figure 22-34). The idea is a natural extension of what was discussed in Chapter 9, "Other Calibration Procedures" for the 2-Port case. A series of 1-Port calibrations are combined with a requisite number of throughs or reciprocals to generate a complete N port cal. The choices in the dialog are fairly obvious. Like the multiport calibrations discussed earlier, there is a minimum coverage requirement for the throughs/reciprocals. At least two throughs are needed for a 3-Port cal and at least three throughs are needed for 4-Port cal (and they must touch all ports). Any or all of these "throughs" may actually be reciprocals and this is commonly of interest. Consider the case of wishing to create a 3-Port cal from a series of one port calibrations on-wafer where Ports 1 and 2 are coplanar waveguide (with corresponding cal standards) with a high quality interconnecting through and Port 3 is microstrip (with a more poorly defined "through" linking the other ports). The 1-Port calibrations for Ports 1 and 2 would be performed using a non-dispersive (or coaxial) media type while the cal for Port 3 would likely be performed using the microstrip media type. In completing the hybrid cal, one would likely select a through to connect Ports 1 and 2 and a reciprocal to connect Ports 1 and 3 (or 2 and 3).

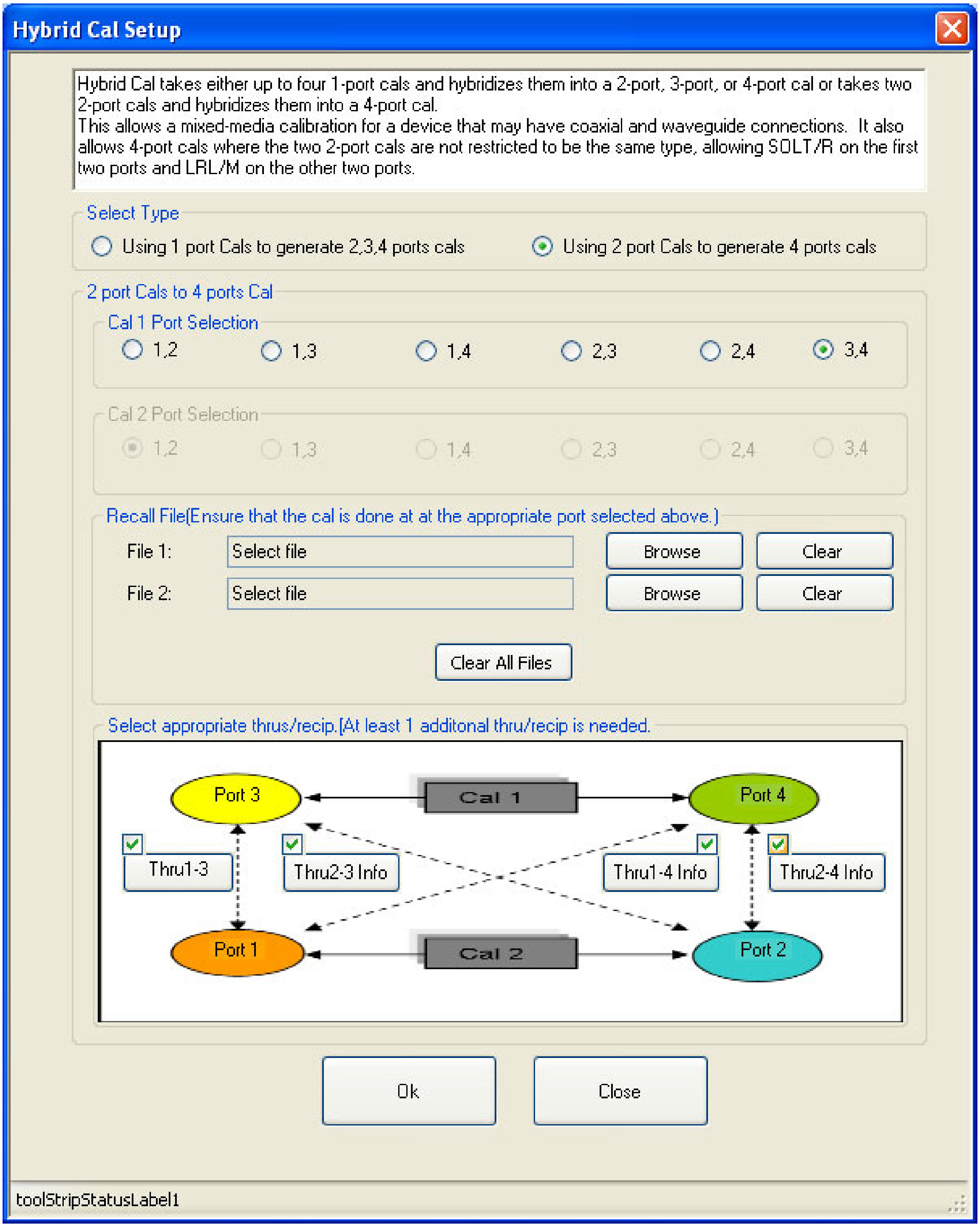
As always, there is a slight uncertainty penalty on transmission tracking for those paths not measured with thrus or reciprocals. For high quality calibrations, this is typically on the order of a few hundredths of a dB.



The Hybrid CAL SETUP dialog box using 1-Port Cals to generate 2-, 3-, and 4-Ports cals - Full 3 Port Cal - Through for Ports 1-3

Figure 22-34. HYBRID CAL SETUP Dialog Box - Using 1-Port Cals to Generate 2-, 3-, or 4-Port Cals

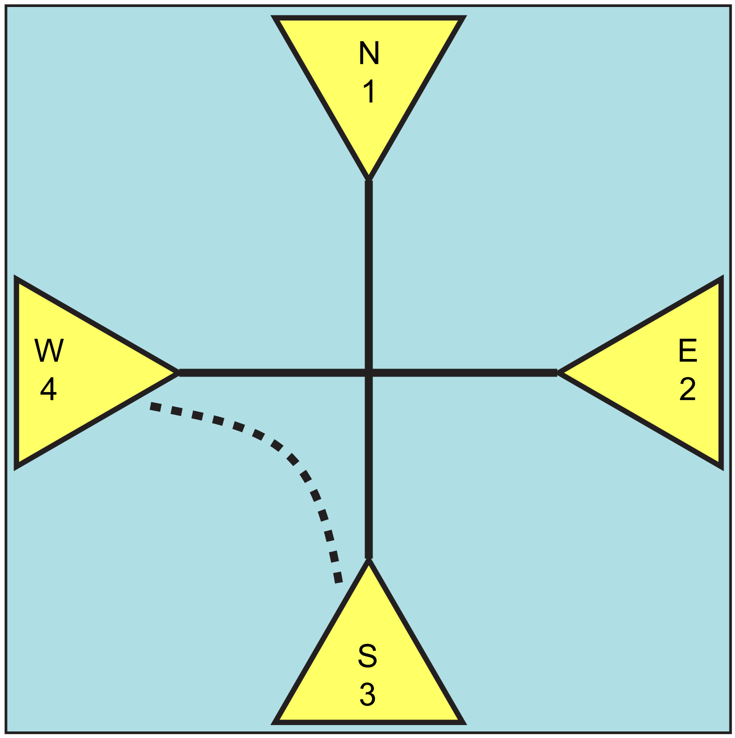
Two 2-Port calibrations can also be combined to create a full 4-Port calibration and this process is illustrated in the dialog shown below. The two 2-Port calibrations used must be disjoint (i.e., they involve different port pairs). The dialog forces this since one only actually selects the first pair. Once the constituent calibrations are selected, at least one additional thru or reciprocal must also be added. As usual, adding additional thrus (if practical) can aid certain transmission measurements.



The Hybrid CAL SETUP dialog box using 2-Port Cals to generate 4-Port cals - Throughs for Ports 1-3, 2-3, 1-4, and 2-4 selected

Figure 22-35. HYBRID CAL SETUP Dialog Box - Using 2-Port Cals to Generate a 4-Port Cals

An example where this might play a role would be the orthogonal probe setup discussed earlier and shown again below (Figure 22-36). Suppose N-S represents a clean path where LRL standards are available while E-W represents a clean path where only SOLT standards are available. Further, the corner paths (e.g., NW) have transmission lines available for calibration but they are of fairly poor quality. The two separate 2-Port calibrations would be performed with the algorithms identified. They would then be combined using the hybrid cal feature with at least one of the corner paths used as a reciprocal.



An on-wafer configuration where some line paths are more likely to be of higher quality than others. The solid lines will generally not be an issue but a transmission path illustrated by the dotted line (S-W) may be electromagnetically compromised at higher frequencies.

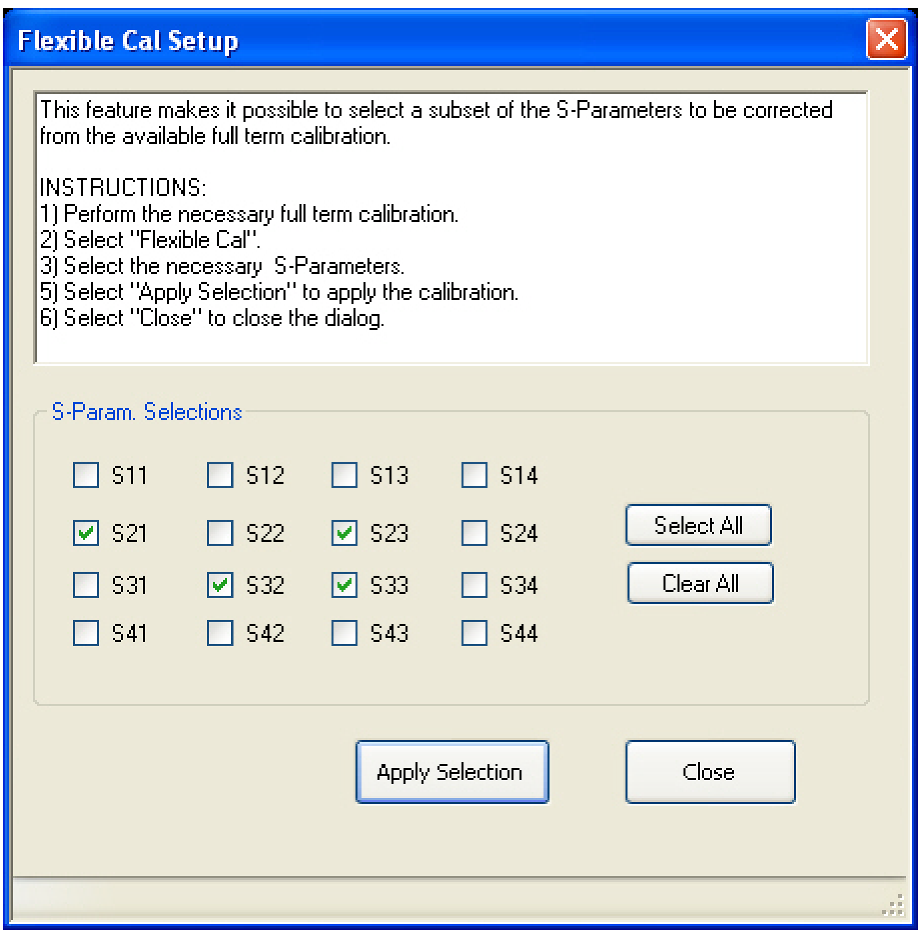
Figure 22-36. On-Wafer Line Path Quality

22-9 Flexible Calibrations

The flexible calibration implementation for multiport is a straightforward extension of that discussed in Chapter 9, “Other Calibration Procedures” for two port systems. The dialog shown below illustrates the 16 possible S-parameters when the parent cal is a full 4-port cal. As discussed before, the objective is to select only those S-parameters one needs for a given measurement and those that may significantly help the uncertainty of the needed measurement. As before, the system will only do the sweeps required to get the requested S-parameters and will do as complete a cal as possible based on those parameters.

Examples

- **Select S_{33} and S_{43}**
- Sweep only with Port 3 driving and use a 1-Path 2-Port cal for the two parameters
- **Select S_{11}, S_{13}, S_{31}, S_{33}, S_{42}, and S_{24}**
- All four ports will have to drive. Use a full 2-port cal between Ports 1 and 3 and a transmission frequency response cal between Ports 2 and 4
- **Select S_{11}, S_{22}, S_{14} and S_{41}**
- Ports 1, 2, and 4 will have to drive. If 1-4 is a low loss path, one may want to also add S_{44} as this will enable load match correction and could help uncertainties of S_{14} and S_{41} (it would be of less use if 1-4 had large insertion loss). If S_{44} was added, a full two port cal between 1 and 4 would be used along with a 1-port reflection-only cal at Port 2.



Note that the items enabled for selection are based on the last calibration performed. Also note that there is only the customize selections since the UI can get complicated with Cal A and Cal B.

Figure 22-37. FLEXIBLE CAL SETUP Dialog Box for Multiport VNAs

22-10 Network Extraction

Following onto the discussion of Chapter 8, "Adapter Removal Calibrations and Network Extraction", there are additional network extraction techniques available to help find the networks for multiport de-embedding problems. The new techniques are labeled Types E, F, and G which apply for 4-Port calibrations. The original types (Types A to D) apply for 1- and 2-port configurations as before.

- **Type E Network Extraction**

  Uses a pair of full 4-port calibrations to fully extract four S2P files describing the arms of the adapter/ fixture assembly. This is a complete solution but assumes the arms of the assembly are not coupled together. This is a 4-port extension of Type C.

- **Type F Network Extraction**

  This is a 4-port back-to-back method where four S2P files are extracted and the four arms of the adapter/ fixture assembly are assumed uncoupled. As with Type D (the 2-port equivalent), match is assigned to the outer planes.

- **Type G**

  This is a 4-Port back-to-back method where two S4P files are generated and the sides are assumed coupled (in a half-leaky sense). Measured cross-coupling is assigned to the outer planes.

For both Types F and G, the inner plane through connection is assumed to be between opposite ports (1-3 and 2-4). As with all other network extraction types, reciprocity is assumed.

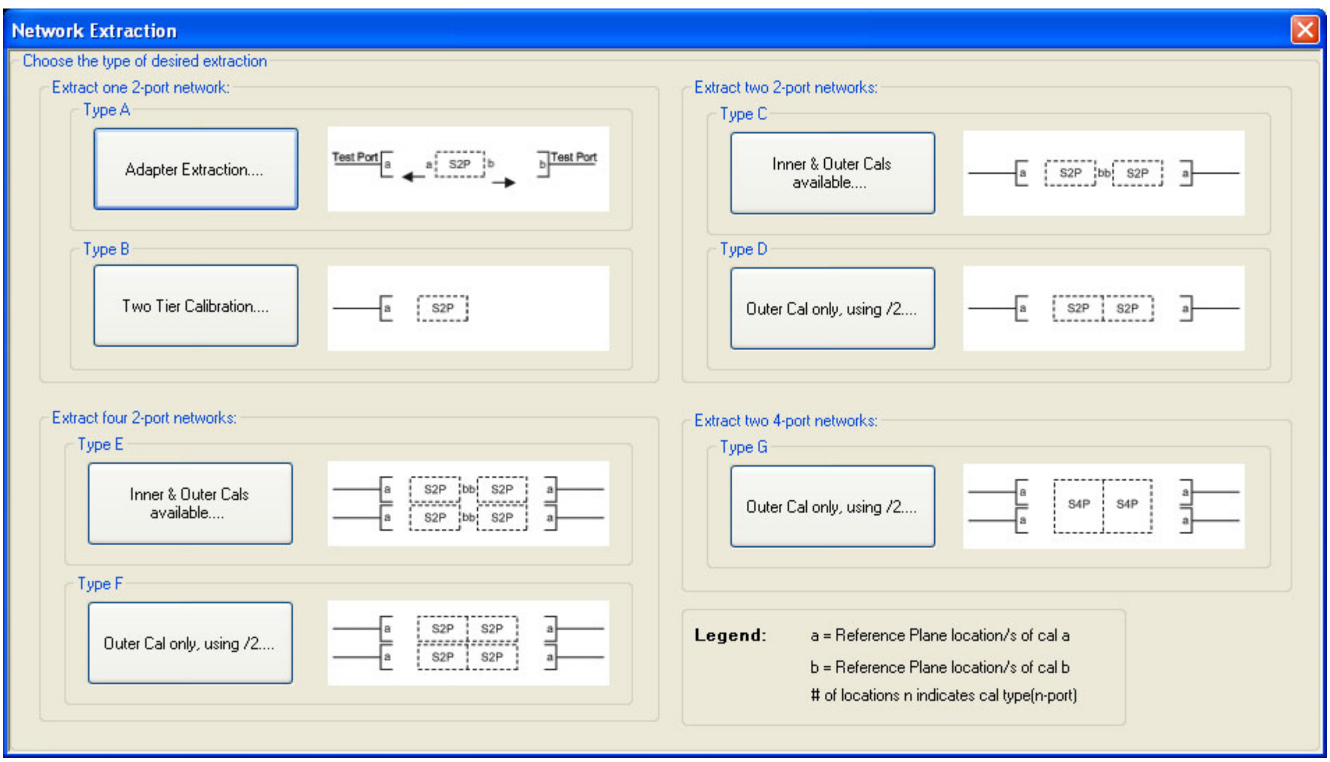


Figure 22-38. NETWORK EXTRACTION Dialog Box - Type Selection - 4-Port VNAs

Type A Network Extraction

Before continuing with the new network extraction types, note that in the case of Type A, there is the additional requirement to specify where the adapter is (in the case of a multiport calibration). The added radio button selections are shown in the dialog below.

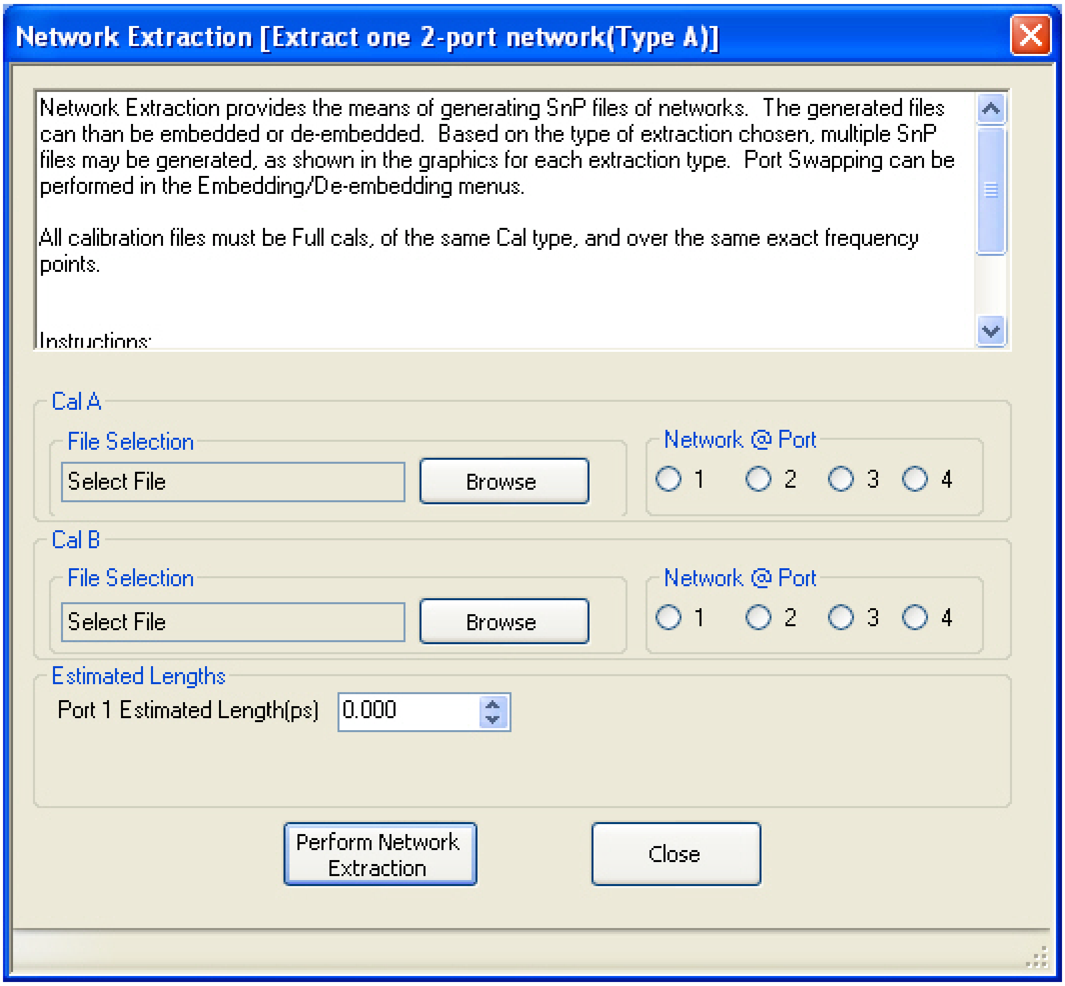


Figure 22-39. NETWORK EXTRACTION TYPE A Dialog Box

Type E Network Extraction

In terms of execution, Type E is very much like Type C. The two full calibration files must be specified (in this case full 4-Port calibrations). Upon execution, a dialog will appear allowing one to name the four S2P destination files. The files will be listed in order of absolute port number.

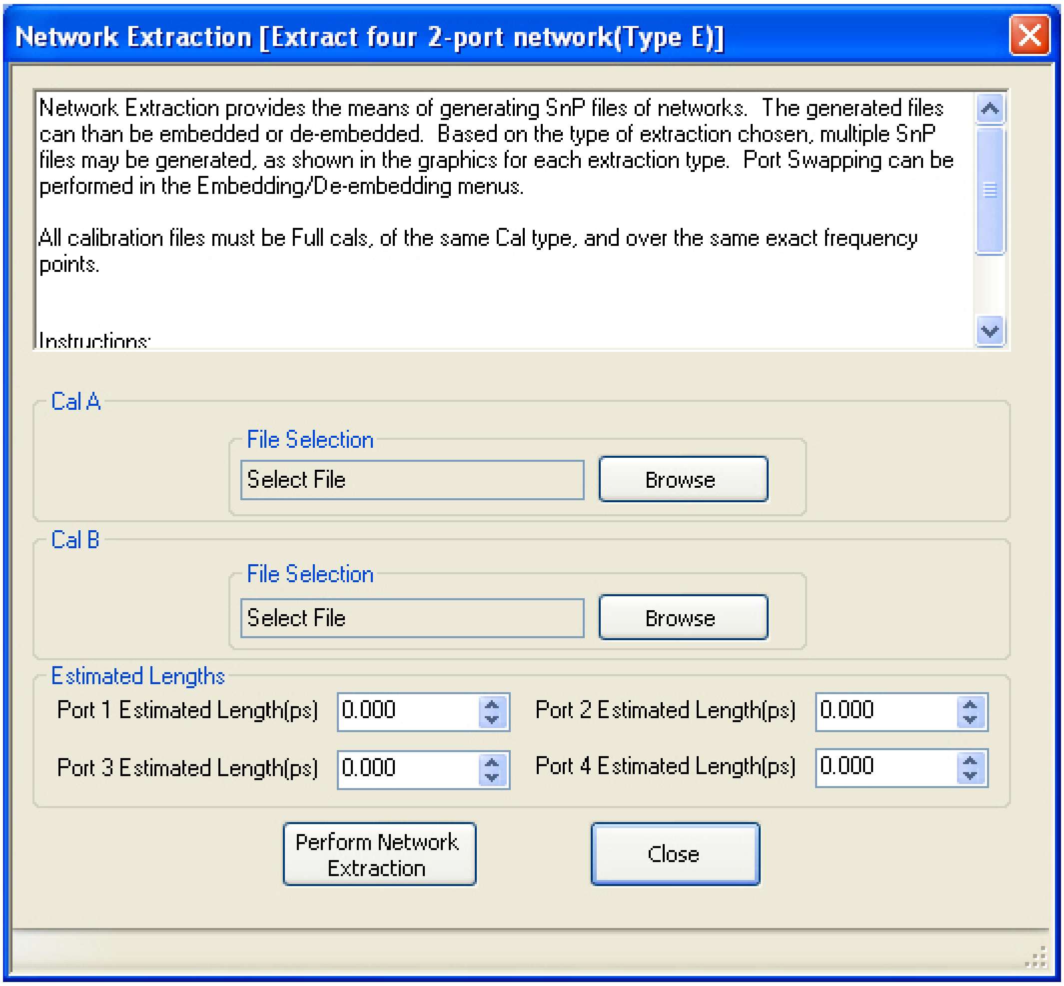


Figure 22-40. NETWORK EXTRACTION TYPE E Dialog Box

As suggested by the overall network extraction dialog, the Type E method treats the fixture as having four, uncoupled, 2-Port arms as shown below (Figure 22-41). These networks are then extracted as S2P files obviously. The required level of “uncoupled-ness” depends on expected uncertainties and other losses in the networks. If the main paths were of very low loss and there was about 40 dB of coupling between arms of the fixture, there could be an added uncertainty of about 0.1 dB from ignoring that coupling with this method. If the coupling was actually 20 dB, there could be ≅ 1 dB of added uncertainty.

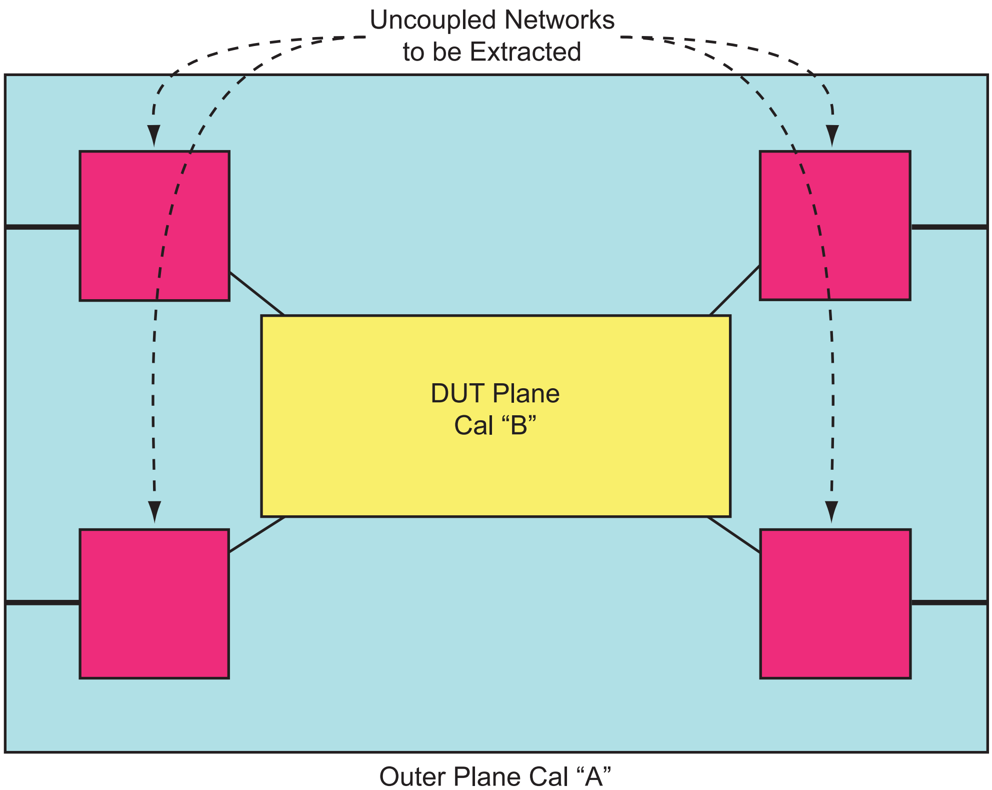


Figure 22-41. Type E Network Extraction - Uncoupled Networks To Be Extracted

Type F Network Extraction

Types F and G operate much like Type D except a full 4-Port cal should be applied upon entering the dialog instead of a full 2-Port cal. The usual file definition dialog will follow. As with Type D, the check box option allows one to zero out all match terms instead of assigning mismatch to the outer plane.

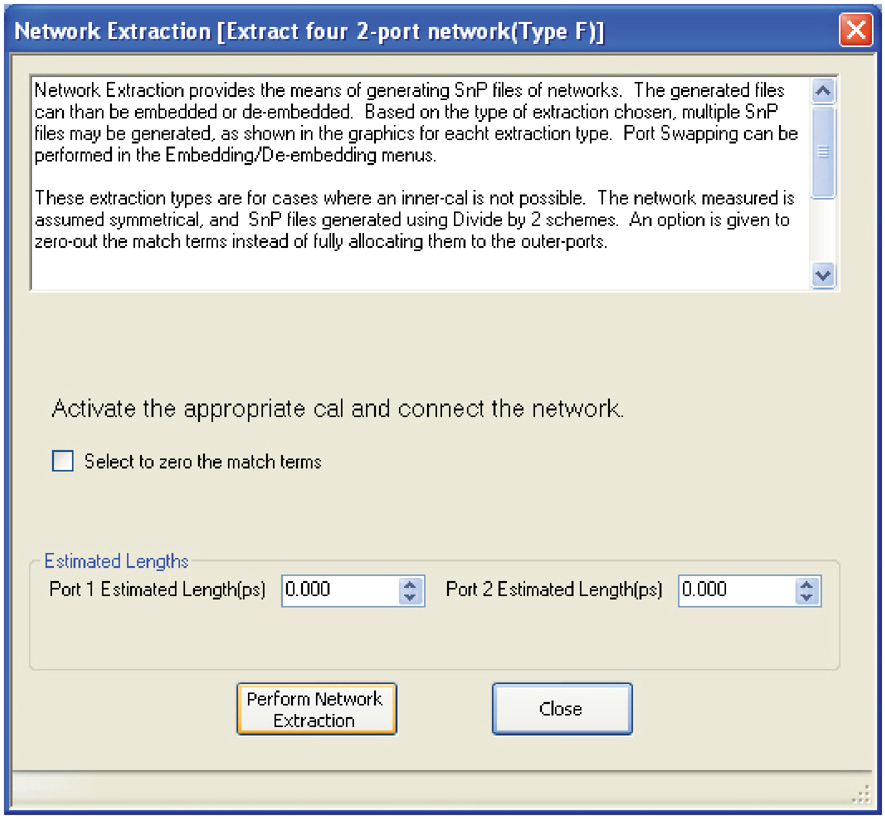


Figure 22-42. NETWORK EXTRACTION TYPE F Dialog Box

In the case of Type F, the networks are again assumed uncoupled. It is a method appropriate for the same situations as Type E except when inner calibration standards are not feasible or of reliable uncertainty. The interconnect assumed is between opposite ports (Ports 1 and 3, Ports 2 and 4) during this measurement.

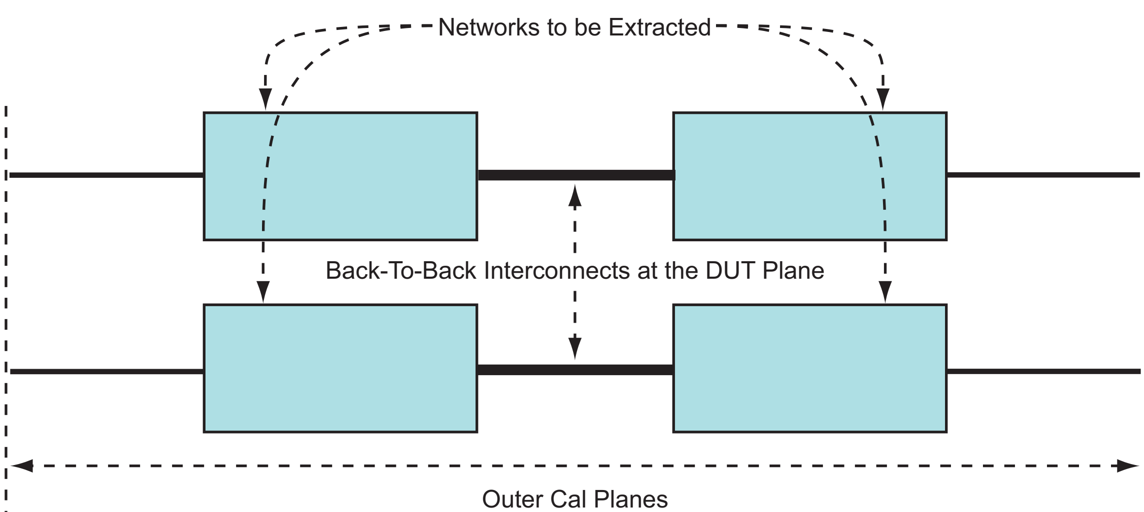


Figure 22-43. Type F Network Extraction - Back-to-Back Interconnects at the DUT Plane - Type F

Type G Network Extraction

In the case of Type G, the S-parameter matrix will take on a very particular form. Ports 1 and 2 of the left network are assumed to be the outer ports and the inner ports for that network will be assigned Ports 3 and 4 for the S4P definition. Because of the match and cross-coupling assumptions, the matrix saved will take on the form below (Eq. 22-17).

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & 0 \\ S_{14} & S_{24} & 0 & 0 \end{bmatrix} \tag{22-17}$$

An eigen-structure based solution is used to split the composite results in the upper right and lower left quadrants into the two “halves”. In most cases, there should not be convergence issues with the process unless the return loss of the structure gets very close to 0 dB. As shown, reciprocity is enforced. $S_{11} = S_{22} = 0$ if the check box is selected. The entire upper left quadrant is a direct map from the measurement as match and cross-coupling are assigned to the outer ports.

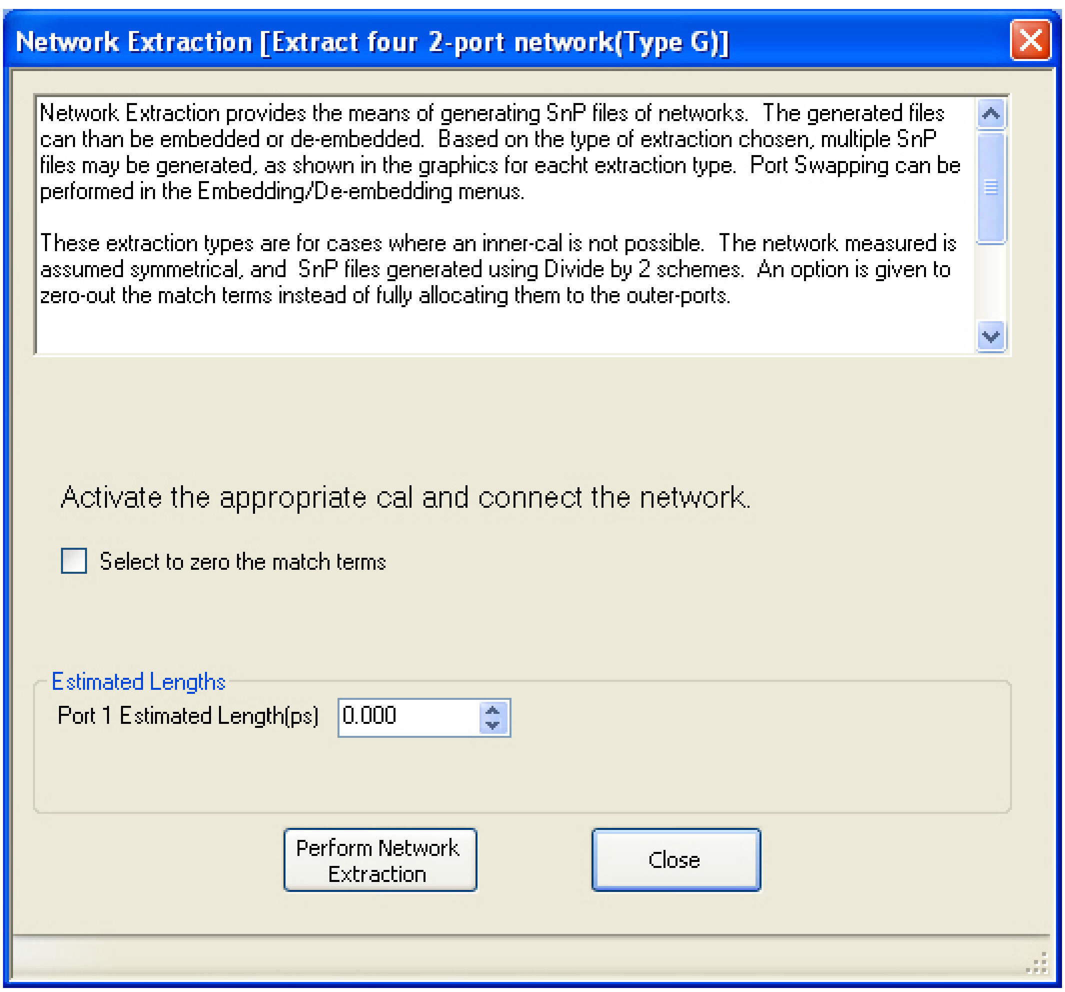


Figure 22-44. NETWORK EXTRACTION TYPE G Dialog Box

Structurally, the measurement is the same as in Type F. The only difference is in the matrix structure of the extracted parameters.

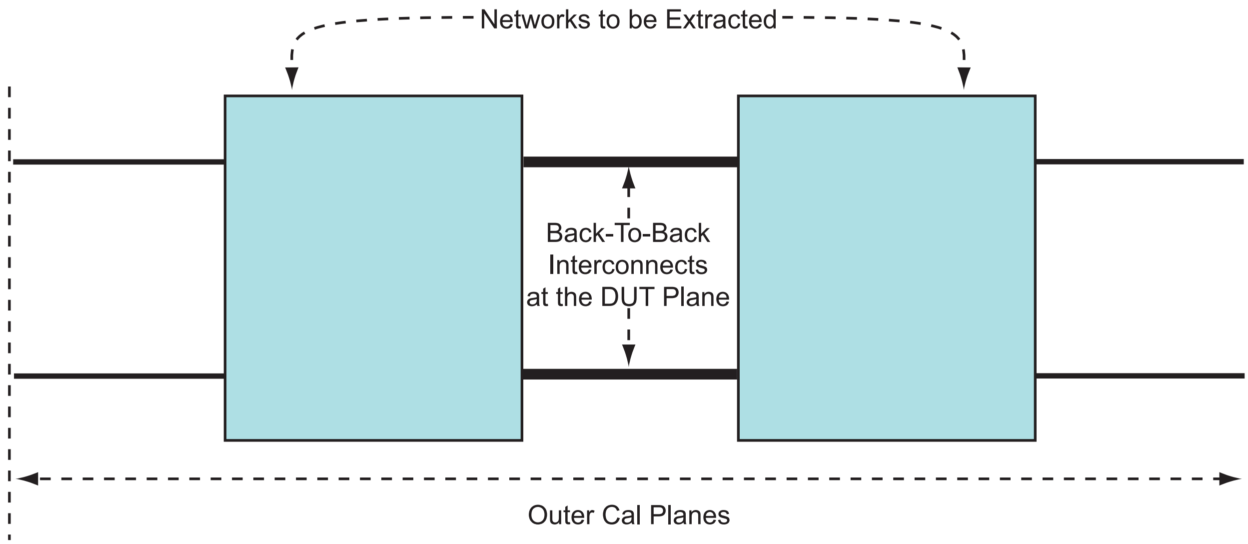


Figure 22-45. Back-to-Back Interconnects at the DUT Plane - Type G

22-11 Embedding/De-embedding

The main addition relative to the embedding/de-embedding discussion in Figure 10 is the ability to embed or de-embed (E/DE) 4-Port networks thus allowing the use of differential and other coupled circuits. The usual single-port E/DE with 2-Port networks is still supported with a multiport cal (for uncoupled networks) and the interface works exactly the same as in Chapter 10, "Calibration and Measurement Enhancements" (with the obvious change that the 2-Port networks can now be connected to any of the 4 ports). As before, a check will be completed between the embedding/de-embedding configuration requested and the current calibration in place. If the current cal does not support the E/DE request, an error will be generated (for example, trying to embed a network on Port 4 when only a 1-2 two-port cal exists).

The new addition, shown in the below dialog, is that now one may specify port pairs to which a network is connected.

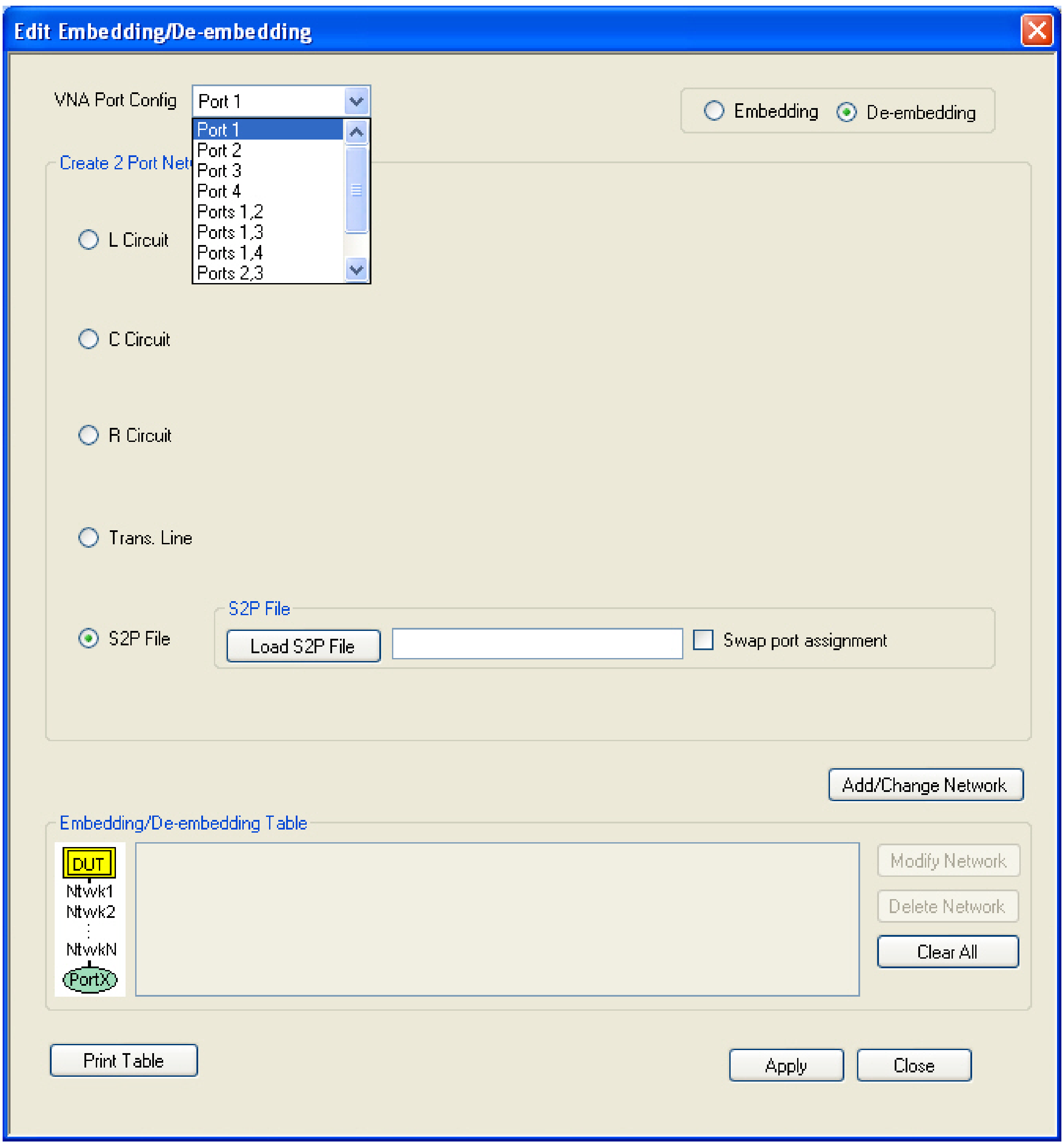


Figure 22-46. EDIT EMBEDDING/DE-EMBEDDING (E/DE) Dialog Box - S2P File - 4-Port VNAs

The inductive, capacitive and resistive elements are all quite simple and the inductive entry field is shown below as an example. As before, the respective default units are nH, pF and Ohms. Note that these elements are all cross-elements between ports. For series elements or elements to ground, one would use the original single port E/DE discussed earlier.

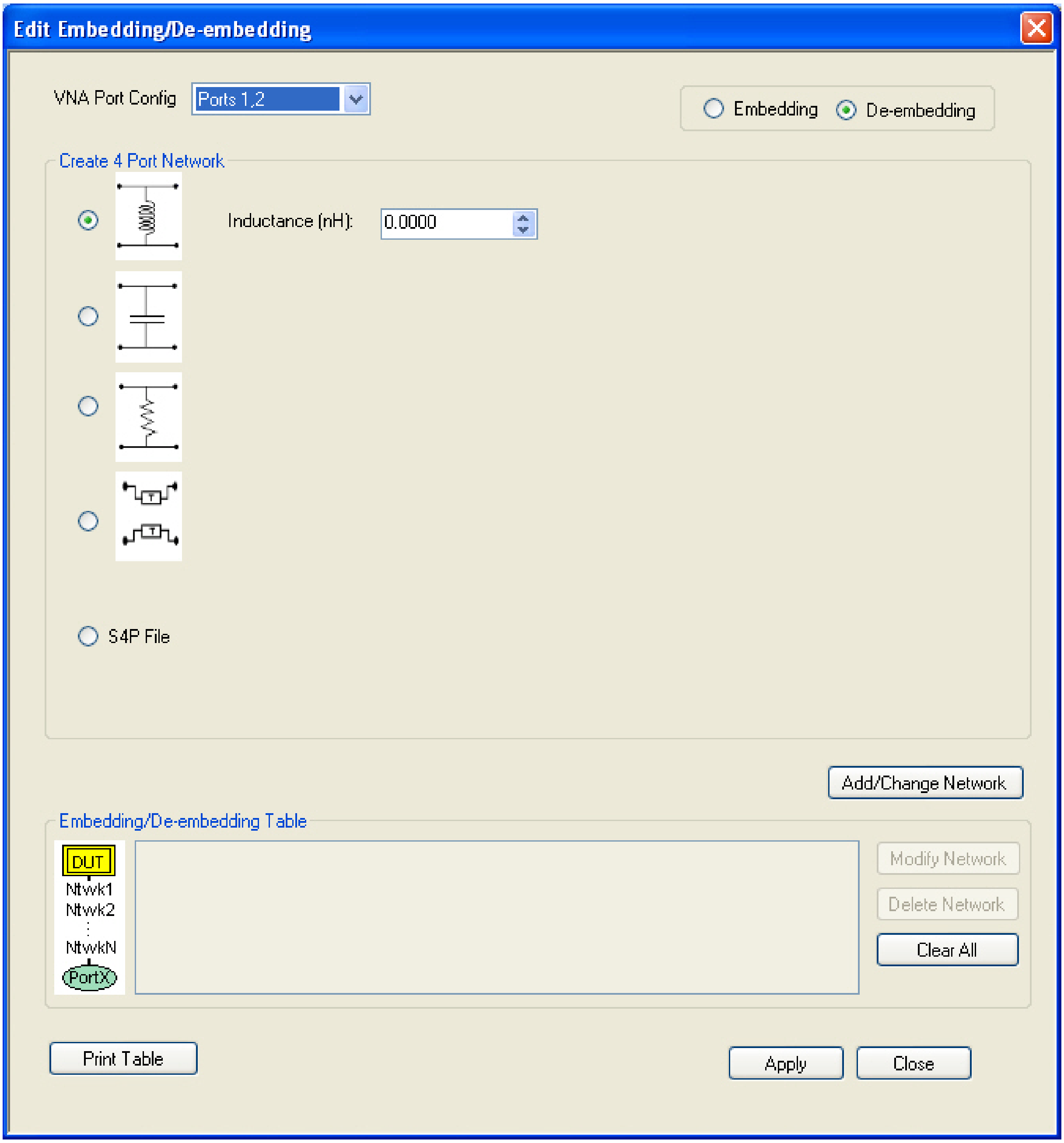


Figure 22-47. E/DE Dialog Box - S2P File - Inductance - 4-Port VNAs

The transmission line element is a bit more complicated in that a general coupled transmission line was desired. As shown in the below dialog, the impedance, effective dielectric constant (and hence electrical length) and loss can be specified separately for the even and odd modes on the transmission line. The same loss scaling with frequency rules apply as with single port (2 port network) E/DE. If 0 is entered as the reference frequency (f0, the "*@frequency*" box), the loss value will be applied uniformly at all frequencies.

$$Loss\ (f) = Loss\ (f_0) \times \sqrt{\frac{f}{f_0}}$$

(22-18)

While coupled line theory is too large a topic to cover here in detail (for a brief treatment, see, e.g., D. Pozar, *Microwave Engineering*, Chapter 8, Addison-Wesley, 1990), there is a relationship between the even and odd impedances and the level of coupling that holds when the even and odd effective dielectric constants are close.

$$Z_{0e} \approx Z_0 \sqrt{\frac{1 + C}{1 - C}}$$

$$Z_{0o} \approx Z_0 \sqrt{\frac{1 - C}{1 + C}}$$

(22-19)

Where C is the voltage coupling coefficient. For highly dispersive structures, the relationship is more complicated and one may want to resort to S4P file definition.

The S4P file loading works very similarly to the S2P loading discussed earlier. As in that case, the system will attempt to interpolate and extrapolate the best it can when the file frequency range and the sweep frequency range do not match exactly. If there is no overlap between frequency ranges, an error will be generated.

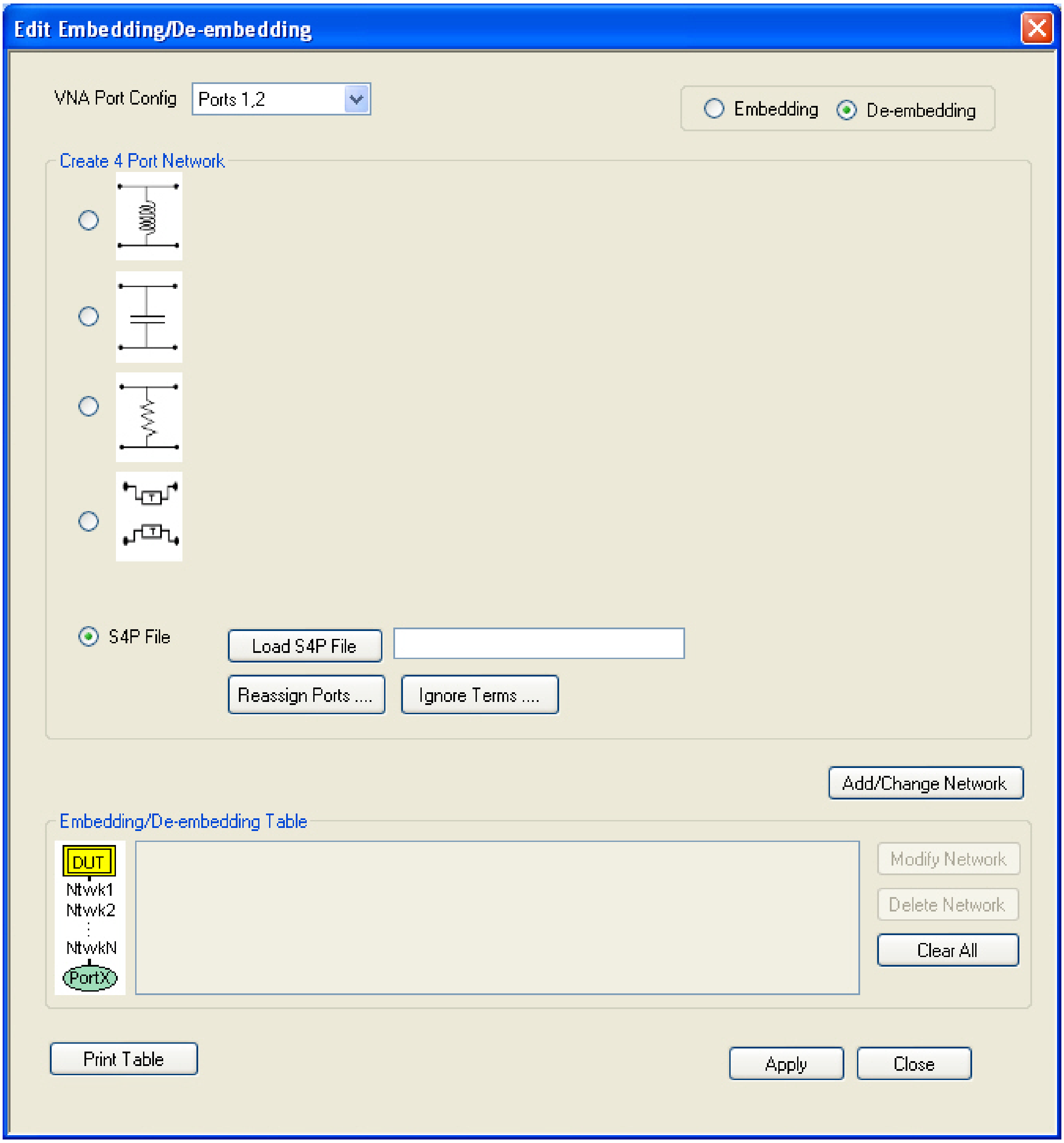


Figure 22-48. E/DE Dialog Box with Load S4P Selected - 4-Port Networks

Reassign Ports Options

Instead of a “swap ports” option, there is a more general “reassign ports selection” whose dialog is shown next. This is useful in the case that the port assignment used during file generation does not match how one wants to embed or de-embed that data. The dialog allows an arbitrary reassignment but, of course, the port mappings must all be distinct (one cannot map both Ports 1 and 2 onto Port 4). The example below (Figure 22-49) shows Ports 1, 2, 3 and 4 reassigned to Ports 4, 3, 2, and 1.

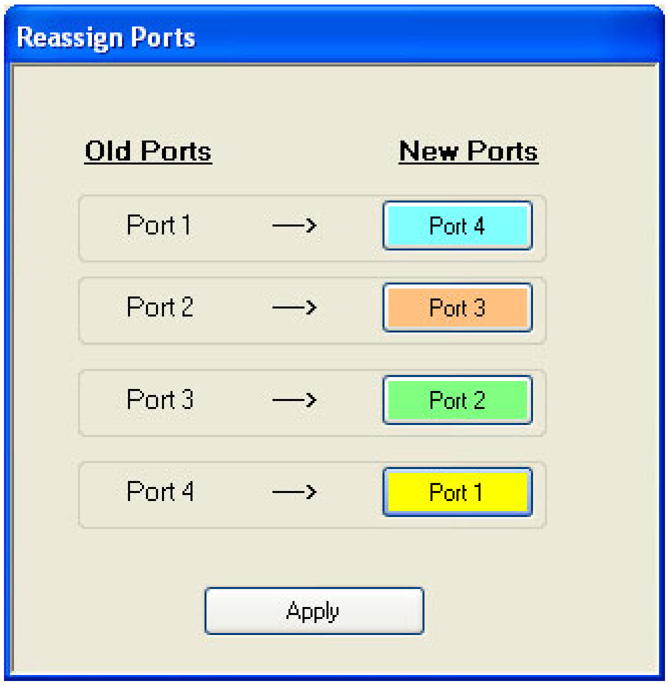
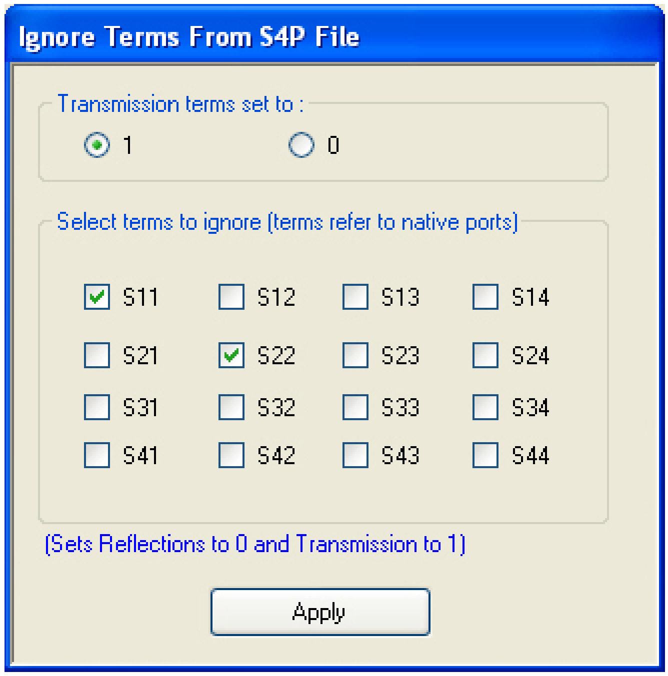


Figure 22-49. REASSIGN PORTS Dialog Box - Linked from E/DE dialog box and Reassign Ports button

Ignore Terms Options

The “ignore terms” is another dialog selection which allows one to omit match terms or leakage terms in the S4P file that may not be meaningful. A check box in this matrix will suspend loading of that parameter for that file. An example of this use might be the files generated from Type G network extraction where one now decides that the match terms (S_{11} and S_{22}) really are not that meaningful. In this case, the check boxes for those two parameters would be selected.



Transmission Terms set to 1, with Terms S_{11} and S_{22} to be ignored.

Figure 22-50. IGNORE TERMS From S4P File Dialog Box

22-12 Summary

This chapter has focused on the differences in response selection/definition and calibration differences when using a 4-Port version of the MS4640A Series VNA system. Other functions are affected in certain ways and this will be dependent on software versions. Significant changes are covered in later chapters.

Many of the post-processing functions from the two-port VNA carry over unchanged into the multiport measurement context. Graph types, marker readouts and trace data readout are all trace local and will feed off the defined parameter. The same is true for time domain since this operates on any trace-level parameter (although it will not be useful generally for an unratioed parameter such as b4/1 since phase is not well-defined but this is no different from the two-port case). In particular, time domain applies to all of the mixed mode parameters. Smoothing and parameter conversion fall in the same category.

22-13 References

1. J. Martens, D. Judge, and J. Bigelow, “Multiport vector network analyzer measurements,” *Microwave Magazine*, vol. 6, Dec. 2005, pp. 72-81.
2. D. E. Bockelman and W. R. Eisenstadt, “Combined differential and common mode scattering parameters: Theory and simulation,” *IEEE Trans. Micr. Theory Tech.*, vol. MTT-43, July 1995, pp. 1530-1539.
3. D. E. Bockelman, W. R. Eisenstadt, and R. Stengel, “Accuracy estimation of mixed-mode scattering parameter measurements,” *IEEE Trans. Micr. Theory Tech.*, vol. MTT-47, Jan. 1999, pp. 102-105.
4. G. Sundberg, “Grasping the meaning of mixed-mode S-parameters,” *Microwaves and RF*, vol. 40, May 2001, pp. 99-104.
5. J. Dunsmore, “New measurement results and models for non-linear differential amplifier characterization,”*64th ARFTG Dig.*, Dec. 2004, pp. 143-146.
6. J. Dunsmore, “New methods and non-linear measurements for active differential devices,” *2003 IEEE Int. Micr. Symp. Dig.*, June 2003, pp. 1655-1658.
7. J. Martens, D. V. Judge, and J. A. Bigelow, “Uncertainties associated with many-port (>4) S-parameter measurements using a four-port vector network analyzer,” *IEEE Trans. Micr. Theory Tech.,* vol. 52, May 2004, pp. 1361-1368.

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