

ShockLine™

MS46122A/B and MS46322A/B Series

Vector Network Analyzer

MS46122A/B-010 VNA, 1 MHz to 8 GHz, 2-Port

MS46122A/B-020 VNA, 1 MHz to 20 GHz, 2-Port

MS46122A/B-040 VNA, 1 MHz to 43.5 GHz, 2-Port

MS46322A-004, 1 MHz to 4 GHz, 2-Port

MS46322A/B-010 VNA, 1 MHz to 8 GHz, 2-Port

MS46322A-014, 1 MHz to 14 GHz, 2-Port

MS46322A/B-020 VNA, 1 MHz to 20 GHz, 2-Port

MS46322A-030, 1 MHz to 30 GHz, 2-Port

MS46322A/B-040 VNA, 1 MHz to 43.5 GHz, 2-Port



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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 ShockLine™ MS46122A/B and MS46322A/B Series Vector Network Analyzer (VNA) 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

Product Information, Compliance, and Safety

- ShockLine™ Product Information, Compliance, and Safety (PICS) – 10100-00067

ShockLine™ MS46122A/B Vector Network Analyzers

- MS46122A Series VNA Technical Data Sheet – 11410-00822
- MS46122B Series VNA Technical Data Sheet – 11410-00995
- MS46122A/B Series VNA Operation Manual – 10410-00340
- MS46122A/B Series VNA Measurement Guide – 10410-00336
- MS46122A/B Series VNA User Interface Reference Manual – 10410-00337
- MS46122A/B Series VNA Programming Manual – 10410-00338
- MS46122A/B Series VNA Maintenance Manual – 10410-00341
- MS46122A/B Series VNA User Documentation – 2300-559-R

ShockLine™ MS46322A/B Vector Network Analyzers

- MS46322A Series VNA Technical Data Sheet – 11410-00751
- MS46322A/B Series VNA Operation Manual – 10410-00335
- MS46322A/B Series VNA Measurement Guide – 10410-00336
- MS46322A/B Series VNA User Interface Reference Manual – 10410-00337
- MS46322A/B Series VNA Programming Manual – 10410-00338

Calibration, Verification, and System Performance Verification

- 3653A Mechanical Calibration Kit Reference Manual – 10410-00278
- Performance Verification Software (PVS) User Guide – 10410-00739
- PVS Quick Start Guide – 10410-00740

Calibration, Verification, and System Performance Verification

- MN25208A, MN25218A, MN25408A, MN25418A SmartCal Quick Start Guide – 10410-00741
- MN4765B O/E Calibration Module Technical Data Sheet (TDS) – 11410-00843
- MN4765B O/E Calibration Module Operation Manual (OM) – 10410-00742
- 36585K Precision Auto Calibrator (AutoCal) Module Reference Manual – 10410-00279
- 3650A, 3652A, and 3654D Mechanical Calibration Kit Reference Manual – 10410-00278
- 366X-1 Verification Kits (3666-1 3.5mm Connectors, 3668-1 K Connectors) and 2300-527 Performance Verification Software (PVS) User Guide – 10410-00270
- 366X-1 Verification Kit and 2300-527 PVS Quick Start Guide – 10410-00285

1-4 Calibration Kits, Verification Kits, and Test Port Cables

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 ShockLine™ MS46122A/B and MS46322A/B 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 1-1. Calibration Equipment Listing (1 of 2)

Part Number	Name	Specifications	Connectors
Precision AutoCal Modules			
36585K-2M	Precision AutoCal Module	70 kHz to 40 GHz	K(m) to K(m)
36585K-2F	Precision AutoCal Module	70 kHz to 40 GHz	K(f) to K(f)
36585K-2MF	Precision AutoCal Module	70 kHz to 40 GHz	K(m) to K(f)
36585V-2M	Precision AutoCal Module	70 kHz to 70 GHz,	V(m) to V(m)
36585V-2F	Precision AutoCal Module	70 kHz to 70 GHz,	V(f) to V(f)
36585V-2MF	Precision AutoCal Module	70 kHz to 70 GHz,	V(m) to V(f)
MN25208A	Precision 2-port SmartCal module	300 kHz to 8.5 GHz	N(f)
MN25408A	Precision 4-port SmartCal module	300 kHz to 8.5 GHz	N(f)
MN25218A	Precision 2-port SmartCal module	1 MHz to 20 GHz	K(f)
MN25418A	Precision 4-port SmartCal module	300 kHz to 20 GHz	K(f)
Type N Connector Manual Calibration Kit			
3653A	Type N Calibration Kit With fixed loads	With fixed loads	Type N
OSLN50A-8	Precision Mechanical Calibration Tee	Open/Short/Load	N(m)
OSLNF50A-8	Precision Mechanical Calibration Tee	Open/Short/Load	N(f)
TOSLN50A-	Precision Mechanical Calibration Tee	Through/Open/Short/Load	N(m)
TOSLNF50A-8	Precision Mechanical Calibration Tee	Through/Open/Short/Load	N(f)
Type N Connector Manual Calibration Kit			
3653A	Type N Calibration Kit	With fixed loads	Type N
OSLN50A-8	Precision Mechanical Calibration Tee	Open/Short/Load	N(m)
OSLNF50A-8	Precision Mechanical Calibration Tee	Open/Short/Load	N(f)
TOSLN50A-8	Precision Mechanical Calibration Tee	Through/Open/Short/Load	N(m)
TOSLNF50A-8	Precision Mechanical Calibration Tee	Through/Open/Short/Load	N(f)
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

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

Part Number	Name	Specifications	Connectors
3652A-1	K(2.92 mm) Calibration Kit	With sliding loads	K
TOSLK50A-20	Precision Mechanical Calibration Tee	Through/Open/Short/Load	K(m)
TOSLK50A-20	Precision Mechanical Calibration Tee	Through/Open/Short/Load	K(f)
TOSLK50A-40	Precision Mechanical Calibration Tee	Through/Open/Short/Load	K(m)
TOSLK50A-40	Precision Mechanical Calibration Tee	Through/Open/Short/Load	K(f)

Verification Kits

3663-2	Type N Connector Verification Kit	NIST traceable standards with two attenuators, an airline, and a stepped impedance airline Beatty Standard. Includes the Performance Verification Software application and related documentation.	
3666-2	3.5 mm/SMA Verification Kit		

Test Port Cables

15KK50-1.0A	Test Port Cable, Armored, Phase Stable	1.0 m	K(m) to K(m)
15KKF50-1.0A	Test Port Cable, Armored, Phase Stable	1.0 m	K(m) to K(f)
15LL50-1.0A	Test Port Cable, Armored, Phase Stable	1.0 m	3.5 mm(m) to 3.5 mm(m)
15LLF50-1.0A	Test Port Cable, Armored, Phase Stable	1.0 m	3.5 mm(m) to 3.5 mm(f)
15NNF50-1.0B	Test Port Cable, Flexible, Phase Stable	1.0 m	N(f) to N(m)
15NNF50-1.5B	Test Port Cable, Flexible, Phase Stable	1.5 m	N(f) to N(m)
15NN50-1.0B	Test port Cable, Flexible, Phase Stable	1.0 m	N(m) to N(m)
3671KFS50-60	Test port cables, flexible, high performance	1 each 63.5 cm (25 in)	K (female) to 3.5 mm (male)
3671KFK50-60	Test port cables, flexible, high performance	1 each, 63.5 cm (25 in)	K (female) to K (male)
3671KFKF50-60	Test port cables, flexible, high performance	1 each 63.5 cm (25 in)	K (female) to K (female)
3671KFK50-100	Test port cables, flexible, high performance	1 each, 96.5 cm (38 in)	K (female) to K (male)

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)
36801K	Right Angle Launcher	DC to 40 GHz 1 cm (min) to 4 cm max	

1-5 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 SmartCal™ module is a plug and play device that automatically powers on and loads calibration coefficients from its on-board memory into ShockLine software. SmartCal has auto sense and port mapping features, allowing it to auto sense the VNA port number to which it is connected. In addition, port mapping allows the user to assign any SmartCal port to any of the VNA ports.

The 36585K Calibration 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 Calibration 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 serial control cable that runs to the VNA, and the characterization data provided on a USB memory device. Serial to USB adapter (2000-1809-R) is also required for operating the AutoCal module on the MS46322A/B and MS46122A/B VNAs.

Calibrations Available

Of the various calibration types described for the instrument, most are available with the Calibration unit. Frequency response calibrations are omitted since the Calibration 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 S_{11} and S_{21} or calibrate S_{22} and S_{12})

1-6 SOLT/SOLR Kits (365xx)

This kit, 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 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)

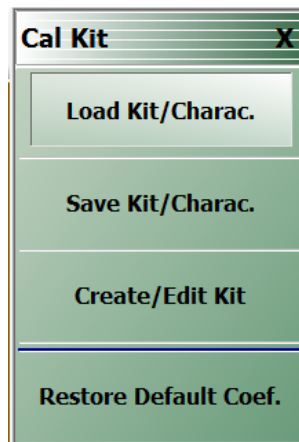


Figure 1-1. CAL KIT Menu

The CAL KIT 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.

1-7 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

1-8 Microstrip/Coplanar Waveguide Kits for the UTF (36804-XXX)

For certain microstrip and coplanar waveguide measurements, the Universal Test Fixture (UTF) 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.

1-9 Calibration Algorithms

The ShockLine MS46122A/B and MS46322A/B provide for the following calibration methods:

- Short-Open-Load-Through (SOLT) with Fixed or Sliding Load
- Short-Open-Load-Reciprocal (SOLR) – “B” models only.
- Reciprocal or Unknown Through Method – “B” models only.
- Offset Short (SSLT) Calibration
- Triple Offset Short (SSST) Calibration
- Line-Reflect-Line (LRL) / Line-Reflect-Match (LRM) AutoCal – “B” models only.
- Adapter Removal Calibration

1-10 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 MS46122A/B and MS46322A/B 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 1-2. MS46122A/B and MS46322A/B 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}	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 S_{12} and S_{21})	Normalization only. Fast, lower accuracy

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 1-3. 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, like above but with "Reciprocal" instead of "Through." Available with the "B" models only.	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 Through-Reflect-Line or TRL). Available with the "B" models only.	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

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

Table 1-4. Calibration Types and Calibration Algorithms

VNA Mode	Type	SOLT	SSLT	SSST	SOLR/SSLR/SSSR "B" models	LRL "B" models	ALRM
2-Port Mode	Full 2 Port	YES	YES	YES	Yes	Yes	Yes
	Full 1 Port	YES	YES	YES	Yes—Can be selected for these types, but the reciprocal nature is not used and will function like the base calibration	-	-
	1 Path 2 Port	YES	YES	YES		-	-
	Frequency Response	YES	YES	YES		-	-

1-11 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 10 Hz to 300 kHz on the MS46122A/B and MS46322A/B are allowed with the RMS trace noise ranging from < 6 mdB at the low end to a few hundred mdB at the high end (for high level signals, more for lower level signals).

- **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 MS46122A/B and MS46322A/B VNA receivers.

1-12 Types of Calibrations

The types of calibrations are defined by what ports are involved and what level of correction is accomplished (see [Table 1-2, “MS46122A/B and MS46322A/B Calibration Types” on page 1-8](#)).

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.

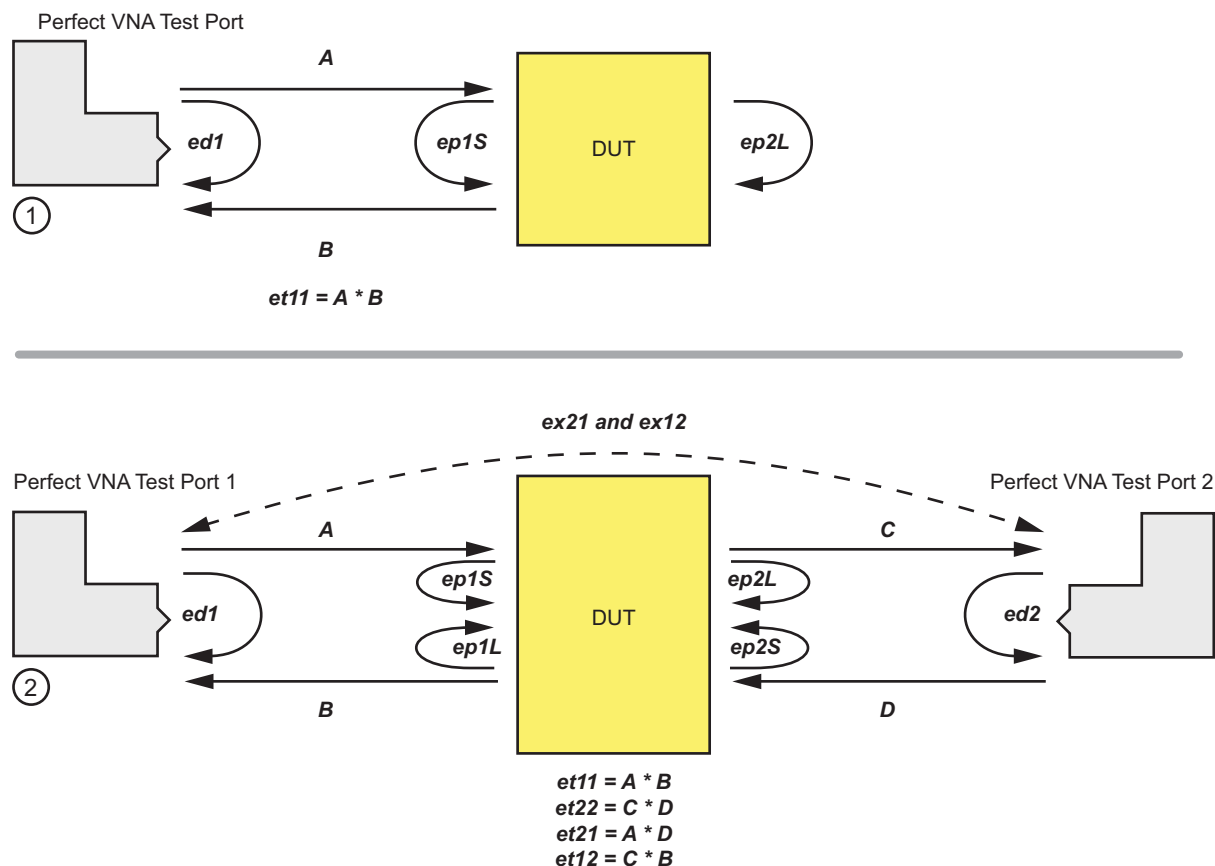
1 Path 2 Port (Forward or Reverse)

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 ($\cong >10\text{-}20$ 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. 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 on page 1-11](#)).



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.

- **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.

1-13 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:

$$v_{ph} = \frac{c}{\sqrt{\epsilon_r}}$$

= Phase velocity for coaxial and non-dispersive media

Equation 1-1

Where:

- c is the speed of light in a vacuum (~2.9978108 m/s) and
- ϵ_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:

$$v_{ph} = \frac{c}{\sqrt{\epsilon_r} \times \sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

$$= \frac{c}{\sqrt{\epsilon_r - \left(\frac{f_{c0}}{f}\right)^2}}$$

= phase velocity for waveguide

Equation 1-2

Where:

- ϵ_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:

$$v_{ph} = \frac{c}{\sqrt{\epsilon_{r, eff}}}$$

$$= \text{low frequency limit}$$

Equation 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:

$$v_{ph} = \frac{c}{\sqrt{\frac{\epsilon_{r, eff} + \epsilon_r \cdot \left(\frac{f}{f_t}\right)^2}{1 + \left(\frac{f}{f_t}\right)^2}}} \quad \text{where} \quad f_t = \frac{Z_c \epsilon_0 \sqrt{\epsilon_r c^2}}{2t \sqrt{\epsilon_{r, eff}}}$$

Equation 1-4

Where:

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

1-14 Connector Precautions

Pin Depth

Before mating, measure the pin depth (Figure 1-3) of the device that will mate with the RF component, using an **Anritsu Pin Depth Gauge** or equivalent (Figure 1-4). 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 with respect to the reference plane of the connector.)

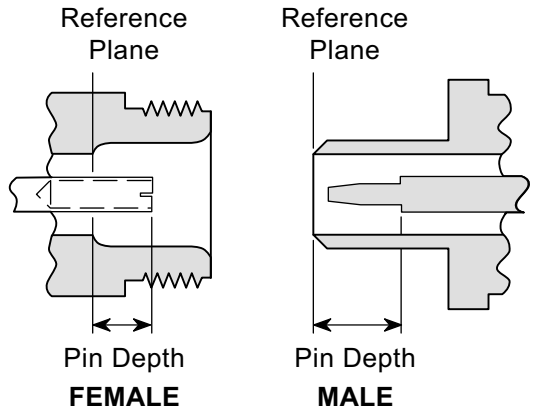
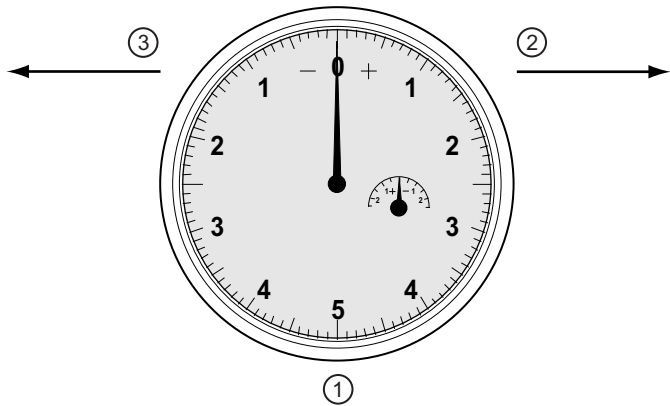


Figure 1-3. N Connector Pin Depth

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 1-5, “Pin Depth Tolerances” on page 1-16 in the “+” region of the gauge (Figure 1-4), the center pin is too long. Mating under this condition will likely damage the termination connector.



Index	Description
1	Pin Depth Gauge with needle setting at zero.
2	Positive needle direction clockwise to right.
3	Negative needle direction counter-clockwise to left.

Figure 1-4. 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.

Table 1-5. Pin Depth Tolerances

Connector Type	Pin Depth (Inch)	Pin Depth (mm)
7/16 Male	+0.0579	+1.47
	+0.0697	+1.77
7/16 Female	–0.0697	–1.77
	–0.0815	–2.07
GPC-7	+0.000	+0.000
	–0.003	–0.076
N Male	–0.207	– 5.258
	–0.210	–5.334
N Female	+0.207	+5.258
	+0.204	+5.182
WSMA Male (3.5 mm)	–0.0025	–0.0635
WSMA Female (3.5 mm)	–0.0035	–0.0889
K Male (2.92 mm)	+0.000	+0.000
K Female (2.92 mm)	–0.0050	–0.127

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.

1-15 Connector Cleaning Instructions

To prevent unnecessary early failure and inaccurate measurements, connector interfaces must be kept clean and free of dirt and other debris. With repeated connections and disconnections, the threads and outer conductor mating interface builds up a layer of dirt and metal chips which can severely degrade connector electrical and mechanical performance. This debris can also increase the coupling torque required for a good connection which can then damage the mating interfaces.

Caution Use the correct sized cotton swabs that are made specifically for cleaning small areas. Oversized cotton swabs can put lateral pressure on the center pin and damage it. Be sure that no cotton strands get caught in the connector.

Required Cleaning Items

- Low-pressure dry, compressed air (oil free, solvent free), maximum pressure: 40 PSI,
- Lint-free cotton swabs
- Isopropyl alcohol (IPA), 90 %
- Microscope

Caution Do not use compressed air on power sensors. Some power sensors have components internally located near the connector that can be damaged from excessive air pressure.

Teflon Tuning Washers:

Note The center conductor on some 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 washer's location is critical to the RF component's performance. Be careful not to disturb it with a cotton swab or compressed air and don't apply alcohol to it.

Cleaning Procedure

Caution Do not use industrial solvents or water to clean the connector. Use 90 % Isopropyl Alcohol (IPA) only.

Do not spray alcohol directly onto connector surfaces.

Do not saturate the swab with alcohol. Instead, lightly dampen it by touching the tip onto a bead of alcohol formed at the bottle tip as shown.

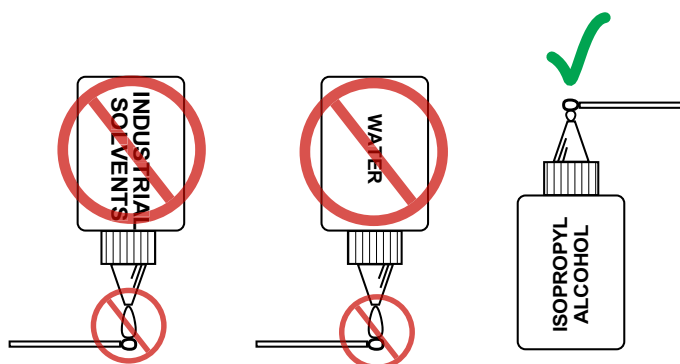


Figure 1-5. Isopropyl Alcohol Only

1. Remove loose particles on the mating surfaces, threads, and similar surfaces using low-pressure (42 PSI max) compressed air applied at a shallow angle so dirt is not forced down into the connector.

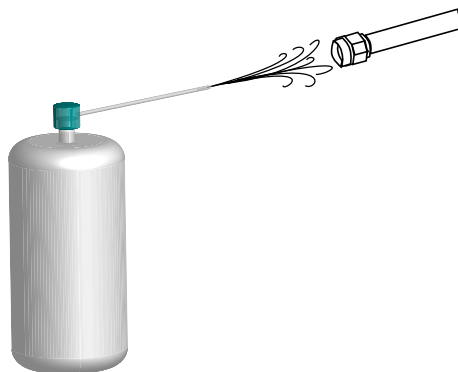


Figure 1-6. Low Pressure Compressed Air Cleaning

2. Clean the threads of the connector with a lint-free cotton swab dampened with IPA.

Caution Do not insert cotton swabs at an angle. Doing so can damage the center pin. Do not use a cotton swab that is too large. It can stress and damage the center pin.

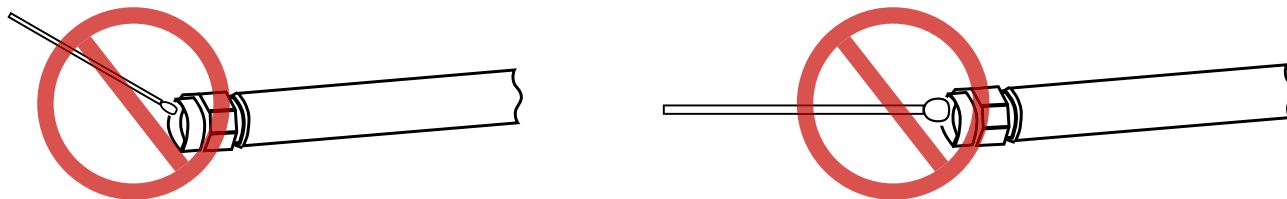


Figure 1-7. Avoid Angled or Large Swab

3. Clean the mating plane surfaces and connector threads by gently moving the cotton swab around the center pin. Do *not* touch the center pin.

When the connector is clean, you should be able to hand tighten the connector to within approximately one half turn of the specified torque.

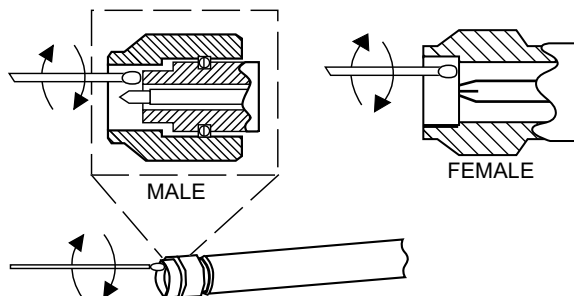


Figure 1-8. Cleaning Connector with Cotton Swabs

4. After cleaning with swabs, again use low-pressure compressed air to remove any remaining small particles and dry the connector surfaces.

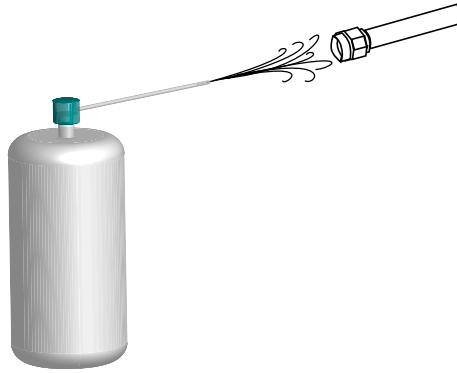


Figure 1-9. Compressed Air Drying

5. With the aid of magnification and adequate lighting, inspect the connectors for damage, cotton strands or other debris.

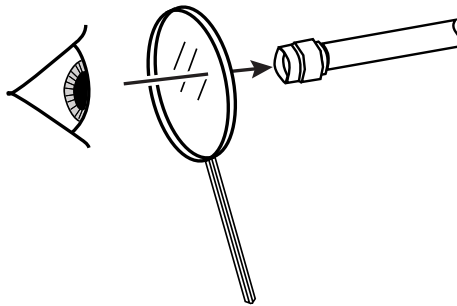


Figure 1-10. Final Inspection

Chapter 2 — Automatic Calibration Procedures

2-1 Chapter Overview

This chapter describes common procedures for both Internal Through and True-Through calibration using Anritsu the 36585-Series Precision AutoCal Modules and the SmartCal Modules. This chapter provides two examples of using a precision adapter with an AutoCal and SmartCal unit to create difference-gender reference planes as is adapter removal with an AutoCal and SmartCal unit.

Note	The MS46122A/B requires a PC Controller to operate the MS46122A/B VNA and the Calibrator Modules. Detailed setup descriptions in this chapter start at “MS46122A/B Typical Calibrator Connections” on page 2-8.
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2-2 Automatic Calibration 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 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 SmartCal 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 a 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 automatic calibration results may not be better than that of an calibration performed during factory characterization, but is far better than that typically done.

2-3 Automatic Calibration Terms

This section defines various terms used with SmartCal and AutoCal calibration modules and procedures used with the ShockLine VNA.

Note

Because in many cases, either module can be utilized using the same setups described in this chapter, they are referred to as Calibration Modules or Calibrators.

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 N and K 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 Calibration calibration.

- **Internal Through (“Internal Thru”)**

An Internal Through is an internal path through the calibrator requiring no operator involvement in the Calibration Module 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

- **AutoCal Module**

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.

- **SmartCal Module**

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

Characterization File

AutoCal Module

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 VNA USB port. This file can be installed by navigating to the INSTALL (AUTOCAL CHARACTERIZATION/CAL KIT) dialog box: [Figure 2-1](#).

SmartCal Module

All calibration data needed for the SmartCal is located within the SmartCal module memory. Connect SmartCal to the USB port of the VNA and it is ready.

- MAIN MENU | Calibration | CALIBRATION | Cal. Kit Options | LOAD KIT / CHARAC. |

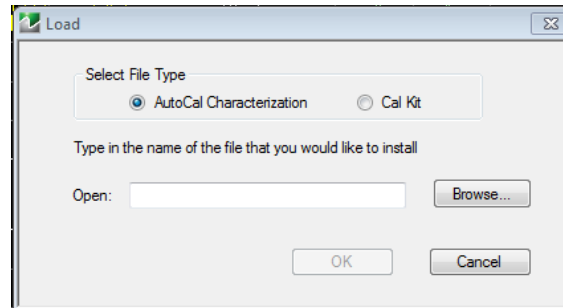


Figure 2-1. Load CalKit Dialog Box

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 calibration 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.

2-4 Available Calibrator Modules and Adapters

The two calibrator module models available are the SmartCal Module and the AutoCal Module. [Figure 2-2](#)



- | | |
|-----------------------------|--------------------------|
| 1. MN25418A SmartCal Module | 2. 36585V AutoCal Module |
|-----------------------------|--------------------------|

Figure 2-2. Automatic Calibration Modules

AutoCal Modules and Adapters

The table below shows the available AutoCal modules.

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

Part Number	Name	Frequency Range and Connectors
Precision AutoCal Kits		
36585K and 36585V Series Precision AutoCal Modules can be used with ShockLine VNAs with adapters. The calibration range is limited to that of the VNA.		
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)

SmartCal Modules and Adapters

The table below shows the available SmartCal modules.

Table 2-2. Precision and Standard SmartCal Kits and Adapters

Part Number	Name	Frequency Range and Connectors
Precision AutoCal Kits		
MN252x8A and MN254x8A-Series Precision SmartCal Modules can be used with ShockLine VNAs with adapters. The calibration range is limited to that of the VNA.		
MN25208A-001	SmartCal Automatic Calibration Unit, N(f) to N(f), 2-Port	300 kHz to 8.5 GHz, N(f) to N(f)
MN25208A-002	SmartCal Automatic Calibration Unit, K(f) to K(f), 2-Port	300 kHz to 8.5 GHz, K(f) to K(f)
MN25208A-003	SmartCal Automatic Calibration Unit, 3.5 mm(f) to 3.5 mm(f), 2-Port	300 kHz to 8.5 GHz, 3.5 mm(f) to 3.5 mm(f)
MN25208A-004	SmartCal Automatic Calibration Unit, SMA(f) to SMA(f), 2-Port	300 kHz to 8.5 GHz, SMA(f) to SMA(f)
MN25408A-001	SmartCal Automatic Calibration Unit, N(f) to N(f), 4-Port	300 kHz to 8.5 GHz, N(f) to N(f)
MN25218A-002	SmartCal Automatic Calibration Unit, K(f) to K(f), 2-Port	1 MHz to 20 GHz, K(f) to K(f)
MN25418A-002	SmartCal Automatic Calibration Unit, K(f) to K(f), 4-Port	300 kHz to 20 GHz, K(f) to K(f)

AutoCal Components

The AutoCal unit consists of the Calibrator 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 to USB adapter (Anritsu part number 2000-1809-R) with the USB connector attached to the VNA.

SmartCal Module

The SmartCal module is a plug and play device that automatically powers on and loads calibration coefficients from its on-board memory into the ShockLine software. SmartCal has auto sense and port mapping features, allowing it to auto sense the VNA port number to which it is connected. In addition, port mapping allows the user to assign any SmartCal port to any of the VNA ports.

Connector Care

Since an automatic calibration is a very high performance calibration, connector care is of the utmost importance. See [Figure 1-14, “Connector Precautions” on page 1-15](#)

Calibration Parameters and Types

The AutoCal and SmartCal require four general parameters be defined, as shown in the dialog box: [Figure 2-3](#)

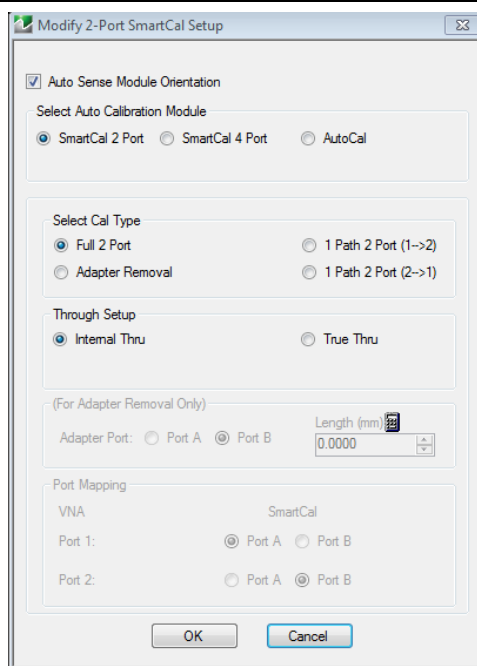


Figure 2-3. MODIFY 2-PORT SMARTCAL or AUTOCAL SETUP Dialog Box

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

Most standard calibration types are available with the AutoCal units. Frequency response calibrations are the only ones omitted since the SmartCal and AutoCal unit would provide no benefit in these cases since only a through or high reflect standard is needed for these calibrations. The SmartCal and 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 calibrator unit (e.g. F-F DUT and the auto cal is M-F). 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 Thru calibration options:

- **Internal Thru**

The calibration 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**

The calibration 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.

SmartCal Test Port 1 / Port 2 Naming Assignments

The SmartCal module setup allows the user to specify the Port 1,2 identification of the test port cables as either:

- **SmartCal Module Orientation = Port A**

Where the module determines the Port A / Port B identification of the test port cables

- **SmartCal Module Orientation = Port B**

Where the module determines the Port A / Port B identification of the test port cables

AutoCal 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**

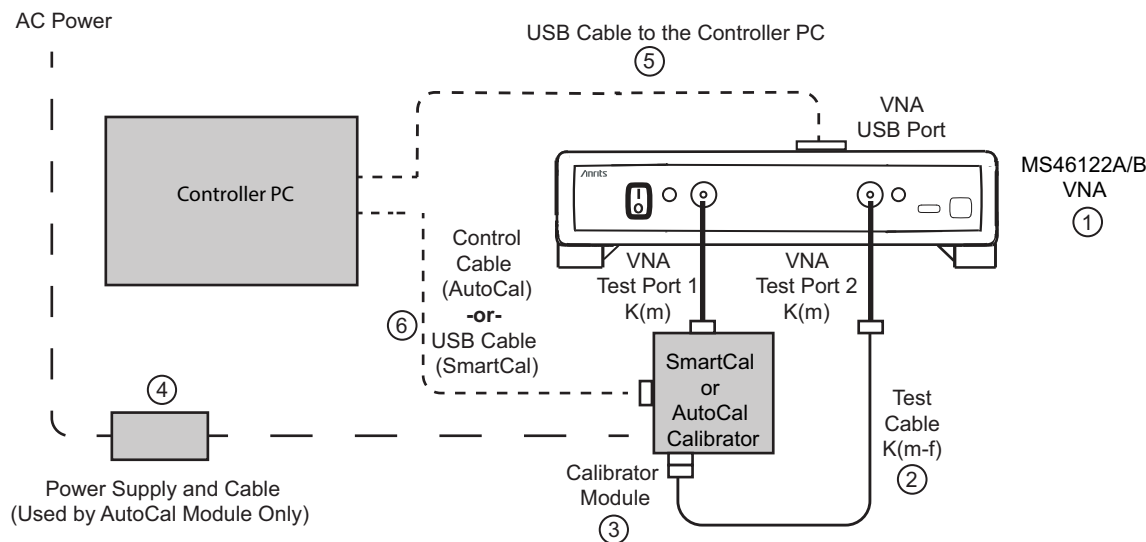
Where the module determines the left/right identification of the test port cables

- **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.

2-5 MS46122A/B Typical Calibrator Connections

The typical F-F calibrator connections for MS46122A/B are shown below in [Figure 2-4](#). For MS46322A/B typical calibrator connections see [Figure 2-5](#).



1. MS46122A/B VNA with K connectors.

2. Test Cable K(m-f)

3. SmartCal or AutoCal Calibrator Module

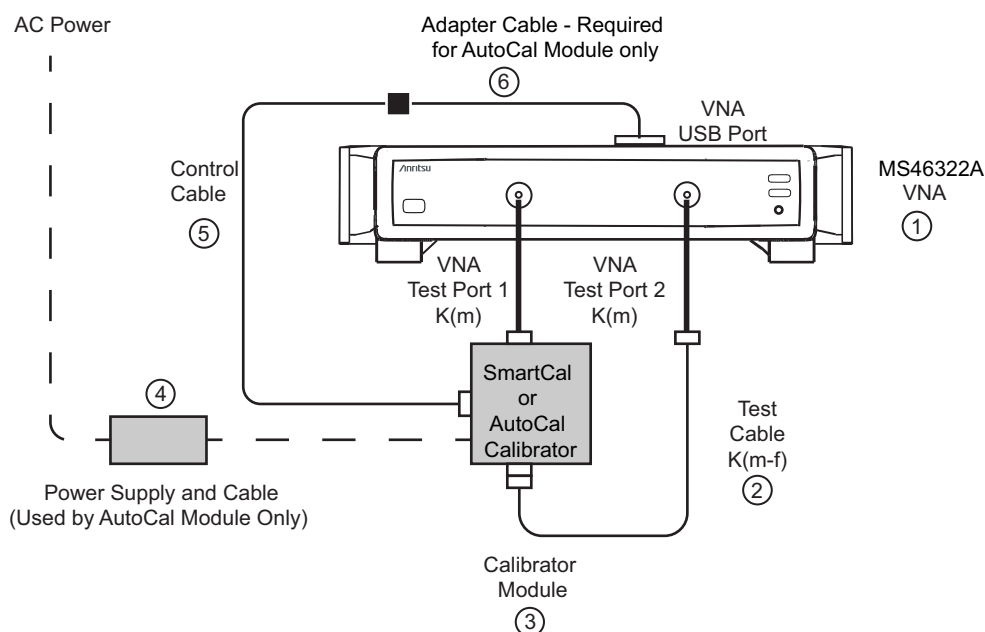
4. Interface Cable to PC Controller

Figure 2-4. MS46122A/B Calibration Module Connections for Internal Through

1. Prepare the MS46122A/B and power it up. This instrument example has two K(m) test ports.
2. Connect the Calibration Module directly to VNA Test Port 1 K(m).
3. Connect a USB cable from the Calibrator to the Controller PC.
4. Connect the 3-2000RS-1815 USB 2.0 A to Mini B cable from the MS46122A/B to the Controller PC.
5. The second Calibrator K(f) connector is connected to the K(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 K(f) end of the Test Cable to the VNA Test Port 2 K(m).

2-6 MS46322A/B Typical Calibrator Connections

The typical F-F calibrator connections for MS46122A/B are shown in [Figure 2-4](#). For MS46322A/B typical calibrator connections, see [Figure 2-5](#).



1. MS46322A/B VNA with K connectors.	5. AutoCal—Uses Calibrator DB9 (m-m) Control Cable connected between Calibrator Module and Adapter Cable (6) SmartCal—Uses Micro-B to USB cable into VNA USB Port
2. Test Cable K(m-f)	6. AutoCal—Uses USB to Serial Adapter (2000-1808-R)
3. SmartCal or AutoCal Calibrator Module	
4. AutoCal Power Supply Module with extension able to local AC Mains power (Used with AutoCal module).	

Figure 2-5. MS46322A/B Calibration Module Connections for Internal Through

6. Prepare the MS46322A/B and power it up. This instrument example has two K(m) test ports.
7. Connect the Calibration Module directly to VNA Test Port 1 K(m).
8. The AutoCal module is then connected to its AC Power Supply Module and it to AC power. The SmartCal module is powered from the USB of the VNA.
9. Connect the Serial to USB Adapter between the DB-9 connector on the top of the Calibration Module and the Serial Adapter (2000-1809-R) on the MS46322A/B rear panel.
10. The second Calibrator K(f) connector is connected to the K(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 K(f) end of the Test Cable to the VNA Test Port 2 K(m).

Schematically, this setup is shown in [Figure 2-6](#).

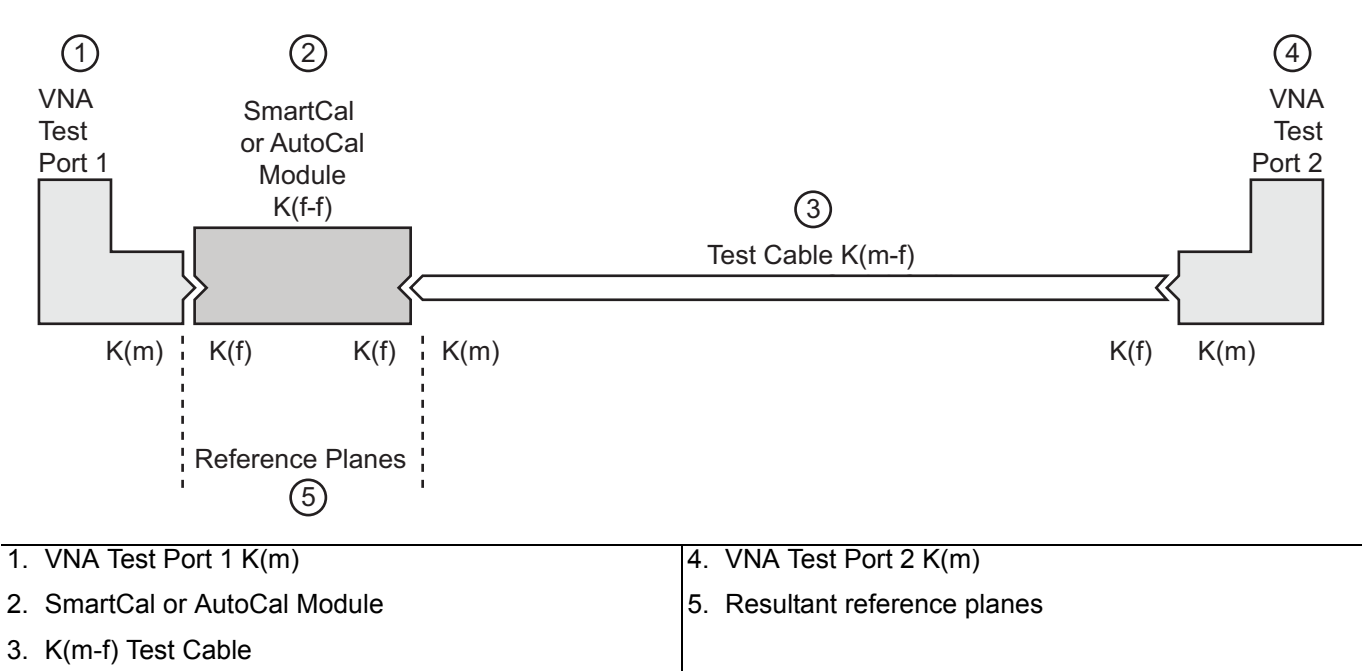


Figure 2-6. Schematic of the Calibrator Connections for Internal Thru

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 Calibration Module

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

- 1. Power up the VNA and connect the control cable to the Calibration unit.
- 2. Install the characterization file if not already done.

Note

The SmartCal Characterization File is provided internally within the SmartCal memory and can be installed directly from that device.

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 MS46122A/B and MS46322A/B 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. Setup the Calibrator and the VNA by connecting:
 - Calibrator Module directly to one VNA Test Port
 - A test cable between the Calibrator and VNA Test Port
 - For SmartCal, the USB cable connects between the Calibrator module and the VNA USB port.
 - For AutoCal, the Serial to USB cable will be placed in the path between the Calibrator module and the VNA USB port.

4. Connect the Calibration Module to its power supply
 - For SmartCal, power is supplied through the USB cable.
 - For AutoCal, connect the Calibration module to its power supply and AC power
 - For the SmartCal Module, the yellow Power LED illuminates immediately. When the module is recognized, the Operate LED will illuminate green.
 - For the AutoCal Module, the green Power LED illuminates immediately. When the module is at operating temperature, the Operate LED will illuminate blue.
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 Calibrator parameters of interest and connect the test port cables to the Calibrator 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 Calibration sequence has started. The status messages define how far the program has progressed and if any user actions are required.
9. At any time, the Calibration sequence can be canceled 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 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.

2-7 Copying the Calibrator Characterization File

The AutoCal Characterization File (.acd file) is provided on a USB memory device provided with the AutoCal Module.

Procedure

1. Inspect the Calibrator kit and make a note of its serial number. Typical Calibrator Kit serial numbers are six-digit integers such as “123456.”
2. Insert the AutoCal Characterization Memory Device (USB memory device) into one of the ShockLine VNA USB Ports.
3. Navigate to the CAL KIT menu:
 - MAIN | Calibration | Cal Kit Options| CAL KIT

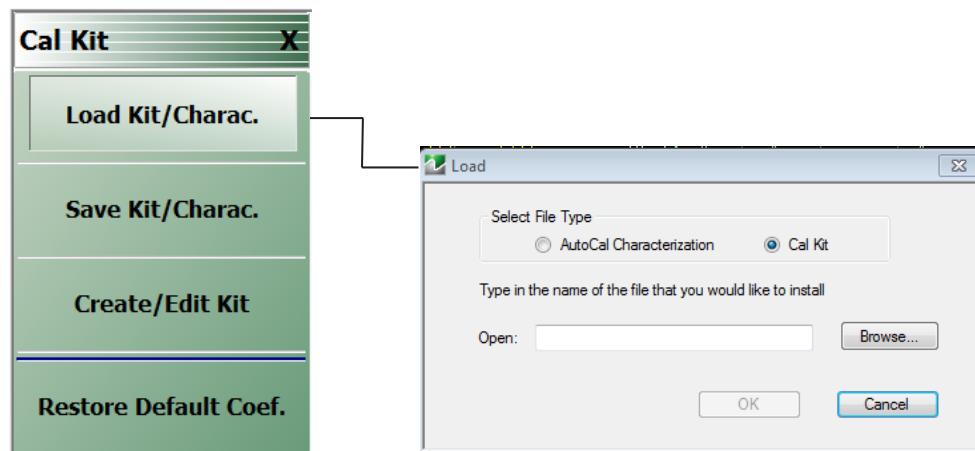


Figure 2-7. CAL KIT Utility Menu – INSTALL CHARACTERIZATION FILE Dialog Box

4. On the CAL KIT menu, select Load 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 Calibration 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 Calibration controller serial number, which is not the module serial number). Click Install in this box close it.
9. On the CAL KIT 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 MS46122A/B or MS46322A/B is C:\AnritsuVNA\AutoCal
11. Click Save. The Save dialog box closes, the CAL KIT menu reappears.
12. Repeat the steps above to copy each new Calibration Characterization File to the MS46122A/B or MS46322A/B.

2-8 Loading a Previously Stored AutoCal Characterization

This procedure applies to the AutoCal Module only. Use this procedure if the Calibration Characterization File has already been copied onto the ShockLine VNA hard drive.

Procedure

1. Navigate to CAL KIT menu.
 - MAIN | Calibration | CALIBRATION | CalKit Options | CAL KIT
2. On the CAL KIT menu, select Load 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 Calibration Characterization file for the Calibration module in use. The recommended directory destination on the MS46122A/B or MS46322A/B is C:\AnritsuVNA\AutoCal
5. Select the Calibration Characterization file, such as “V123456.ACD,” where “123456” is the serial number of the Calibration kit. Click Open.
6. Click OK in the Install dialog box. Another install dialog box appears (this one showing the Calibration Module 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 menu is again available.

2-9 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 Calibration 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 13-3](#).

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.

Example Procedure

This example procedure assumes the ShockLine VNA is equipped with the Option 040 (1 MHz to 43.5 GHz) 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: 10 MHz
- Frequency Stop: 40 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 MS46122A/B or MS46322A/B and allow it to stabilize its internal temperature.

3. Navigate to the FREQUENCY menu:
 - MAIN | Frequency | FREQUENCY

The screenshot shows a vertical menu titled "Frequency" with a close button "X" in the top right corner. The menu contains several input fields with labels and values:

- Start**: 10.000000 MHz
- Stop**: 40.000000000 GHz
- Center**: 20.005000000 GHz
- Span**: 39.990000000 GHz
- # of Points**: 200
- StepSize**: 199.950000 MHz
- CW Mode**: OFF
- CW Frequency**: 10.000000 MHz

1 – FREQUENCY Menu

Figure 2-8. FREQUENCY Menu - Setting Initial Calibration Parameters

4. On the FREQUENCY menu, click the Start frequency button
 - The frequency Start toolbar appears just below the icon toolbar
5. Enter the required start frequency number value.
 - For this example, set the start frequency value at 10 MHz.
6. Enter the required start frequency units.
 - For this example, set the units to megahertz by clicking MHz.
 - The Start frequency field button now shows 10 MHz
7. On the FREQUENCY menu, click the Stop frequency field button
 - The frequency Stop toolbar appears
8. On the Stop frequency toolbar, enter the required frequency number value and units.
 - For this example, set the stop value at 40 and click the GHz units button.
 - The Stop frequency button now shows 40.000000000 GHz
9. The Center and Span display buttons show calculated values based on settings made above
 - The Center frequency field button shows a value of 20.005000000 GHz
 - The Span frequency field button shows a value of 39.990000000 GHz
10. On the Frequency menu, click the # of Points (Number of Points) button

- The # of Points toolbar appears
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
 - The Step Size display button automatically calculates the step size of 199.950000 MHz.
12. Click the CW Mode toggle button so it is set to OFF.
13. If optional parameters are required, do any of the following optional procedures described elsewhere in this manual:
- [“Frequency-Based Segmented Sweep” on page 13-3](#)
 - [“IFBW” on page 11-21](#)
 - Averaging
 - Power and Attenuation
14. If no optional parameters are required, the Calibration is ready to proceed.
- [“Calibration - Full Two Port - Internal Through” on page 2-17](#)

2-10 Calibration - Full Two Port - Internal Through

This procedure performs a calibration using a full two port calibration with an internal through, which is sufficiently accurate for most DUTs. For AutoCal the Calibration Characterization file has already been loaded onto the MS46122A/B or MS46322A/B.

Note

The navigational path to the Calibration setup applies to both the SmartCal and AutoCal calibration modules. Make the selection of the calibration module once you navigate through:

MAIN | Calibration | CALIBRATION | AutoCal| AUTOCAL | 2-Port Cal | SMARTCAL SETUP |

Any selection in the SMARTCAL SETUP menu brings up the menu similar to the one in [Figure 2-9](#). This is where you choose the SmartCal or AutoCal module for your application.

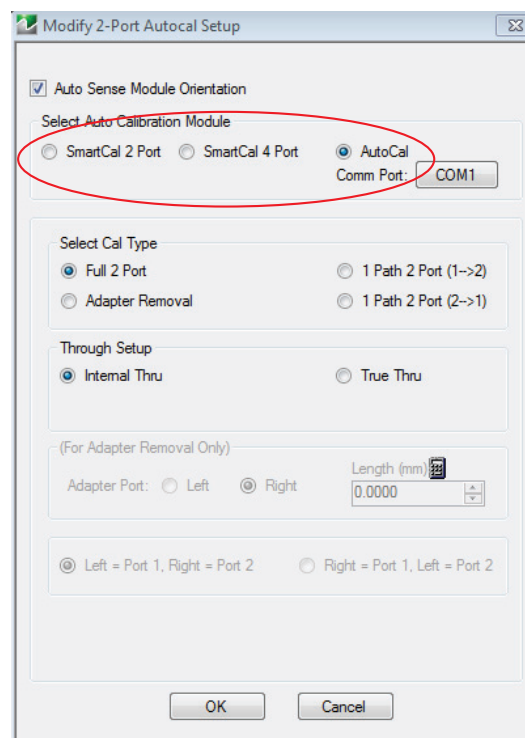


Figure 2-9. Select SmartCal or AutoCal

Required Equipment

- MS46122A/B or MS46322A/B VNA with K(m) test port connectors.
- Calibrator Module with K(f) connectors and required power and control cables. The Calibration Characterization File has been loaded onto the ShockLine VNA.
- Test port cable, K(f) to K(m)

Procedure

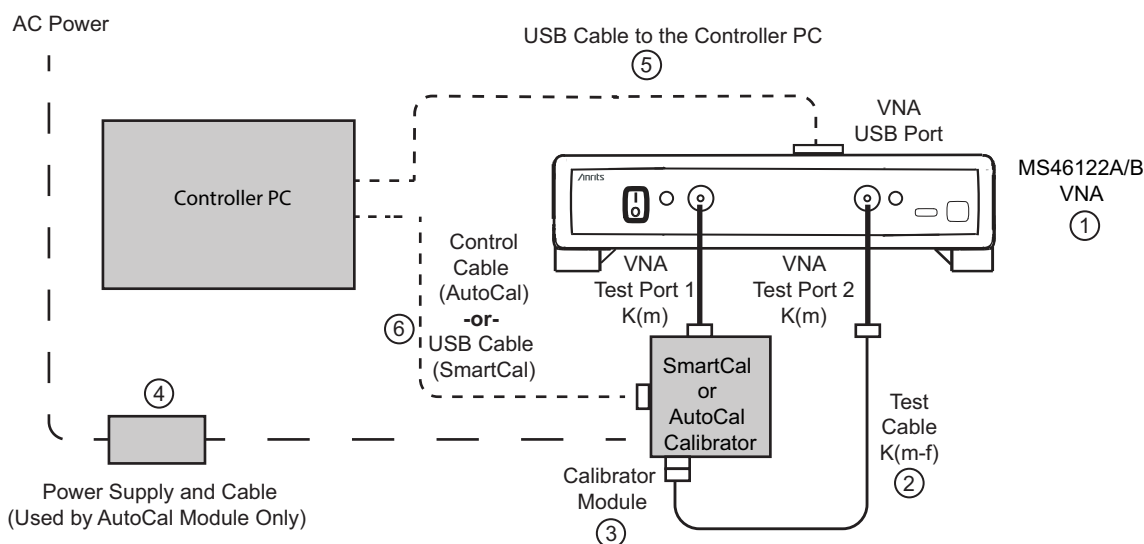
1. Power up the MS46122A/B or MS46322A/B VNA.
2. Set the required Frequency Start, Frequency Stop, and Number of Points parameters.
 - See [“Pre-Calibration Instrument Setup”](#) on page 2-14.
3. If required, set up other parameters as required such as Segmented Sweep, IFBW, Averaging, and Power and Attenuation.

4. Navigate to CAL KIT menu.

- MAIN | Calibration | CALIBRATION | AutoCal| AUTOCAL | 2-Port Cal| SMARTCAL SETUP| Thru Type

Calibrator Module Connections

5. Connect the Calibrator K(f) connector directly to the VNA left side K(m) Test Port 1.
6. If calibrating a MS46322A/B, skip to step 10.
7. If using a MS46122A/B, refer to [Figure 2-10, “MS46122A/B Calibrator Cable Connections for Internal Through”](#).
8. If using a MS46122A/B:
 - Connect one USB cable from the Calibrator to the Controller PC.
 - Connect the 3-2000RS-1815 USB 2.0 A to Mini B cable from the MS46122A/B to the Controller PC.
9. Skip to step 13
10. If using a MS46322A/B, refer to [Figure 2-11, “MS46322A/B Calibrator Cable Connections for Internal Through”](#).
11. Connect the Serial to USB Adapter between the DB-9 connector on the top of the Calibration Module and the Serial Adapter (2000-1809-R) on the MS46122A/B rear panel.
12. Connect the coaxial power plug from the Power Supply Module (AutoCal Module only) to the AutoCal Module.
13. Once connected to power, the Calibration Module Power LED will illuminated green. When the module has warmed up to operating temperature, the LED illuminates blue for the AutoCal Module and Green for the SmartCal Module.
14. Connect the test cable between the K(m) Test Port 2 and the remaining AutoCal K(f) port



1. MS46122A/B VNA with K connectors.

2. Test Cable K(m-f)

3. SmartCal or AutoCal Calibrator Module

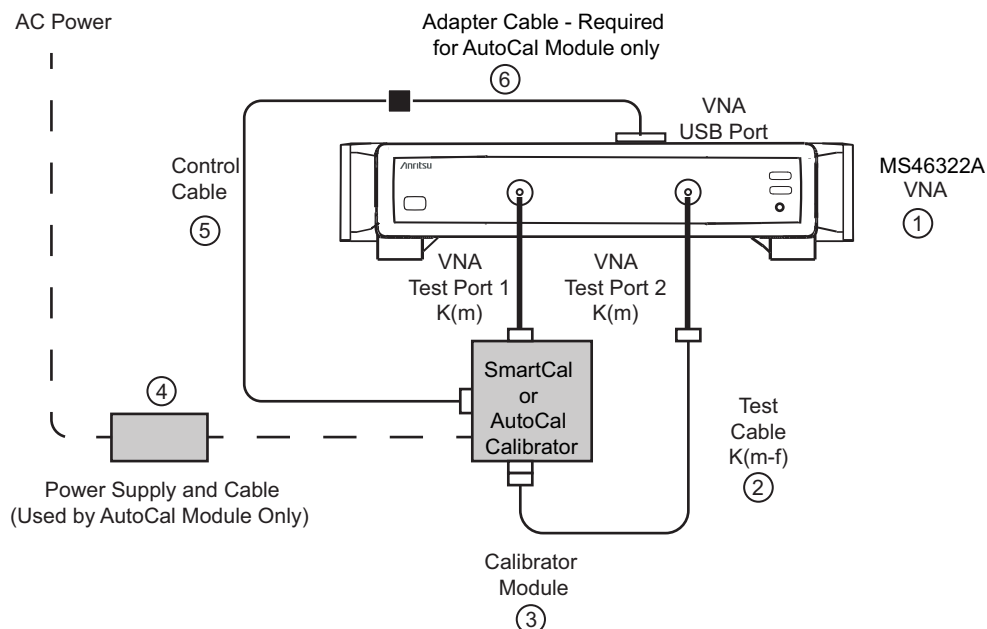
4. AutoCal Power Supply Module connected to AC Power (Used with AutoCal module only)

5. USB control cable from MS46122B to controller PC

6. DB9 (m-m) Control Cable (**AutoCal**) and RS232 to USB Adapter cable (2000-1809-R)-**or**- USB Cable (**SmartCal**)

Figure 2-10. MS46122A/B Calibrator Cable Connections for Internal Through

..



- | | |
|--|--|
| 1. MS46322A/B VNA with K connectors. | 5. AutoCal—Uses Calibrator DB9 (m-m) Control Cable connected between Calibrator Module and Adapter Cable (6)
SmartCal—Uses Micro-B to USB cable into VNA USB Port |
| 2. Test Cable K(m-f) | 6. AutoCal—Uses USB to Serial Adapter (2000-1808-R) |
| 3. SmartCal or AutoCal Calibrator Module | |
| 4. AutoCal Power Supply Module with extension able to local AC Mains power (Used with AutoCal module). | |

Figure 2-11. MS46322A/B Calibrator Cable Connections for Internal Through

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

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

16. 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

17. 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.

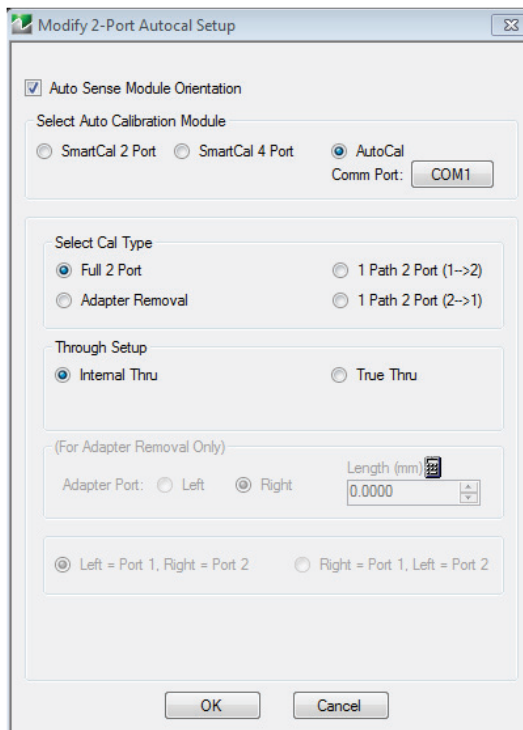


Figure 2-12. MODIFY 2-PORT AUTOCAL SETUP Settings

18. On the MODIFY 2-PORT AUTOCAL SETUP dialog box, select the settings:
- Cal Type Select area: Select the Full Two Port radio button.
 - Thru Select area: Select the Internal Thru radio button.
 - Auto Sense Module Orientation check box selected: Allows the AutoCal module to determine left/right cable identification or the SmartCal Port A/B cable identification.
 - When the settings are complete, select OK to close the dialog box.
19. The AUTOCAL SETUP (2-Port) menu reappears with new values for Cal Type, Thru Type, and Module Orientation.
20. The window area at the bottom of the instrument display area appears with general instructions:
- Ensure correct cable connections to Calibration module.
 - Ensure that the Power and Operate LEDs are both illuminated.
 - Ensure characterization file is loaded before starting Cal. To load characterization file, go to the LOAD (AUTOCAL CHARACTERIZATION) dialog box.
 - MAIN | Calibration | CALIBRATION | CalKit Options | CAL KIT |Load Kit/Charc. | LOAD (AUTOCAL CHARACTERIZATION)
 - Existing system setups such as averaging, power level, etc. will be applied during the cal

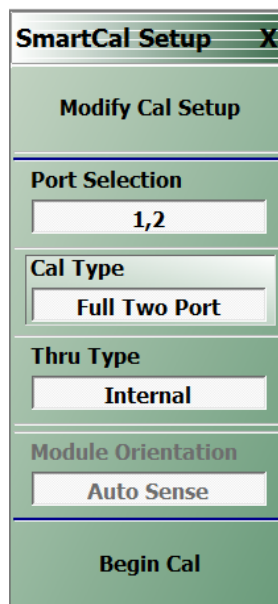


Figure 2-13. Configured SmartCal 2-Port Menu Setup

21. When ready, click the **Begin Cal** button.
22. If the Calibration module is connected incorrectly, SmartCal Module Not Detected warning message appears.
 - Connect the connections as required and click Reply..

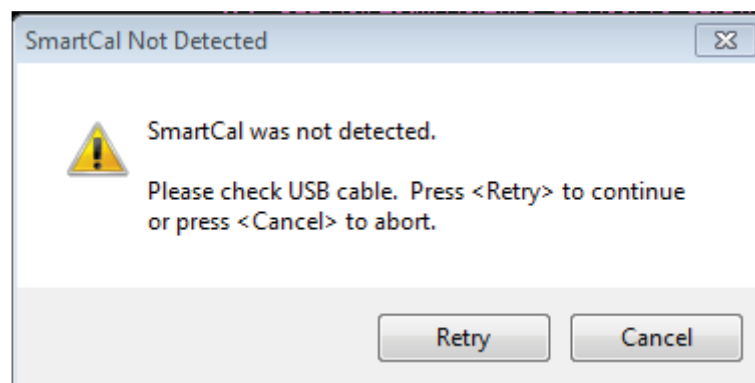


Figure 2-14. Not Detected Dialog

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 Calibration 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.

23. 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.

2-11 Calibration - Two Port Cal - True Through

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

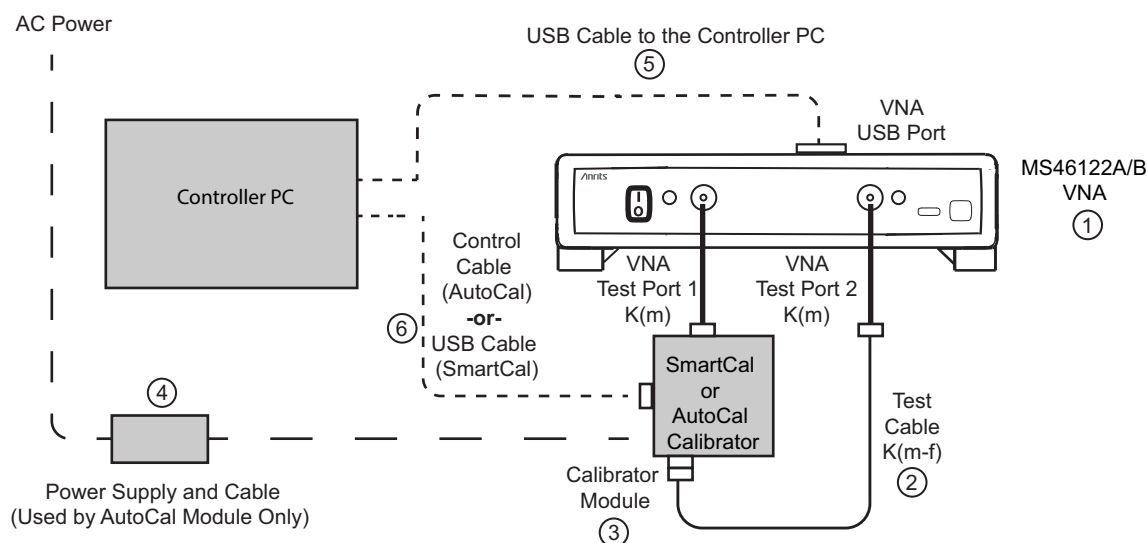
Required Equipment

- MS46122A/B or MS46322A/B VNA with K(m) or N(f) test port connectors
- Calibrator Module with K or N (with (f) and (m) connectors) and required power and control cables. For AutoCal, the Calibration Characterization File has been loaded onto the MS46122A/B or MS46322A/B VNA.
- Test port cable K or N (f) to K or N (m)
- Test port cable K or N (f) to K or N (f), or a K or N (f) to K or N (f) adapter.

Procedure

1. Power up the MS46122A/B or MS46322A/B.
2. Set the required Frequency Start, Frequency Stop, and Number of Points parameters.
 - [“Pre-Calibration Instrument Setup” on page 2-14.](#)
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 **Calibrator Module** and the **MS46122A/B or MS46322A/B** ([Figure 2-15 on page 2-23](#)):
 - a. Connect the **Test Cable** between Test Port 2 and the Calibrator port.
 - b. Connect the **Test Cable** between Test Port 1 and the Calibrator port.
 - c. If using **AutoCal**, connect the **Serial to USB Adapter** between the DB-9 connector on the Calibration Module and the **USB Port** on the MS46122A/B or MS46322A/B rear panel.

If using **SmartCal**, connect the USB cable between the Calibration Module and a USB port on the MS46122A/B or MS46322A/B front or rear panel.
 - d. Connect the **coaxial power plug** on the Power Supply Module (AutoCal Module only) to the AutoCal Module and the other end to AC power.
5. Once connected to power, the **Power LED** illuminates as green. When the Calibration module has warmed up, the **LED** illuminates as blue.



1. MS46122A/B VNA with K connectors.

2. Test Cable K(m-f)

3. SmartCal or AutoCal Calibrator Module

4. AutoCal Power Supply Module connected to AC Power (Used with AutoCal module only)

5. USB control cable from MS46122B to controller PC

6. DB9 (m-m) Control Cable (**AutoCal**) and RS232 to USB Adapter cable (2000-1809-R)-**or**- USB Cable (**SmartCal**)

Figure 2-15. MS46122A/B Calibrator Cable Connections for True Through

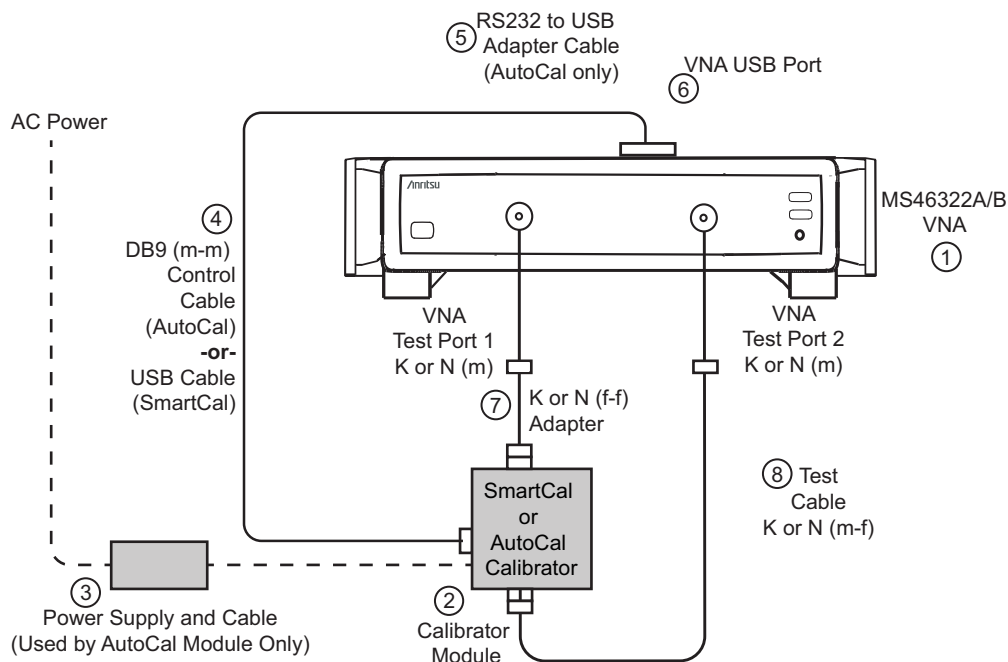
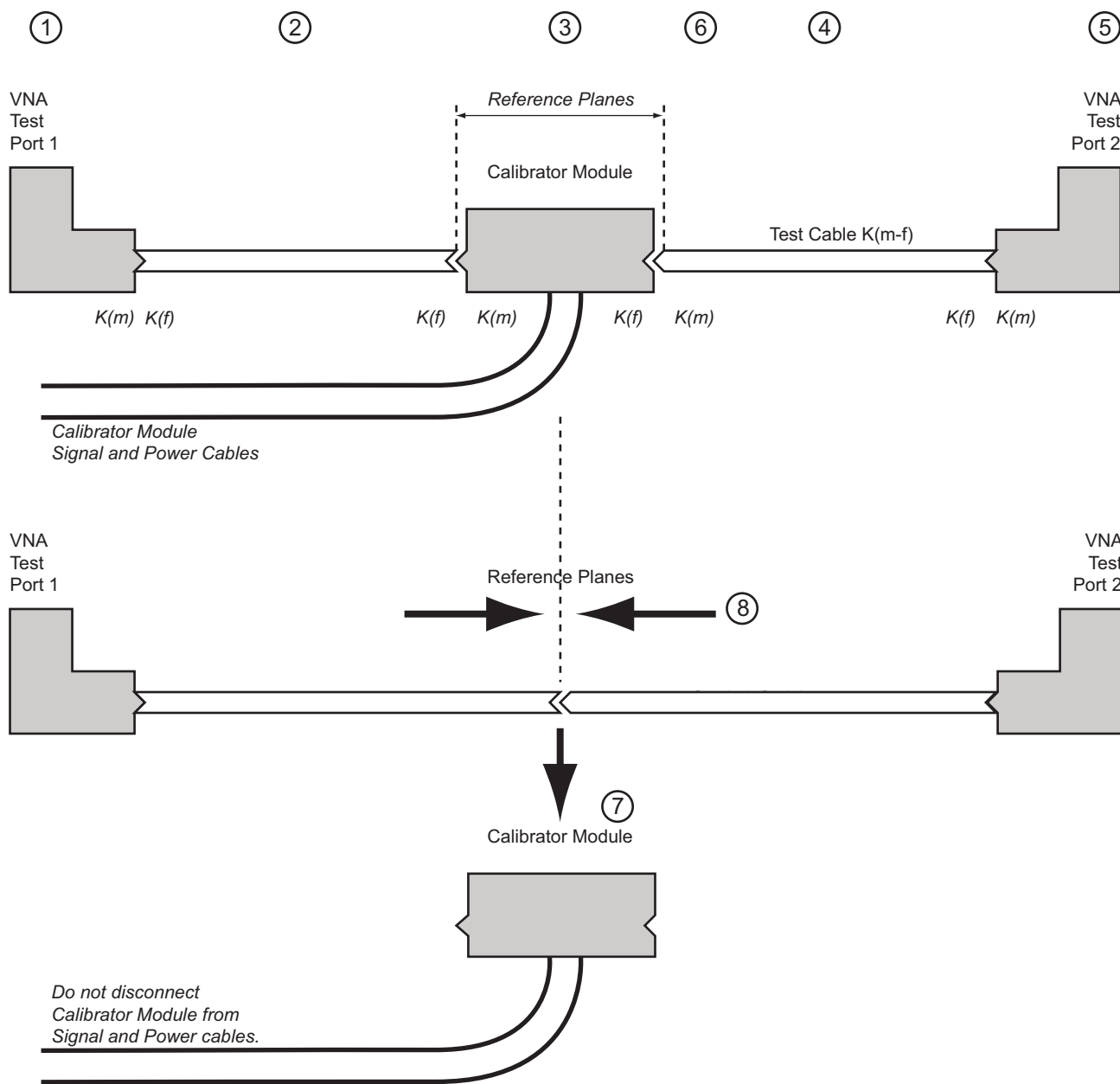


Figure 2-16. MS46322A/B Calibrator Cable Connections for True Through

- | | |
|--|--|
| 1. MS46522B VNA with K or N (m) Test Port Connectors | 4. DB9 (m-m) Control Cable (AutoCal) -or- USB Cable (SmartCal) |
| 2. SmartCal (K or N) or AutoCal (K) Calibrator (AutoCal does not support N connectors) | 5. RS232 to USB Adapter Cable (2000-1809-R) |
| 3. AutoCal Power Supply Module connected to AC Power (Used with AutoCal module only) | 6. VNA USB Port |
| | 7. K or N (f-f) Adapter connected to VNA Test Port 1 |
| | 8. K or N (m-f) Test Cable connected to VNA Test Port 2 |

Figure 2-16. MS46322A/B Calibrator Cable Connections for True Through

Schematically, the connections shown in [Figure 2-15](#) and [Figure 2-16](#) above are shown in [Figure 2-17](#).

**Figure 2-17.** Calibration Module True-Through Connections (1 of 2)

Part 1 – Calibration True Thru Procedure

1. VNA Test Port 1 K(m)
2. K(f-f) Test Cable
3. Calibrator Module
4. K(m-f) Test Cable
5. VNA Test Port 2 K(m)
6. Resultant reference planes during first Calibration procedure.

Part 2 – Calibration True Thru Procedure

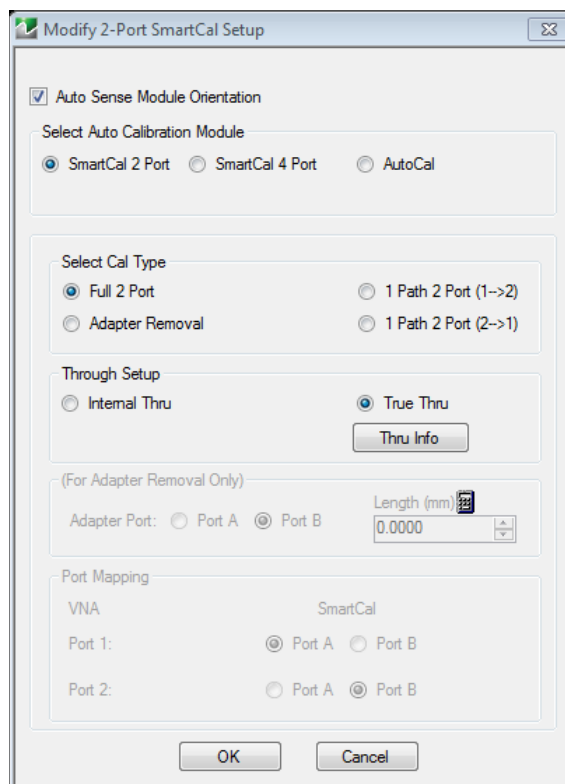
7. After initial calibrations, user is directed to remove Calibration module and connect test cables.
8. Connect the two Test Cables together to complete the through calibration.

Figure 2-17. Calibration Module True-Through Connections (2 of 2)

6. Navigate to the AUTOCAL SETUP menu:

- MAIN | Calibration | CALIBRATION | Calibrate | CALIBRATE | AutoCal | AUTOCAL PORTS | 2-Port Cal | SMARTCAL 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.

**Figure 2-18.** True Thru Selected

- 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 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.

8. Select the Auto Sense Module Orientation check box
9. 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.
-------------	---

10. When ready, click the **Begin Cal** button.
11. A status dialog box with a progress bar appears after an Calibration sequence has started. The status messages define how far the program has progressed and if any user actions are required.
12. At any time, the Calibration sequence can be canceled by clicking the dialog box **Abort** button.

Connect the True Through

1. A dialog box will appear when the true through is to be connected.
 - If using a MS46122A/B ShockLine VNA, refer to [Figure 2-20](#) when connecting the True-Through
 - If using a MS46322A/B ShockLine VNA, refer to [Figure 2-21](#) when connecting the True-Through
2. Connect the Test Port 1 test cable to the Test Port 2 test cable.

If the Calibration module is connected incorrectly, the AUTOCAL MODULE NOT DETECTED warning message appears, [Figure 2-19](#). Correct connections as required and click the Retry button..

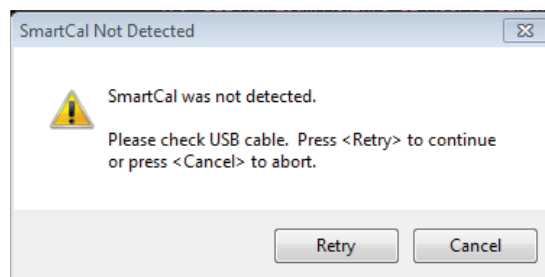
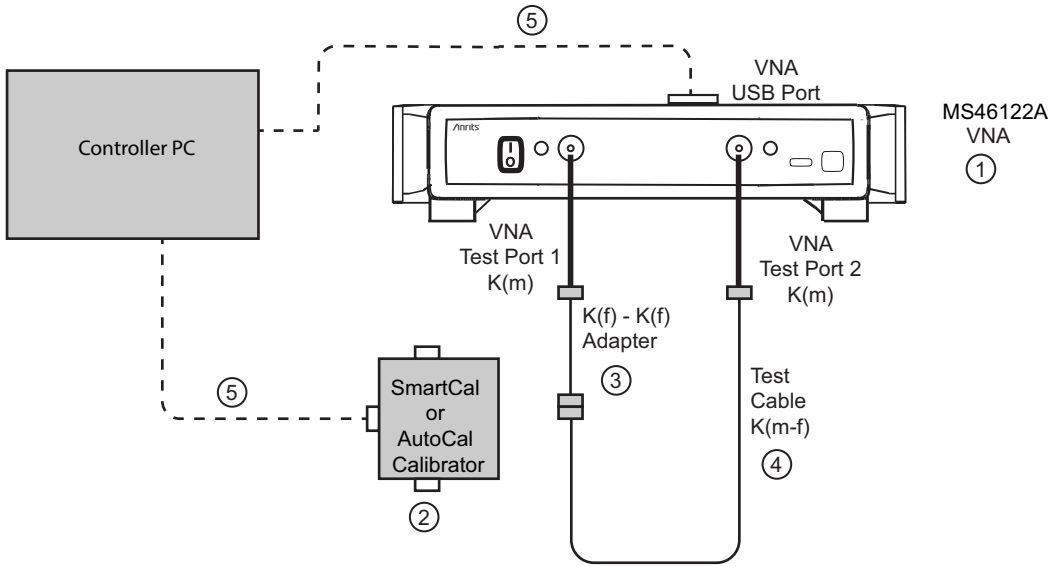
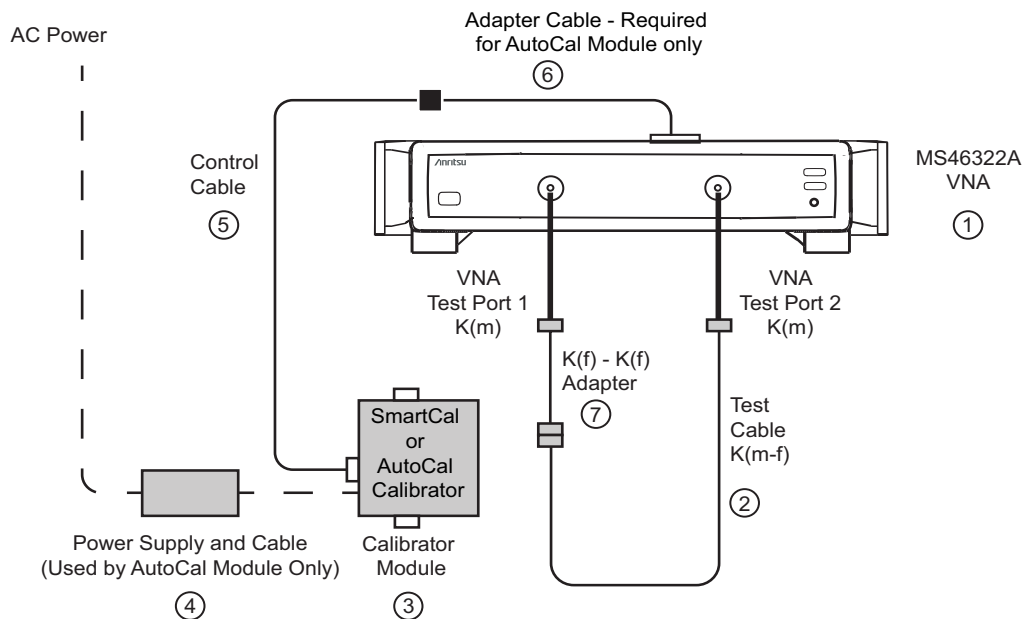


Figure 2-19. SmartCal Not Detected.



1. MS46122A/B with K Test Port Connectors	4. K(m-f) Test Cable connected to K(f-f) adapter and Test Port 2 K(m)
2. SmartCal or AutoCal Calibrator Module	
3. K(f) to K(f) Adapter connected to Test Port 1 K(m)	5. USB cable for SmartCal or serial cable and USB to serial adapter for AutoCal

Figure 2-20. MS46122A/B True-Through Connections - Module Removed



- | | |
|---|--|
| 1. MS46322A/B with K Test Port Connectors | 4. Calibration Module DB9 (m-m) Signal Cable connected to VNA Rear Panel Serial 10101 Port |
| 2. SmartCal or AutoCal Calibrator Module | 5. K(f) to K(f) Adapter connected to Test Port 1 K(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. K(m-f) Test Cable connected to K(f-f) adapter and Test Port 2 K(m) |

Figure 2-21. MS46322A/B True-Through Connections - Module Removed

3. After connecting the through, select **Continue**.
4. 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**.
5. Close the dialog box returns to the **CALIBRATION** menu.

2-12 Calibration 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 Calibration module.
3. Connect the Calibration module to the reference planes, apply power, and connect the control cable to both the Calibration module and to the ShockLine VNA. Allow the Calibration 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.

Note This navigation path applies to both AutoCal and SmartCal calibration modules

5. Save the characterization file as appropriate. Note that the characterization file will be tied by serial number to the particular Calibration module that was characterized.

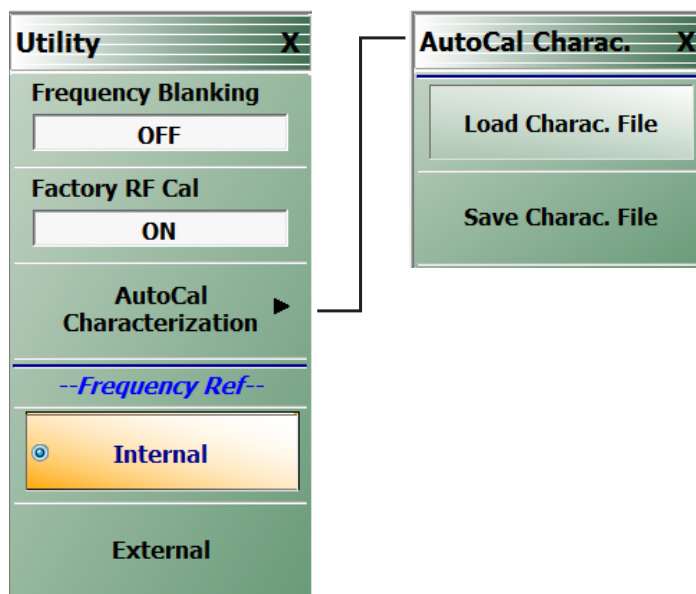


Figure 2-22. AUTOCAL CHARAC. (AUTOCAL CHARACTERIZATION) Menu

2-13 Adapter Removal - M-M or F-F Reference Plane

Adapter Removal Overview

Adapter removal for Calibration 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 Calibration module and M-M reference planes are required. A separate menu item is provided for Calibration 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 part 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 Calibration unit), then this Calibration-specific adapter removal technique may not be applied; see the standard adapter removal section.

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

Required Equipment

- **VNA**
MS46122A/B or MS46322A/B VNA with K Test Port Connectors
- **Calibration Module**
Precision Calibration Module, with K(f-m) connectors. Includes the necessary Power Supply Module with cords to AutoCal Module and to AC power or the SmartCal Calibrator module that only requires the USB cable connection to the PC Controller.
- **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:

- Calibration Characterization file previously loaded.
- MS46122A/B or MS46322A/B is 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 ShockLine VNA back panel.
 - When the blue Operate LED is illuminated, the module has warmed up and is ready for calibration operations.
2. Connect the K(f-f) Adapter to the Calibration Module K(m) connector.

- Consider the Adapter and Calibration module as an “assembly” for the duration the Calibration procedure.

Note

Once assembled, do not break the connection between the adapter and the Calibration module, do not disconnect the assembly from the USB Port, and do not disconnect the assembly from AC power. If the connection between the adapter is broken before the Calibration procedure is completed, the entire calibration is invalidated and must be repeated.

- Connect the remaining 36583K(f) connector to the MS46122A/B or MS46322A/B Test Port 1 K(m) connector.
- Connect the Test Cable K(f) connector to the MS46122A/B or MS46322A/B Test Port 2 K(m) connector.
- Connect the Test Cable K(m) connector to the Calibration Module K(f) connector.

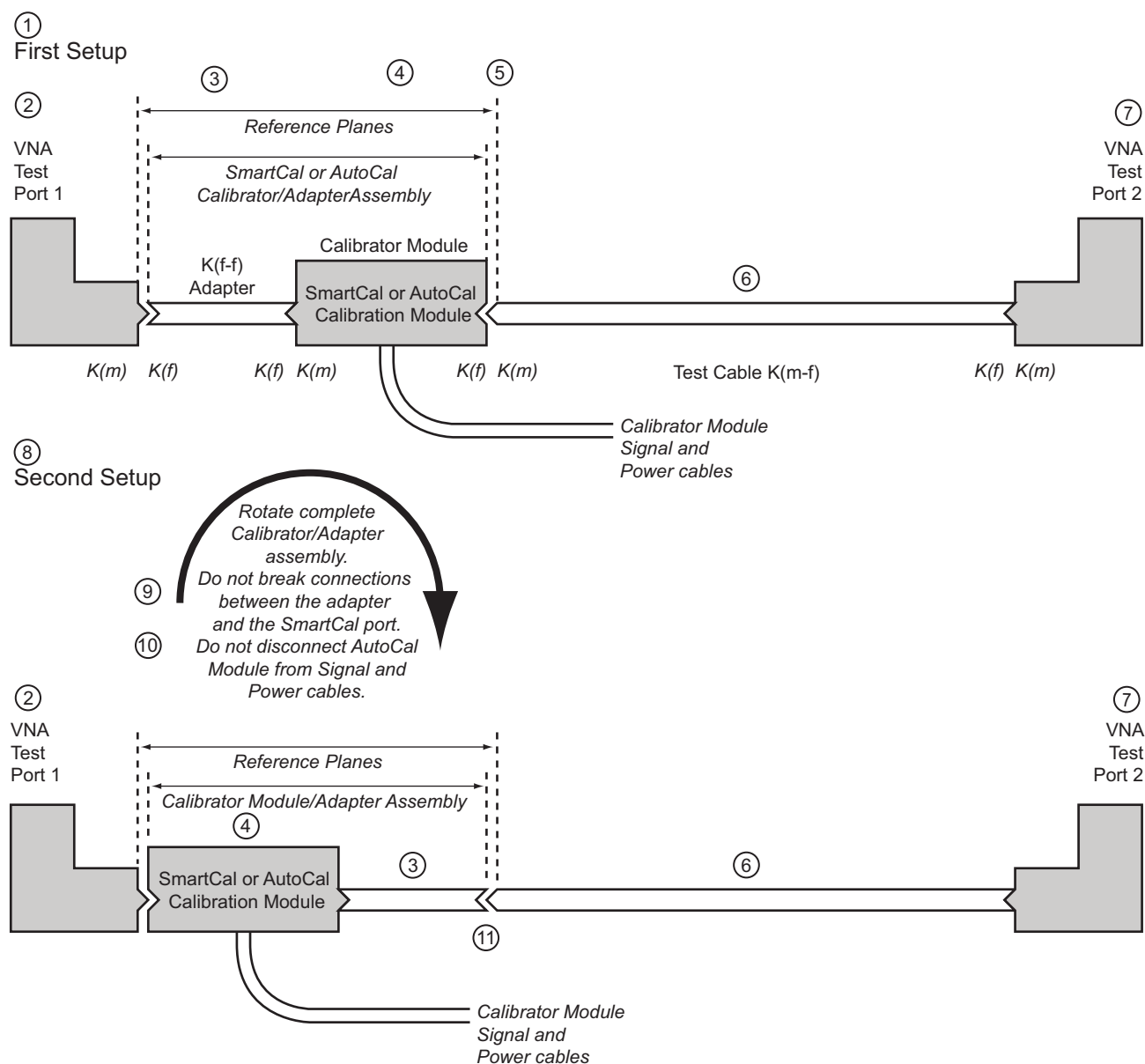


Figure 2-23. Calibrator, Adapter Removal, Internal Thru (1 of 2)

Part 1 – Calibration Adapter Removal Procedure	Part 2 – Calibration Module Adapter Removal Procedure
<ol style="list-style-type: none"> 1. First setup for the Adapter Removal procedure. 2. VNA Test Port 1 3. K(f-f) Adapter 4. Calibration Module– For the duration of the calibration, the K(f-f) Adapter and the Calibration 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 	<ol style="list-style-type: none"> 8. Second setup for the Adapter Removal procedure. 9. After the first calibration, rotate the complete assembly so that the calibrator K(f) connector is connected to VNA Test Port 1. Do not disconnect the Adapter from the Calibration module. 10. Do not disconnect the Calibration Module from its Power or Signal cables. 11. Connect the 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.

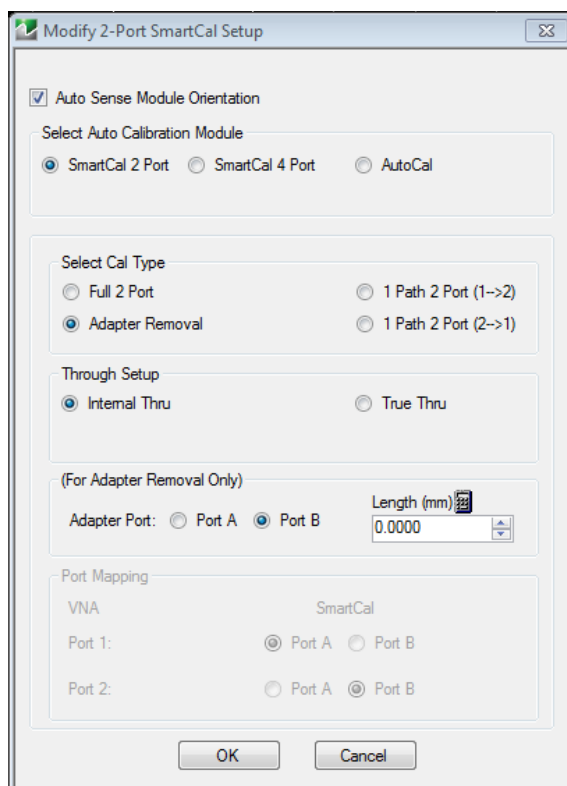
Figure 2-23. Calibrator, Adapter Removal, Internal Thru (2 of 2)

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 Calibration Setup dialog box appears.

**Figure 2-24.** Adapter Removal Selected

8. Make the following changes to the Modify Calibration Setup dialog box settings:
 - a. Select the Auto Sense Module Orientation check box which allows the Calibration module determine the AutoCal Module left/right cable identification or SmartCal Module Port A/B 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 Calibration 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 Calibration module is connected incorrectly, the Calibration 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 Calibration sequence has started. The status messages define how far the program has progressed and if any user actions are required.
12. At any time, the calibration sequence can be canceled by clicking the dialog box Abort button.
 - When the first calibration process is complete, the user is prompted to reverse the Adapter/Calibration assembly.

Note	Once assembled, do not break the connection between the adapter and the Calibration module. If the connection between the adapter is broken before the Calibration 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 2-23, “Calibrator, Adapter Removal, Internal Thru” on page 2-31](#) above, disconnect the Adapter from Test Port 1 and the Calibration Module from the Test Cable on Test Port 2.
15. Reverse the Adapter/Calibration Module assembly so that the Adapter end is pointing towards Test Port 2.
16. On the Calibration module, connect the free 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 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 (SOLT/R) 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.

Note	SOLR and LRL/LRM calibration methods are available with the “B” models only.
-------------	--

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.

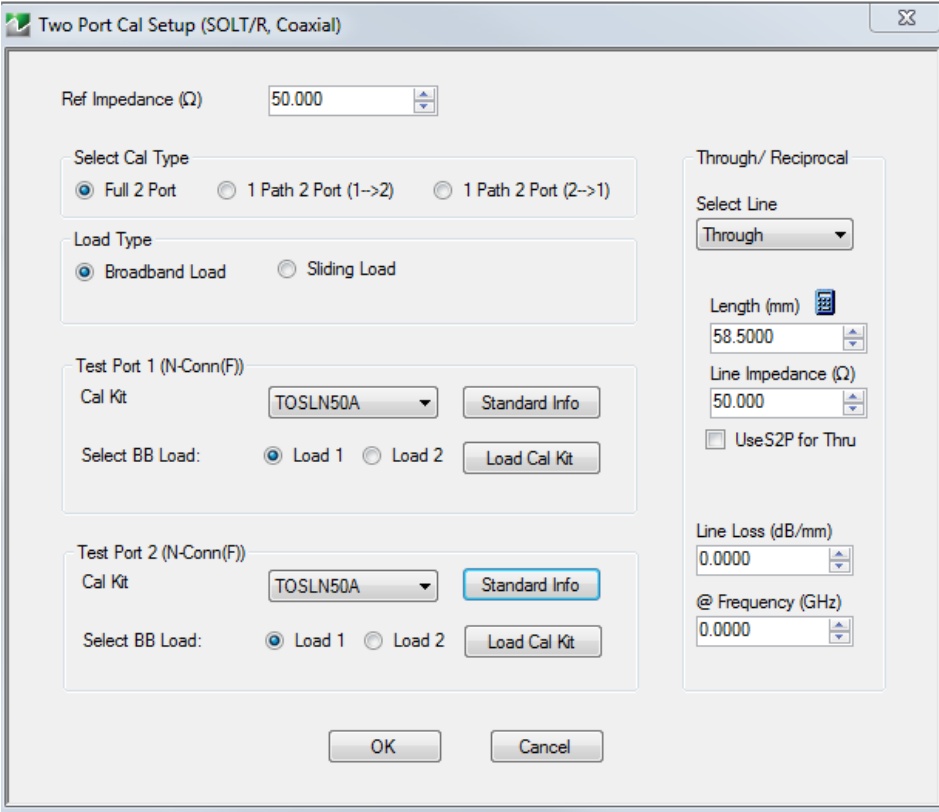
Note that a sliding load can be used in lieu of a fixed load. The sliding load is based on a sliding termination embedded in an airline and the transmission line properties of that airline are used to deduce a more nearly perfect synthetic load. Because of the transmission line dependence, a fixed load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

Thru

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

3-3 Setup

The coaxial setup dialog for SOLT/R full 2-Port calibration is shown in below.



The dialog box is titled "Two Port Cal Setup (SOLT/R, Coaxial)". It contains the following fields and controls:

- Ref Impedance (Ω)**: A text box with the value "50.000".
- Select Cal Type**: Three radio buttons: "Full 2 Port" (selected), "1 Path 2 Port (1->2)", and "1 Path 2 Port (2->1)".
- Load Type**: Two radio buttons: "Broadband Load" (selected) and "Sliding Load".
- Test Port 1 (N-Conn(F))**:
 - Cal Kit**: A dropdown menu showing "TOSLN50A" and a "Standard Info" button.
 - Select BB Load**: Two radio buttons: "Load 1" (selected) and "Load 2", with a "Load Cal Kit" button.
- Test Port 2 (N-Conn(F))**:
 - Cal Kit**: A dropdown menu showing "TOSLN50A" and a "Standard Info" button.
 - Select BB Load**: Two radio buttons: "Load 1" (selected) and "Load 2", with a "Load Cal Kit" button.
- Through/ Reciprocal**:
 - Select Line**: A dropdown menu showing "Through".
 - Length (mm)**: A text box with the value "58.5000".
 - Line Impedance (Ω)**: A text box with the value "50.000".
 - Use S2P for Thru**: An unchecked checkbox.
 - Line Loss (dB/mm)**: A text box with the value "0.0000".
 - @ Frequency (GHz)**: A text box with the value "0.0000".
- Buttons**: "OK" and "Cancel" buttons at the bottom.

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

The setup dialog above is for coaxial and non-dispersive line types. In the 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/SOLR is not recommended for waveguide due to the difficulty in modeling and open standards

A waveguide SOLT/R setup is shown in [Figure 3-2](#) and a setup for microstrip is shown in [Figure 3-3](#).

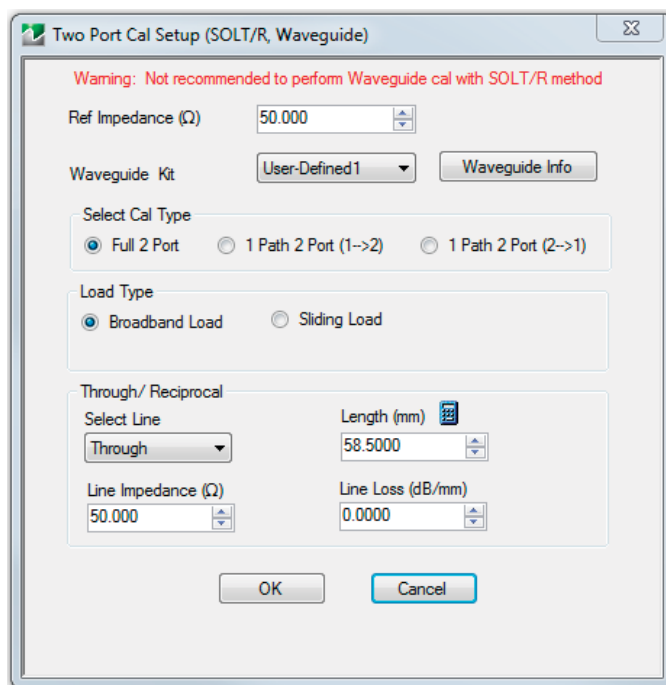


Figure 3-2. TWO PORT CAL SETUP (SOLT/R, WAVEGUIDE) Dialog Box

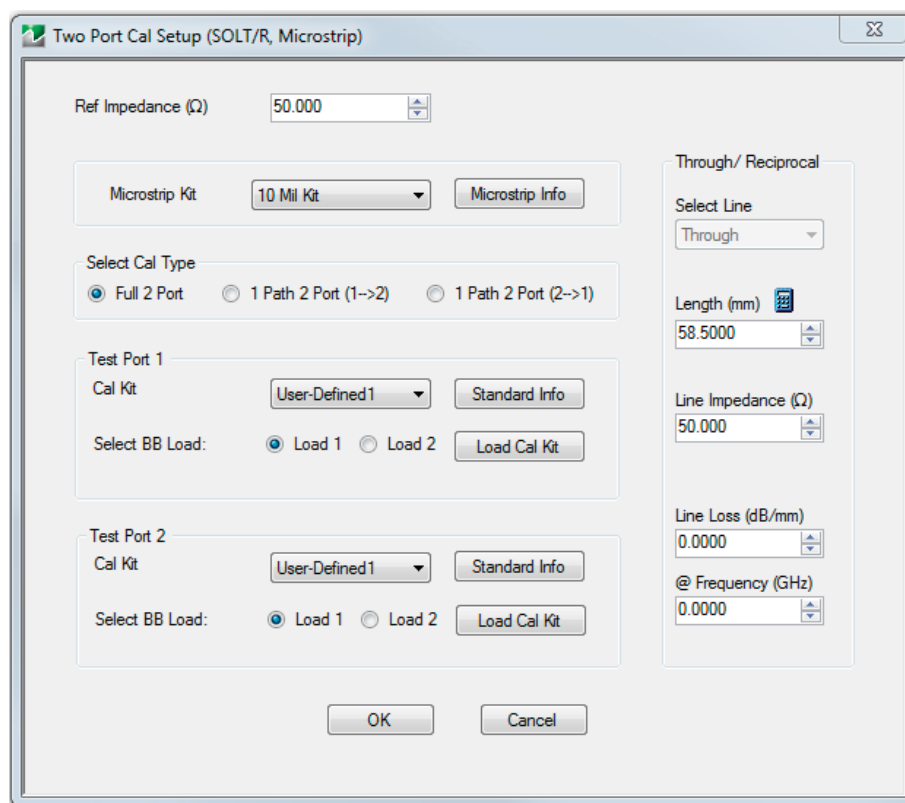


Figure 3-3. TWO PORT CAL SETUP (SOLT/R, MICROSTRIP) Dialog Box

The standards information dialog for SOLT/R is shown in [Figure 3-4](#).

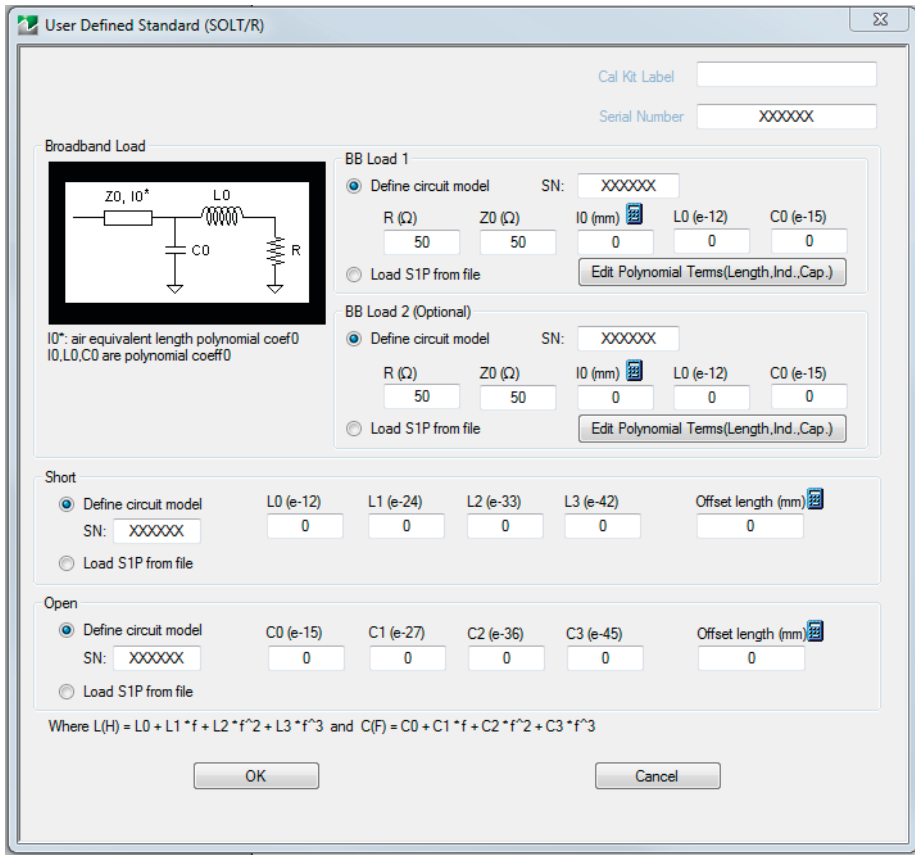
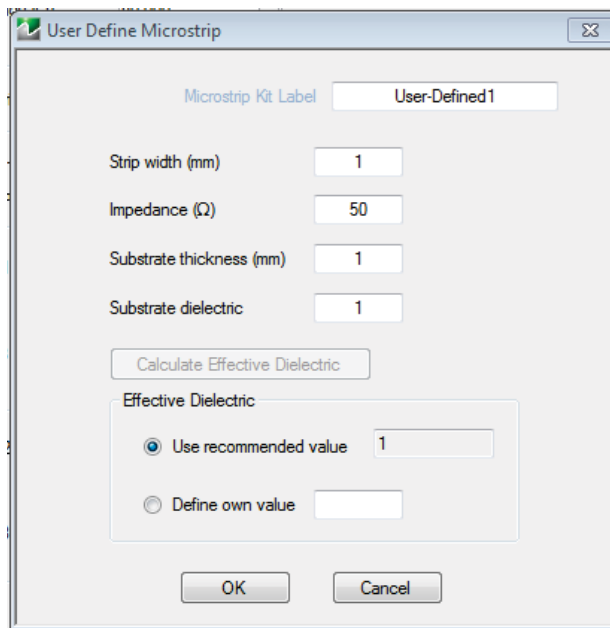


Figure 3-4. STANDARD INFO (SOLT/R)

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.

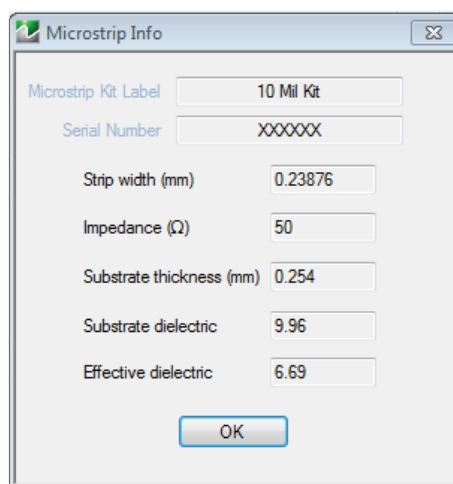
The standards information for microstrip does not change but the microstrip media information must be either user-defined (Figure 3-5) or selected from an Anritsu microstrip cal kit (Figure 3-6, typically used with Anritsu Universal Test Fixtures).



The 'User Define Microstrip' dialog box is shown. It has a title bar with a close button. The 'Microstrip Kit Label' field contains 'User-Defined1'. Below this are four input fields: 'Strip width (mm)' with value '1', 'Impedance (Ω)' with value '50', 'Substrate thickness (mm)' with value '1', and 'Substrate dielectric' with value '1'. There is a 'Calculate Effective Dielectric' button. Below that is a section titled 'Effective Dielectric' with two radio buttons: 'Use recommended value' (selected) and 'Define own value'. The 'Use recommended value' option has a value of '1' next to it. At the bottom are 'OK' and 'Cancel' buttons.

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

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



The 'Microstrip Info' dialog box is shown. It has a title bar with a close button. The 'Microstrip Kit Label' field contains '10 Mil Kit'. The 'Serial Number' field contains 'XXXXXX'. Below these are five input fields: 'Strip width (mm)' with value '0.23876', 'Impedance (Ω)' with value '50', 'Substrate thickness (mm)' with value '0.254', 'Substrate dielectric' with value '9.96', and 'Effective dielectric' with value '6.69'. At the bottom is an 'OK' button.

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).

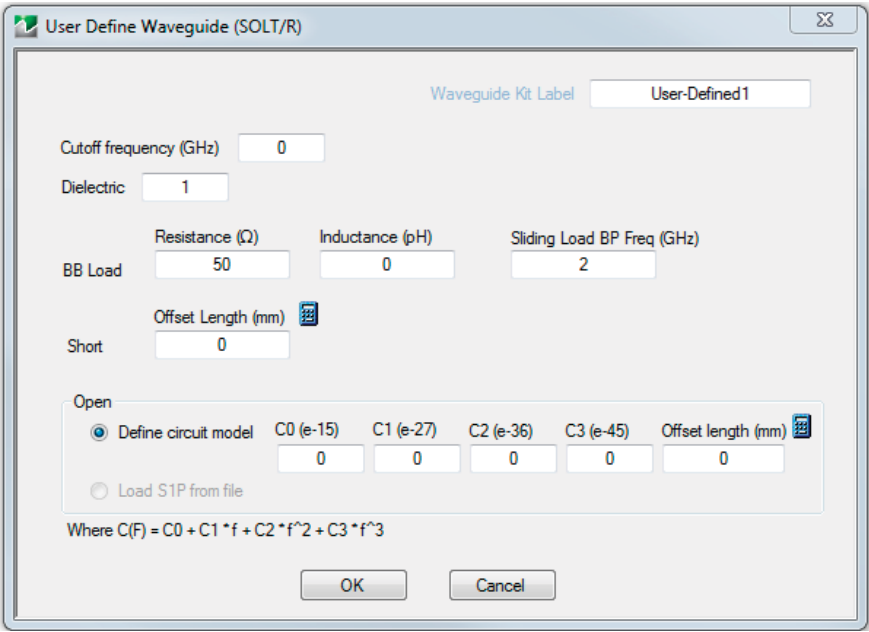


Figure 3-7. USER-DEFINED WAVEGUIDE (SOLT/R) Information Dialog Box

3-4 SOLT/SOLR Calibration

The following example presumes an MS46122A/B or MS46322A/B Series VNA with N 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/SOLR 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.

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/SOLR, COAXIAL) dialog box appears which describes the calibration components:
 - a. Reference impedance defaults to 50 ohms. This value is used for referencing the standards reflection coefficients and for reference plane shift and Smith chart calculations. 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 (< 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. Reciprocal is not available at this time.
 - d. For **Port 1**, select a DUT connector of N(f). Note the dialog will then indicate that port connector is N(m).
 - e. For **Port 2**, select a DUT connector of N(m). The dialog will indicate a port connector of N(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/SOLR (SOLT/R) 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/SOLR 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/R dialog (Figure 4-3). The standards information dialog box is different and is shown below.

The dialog box is titled "User Define Standard (SSLT)". It contains the following sections:

- Cal Kit Label:** W1-Conn(F)
- Serial Number:** XXXXXX
- Broadband Load:** Includes a circuit diagram with components $Z0$, 10^* , $L0$, $C0$, and R . Below the diagram is the text "10*: air equivalent length polynomial coef0".
- Sliding Load BreakPoint Freq (in GHz):** 2
- BB Load 1:** Includes a radio button for "Define circuit model" (selected) and "Load S1P from file". The "Define circuit model" section has fields for SN: XXXXXX, R (Ω): 50, Z0 (Ω): 50, l0 (mm): 0, L0 (e-12): 0, and C0 (e-15): 0. There is an "Edit Polynomial Terms(Length,Ind.,Cap.)" button.
- Offset Short 1:** Includes a radio button for "Define circuit model" (selected) and "Load S1P from file". The "Define circuit model" section has fields for SN: XXXXXX, L0 (e-12): -4.193, L1 (e-24): 1308.5, L2 (e-33): -25.137, L3 (e-42): 0.1282, and Offset length (mm): 2.02.
- Offset Short 2:** Includes a radio button for "Define circuit model" (selected) and "Load S1P from file". The "Define circuit model" section has fields for SN: XXXXXX, L0 (e-12): 0.945, L1 (e-24): 544.52, L2 (e-33): -12.32, L3 (e-42): 0.0724, and Offset length (mm): 2.65.
- Legend:** Where $L(H) = L0 + L1 * f + L2 * f^2 + L3 * f^3$ and $C(F) = C0 + C1 * f + C2 * f^2 + C3 * f^3$
- Buttons:** Save To Disk, Save To Memory, Cancel

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

Variations for other line types (waveguide or microstrip) are similar to those for SOLT/R. 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.

The image shows a software dialog box titled "User Defined Waveguide (SSLT)". It contains several input fields for defining waveguide parameters. The "Waveguide Kit Label" is set to "User-Defined1". The "Cutoff frequency (GHz)" is 0. The "Dielectric" is 1. The "Offset Length (mm)" is 0. There are two "Offset short" fields, both set to 0, each with a calculator icon. The "BB Load" section has a "Resistance (Ω)" of 50 and an "Inductance (pH)" of 0. The "Sliding Load BP Freq (GHz)" is 2. At the bottom are "OK" and "Cancel" buttons.

Parameter	Value
Waveguide Kit Label	User-Defined1
Cutoff frequency (GHz)	0
Dielectric	1
Offset Length (mm)	0
Offset short 1	0
Offset short 2	0
BB Load Resistance (Ω)	50
BB Load Inductance (pH)	0
Sliding Load BP Freq (GHz)	2

Figure 4-2. Typical parameters for an Offset Short Calibration

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 MS46122A/B-322A/B is being used with waveguide adapters (since SSLT is commonly used with waveguide). 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), 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.

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

The screenshot shows the 'Two Port Cal Setup (SSLT, Waveguide)' dialog box. It has the following fields and options:

- Ref Impedance (Ω)**: 50.000
- Waveguide Kit**: WR28 (with a 'Waveguide Info' button)
- Select Cal Type**:
 - ☒ Full 2 Port
 - ☐ 1 Path 2 Port (1-->2)
 - ☐ 1 Path 2 Port (2-->1)
- Load Type**:
 - ☒ Broadband Load
 - ☐ Sliding Load
- Through/ Reciprocal** section:
 - Select Line**: Through
 - Length (mm)**: 0.0000
 - Line Impedance (Ω)**: 50.000
 - Line Loss (dB/mm)**: 0.0000
- Buttons**: OK, Cancel

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.

- MS46122A/B-322A/B MG

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/SOLR 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:

$$\begin{aligned}A &= L_{\text{offset_short2}} - L_{\text{offset_short1}} \\B &= L_{\text{offset_short3}} - L_{\text{offset_short2}}\end{aligned}$$

Equation 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:

$$\begin{aligned}40 &< \frac{720 \cdot f \cdot B}{v_{ph}} < 180 \\40 &< \frac{720 \cdot f \cdot A}{v_{ph}} < 180 \\40 &< \frac{720 \cdot f \cdot (A + B)}{v_{ph}} < 320\end{aligned}$$

Equation 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.

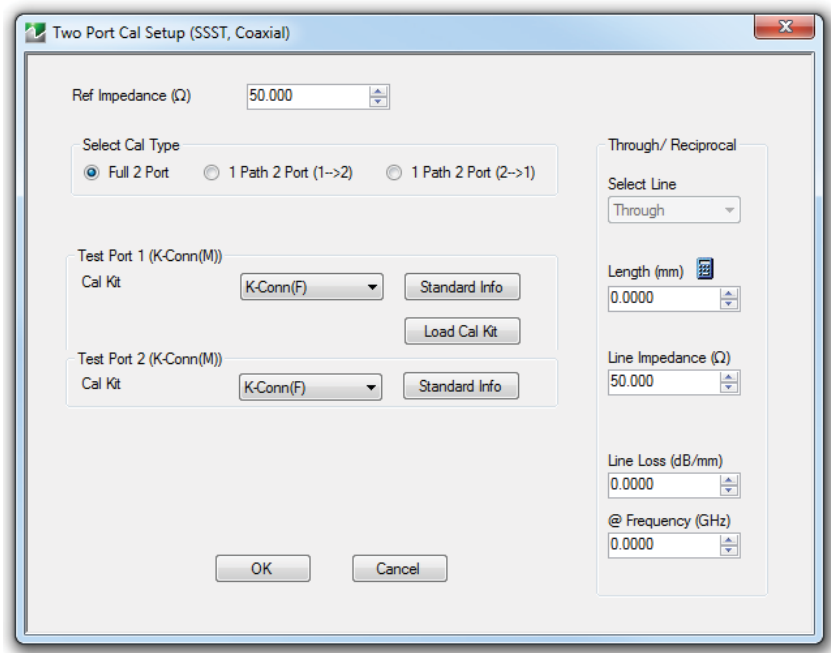


Figure 5-1. TWO PORT CAL SETUP (SSST, COAXIAL)

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.

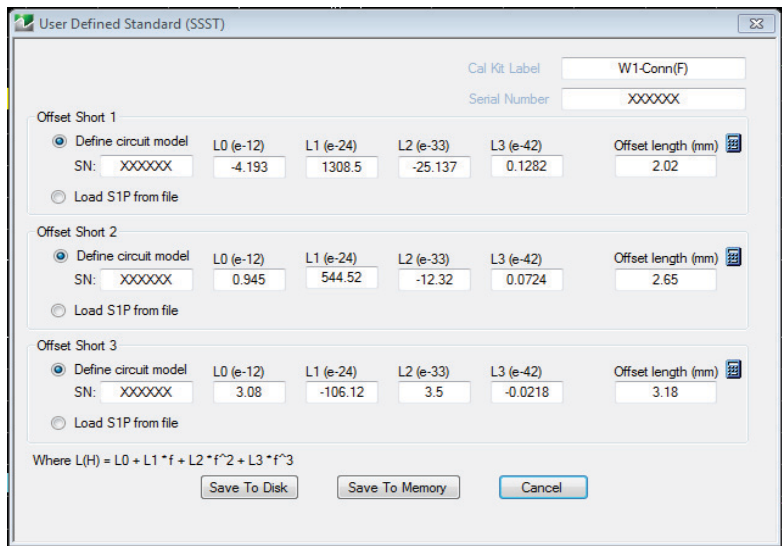


Figure 5-2. STANDARD INFO (TRIPLE OFFSET SHORT) Information Dialog Box

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

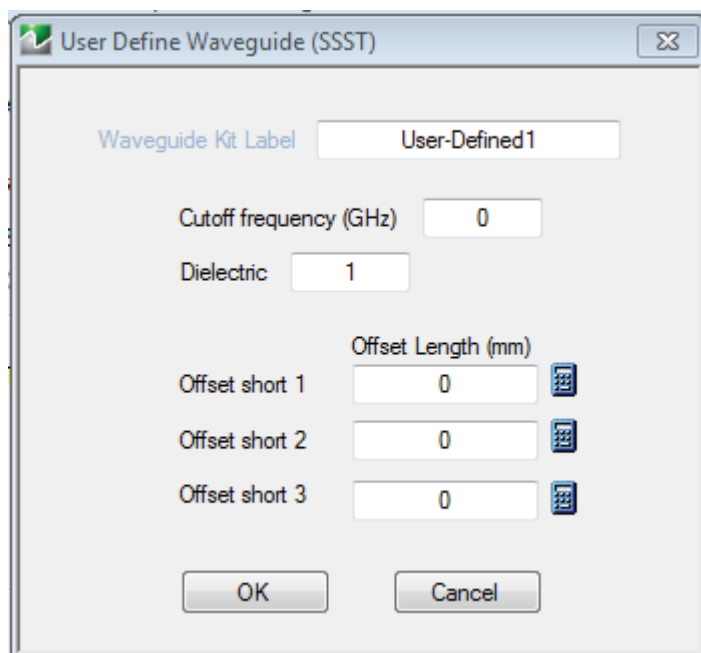


Figure 5-3. USER DEFINED WAVEGUIDE (SSST) Information Dialog Box

5-3 SSST Calibration Example

The following example presumes an MS46122A/B or MS46322A/B Series VNA in a broadband setup with K connectors. 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), 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 and a Line Type of Coaxial.
4. Select Edit Cal Params, the TWO PORT CAL SETUP (SSST, COAXIAL) dialog box appears (shown below).

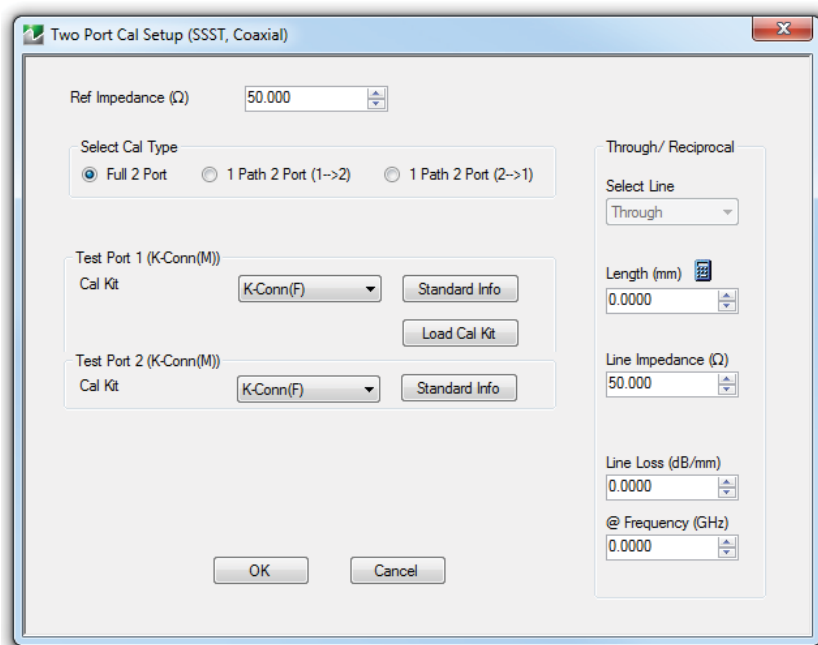


Figure 5-4. TWO PORT CAL SETUP (SSST, COAXIAL) Dialog Box

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. **Reciprocal** is not available at this time.
 - d. For **Test Port 1**, select a DUT connector of **K(f)**. The dialog box then displays a port connector as **W1-Conn (m)**.
 - e. For **Test Port 2**, select a DUT connector of **K(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 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.

Note	SOLR and LRL/LRM calibration methods are available with the “B” models only.
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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.

LRM - Line-Reflect-Match

LRM (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 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:

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

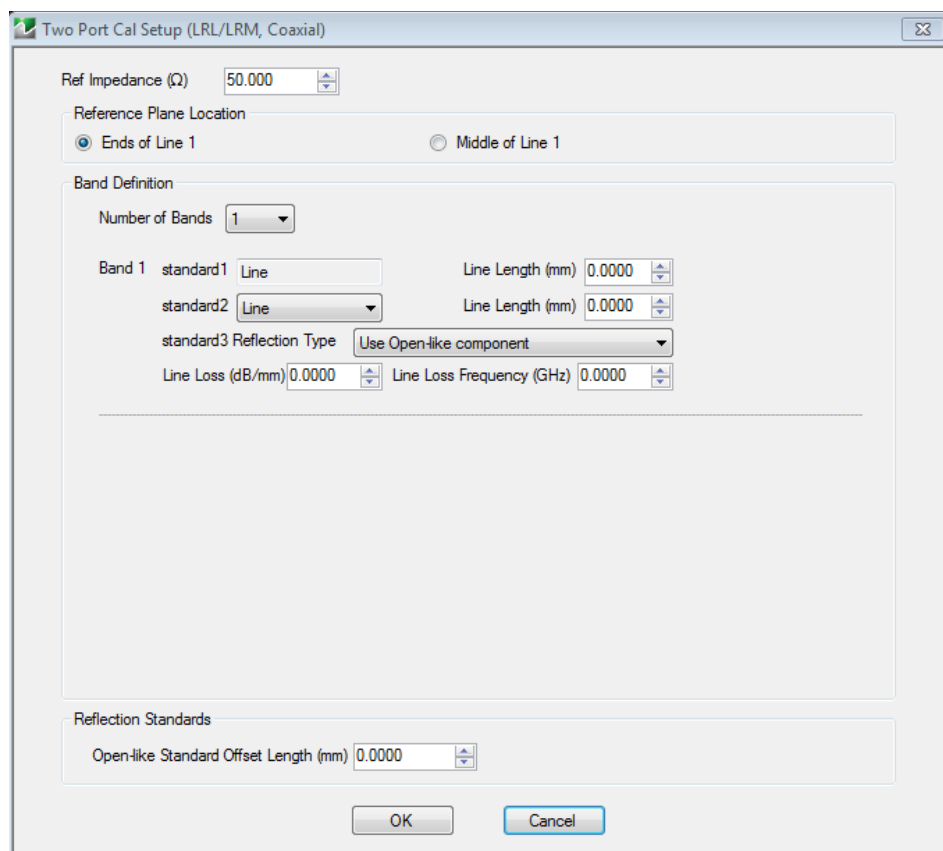
Equation 6-1

Where ΔL is in meters, v_{ph} is the phase velocity of the line ($= 2.9978 \cdot 10^8 \text{ m/s} = c$ 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 (LRM 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.

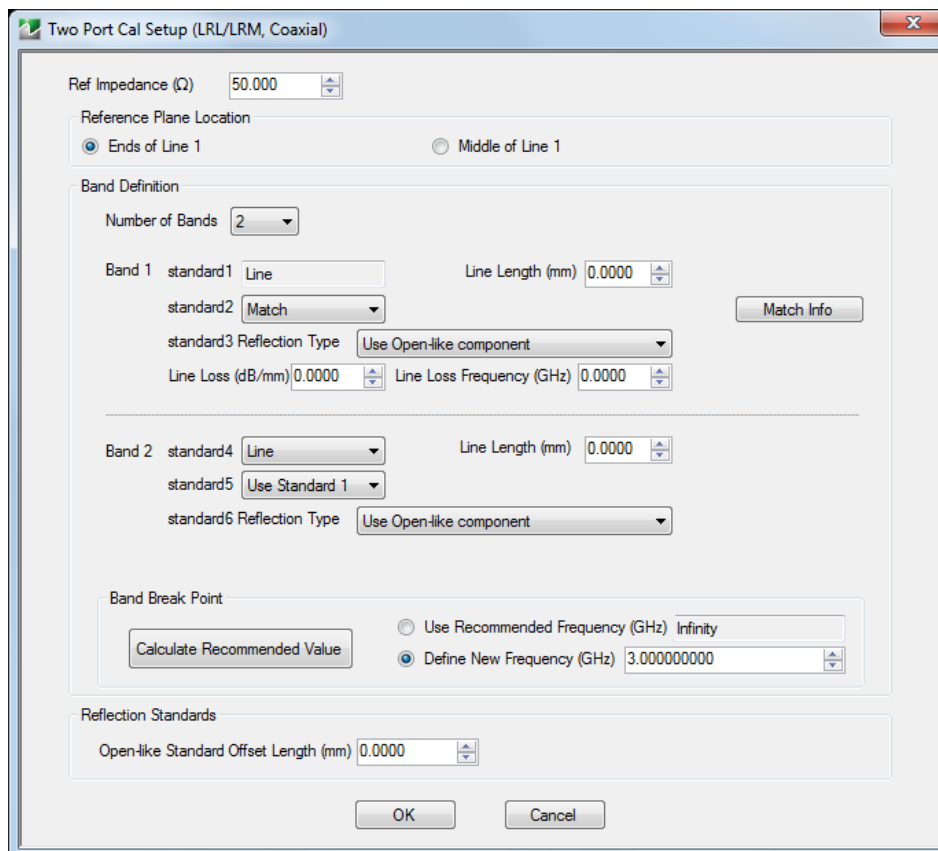
The setup dialog for LRL/LRM is quite flexible with decisions made based on what standards are selected. Several examples are shown in the figures below.

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



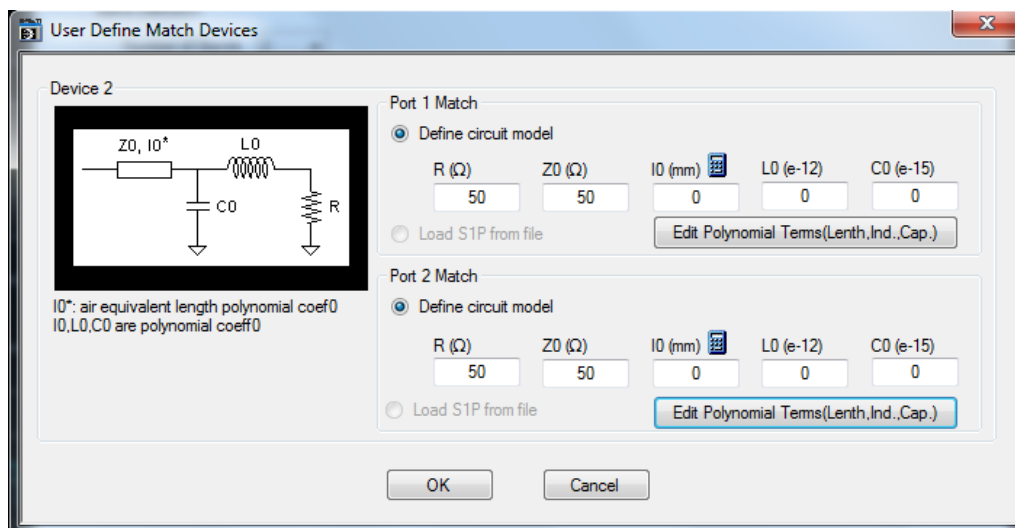
Typical parameters - One-Band LRL calibration

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



Typical parameters – Two-Band LRL calibration: Band 1 LRM - Band 2 LRL

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



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

Figure 6-3. USER DEFINED MATCH DEVICES Dialog Box

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 LRM 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 or fixtured calibrations).

Load Model/Characterization for LRM

When a single reflect approach is taken within ALRM, it behaves like a classical LRM (see [Figure 6-4](#)). For slightly more advanced use, complete load models can be entered for the two matches independently. The same model as described for SOLT/SOLR 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.

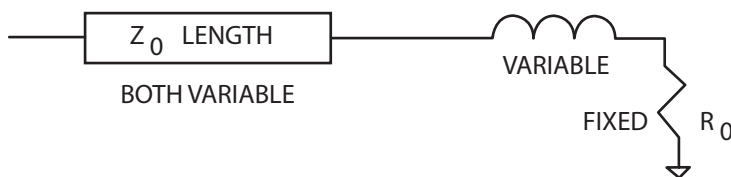
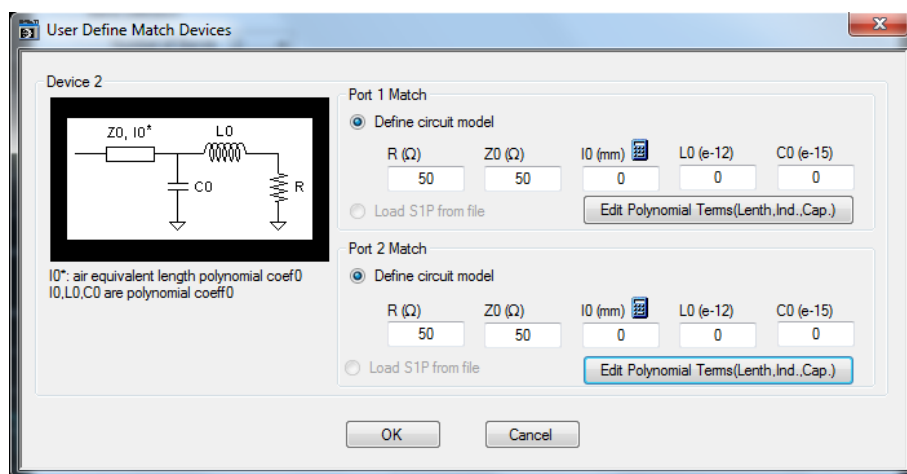


Figure 6-4. Load Model/Characterization for LRM

The dialog box ([Figure 6-5](#) 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 6-5. LRM MATCH DEVICES CALCULATED VALUES (BAND 1) Dialog Box

The dialog boxes shown above are for coaxial or non-dispersive line types.

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

The following example presumes a MS46122A/B and MS46322A/B ShockLine VNA are 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.

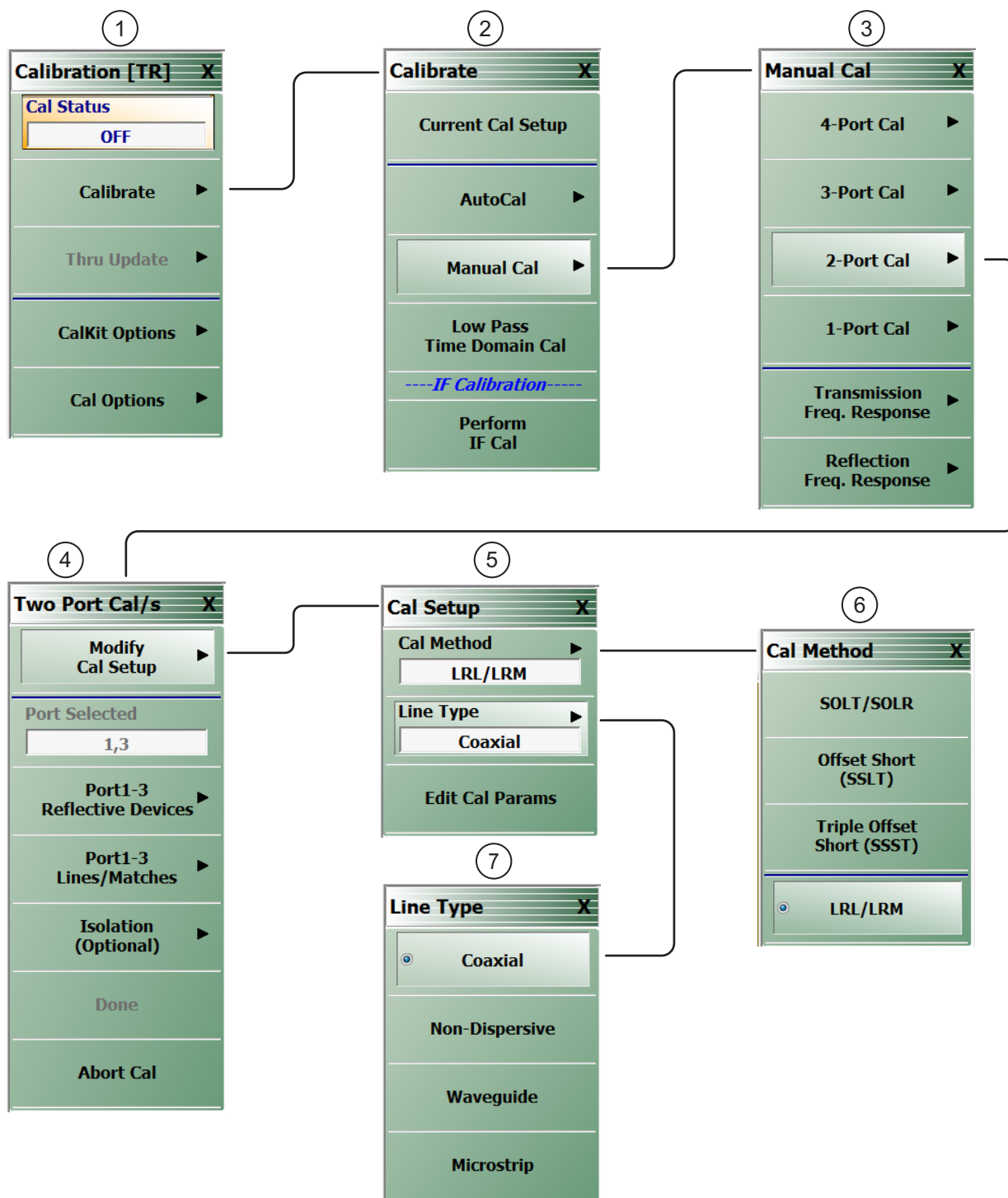


Figure 6-6. Calibration Menu Set for LRL/LRM Coaxial (1 of 2)

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

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

Procedure

The same menu structure appears for Tab A and Tab B. [Figure 6-7](#)

- 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 for more information [“Through \(Thru\) Update”](#) on page 8-1.

- 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.

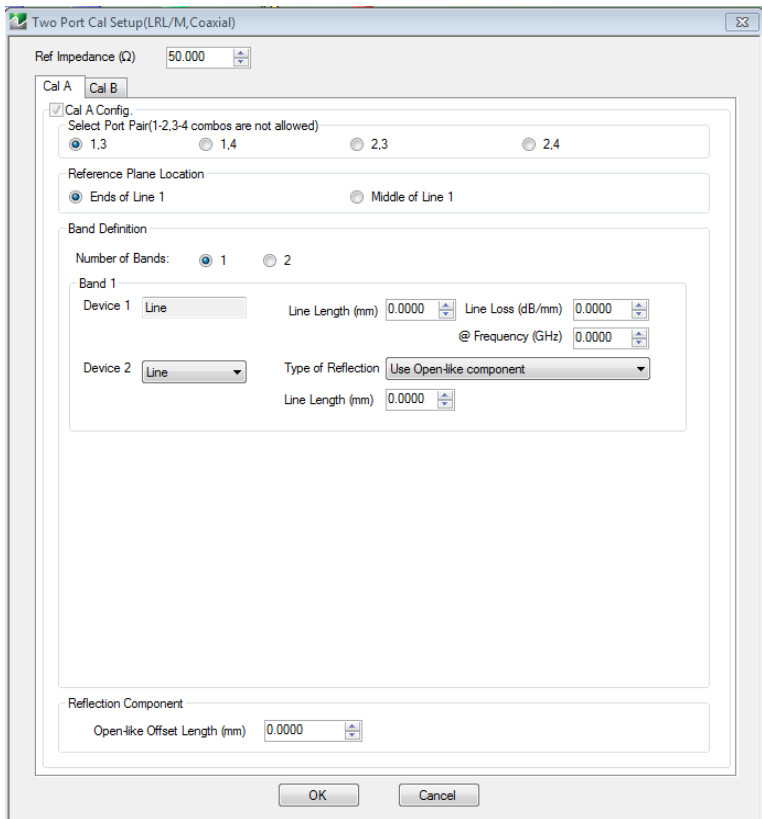


Figure 6-7. Calibration Setup Dialog - TWO PORT CAL SETUP (LRL/LRM, COAXIAL) Dialog Box

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.

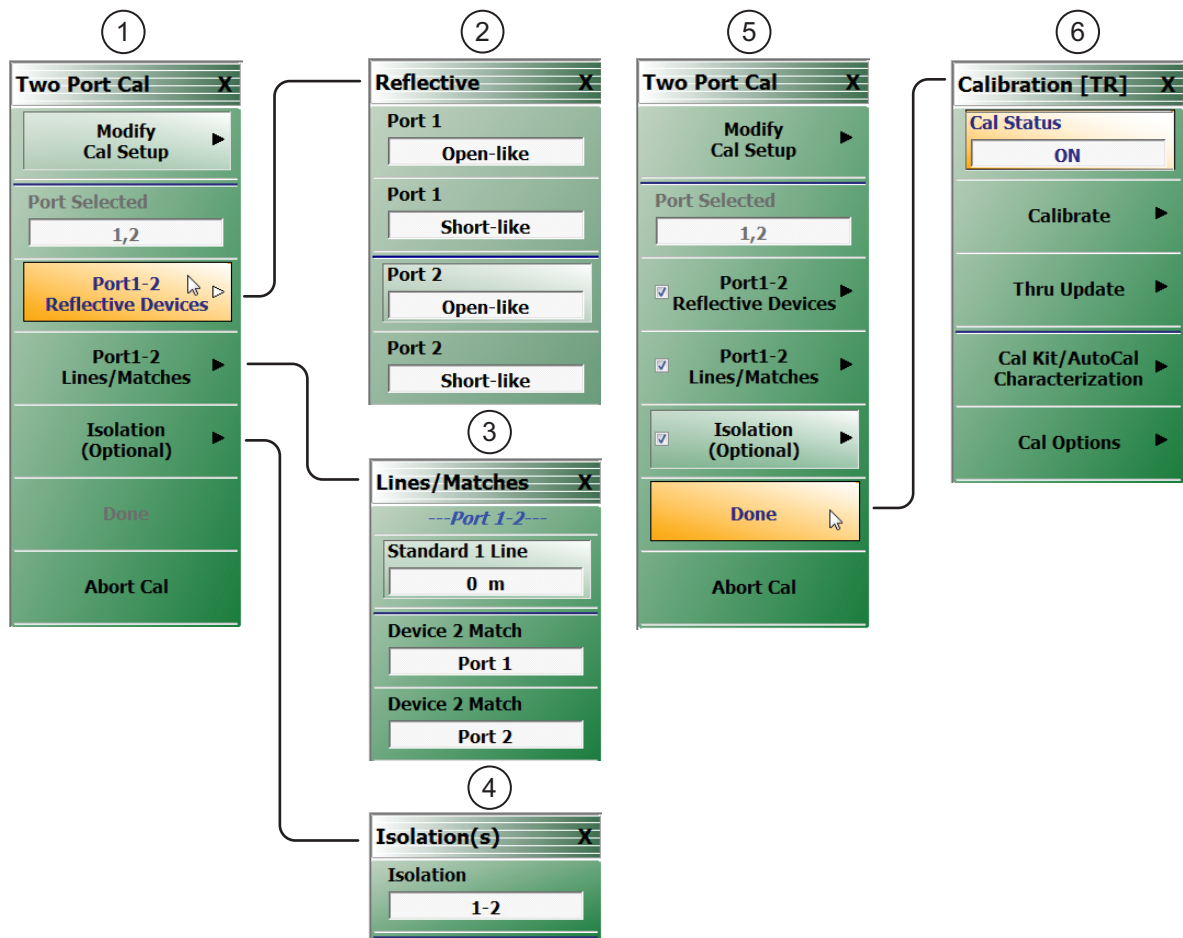


Figure 6-8. Two Port LRL/LRM Coaxial Calibration Procedure Menus (1 of 2)

1. The TWO PORT CAL menu with link/completion buttons for Port 1-2 Reflective Devices, Port 1-2 Lines/Matches, and Isolation (Optional).	4. Optional ISOLATION Port 1-2 Menu
2. REFLECTIVE Port 1-2 Menu	5. TWO PORT CAL menu after all calibration procedures successfully completed. Note Done button is available.
3. LINES/MATCHES Menu	6. CALIBRATION Menu with Cal Status set to ON.

Figure 6-8. Two Port LRL/LRM Coaxial Calibration Procedure Menus (2 of 2)

7. On the TWO PORT CAL menu (above in [Figure 6-8 – #1](#)), select the Port 1-2 Reflective Devices button and its linked REFLECTIVE menu ([Figure 6-8 – #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 6-8 – #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 6-8 – #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 6-8 – #5](#)), the **Done** button on the TWO PORT CAL menu is available. Click on **Done**. The focus returns to the **CALIBRATION** menu (at [Figure 6-8 – #6](#)) where the **Cal Status** button is set to **ON**.

6-4 Hints and Suggestions

Since there are a number of choices involved in setting up the LRL/LRM family of calibrations, some additional hints and points of emphasis may be of assistance:

- Reflect offset lengths are referenced to the ends of Line 1. These lengths are all air-equivalent lengths. The line length entries for the transmission lines are also air-equivalent. If the lengths are known in terms of time delay, the air-equivalent length is given by:

$$\text{time delay (seconds)} \times 2.9978 \times 10^8 \text{ (m/s)}$$
- The frequency breakpoint for 2-band calibrations is calculated from the geometric mean of the theoretical upper limit of the low band and the theoretical lower limit of the upper band. The former is calculated based on the 160 degree delta frequency and the latter is calculated from the 10 degree delta frequency. This decision is somewhat arbitrary and is heavily dependent on the materials involved and uncertainties required. With relatively lossy lines, one can approach the limits more closely than with low-loss lines. The impact is also dependent on transmission line quality. If both lines have an impedance of, for example, 50.1 ohms and one measured a theoretical -80 dB termination, the result would be predictable limited by the line impedance imperfection to about -61 dB at all frequencies. If instead, one line was 50.1 ohms and one was 50.2 ohms, then one gets progressively more effect near the theoretical edge frequencies as shown in the figure below.

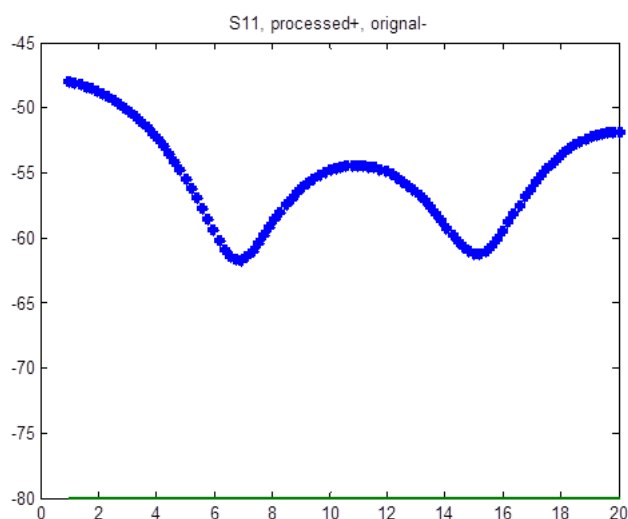


Figure 6-9. The effect of line impedance problems gets magnified as the line length delta approaches the theoretical band edges (the result for a high RL termination measurement when calibrated with unequal line impedances is shown here). This should be considered when deciding on the 2-band breakpoint frequency.

- When doing two band TRL/LRL calibrations, the orientation of the lines between bands can sometimes be confusing. The larger line delta should always be in band 1 (the lower frequency section).
- The TRL family of calibrations is more sensitive to asymmetries in standards (for example: different reflects on the two ports, lines of different impedance) than to problems in the standards themselves. When creating a custom calibration kit, this can be an important point. As an example, the effect on the measurement of a mismatched delay line is shown in [Figure 6-10](#) when there was a global 10 % impedance error on the LRL calibration lines and when the error was on only one line.

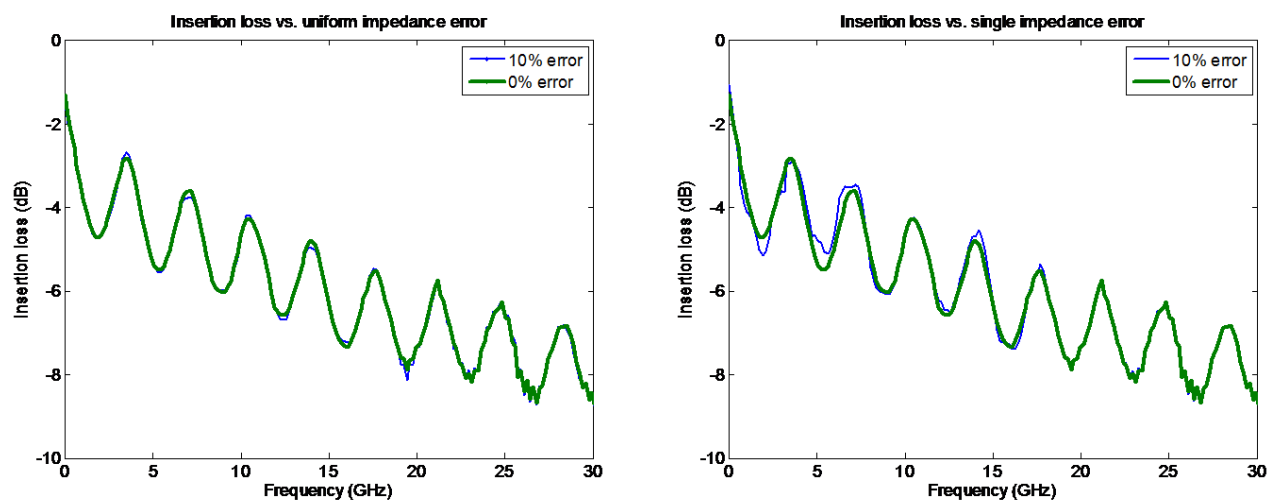


Figure 6-10. TRL/LRL is more sensitive to differences between the line impedances than to the absolute line impedance (although problems on that will shift the reference impedance of the calibration).

Chapter 7 — Adapter Removal Calibrations

7-1 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.

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.

7-2 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 7-1](#) 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 7-1](#) 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.

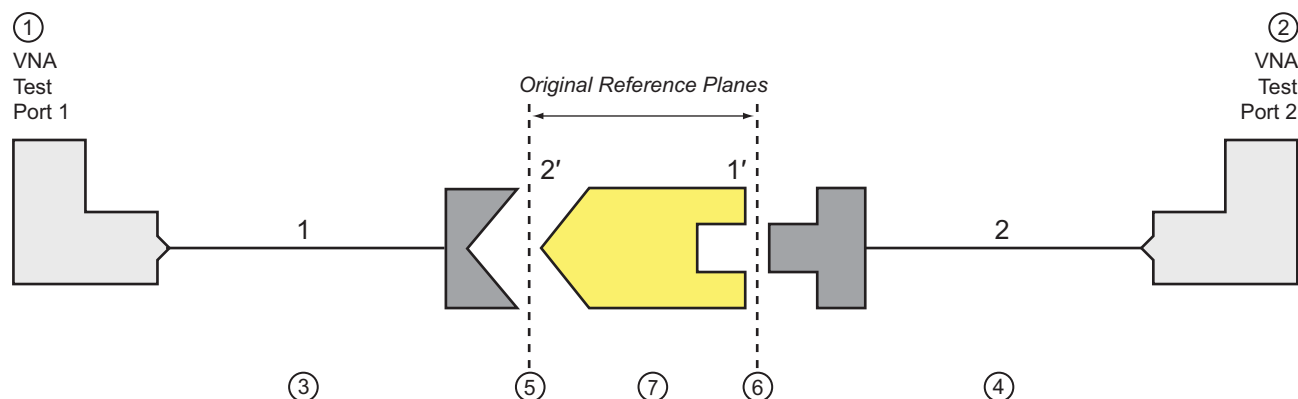


Figure 7-1. Adapter Removal Block Diagram

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

Figure 7-1. 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.

One can enter 0 for the length estimate to force the software to do length estimation internally. This calculation is based on the phase change between frequency points towards the lower end of the sweep range. A linear fit to the phase function is performed and the slope is used to estimate the electrical length as suggested by Figure 7-2. This procedure is quite accurate unless the frequency step size is large relative to the phase change in the measurement. Thus, if the setup uses very long cables, it may help to increase the number of frequency points or at least look at a raw S_{21} phase display (no calibration applied with something of modest insertion loss connected) and see how often the phase wraps.

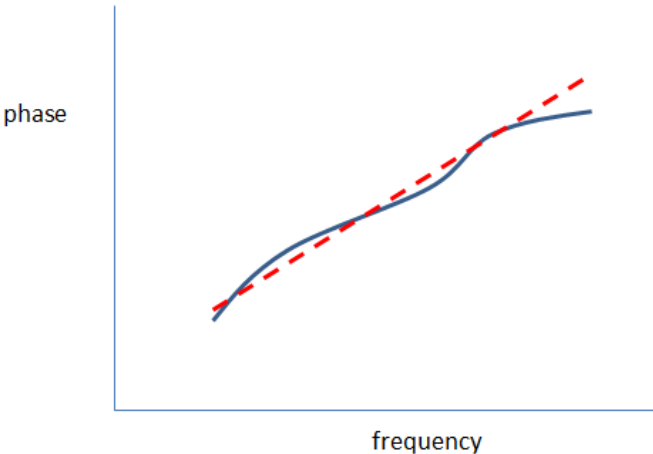


Figure 7-2. By entering 0 as the length estimate, the software calculates a length estimate for you. If the frequency step size is large relative to the electrical length of the setup, this may not be advisable.

In the upper half of [Figure 7-3](#), one can see how the first frequency step size would be adequate for this setup. The phase change between points is well below 180 degrees so linear fitting will not run into aliasing problems. In the second setup (next page), the phase change between points is nearly 360 degrees so one may start to run into aliasing issues with the 0-entry-length-estimation. For this case, the point count should be increased at least somewhat or a manual length entry can still be used in Adapter Removal.

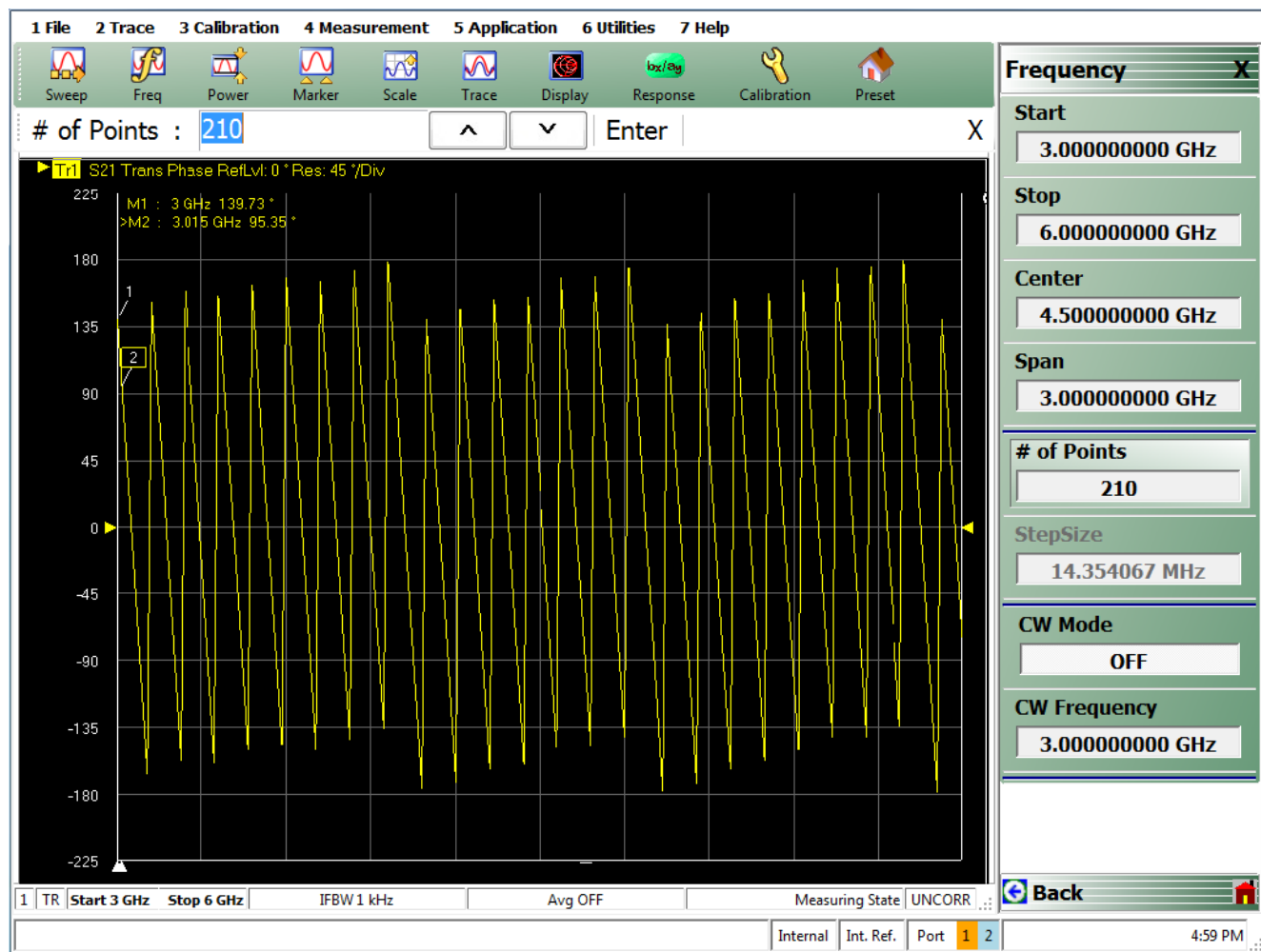


Figure 7-3. Uncalibrated phase plots from an example setup are shown here for two different step sizes. In the second case, the automatic length estimation may run into aliasing problems if much more length is added. (1 of 2)

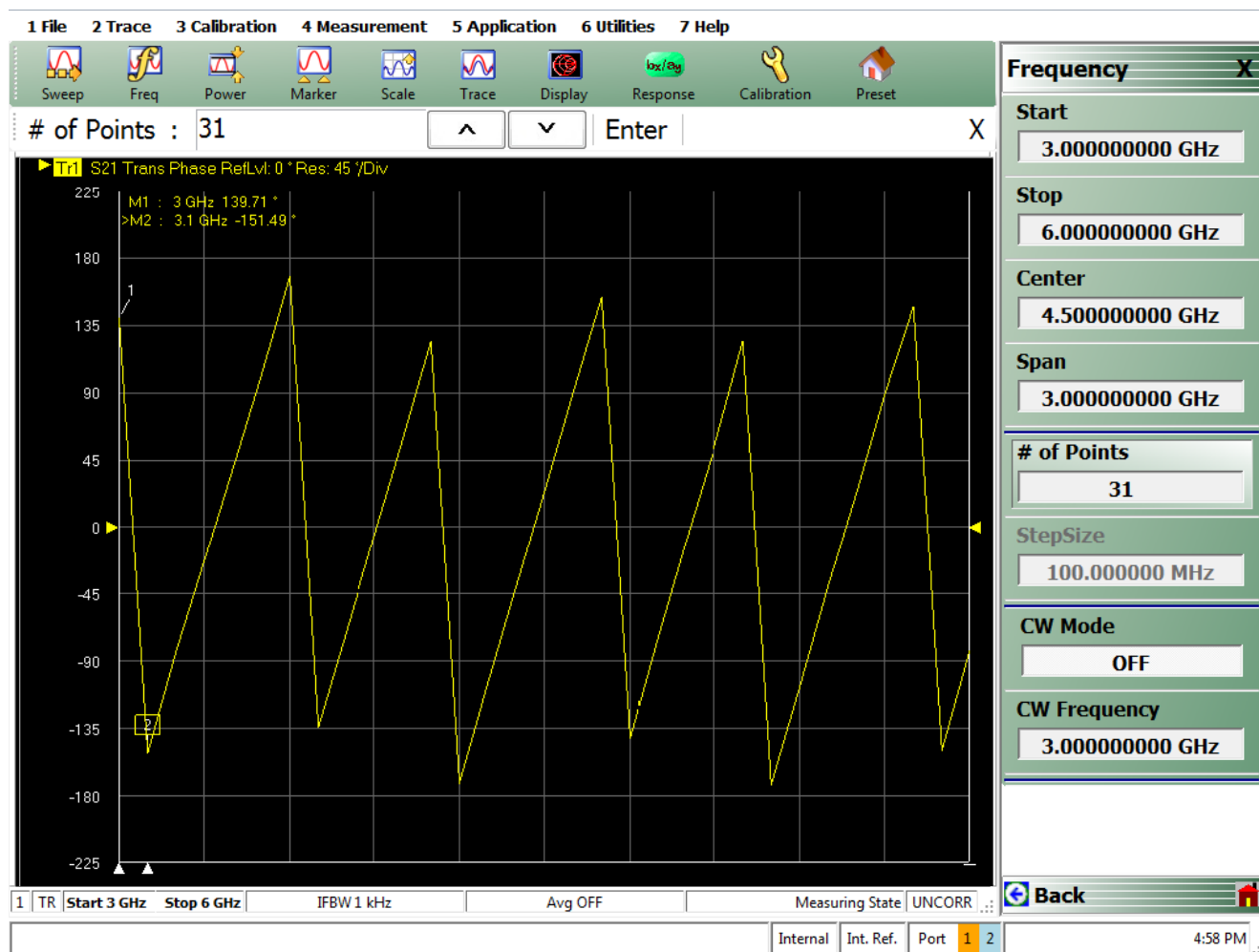


Figure 7-3. Uncalibrated phase plots from an example setup are shown here for two different step sizes. In the second case, the automatic length estimation may run into aliasing problems if much more length is added. (2 of 2)

7-3 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 7-4).

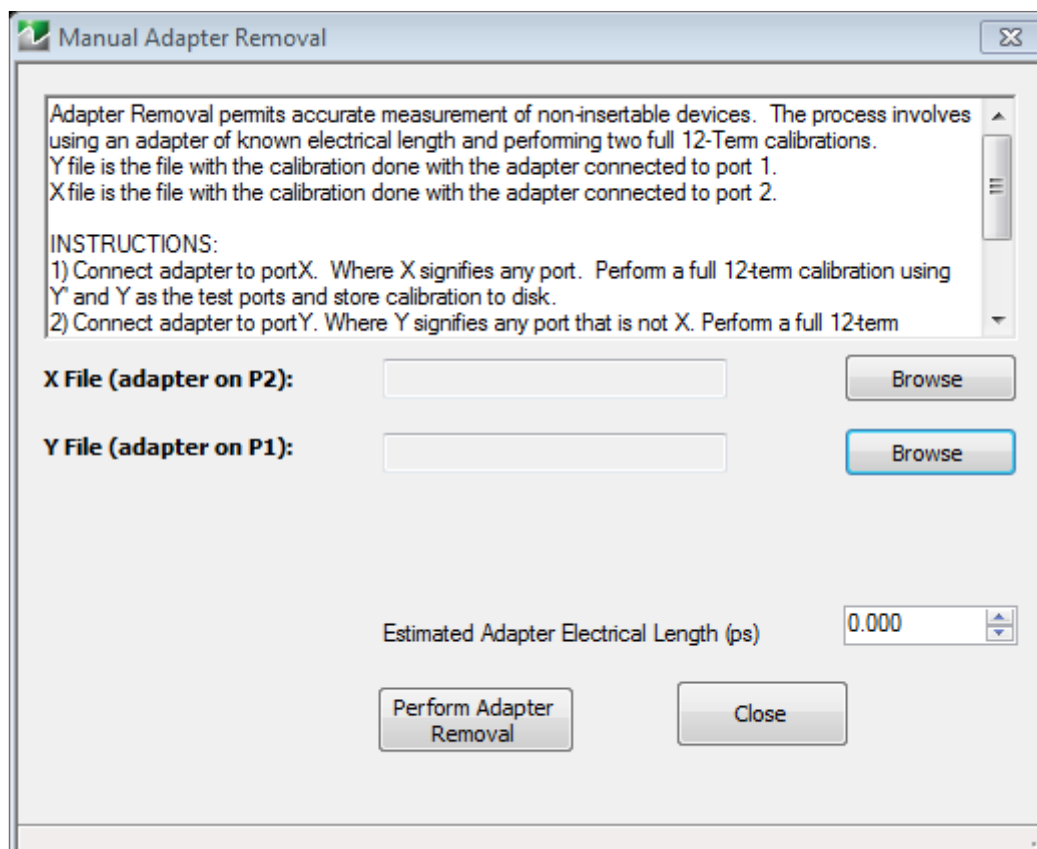


Figure 7-4. MANUAL ADAPTER REMOVAL Dialog Box - 2-Port VNAs

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:

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

Equation 7-1

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 7-5).

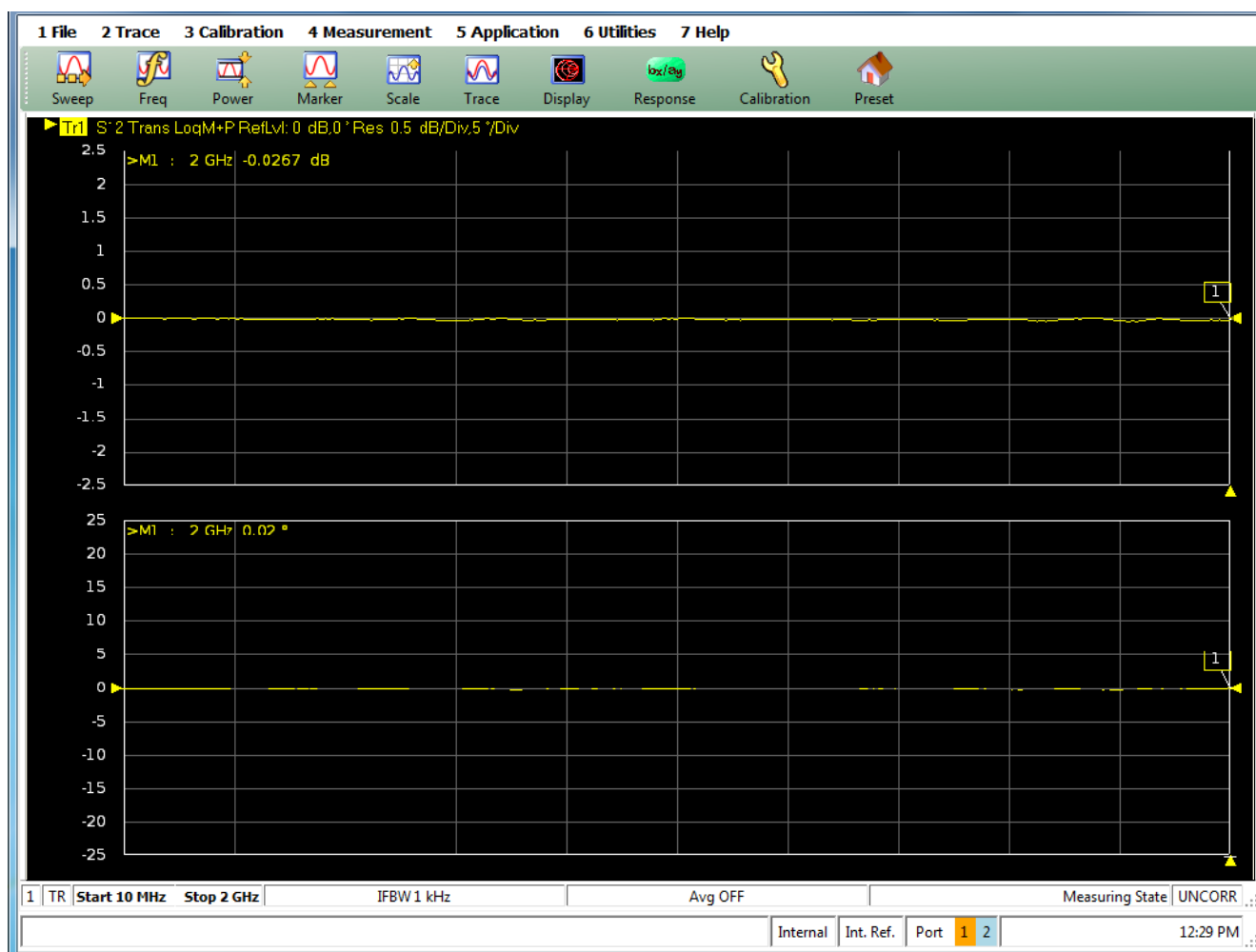


Figure 7-5. VNA Trace Display with Result of Adapter Removal

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.

Chapter 8 — Other Calibration Procedures

8-1 Overview of Other Calibration Procedures

This chapter provides other calibration procedures not covered in the previous material. Thru Update, Interpolation and Hybrid Cal are discussed.

8-2 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/fixtures 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 8-1](#)). The entry methods for these parameters are the same as in the normal calibration procedures.

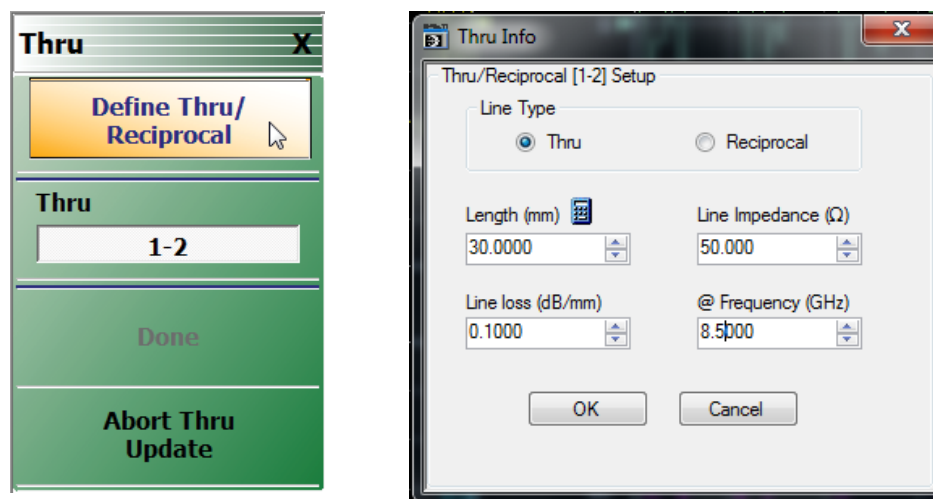
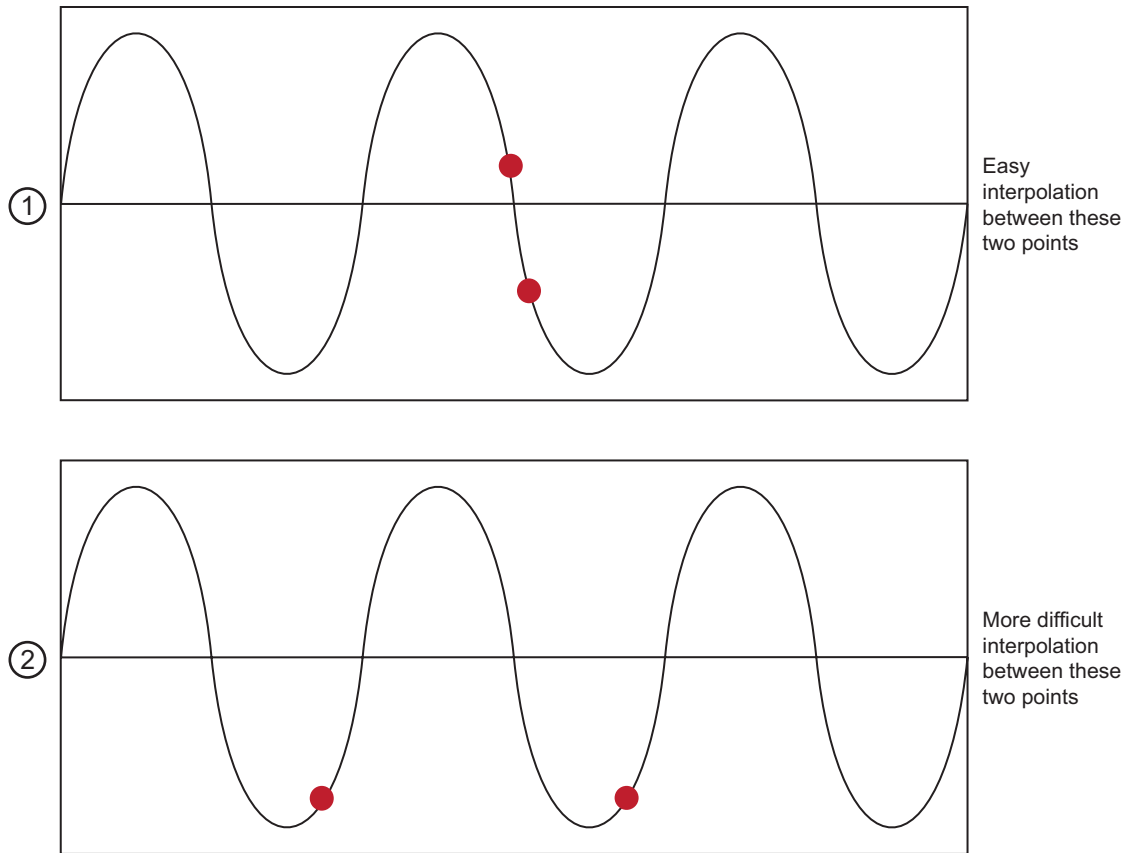


Figure 8-1. THRU UPDATE Setup Menu and THRU INFO Dialog

8-3 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 8-2](#)).



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

Figure 8-2. 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 menu to select interpolation is shown below in [Figure 8-3](#).

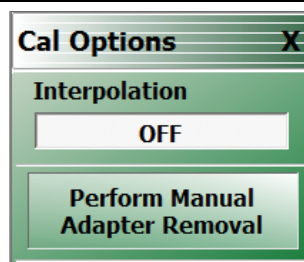


Figure 8-3. CAL OPTIONS Menu

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.

To gain a better understanding of the uncertainty implications of interpolation, it may be helpful to consider how the error terms of a typical calibration vary over frequency. A large scale and zoomed-in version of one parameter (source match) is shown in [Figure 8-4](#). Even with relatively low point densities, the large scale variation in the large-scale plot would be captured by interpolation. The fine scale variation shown in the zoomed-in plot is, however, another matter.

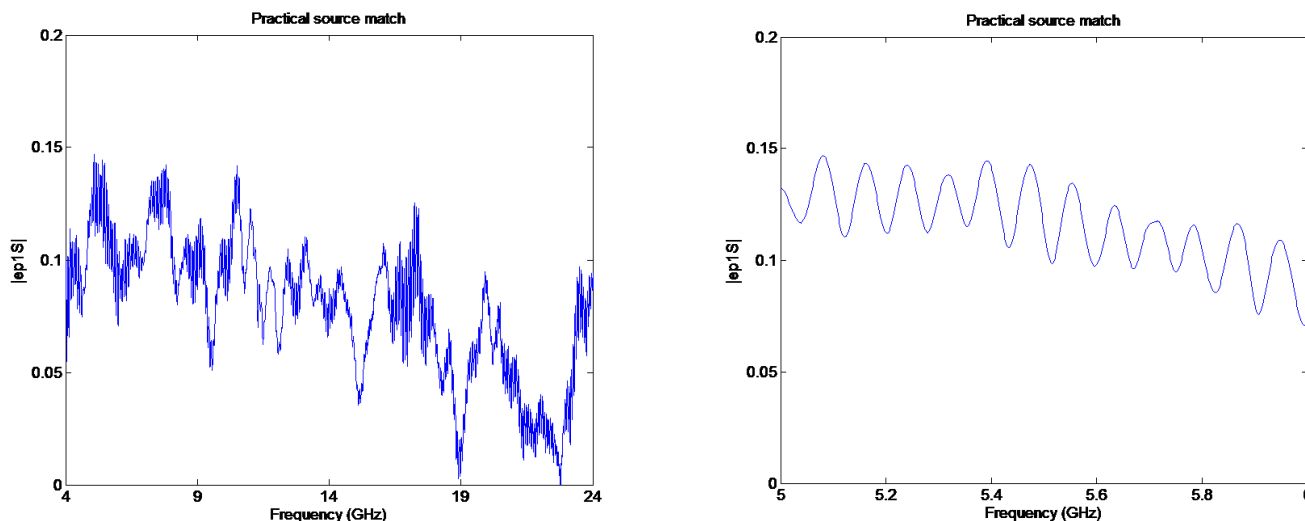


Figure 8-4. Large scale and zoomed-in source match variation over frequency.

Now, consider two different sets of hardware, both with a nominal tracking coefficient of unity (for simplicity). At lower frequencies, set 1 may be readily achieved, but at mm-wave frequencies, set 2 may be more practical. The important point is that the interpolation effects are setup-dependent.

- Set 1: Raw directivity ~ 0.02 (-34 dB) and raw source match ~ 0.1 (-20 dB)
- Set 2: Raw directivity ~ 0.10 (-20 dB) and raw source match ~ 0.3 (-10 dB)

If one calculated the uncertainties for no interpolation and for worst-case interpolation for both of these sets, one would get results like that shown in [Figure 8-5](#) (for a standard SOLT/SOLR coaxial calibration).

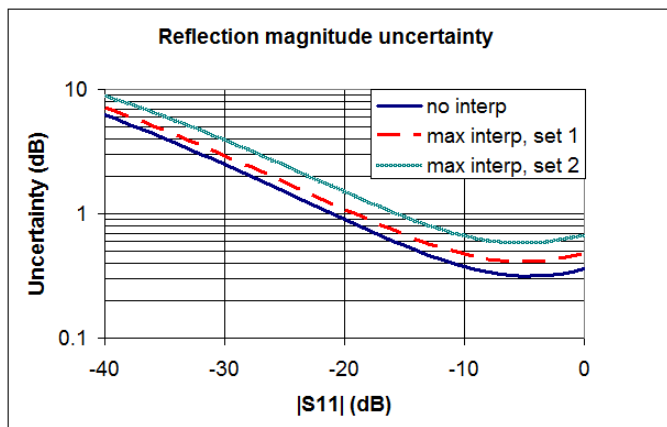


Figure 8-5. The uncertainty penalties possible with worst-case interpolation are shown here for some example setups.

As suggested above, one can get around this problem by increasing the frequency point density. In [Figure 8-6](#), the point count was increased so that there were 10 calibration points per period of the ripple (a proxy for the electrical length of the setup, much like that discussed in [Chapter 4](#)).

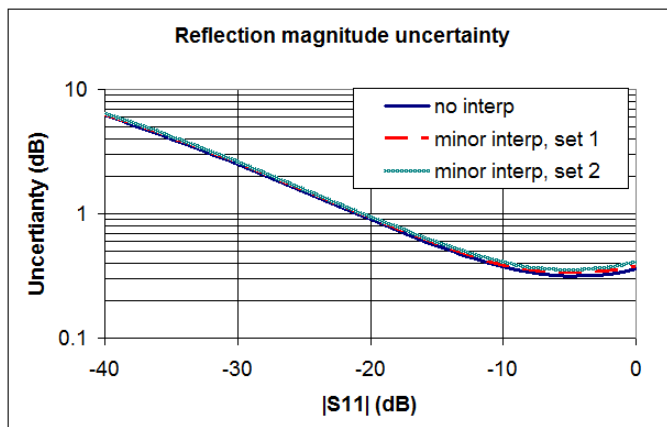


Figure 8-6. An increase in frequency point density can reduce interpolation effects in all setups as would be expected.

8-4 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.

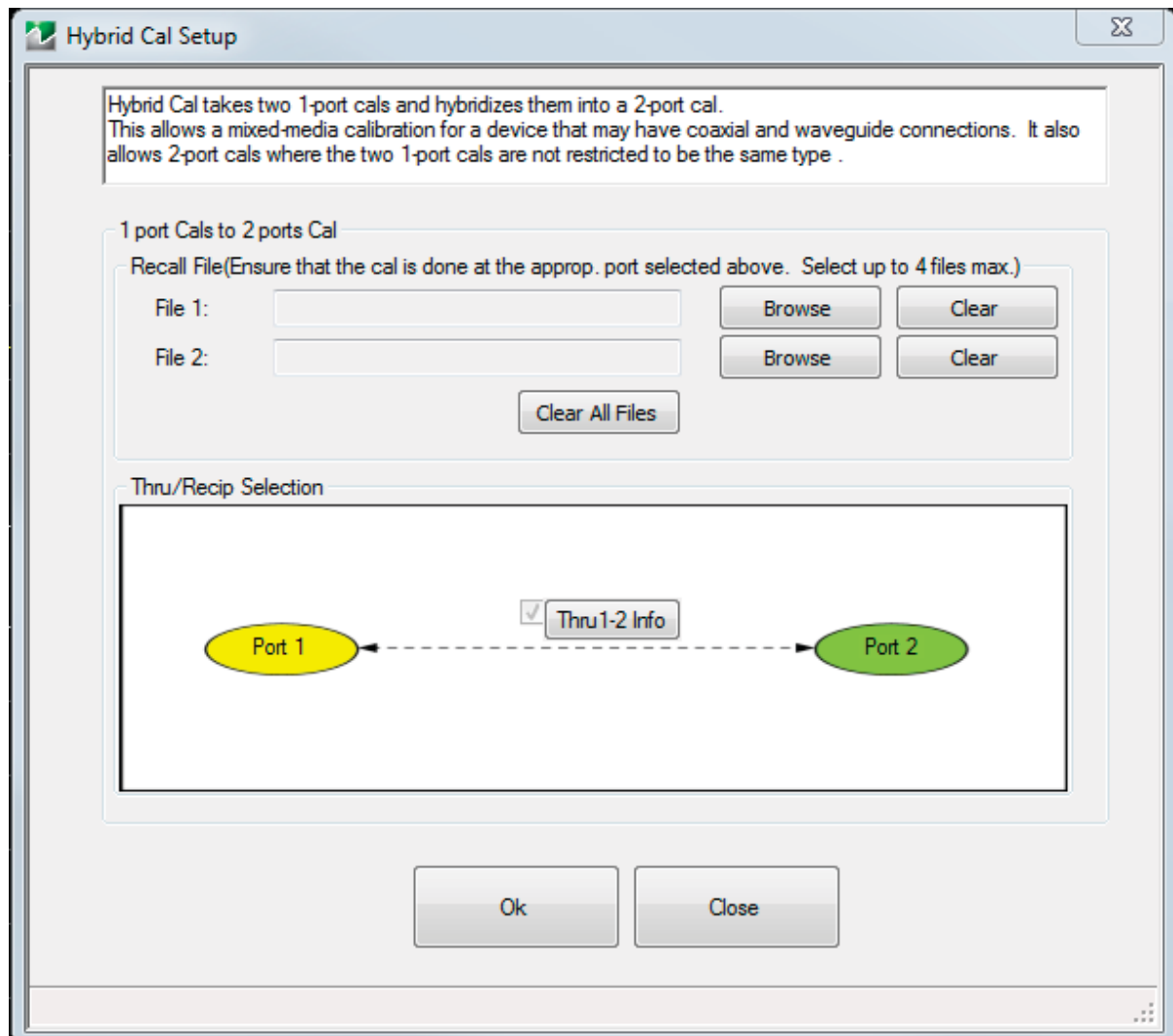


Figure 8-7. HYBRID CAL SETUP Dialog Box

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.

As an example of the mixed-media case where this type of hybrid calibration is helpful, consider a desired coaxial-waveguide combination reference plane. One could perform adapter removal processing as discussed in [Chapter 8](#), but there are occasions where in one of the media planes, one can only perform one port calibrations (due to physical arrangement of the hardware, calibration kit availability, or other reasons). For this example (in WR-42 waveguide), a one-port K calibration was done for one file and a one-port WR-42 waveguide calibration was done for the other file. These two files were combined using the hybrid calibration dialog and the resulting calibration was used to measure the hybrid device of [Figure 8-8](#). Note that this figure refers to a port 1-3 calibration associated with multipoint measurements, but the algorithm is exactly the same for two port systems.

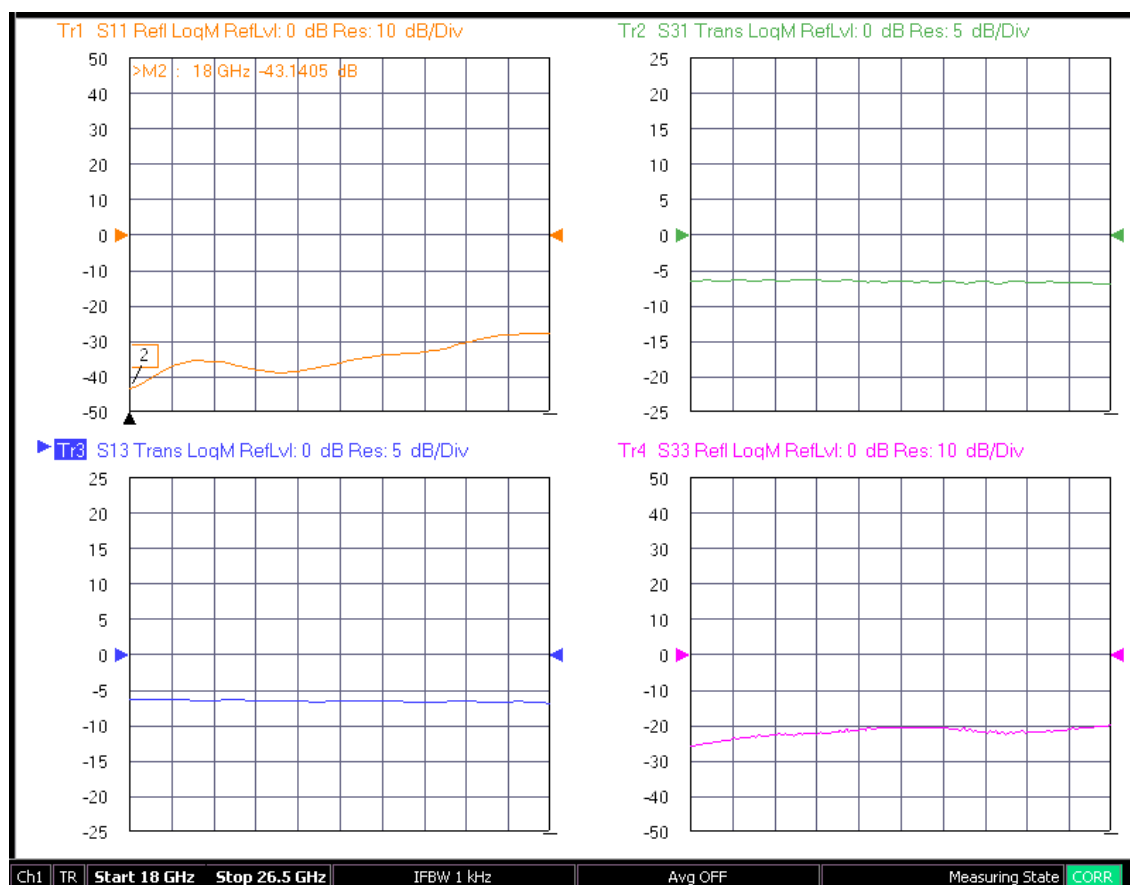


Figure 8-8. An example hybrid waveguide-coaxial measurement is shown here that was enabled by the hybrid calibration dialog.

Chapter 9 — Calibration and Measurement Enhancements

9-1 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.

These functions go 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.

- **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.

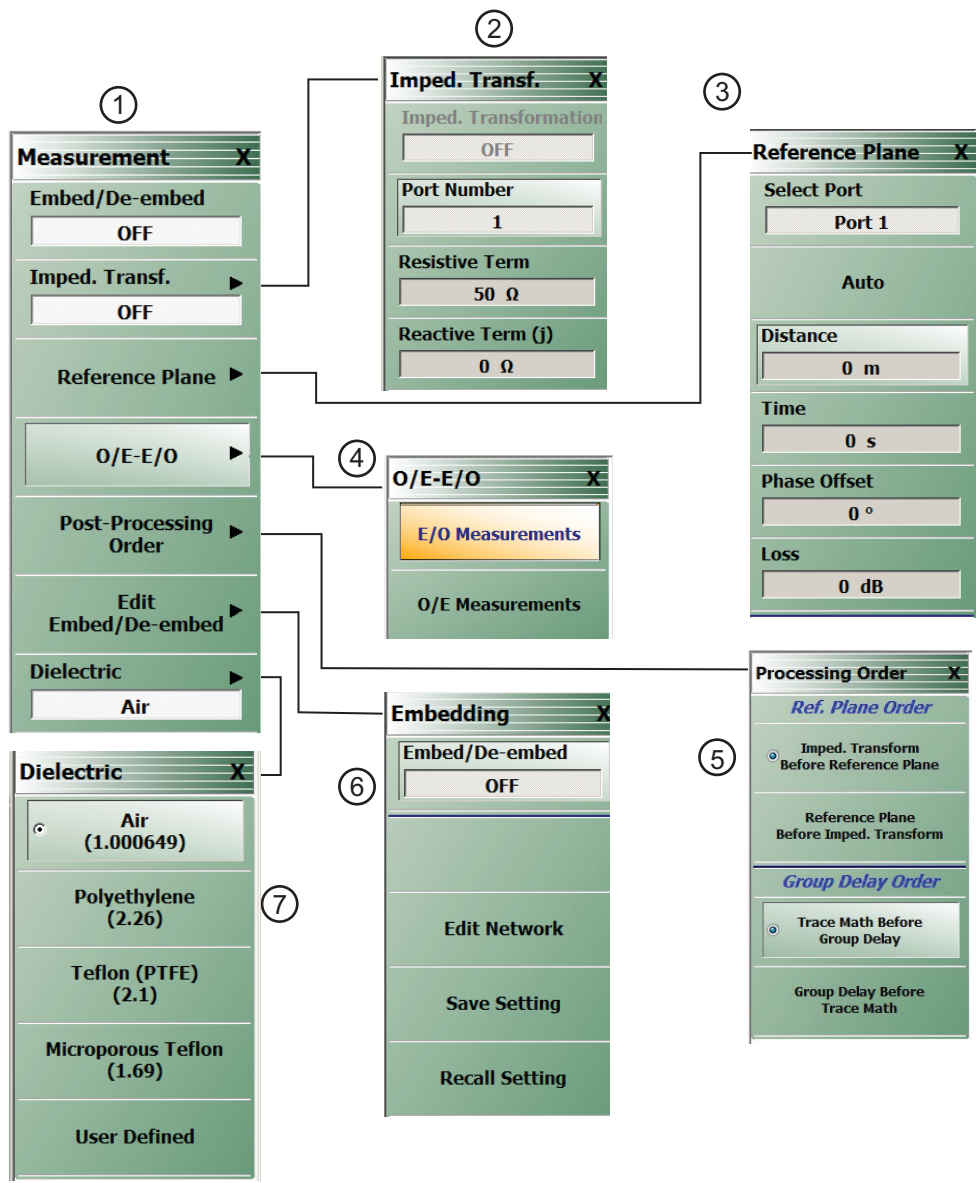
- **Reference Plane Control**

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 9-3, “Reference Plane Control” on page 9-12). Parameter conversions are a per-trace function (as opposed to the others which are per channel) and is listed under the DISPLAY menu.



1. MEASUREMENT Menu	5. PROCESSING ORDER Menu
2. IMPED. TRANSF.(Impedance Transformation) Menu	6. EMBEDDING Menu
3. REFERENCE PLANE Adjustment Menu	7. DIELECTRIC Selection Menu – If User Defined is selected, Value field is available for input.
4. O/E–E/O Menu	

Figure 9-1. MEASUREMENT Menu and Related Submenus

9-2 Embedding/De-embedding (E/DE)

The MS46122A/B and MS46322A/B is 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 MS46122A/B and MS46322A/B 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 ShockLine VNA.

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 9-1) or with a duplicate toggle button at the top of the EMBEDDING control menu as shown below (Figure 9-2).

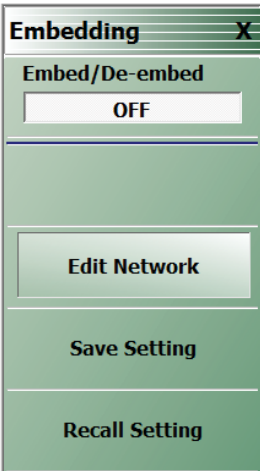


Figure 9-2. EMBEDDING Menu

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.

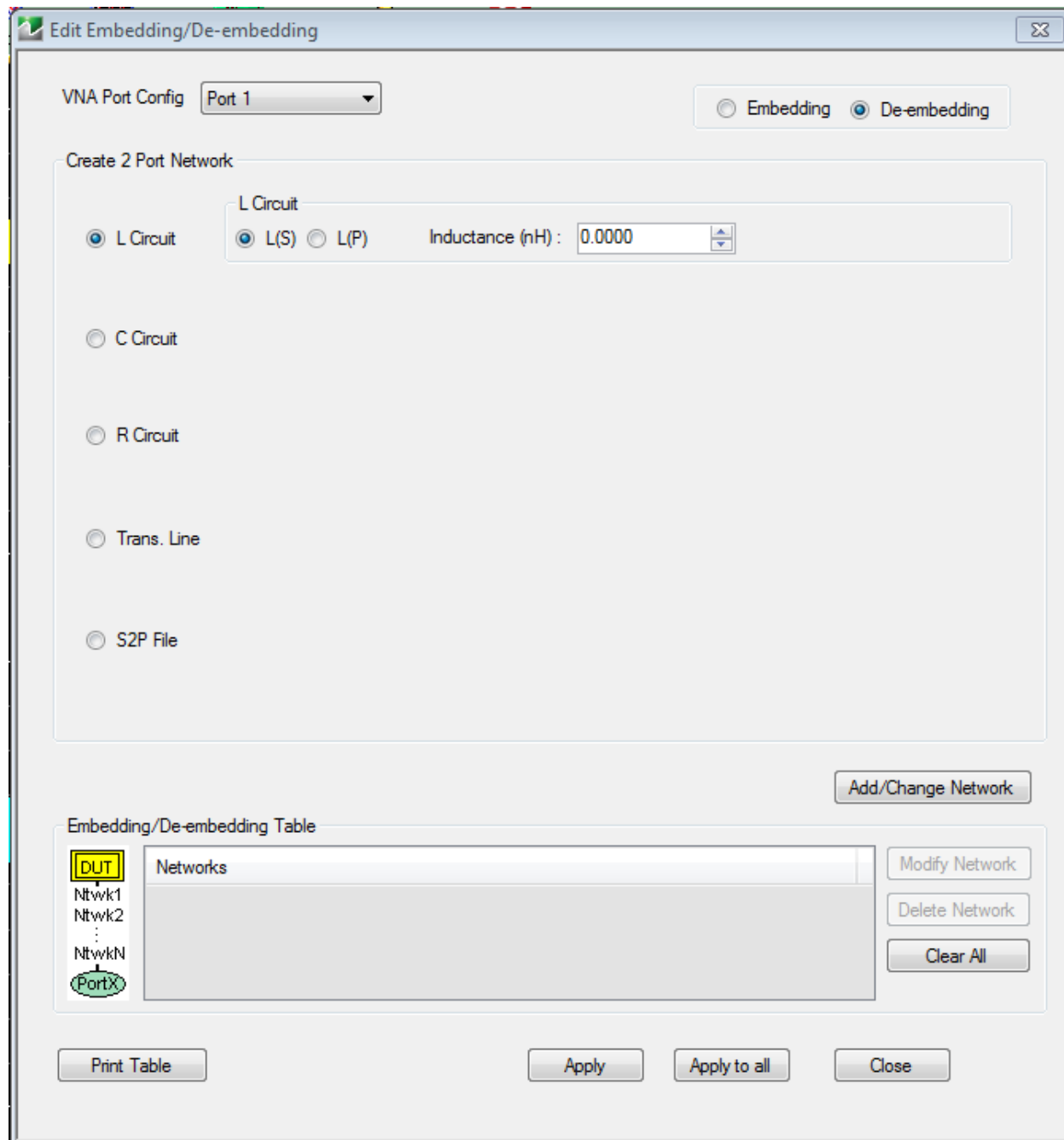


Figure 9-3. EDIT EMBEDDING/DE-EMBEDDING (2 PORT DUT) Dialog Box - L Circuit

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 9-3](#) shows which port’s networks are currently being edited. The diagram in [Figure 9-4](#) illustrates the independence concept.

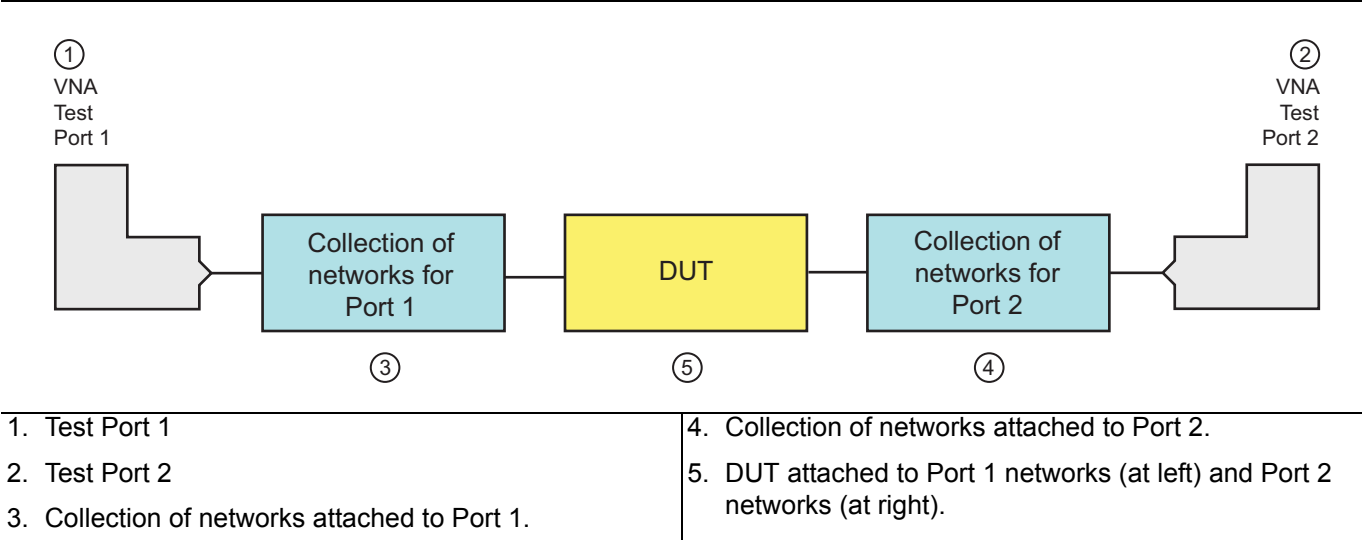


Figure 9-4. Global EDE Diagram Showing Independence of Port Networks

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 9-3](#) 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.

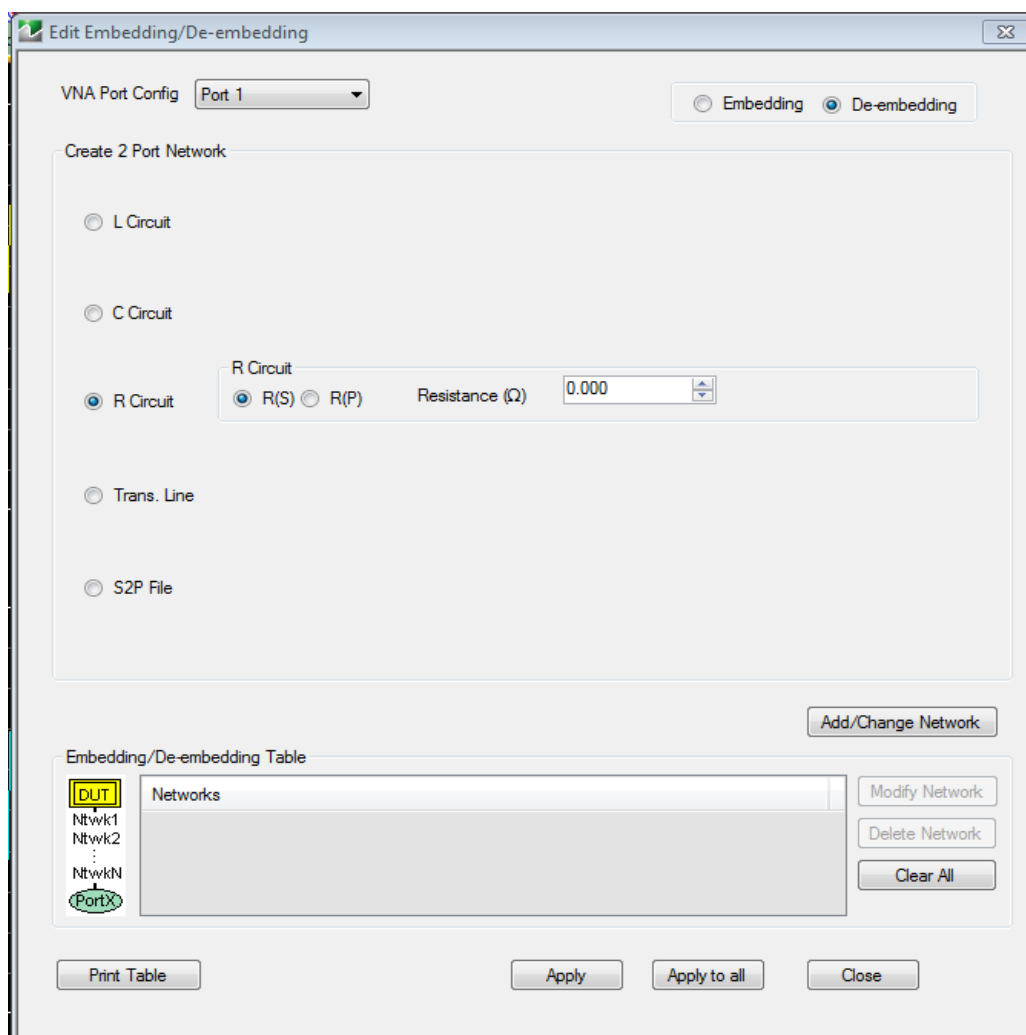


Figure 9-5. EDIT EMBEDDING/DE-EMBEDDING - C Circuit

Entry Mode for Resistive Elements

The entry mode for these resistive elements is shown in the E/DE dialog box below (Figure 9-6). 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.

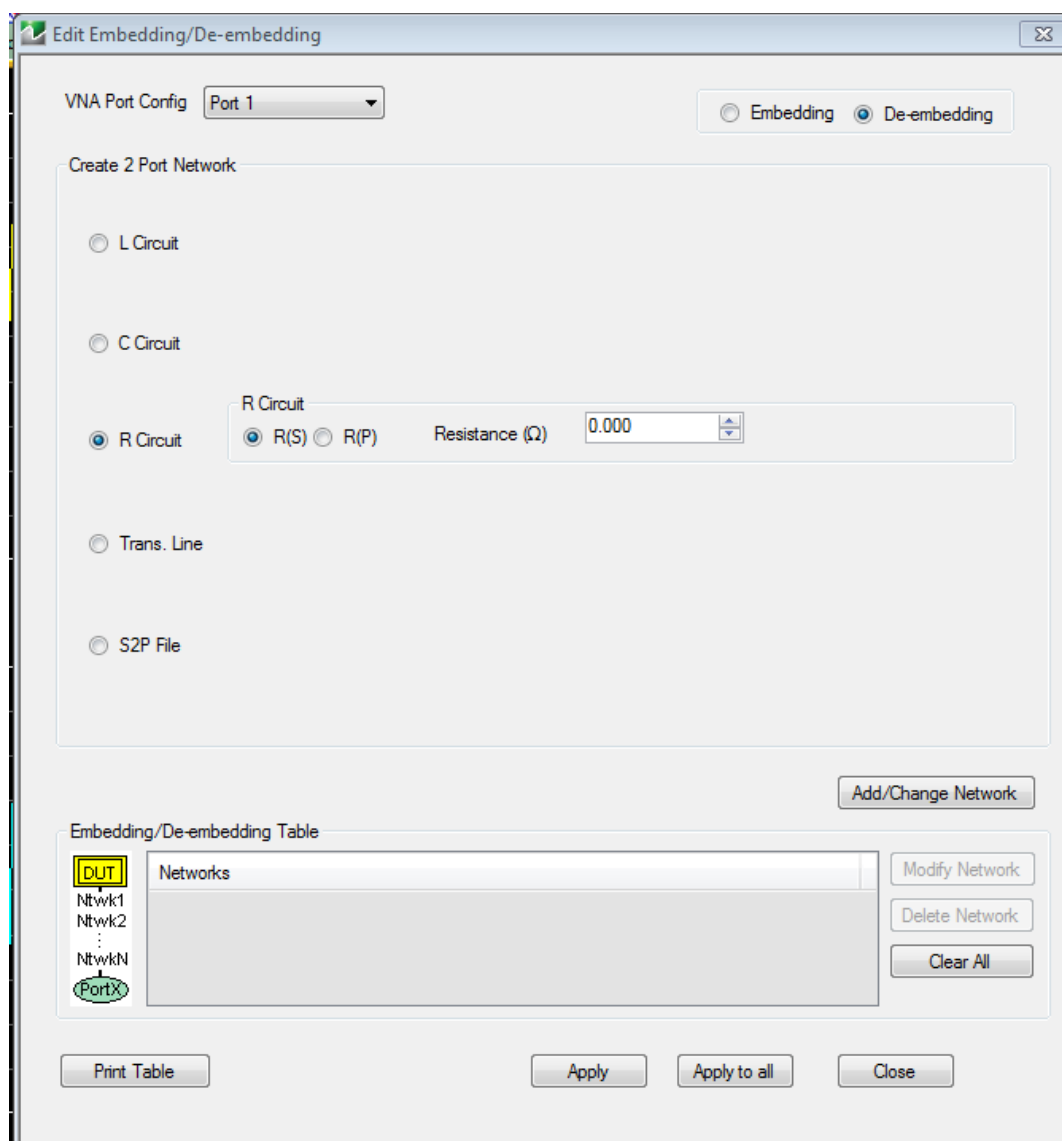


Figure 9-6. EDIT EMBEDDING/DE-EMBEDDING Dialog Box - R Circuit Setup Selected

Entry Mode for Transmission Lines

Transmission line entry is illustrated in the E/DE dialog box below (Figure 9-7). 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:

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

Equation 9-1.

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.

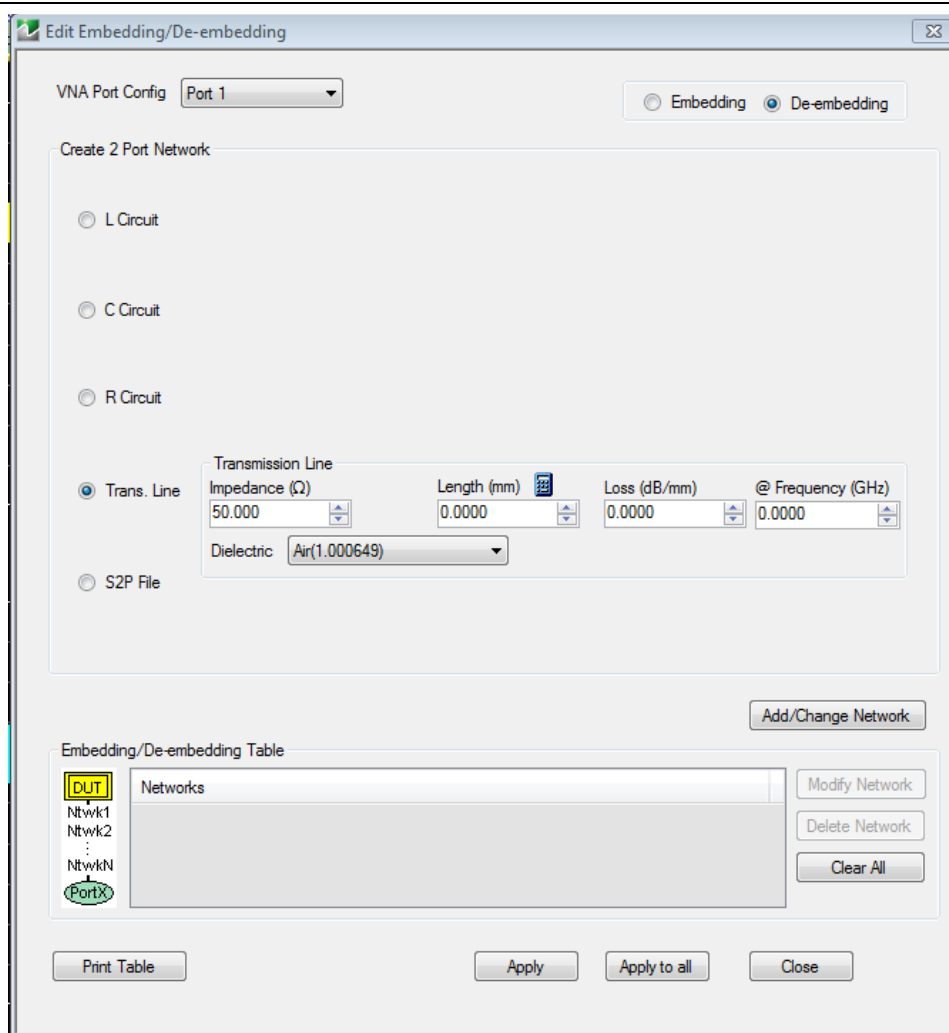


Figure 9-7. EDIT EMBEDDING/DE-EMBEDDING Dialog Box

Physical line length is normally entered here along with a dielectric constant but the calculator icon shown in above in Figure 9-7 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 9-8](#)). 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.

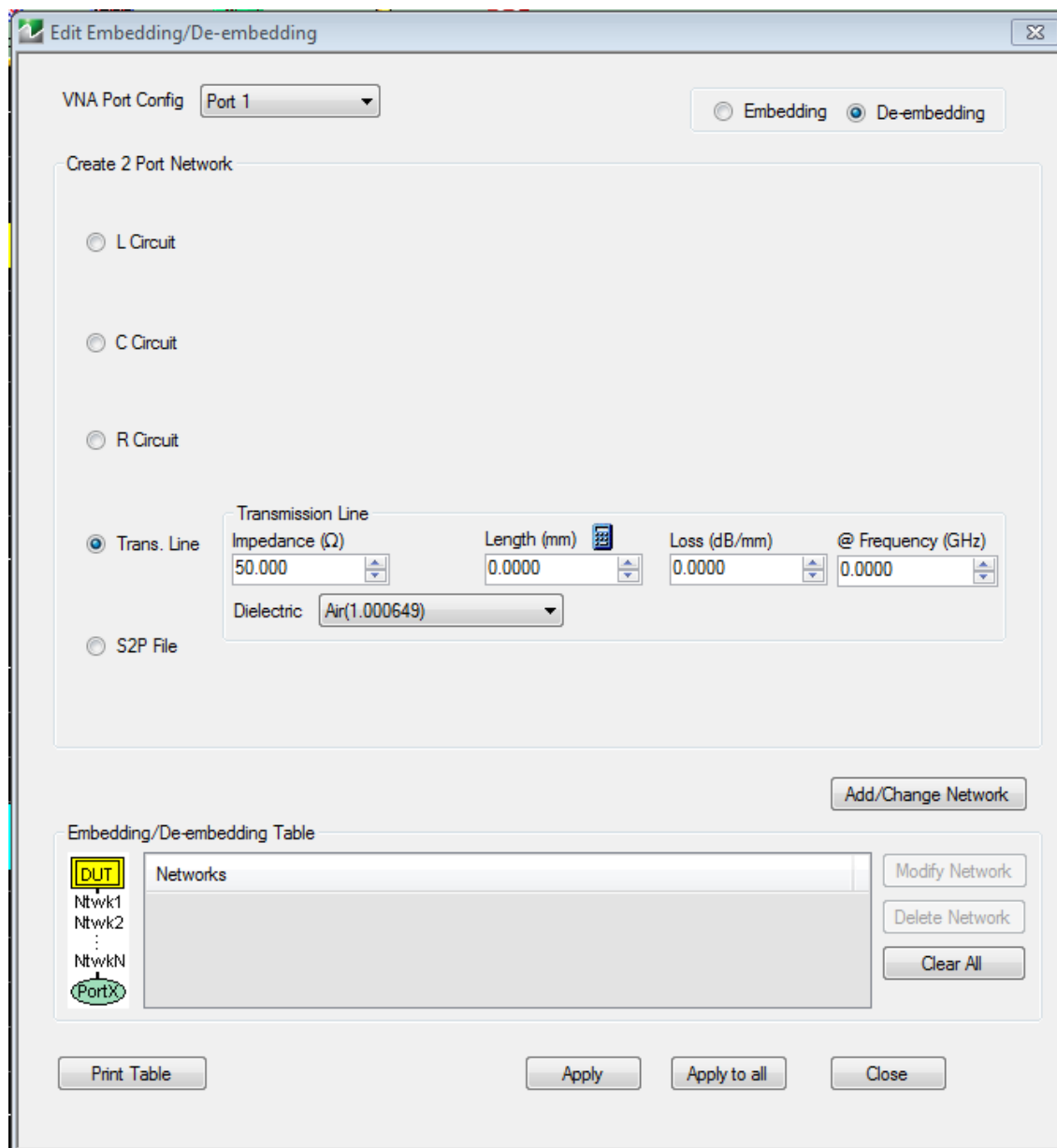


Figure 9-8. EDIT EMBEDDING/DE-EMBEDDING Dialog Box

Note

The network Port 2 is always assumed to be closer to the DUT regardless of which VNA port is involved. See [Figure 9-9](#). If “Swap port assignment” is checked, the relationship is reversed.

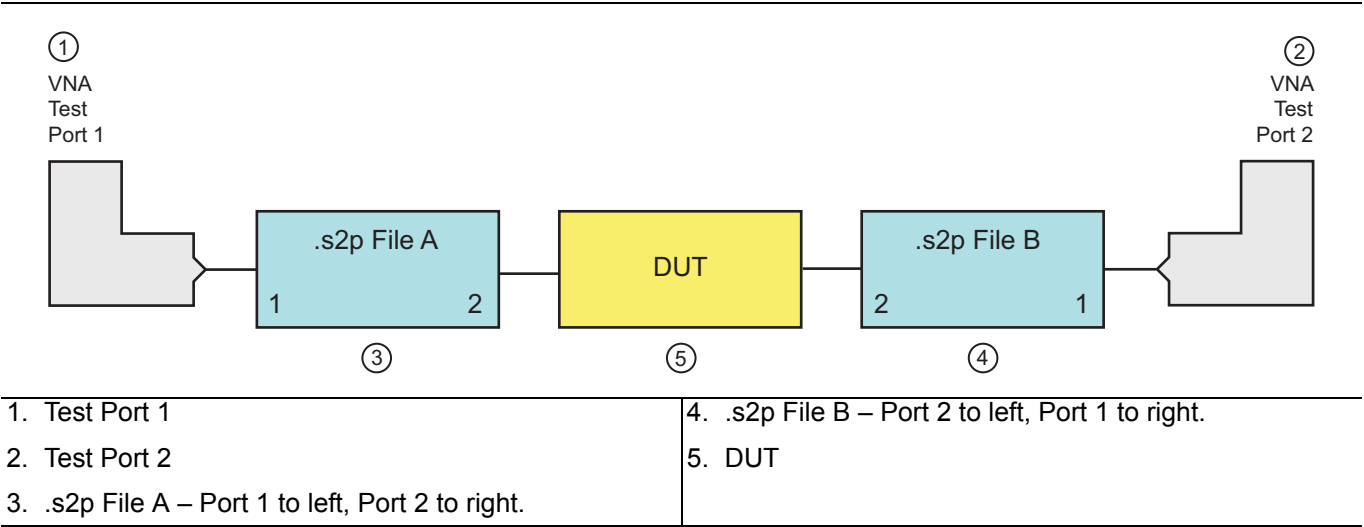


Figure 9-9. Orientation of Loaded S2P Files

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 9-2, “**EMBEDDING Menu**” on page 9-4). 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.

9-3 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 9-10). 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.

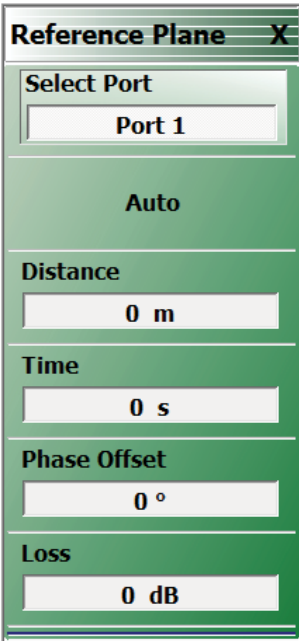
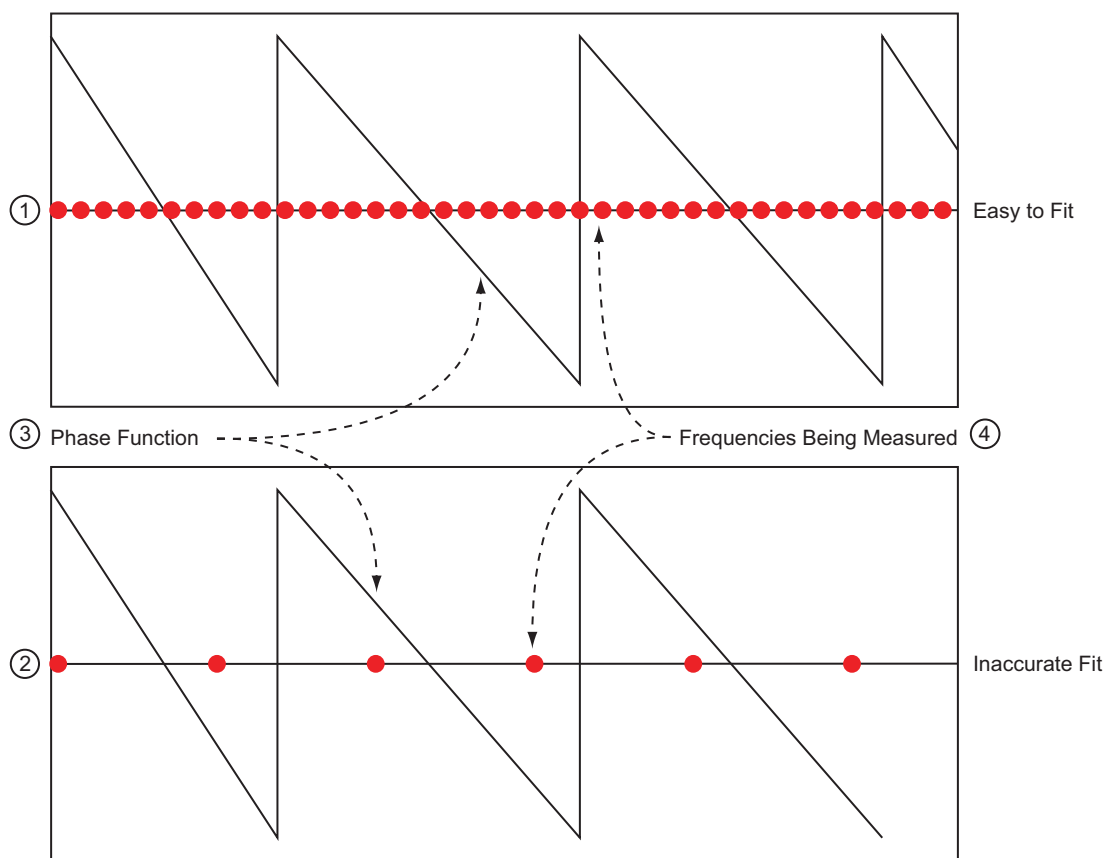


Figure 9-10. REFERENCE PLANE Control Menu

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 9-11 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. | 3. Phase Function |
| 2. Inaccurate Fit – Larger frequency step size compared to phase function is can produce inaccurate results. | 4. Frequencies being measured. |

Figure 9-11. 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.

9-4 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 9-12).

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 with a minimum of 2 ports must be active for impedance transformation to take effect and only those ports currently calibrated will be affected.

Imped. Transf. X

Imped. Transformation

OFF

Port Number

1

Resistive Term

50 Ω

Reactive Term (j)

0 Ω

Figure 9-12. IMPED. TRANSF. (IMPEDANCE TRANSFORMATION) Menu

9-5 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:

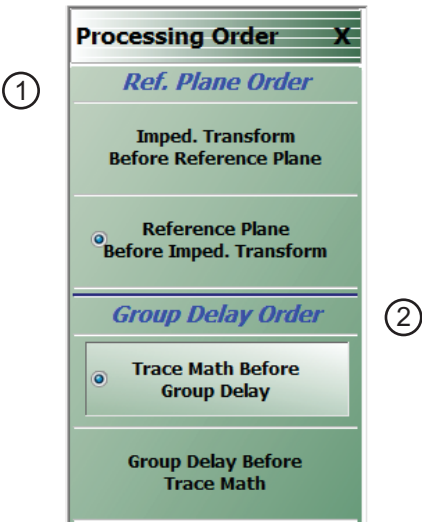
- Acquire raw data and average/filter
- Apply calibration if enabled
- Apply EDE if enabled (impedance transform and reference plane)
- Apply parameter conversions if enabled
- Apply time domain if enabled

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 9-13).

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 9-13. PROCESSING ORDER Menu

9-6 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 ShockLine VNA.

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:

$$Z_{reflection} = Z_0 \frac{1 + X}{1 - X}$$

$$Z_{transmission} = Z_0 \frac{2(1 - X)}{X}$$

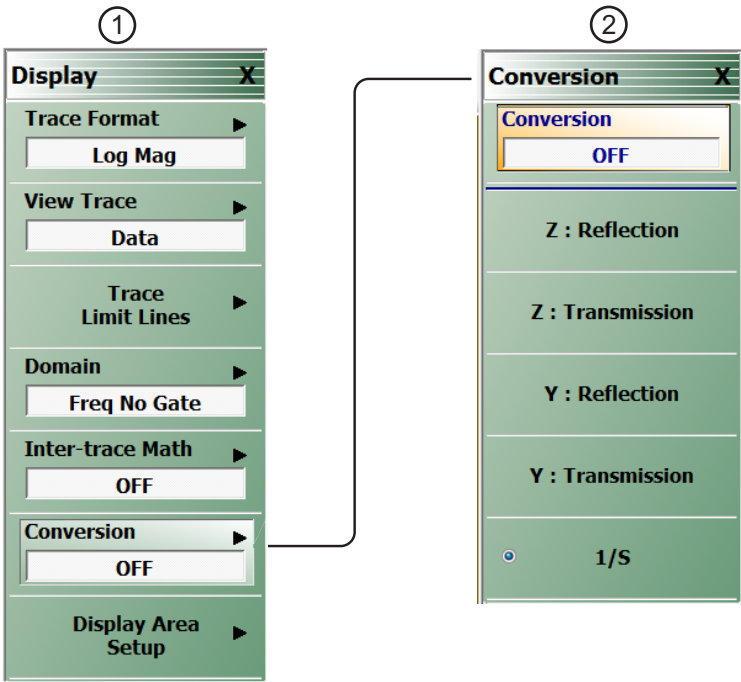
$$Y_{reflection} = \frac{1}{Z_0} \frac{1 - X}{1 + X}$$

$$Y_{transmission} = \frac{1}{Z_0} \frac{X}{2(1 - X)}$$

Equation 9-2.

Note that reflection Z or Y values here represent 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 9-14. Conversion Control Menu

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 9-12](#)) or the trace reference impedance has been changed.

Chapter 10 — Verification

10-1 Introduction to Verification

While there are many ways of verifying instrument performance, including the procedures described in the **ShockLine™ MS46122A/B or MS46322A/B Series VNA Operation 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:

- MS46122A/B Series VNA Operation Manual – 10410-00340
- MS46322A/B Series VNA Operation Manual – 10410-00335
- 3653A Mechanical Calibration Kit Reference Manual – 10410-00278
- Performance Verification Software (PVS) User Guide – 10410-00739
- PVS Quick Start Guide – 10410-00740
- 3663-2 Verification Kit (for Type N Connectors)
- 3668-2 Verification Kit (for Type K Connectors)

See [“Calibration Kits, Verification Kits, and Test Port Cables” on page 1-3](#).

10-2 Basic Concepts

There are many levels to the concept of VNA verification which 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 Calibration) 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:

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

Equation 10-1

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 10-1](#).

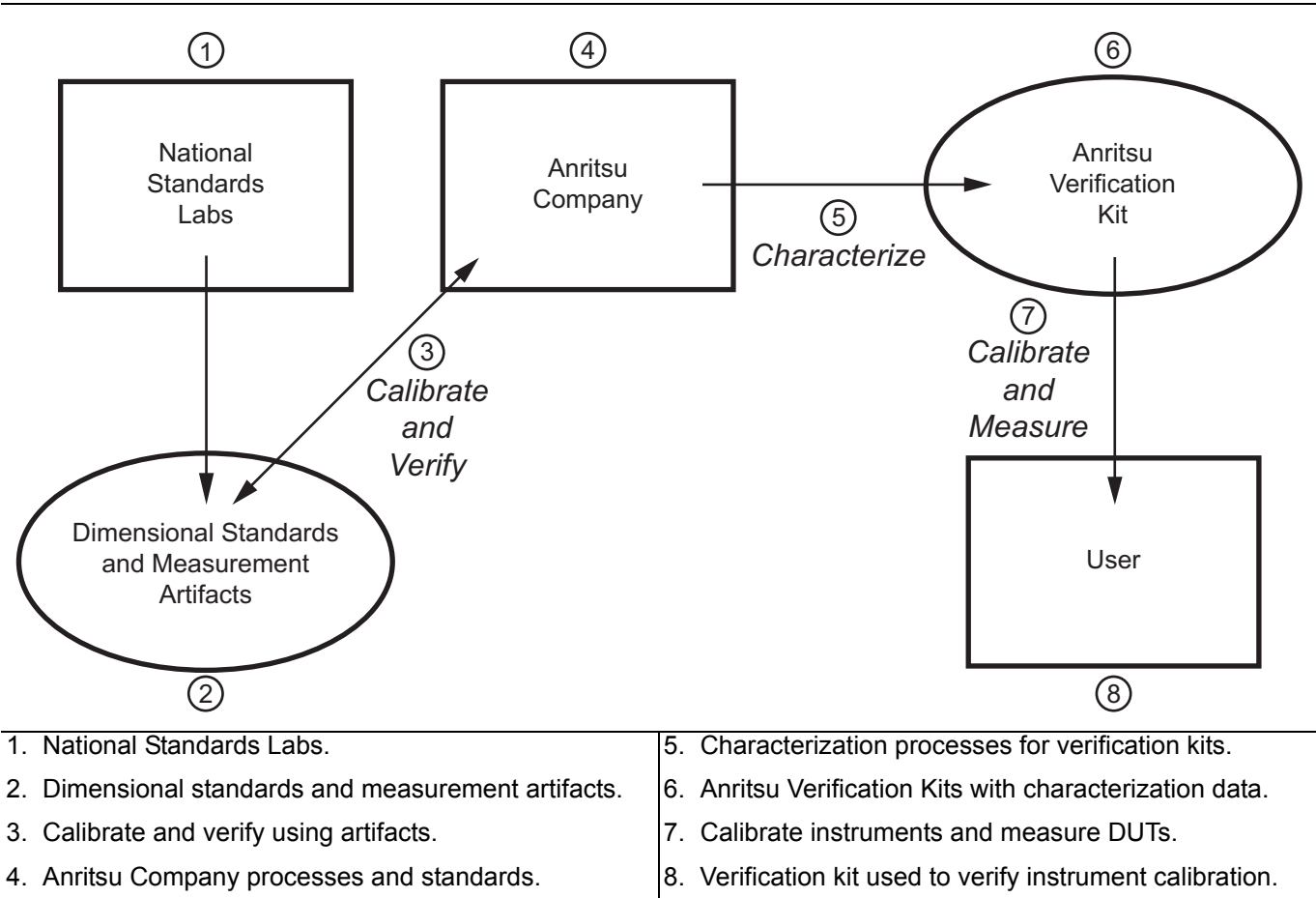


Figure 10-1. General Process of the Creation and Use of a Verification Kit

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).

10-3 Verification Kit Components

The verification kits for the ShockLine Series VNAs are:

- 3663-2 Verification Kit (for Type N Connectors)
- 3668-2 Verification Kit (for Type K Connectors)

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

- Performance Verification Software (PVS) User Guide – 10410-00739
- PVS Quick Start Guide – 10410-00740

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.
- A stepped impedance (Beatty) airline to represent a variable match device with a range of insertion losses.
- A 20 dB attenuator to represent a moderate loss, well-matched device.
- A higher value 50 dB attenuator to represent a very lossy device.

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 10-2, “Regions of Parameter Coverage of Verification Kit Component” on page 10-5](#). 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 10-2](#) illustrates the regions of parameter coverage of the various verification kit components. The regions are not drawn to scale.

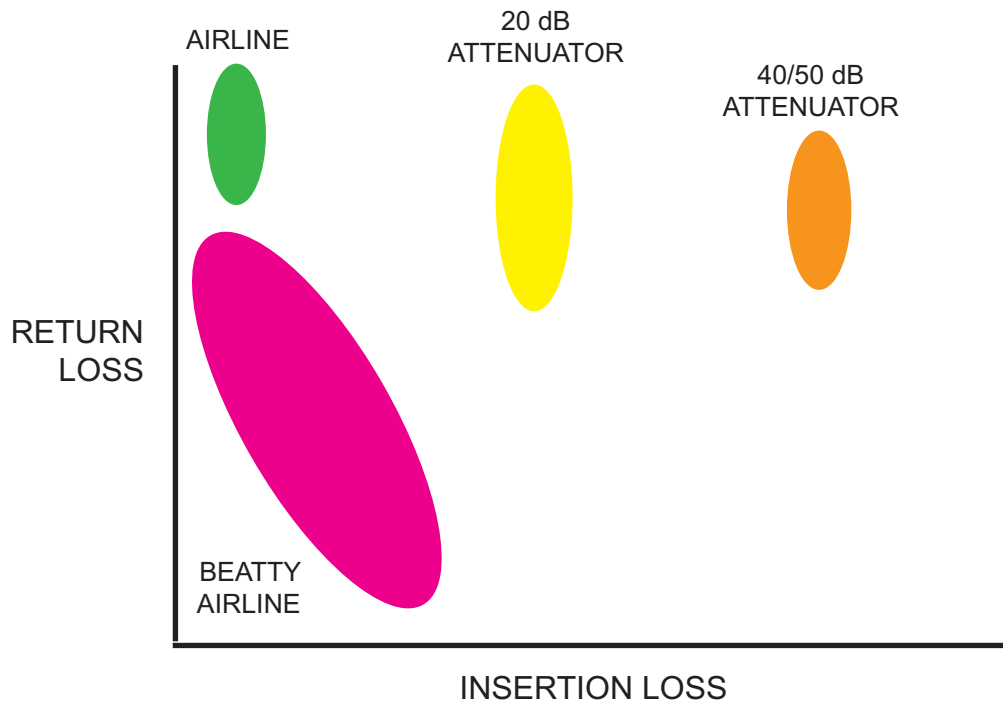


Figure 10-2. Regions of Parameter Coverage of Verification Kit Component

For the MS46122A/B-322A/B s, the verification comparison is valid for calibrations performed with the calibration kits listed under the verification kit:

- 3663-2 Type N Connector Verification Kit
3653A Type N Manual Calibration Kit
- 3668-2 Verification Kit (for Type K Connectors)
TOSLKF50A-40 Type K Manual Calibration Kit
- Performance Verification Software (PVS) User Guide – 10410-00739
- PVS Quick Start Guide – 10410-00740

Other combinations of calibration kits with verification kits are not supported. Verification kits based on other connector types such as GPC-7 exist for other Anritsu VNAs but the MS46122A/B-322A/B verification software does not support all of these.

10-4 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:

- Performance Verification Software (PVS) User Guide – 10410-00739
- PVS Quick Start Guide – 10410-00740
- 3663-2 Verification Kit (for Type N Connectors)
- 3668-2 Verification Kit (for Type K Connectors)

Chapter 11 — Measurement Setup Requirements

11-1 Chapter Overview

This chapter provides general measurement setup fundamental concepts, requirements, and options for different types of measurements. Specifically, this chapter describes traces, limit lines, external analog input/output, averaging and smoothing, and organizes their configuration in the same hierarchy. Traces are concepts that represent a data group with a maximum of 16 traces for MS46122A/B and MS46322A/B. 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.

11-2 Channels and Traces Introduction

Two of the central concepts in the MS46122A/B and MS46322A/B VNA 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

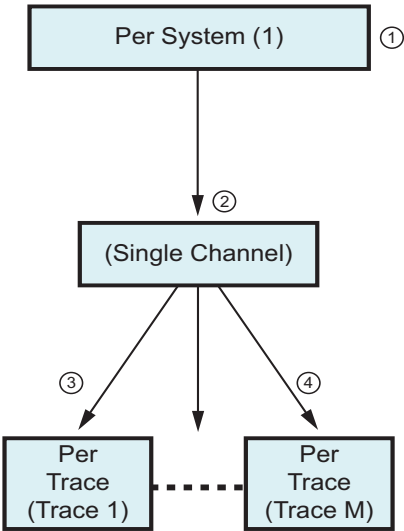
The trace is a concept that represents a data group. Twelve (12) traces are available on the MS46122A/B and MS46322A/B family. Each trace can represent a different response parameter, can be on a different graph type, and have certain different levels of post-processing applied to it.

The objective of this section is to explore how the traces can be setup, what possibilities are available, and what configurations are commonly used.

11-3 Measurement General Concepts

The hierarchy of setups is illustrated in Figure 11-1. 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:

- Certain portions of the hold system and certain triggering functionality
- Cal kit files
- SnP and text file header/format setups
- Blank frequency display (security feature)
- Interface setup items (network config, touchscreen setup)



Setup Hierarchy – System then Traces	
1. Per System Settings – These settings affect the entire instrument.	3. Per Trace Settings – Each trace can be configured as a separate measurement, with separate markers, and a different display method. 4. Each trace can have up to 12 total measurement markers and one (1) reference marker.
2. Single Channel – The default setting. Up to 16 channels can be active.	

Figure 11-1. Setup Information Hierarchy

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 more easily controlled externally. Others fall more in the category of utilities that are somewhat per-system in nature. M (the trace count) may always be up to 12 on MS46122A/B and MS46322A/B.

Per-system variables apply to all measurements on a given physical instrument. These variables include:

- Portions of the hold system and triggering functionality
- AutoCal characterization files and Cal kit files
- SnP and text file header/format setups
- Blank frequency display security feature
- Interface setup items such as network configuration

11-4 Channels and the Channel Menu

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 MS46122A/B-322A/B Series family, the variables include a frequency list, calibrations and sweep control

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 11-2](#).

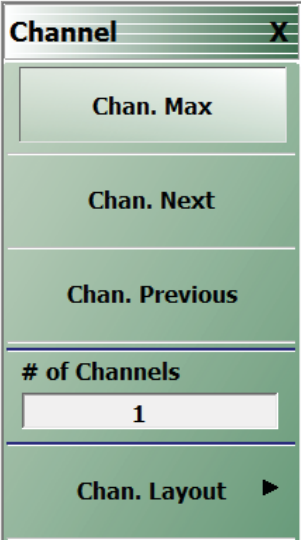


Figure 11-2. CHANNEL Menu

Once a given number of channels is selected, the layout of those channels is selected in a submenu shown in [Figure 11-3](#). 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 11-3](#)).

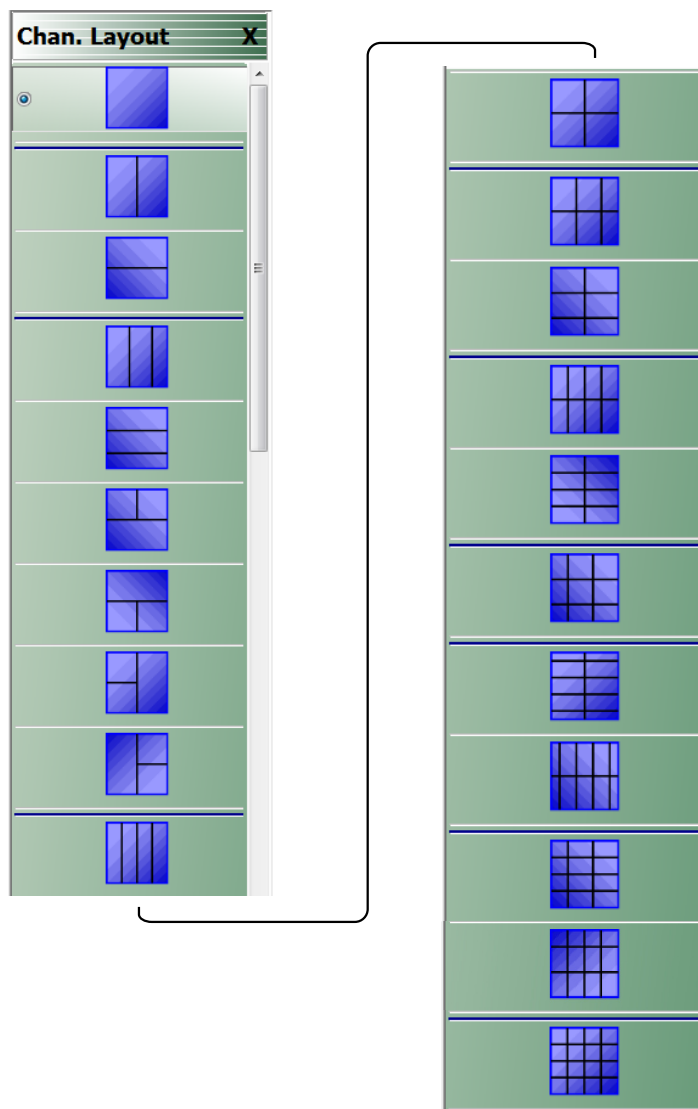


Figure 11-3. CHAN. LAYOUT (CHANNEL LAYOUT) Menu

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 11-3](#) 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
- Embedding/de-embedding and reference plane extensions
- 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)

11-5 Traces

Up to 16 traces can be specified for display using the # of Traces button of the TRACE menu (Figure 11-4), with sequential trace activation provided by the Trace Next and Trace Previous buttons. Traces can be directly activated by clicking on the graph title, as shown in Figure 11-5. The active trace is indicated by the trace number highlighted with a solid background.

The Trace Max button toggles display of the active trace to and from the full graph area, as does double-clicking on the graph title.

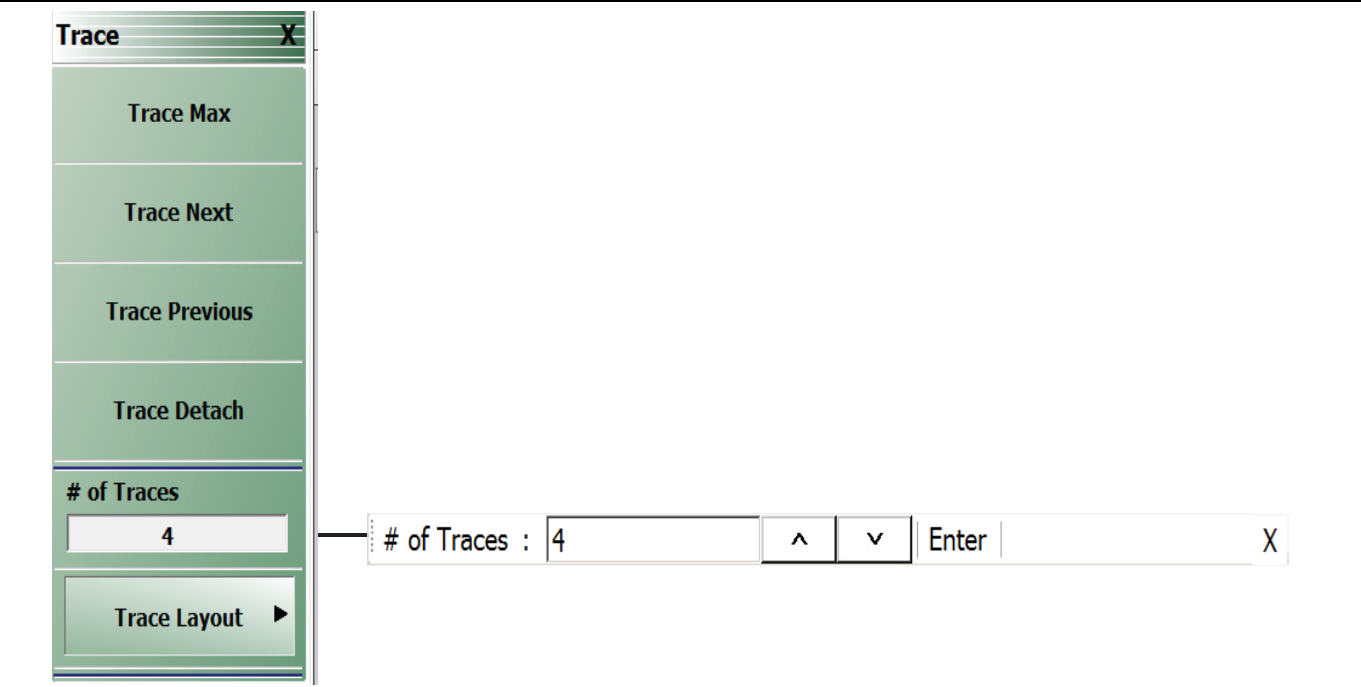


Figure 11-4. TRACE Menu and # of Traces Toolbar

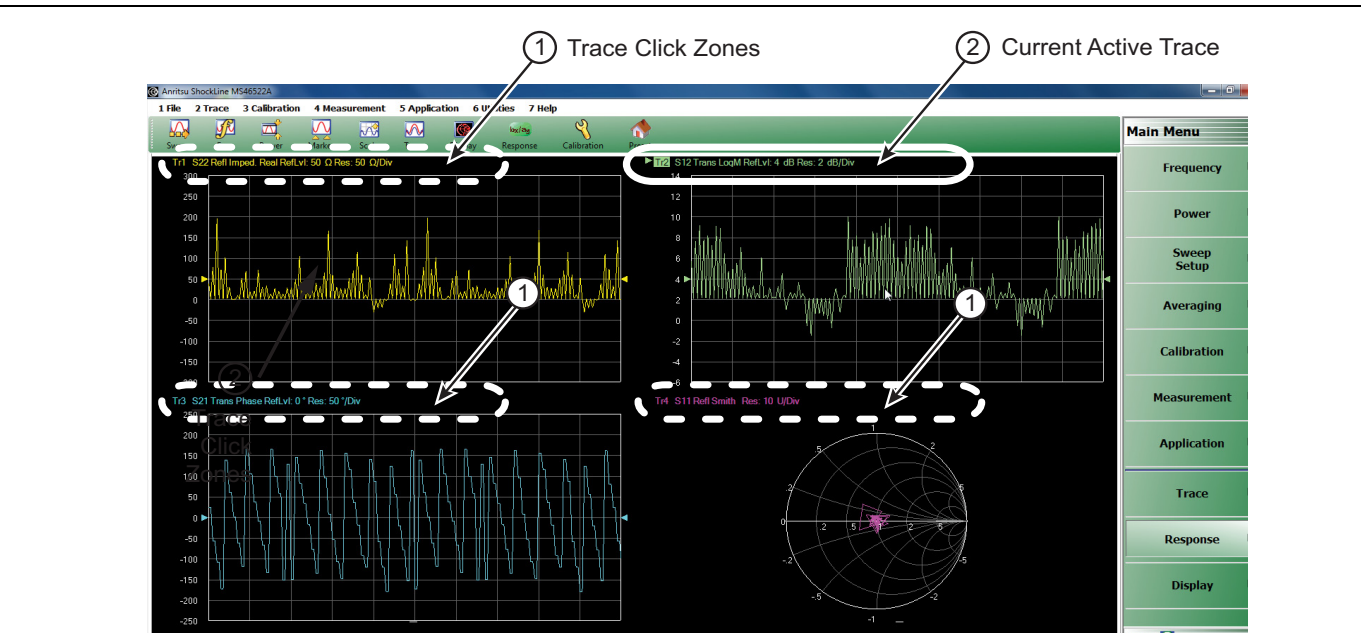


Figure 11-5. Trace Activate Click Zones

The TRACE LAYOUT menu (Figure 11-6) provides 12 trace layout options that support up to 16 traces in any configuration. If the number of traces specified in the # of Traces toolbar exceeds the number of graphs in the selected layout, the extra traces are displayed sequentially as overlays divided among the available graphs, with priority assigned to the first graph.



Figure 11-6. TRACE LAYOUT Menu

For example, if four traces are specified in the # of Traces toolbar with the three vertically stacked graphs layout selected from the TRACE LAYOUT menu, the traces will be assigned as follows:

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

Similarly, a 16-layer overlay can be displayed by specifying 16 traces and selecting the single graph layout.

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)
- 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, unratioed parameter, ext. analog in

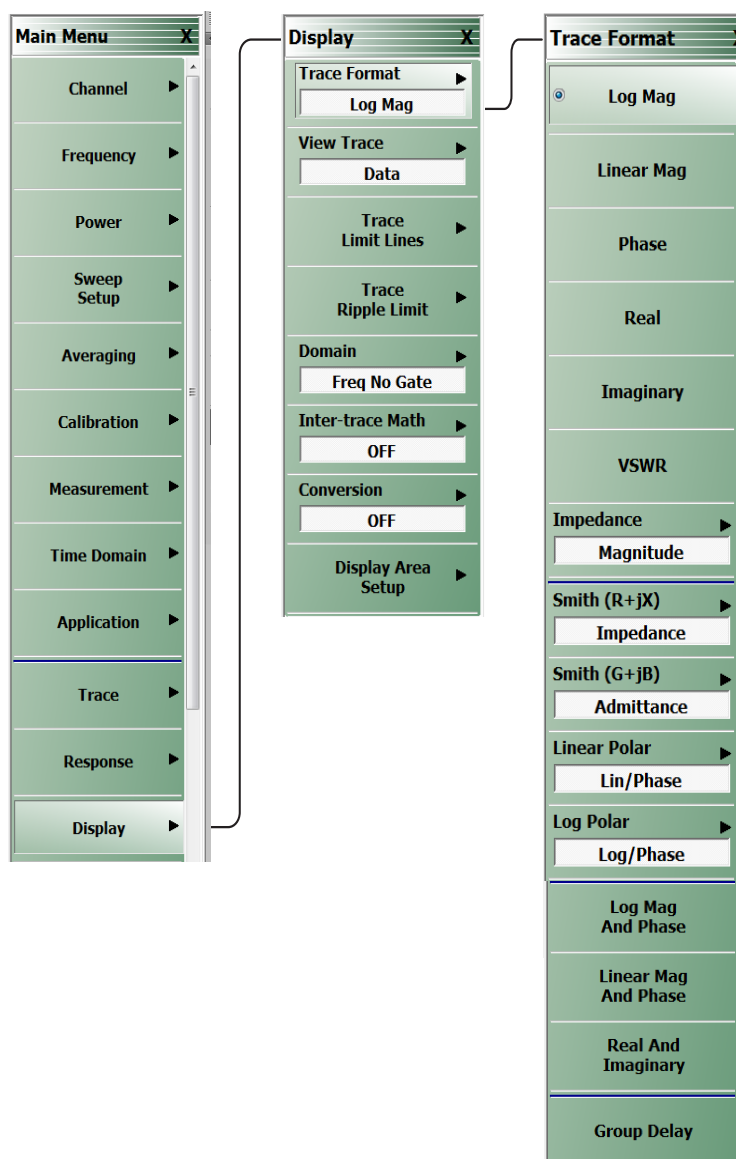


Figure 11-7. TRACE FORMAT Menu

Complex Trace Setup Example

A fairly complex trace setup example is shown in [Figure 11-8](#) below. This example covers multiple graph types and scaling options as well as different transformations applied to the data in certain traces. Symbols at the end of the annotation line provide information about these trace definitions. For example, Trace 2 is showing Data and Memory [D&M], while Trace 3 and Trace 5 are showing Data Memory Math; [D/M], and [D-M] labels. A list of abbreviations and their definitions are shown in [Table 11-1](#). Some of the abbreviations may appear without brackets at the end of the annotation line. Details on these functions can be found in other sections of this measurement guide and the ShockLine™ Operation Manual.

Table 11-1. Trace Labels and Annotations

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

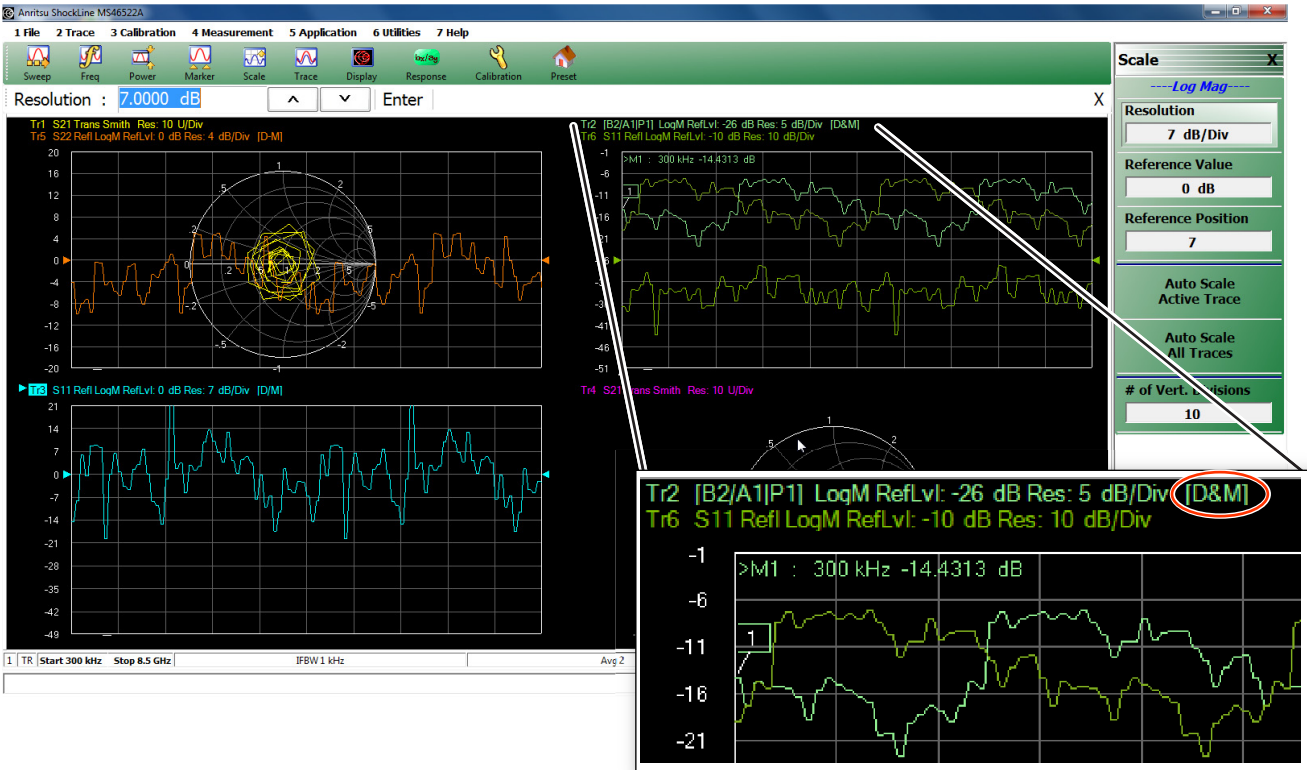


Figure 11-8. Multi-Trace Display with right-side SCALE menu

[Figure 11-8](#) also illustrates an example of a function, auto scale in this case, available on per-trace and per-system levels.

11-6 Markers Overview

The ShockLine VNA provides up to thirteen markers per trace of which twelve can be direct markers and one a reference marker. Each marker can be individually controlled on/off and positioned as required. If the reference marker is off, each marker provides measurement data based on its display position. If the reference marker is on, each marker provides differential measurement data based on its position relative the reference. Other functions for display options and various types of single-peak search are available.

Marker Button Label Changes

The labels for marker buttons 1 through 12 change depending on whether they are on or off and whether the Ref. Mkr function (described below) is on or off.

Marker Unit Changes

The marker units change depending on the selected instrument sweep setting on the SWEEP TYPES menu and settings on the DOMAIN and RANGE menus:

- Frequency Sweep:
 - Marker units set to frequency (GHz, MHz, kHz, Hz)
- Segmented Sweep (Frequency-Based):
 - Marker units set to frequency (GHz, MHz, kHz, Hz)
- Segmented Sweep (Index-Based):
 - Marker units set to Index number.
- Power Sweep (CW Frequency):
 - Marker units set to power (dBm)

Reference Marker OFF or On

If Ref. Mkr is set to OFF, the label is formatted as:

- Mkr # [OFF] if the marker is off (where # is the marker number).
- Mkr # [ON] if the marker is on.
- For example, Marker 1 would be labeled either Mkr #1 [OFF] or Mkr #1 [ON].

If Ref. Mkr. is set to ON, the label is formatted as:

- Mkr#-Ref [OFF] if the marker is off.
- Mkr#-Ref [ON] if the marker is on.
- For example, Marker 1 would be labeled either Mkr#1-Ref [OFF] or Mkr#1-Ref [ON].

Turning Individual Markers Off and On

The MARKERS [1] menu described below is shown with Marker 1 (Mkr 1) through Marker 4 (Mkr 4) turned off. Individual markers can be turned off manually by clicking their buttons.

Turning All Markers On

All markers can be turned on either manually one-by-one (as above) or at the MARKERS [2] menu, by clicking the All Markers On button.

Navigation

MAIN | Markers | MARKERS | More Markers | MARKERS [2] | All Markers On

Note that selecting Inductance/Capacitance on the Smith (Impedance) menu enables marker Inductance or Capacitance measurement readout.

Turning All Markers Off

All markers can be turned off either manually one-by-one or at the MARKERS [2] menu, by clicking the All Markers Off button.

Navigation

- MAIN | Markers | MARKERS [1] | More Markers | MARKERS [2] | All Markers Off

Naming Conventions for Marker Buttons and Toolbars

The following conventions are used to label the marker buttons and toolbars in this section.

Marker Buttons

- Mkr # [Ref] [OFF/ON] is used for all button names (where # is the number of the marker).
- For example, Mkr1 [Ref] [OFF/ON] is used for the Marker 1 button when it is labeled Mkr 1 [OFF], Mkr 1 [ON], Mkr1-Ref [OFF], or Mkr1-Ref [ON].

Marker Toolbars

- Mkr # [Ref] [ON] is used for all marker toolbars (where # is the number of the marker).
- For example, Mkr1-[Ref] [ON] is used for the Marker 1 toolbar when it is labeled Mkr 1 [ON] or Mkr1-Ref [ON].
- Note the marker must be on for the toolbar to be available.

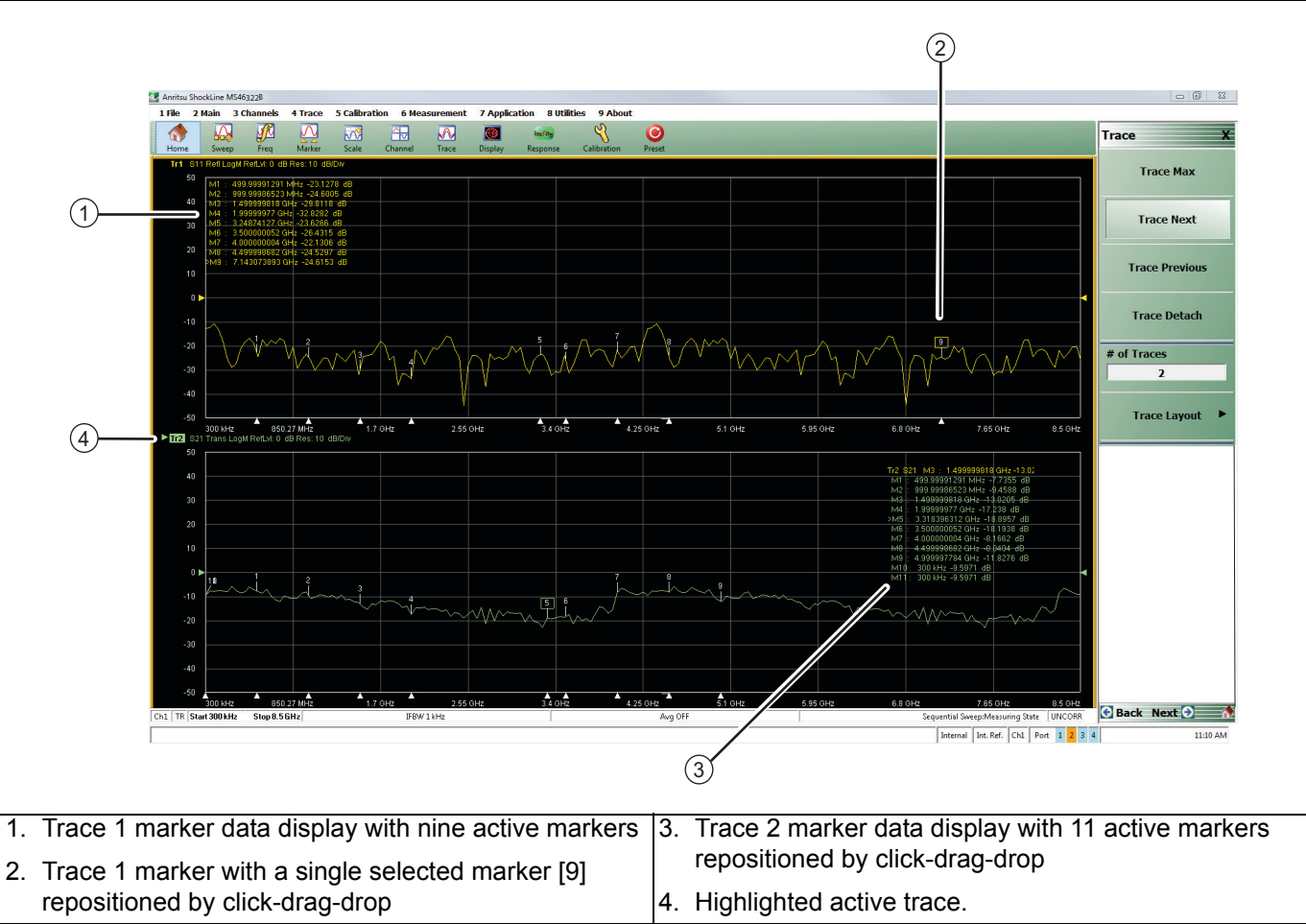
Position Marker(s)

A single marker or an array of marker data displays can be repositioned with a drag/drop within the signal response trace display. See [Figure 11-9 on page 11-12](#). Each marker can be individually controlled on/off and positioned as required on the signal response display.

If the reference marker is off, each marker provides measurement data based on its display position. If the reference marker is on, each marker provides differential measurement data based on its position relative the reference.

The marker(s) can be repositioned while using any parameter setup menu. Note that the marker data display placement area on the main display window may be limited if the detachable trace view windows in use are smaller in size than the main display window.

The example below [Figure 11-9](#), depicts a two trace display. On the top trace display, the individual marker [9] is selected, and repositioned. In the bottom trace, the marker data display is repositioned



- | | |
|---|---|
| 1. Trace 1 marker data display with nine active markers | 3. Trace 2 marker data display with 11 active markers repositioned by click-drag-drop |
| 2. Trace 1 marker with a single selected marker [9] repositioned by click-drag-drop | 4. Highlighted active trace. |

Figure 11-9. Marker Data Display Drag-Drop

11-7 Hold Functions

Hold events and triggering events are per-channel. These menus are shown in [Figure 11-10](#) for hold events. The HOLD FUNCTIONS menu is available from the SWEEP SETUP menu.

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

.Select Hold Conditions provides a toggle for RF on or off.



Figure 11-10. HOLD FUNCTIONS Menu

11-8 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
- Ripple Limit: Setup tasks and test ripple tolerance
- Averaging and smoothing: Functions and their effects on measurements

11-9 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 11-11](#).

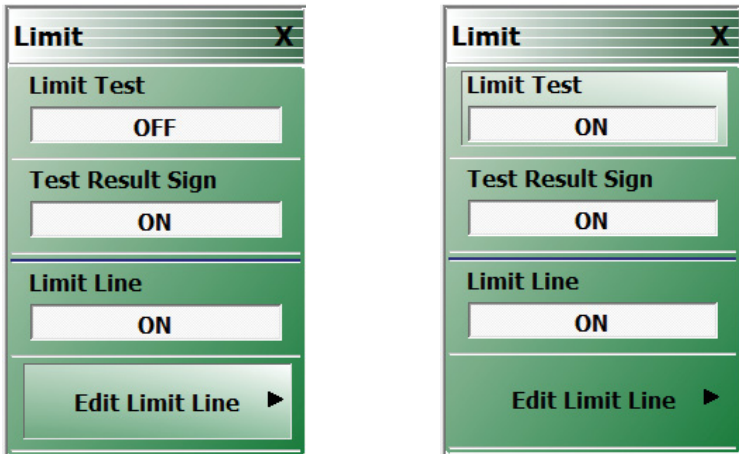


Figure 11-11. LIMIT Menu - Various Functions Toggled ON or OFF

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 11-14](#)) 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 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. If the Test Result Sign function is used with both Limit lines and Ripple limit lines, the test result will be a logical OR between both limit line values meaning if either limit line fails, the FAIL sign will result.



Figure 11-12. 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).

Editing Limit Lines

The editing of the limit lines is controlled on the one submenu and that is shown in [Figure 11-13](#). 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

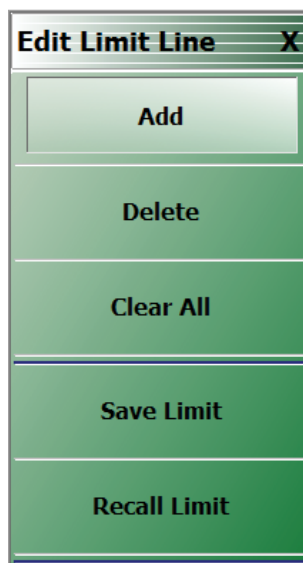


Figure 11-13. EDIT LIMIT LINE Menu

An example limit line table is shown in [Figure 11-14](#) 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).

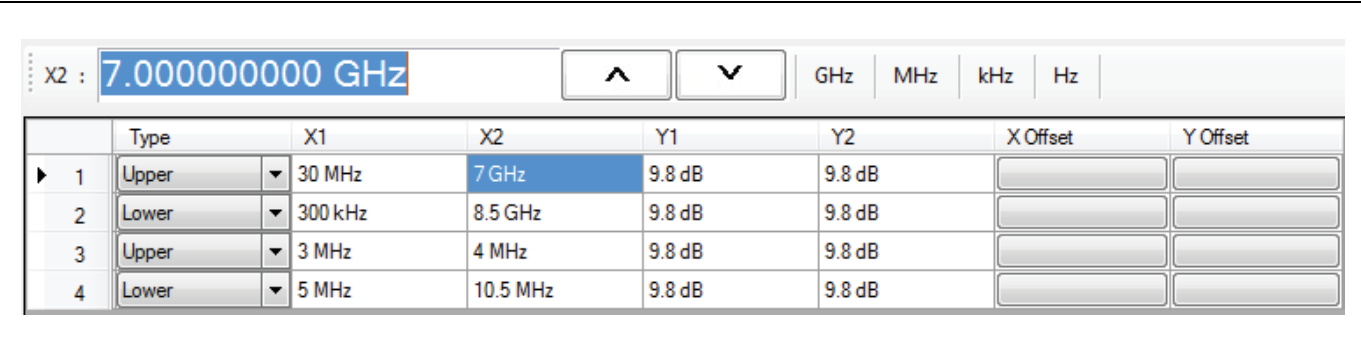


Figure 11-14. Limit Line Table

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.

11-10 Ripple 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.

An adequate number of points must be used for effective use of this function. The ripple line limit will be automatically placed on the ripple based on the frequency start and stop set and ripple value. The ripple value is divided between the upper and lower limit when set. The main Ripple limit line menu is shown in [Figure 11-15](#)

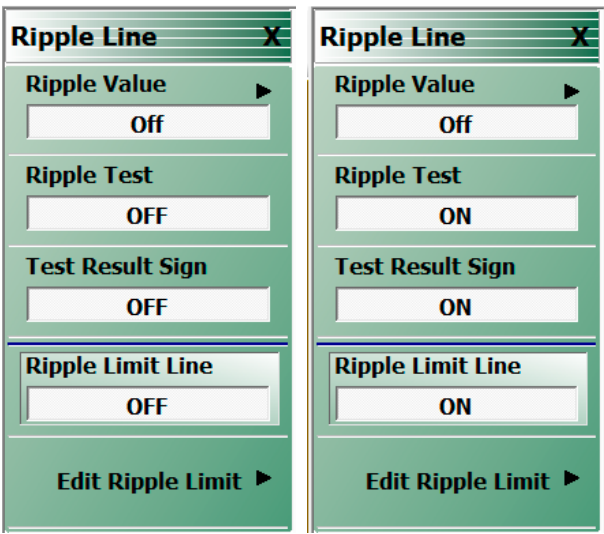


Figure 11-15. Ripple LIMIT Menu - Various Functions Toggled ON or OFF

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

Ripple Value

The Ripple Value button allows the user to set the ripple value setting to Absolute Value or Margin. Absolute Value is the between the minimum and maximum of the ripple while Margin is the difference relative within the ripple limit line.

Ripple Test

The Ripple 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 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 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. If the Test Result Sign function is used with both Limit lines and Ripple limit lines, the test result will be a logical OR between both limit line values meaning if either limit line fails, the FAIL sign will result.

Ripple Limit Line

Displays the current ripple 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).

Editing of Ripple Limit Lines

The editing of the Ripple Limit lines is controlled on the one submenu and that is shown in [Figure 11-15](#). When entering this menu, the Edit Ripple 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).

An example ripple limit line is shown in [Figure 11-17](#) using two frequency segments. The ripple value determines the ripple upper and lower limits. For example, the 300 kHz to 5 GHz start and stop range will have an upper and lower limit of 1 dB about the ripple.

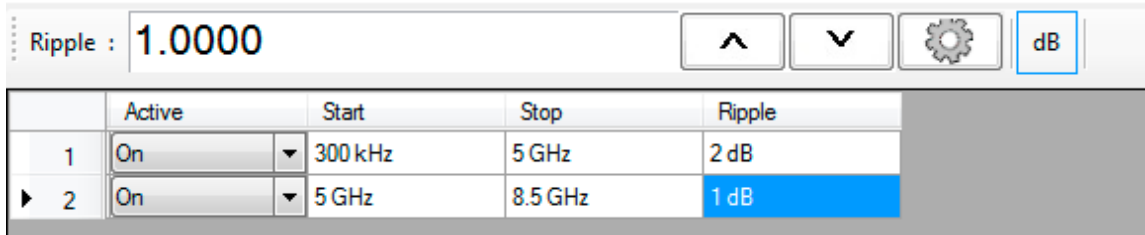
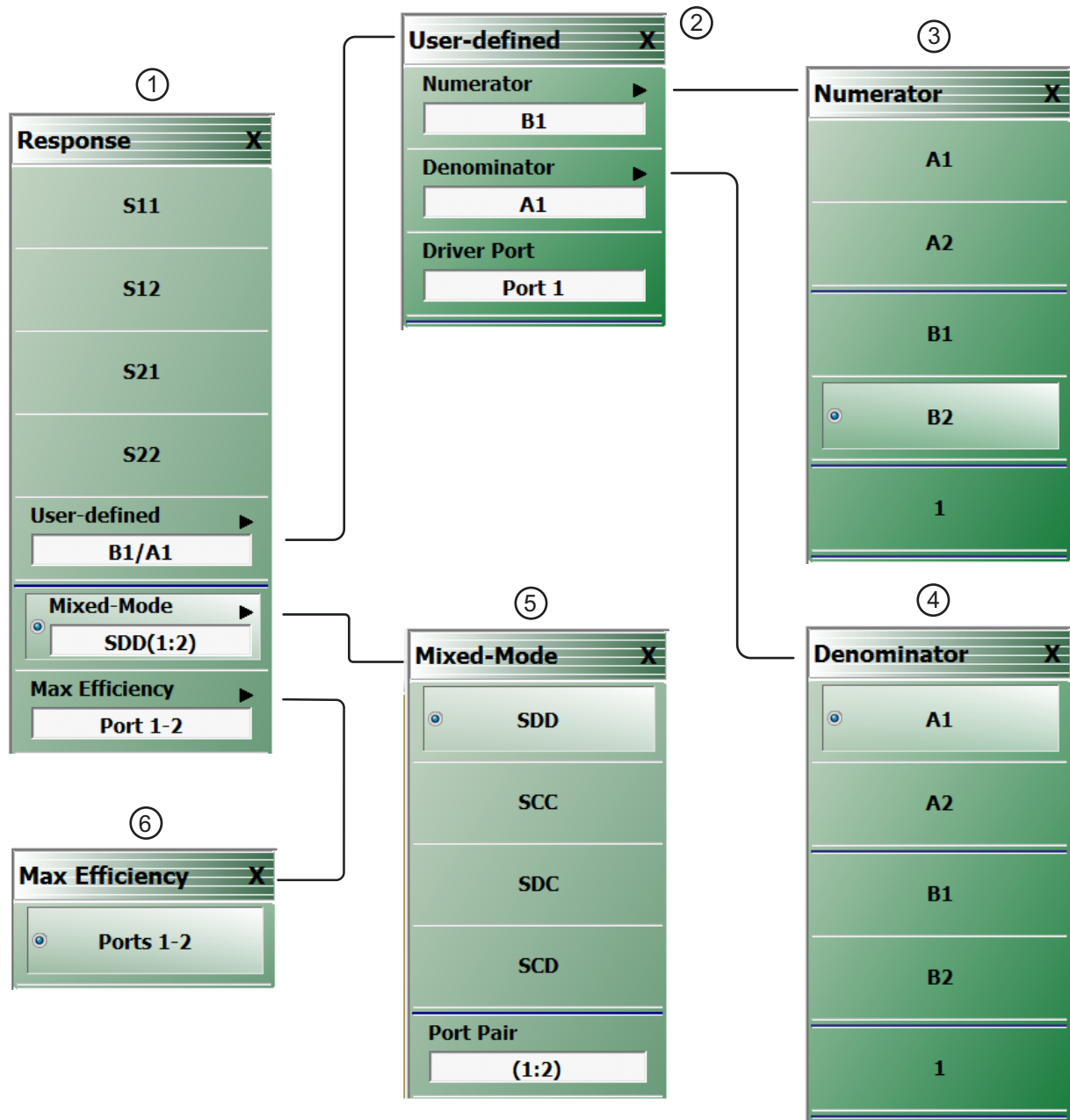


Figure 11-16. Ripple Limit Line

Response Menu

These are selectable on the response menu as shown in Figure 11-17 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.



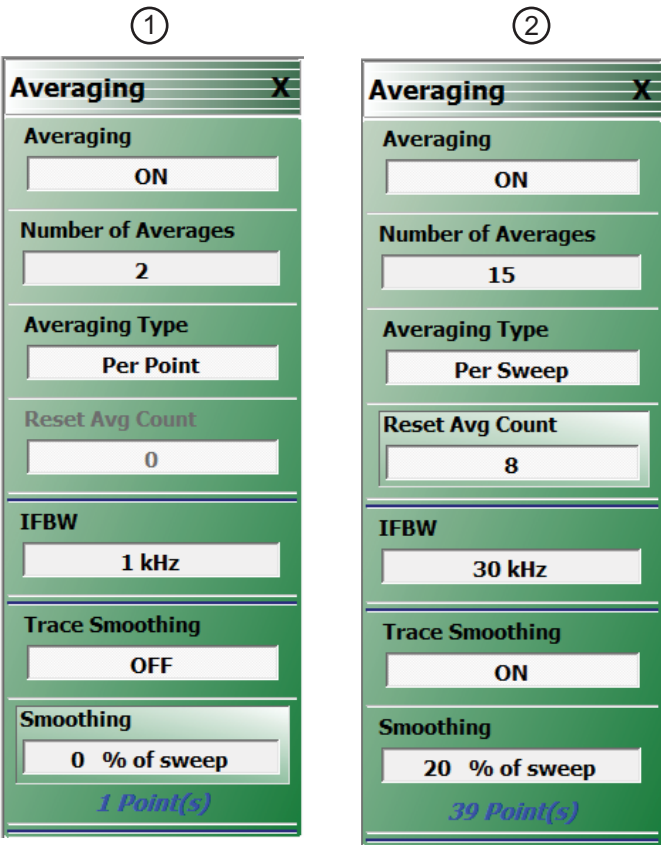
- | | |
|----------------------|------------------------|
| 1. RESPONSE menu | 4. NUMERATOR menu |
| 2. USER-DEFINED menu | 5. DENOMINATOR menu |
| 3. MIXED-MODE menu | 6. MAX EFFICIENCY menu |

Figure 11-17. RESPONSE Menu and Submenus

11-11 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 11-18](#) 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 11-18. AVERAGING Menu - Both menus show that averaging has been toggled on.

Averaging

The Averaging button toggles the function OFF and ON.

Avg. Factor - Number of Averages

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 10 Hz to 300 kHz on the MS46122A/B and MS46322A/B. At lower IFBW, 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.

Chapter 12 — Measurement - Time Domain (Option 002)

12-1 Chapter Overview

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

12-2 Introduction

The time domain option offers the ability to transform the native frequency domain data of the MS46122A/B and MS46322A/B 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 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 12-1 on page 12-2](#).

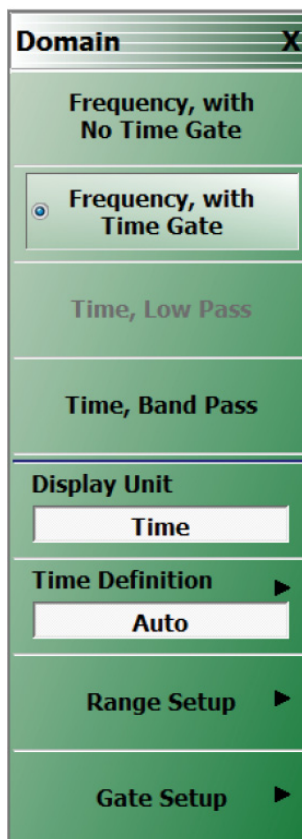


Figure 12-1. DOMAIN Menu - Top Level Domain Menu

12-3 Basic Time Domain Modes

The four basic modes of the Time Domain menu available from the Domain Menu [Figure 12-1, “DOMAIN Menu - Top Level Domain Menu”](#):

- **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.

12-4 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. 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 12-2 on page 12-3](#), 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.

The following menus are accessible through the Display sub-menus. Users can access these same features through the Measurement Setup dialog menu.

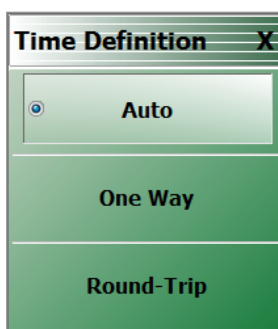


Figure 12-2. TIME DEFINITION Menu

12-5 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 12-3](#). 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.

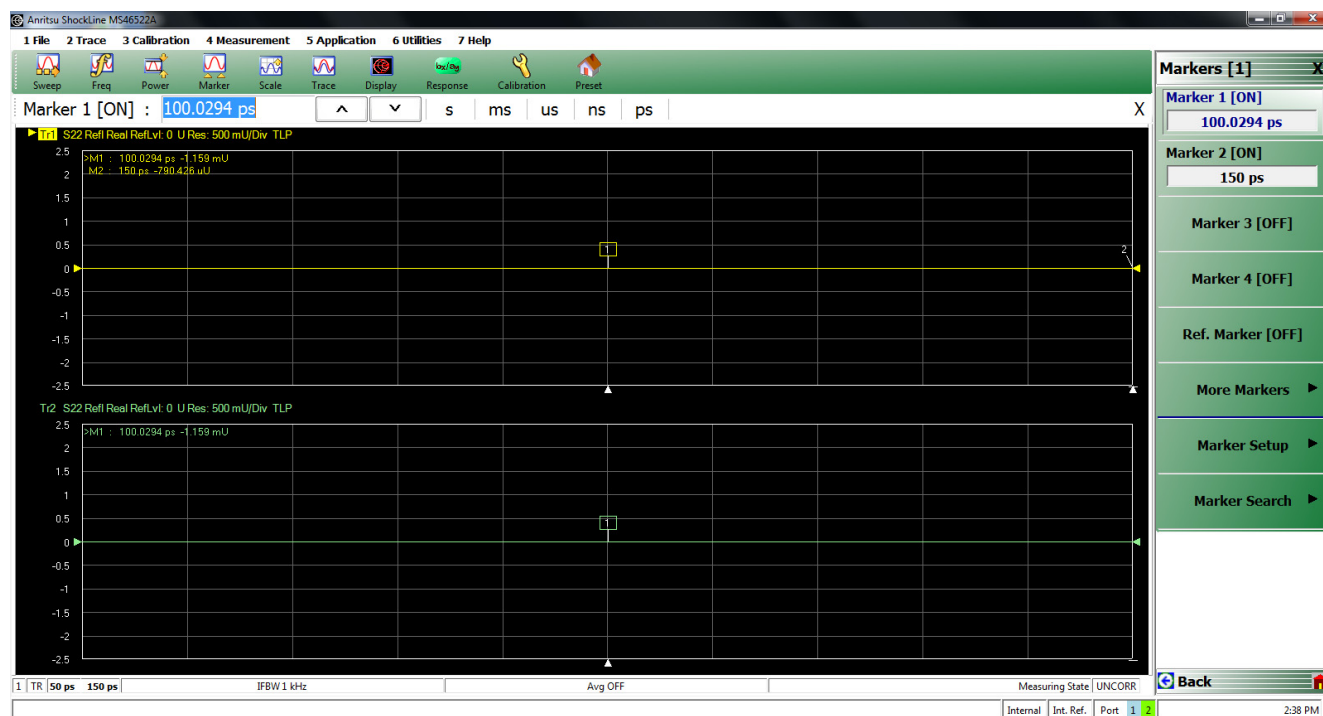


Figure 12-3. Example Low-pass Time Domain Plot

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 12-4](#). 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 12-1](#)).

Figure 12-4. 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 12-1](#)) 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 ShockLine™ MS46122A/B-10 and MS46322A/B-10 VNA cannot get all the way to DC, some additional information is needed to perform this integration. To see this consider:

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

Equation 12-1

DC Term Menu

Note The term menu is only available in low pass time domain mode.

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 12-5](#). The default choice is to allow the system to auto-extrapolate from existing frequency data to estimate the DC value.

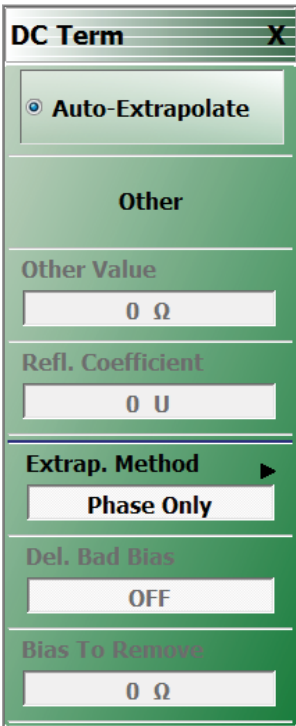


Figure 12-5. DC TERM Selection Menu

There are options on how the extrapolation is done, as shown in [Figure 12-6](#).

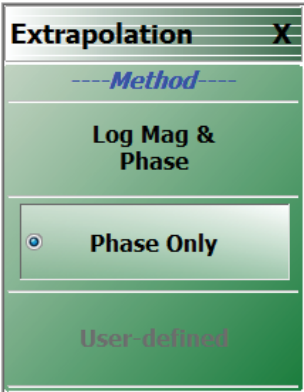


Figure 12-6. The DC Term EXTRAPOLATION Menu

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 12-7](#).

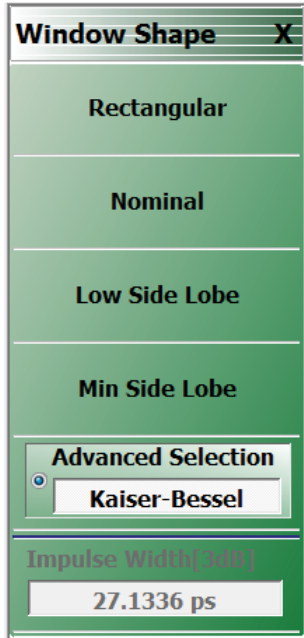


Figure 12-7. WINDOW SHAPE Menu

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 12-8](#). Here the same data appears with the four different window selections. For this plot, data was saved to TXT files and plotted externally.

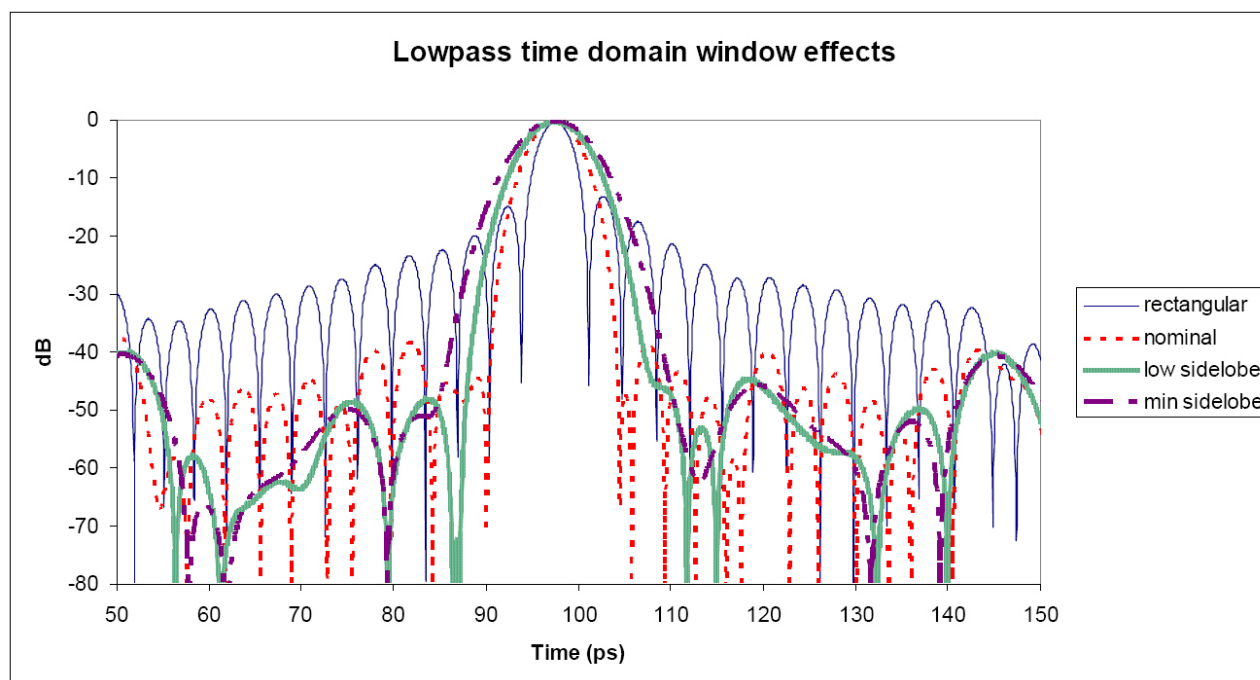


Figure 12-8. Effects of Window Shapes Plot

The Advanced Window selection button brings up the dialog shown in [Figure 12-9](#) that has the previous four choices along with two new parameterized windows, Kaiser-Bessel and Dolph-Chebyshev.

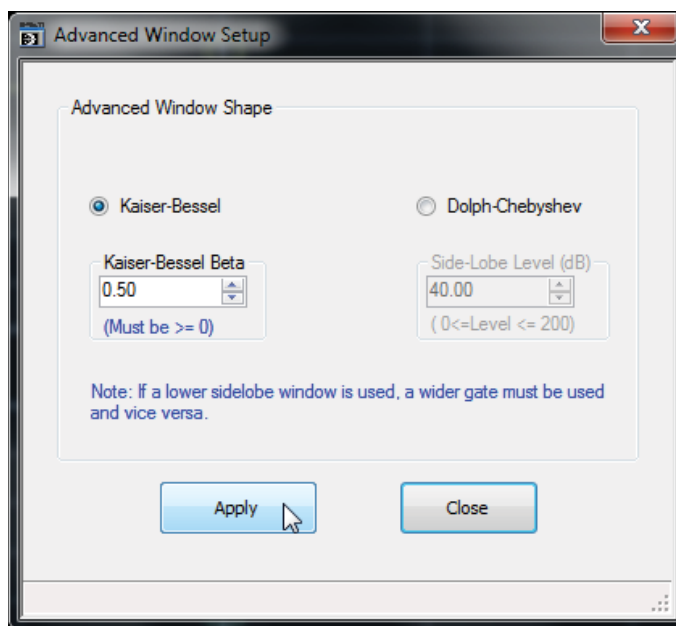


Figure 12-9. Advanced Window Setup Dialog

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 12-10](#) along with the rectangular window for comparison.

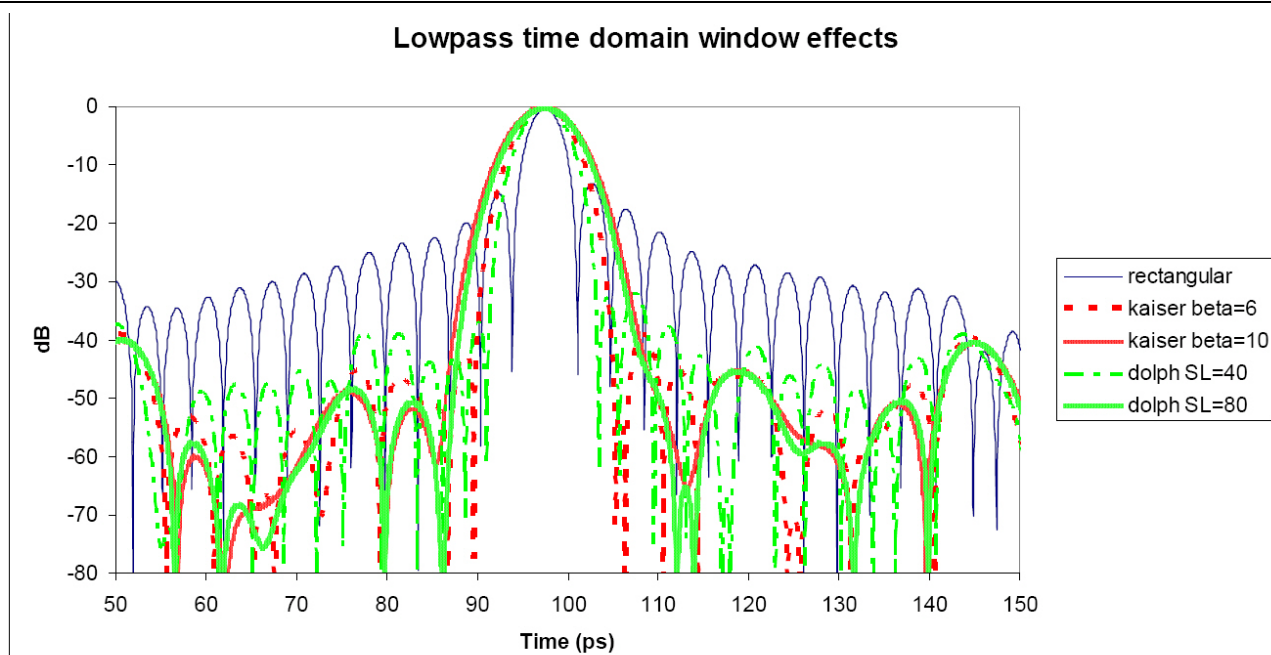


Figure 12-10. Effects of Window Shapes Plot with Advanced Windows Selection

The approximate relationship between these parameters and the main lobe width (null-to-null) is suggested in [Figure 12-11](#). 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.

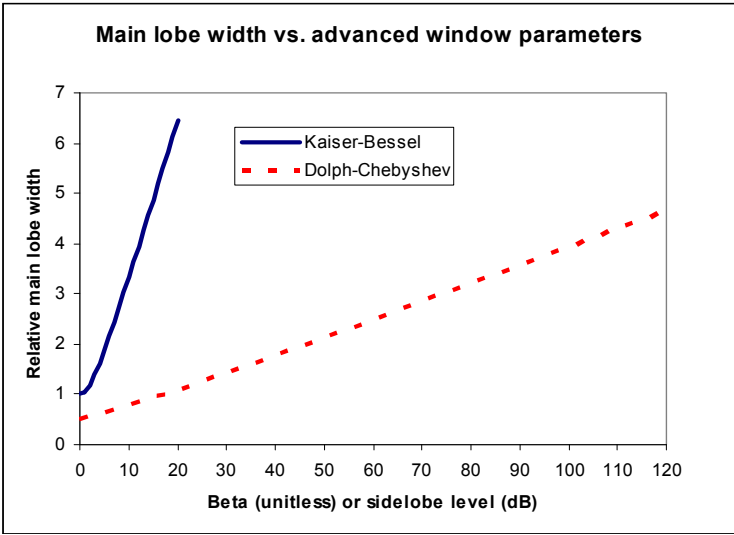


Figure 12-11. Comparison of Lobe Width vs. Window Parameters

12-6 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 12-12](#) 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 12-2](#)) is shown in [Figure 12-17](#). 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.

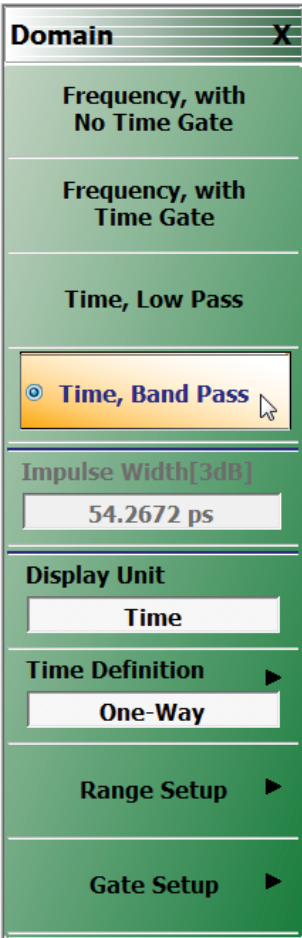


Figure 12-12. Top Level DOMAIN Menu - Time, Band Pass Selected

An example bandpass time domain plot is shown 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.

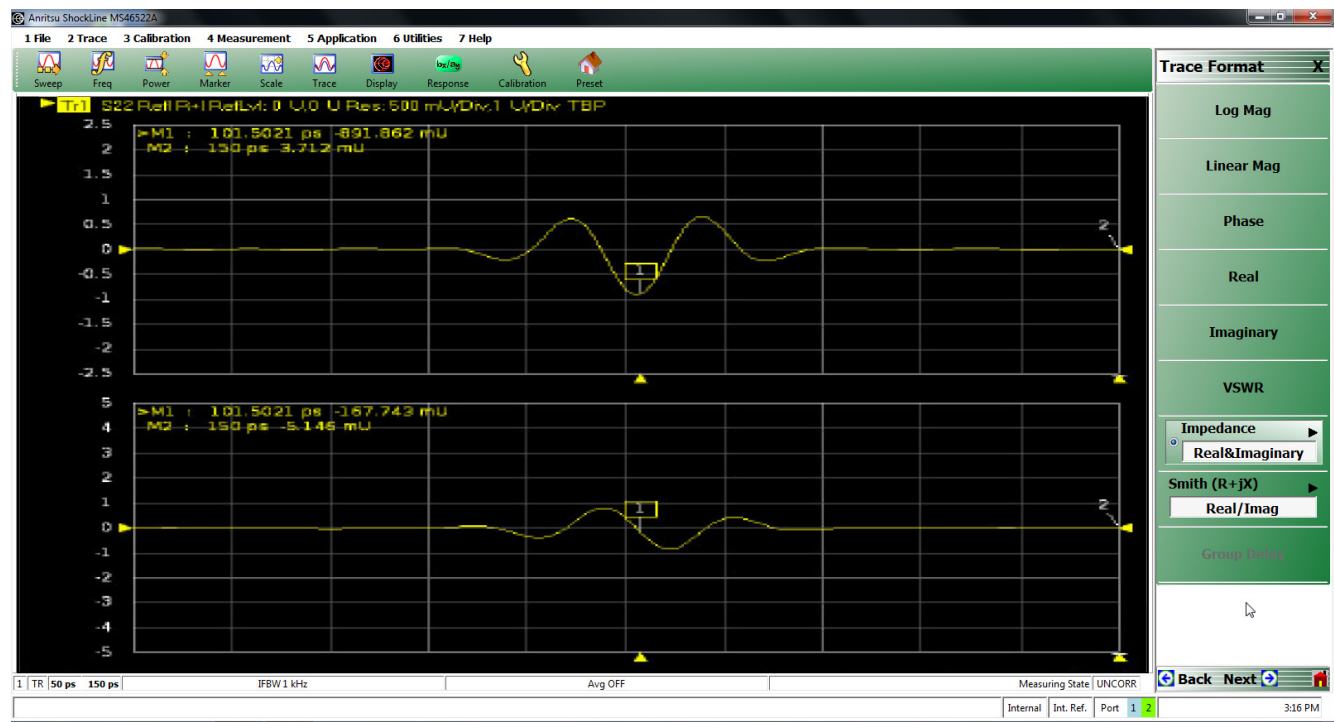
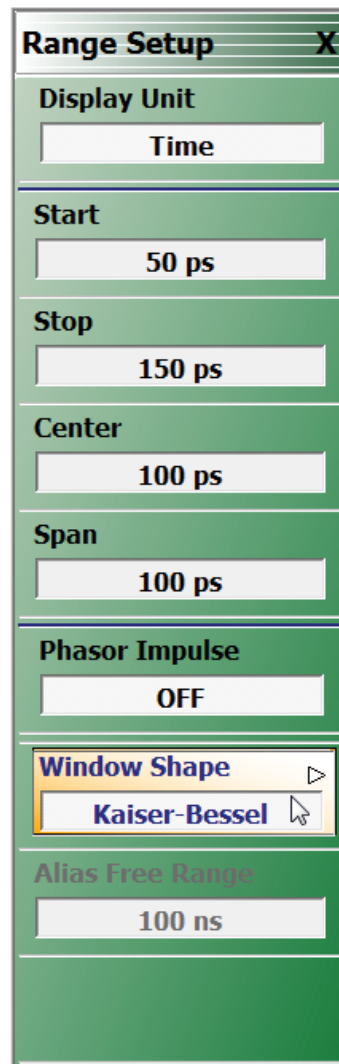


Figure 12-13.Example Band-pass Time Domain Plot

The range menu for bandpass mode is shown in Figure 12-14. 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.



The image shows a 'Range Setup' menu for Bandpass Time Domain. The menu is a vertical stack of green boxes with white text. At the top is a title bar 'Range Setup' with a close button 'X'. Below the title bar are several input fields: 'Display Unit' with 'Time', 'Start' with '50 ps', 'Stop' with '150 ps', 'Center' with '100 ps', 'Span' with '100 ps', 'Phasor Impulse' with 'OFF', 'Window Shape' with 'Kaiser-Bessel' (highlighted with a mouse cursor), and 'Alias Free Range' with '100 ns'.

Parameter	Value
Display Unit	Time
Start	50 ps
Stop	150 ps
Center	100 ps
Span	100 ps
Phasor Impulse	OFF
Window Shape	Kaiser-Bessel
Alias Free Range	100 ns

Figure 12-14. 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 12-15 and correspond to the measurement of Figure 12-13 on page 12-12, 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 12-8 on page 12-8).

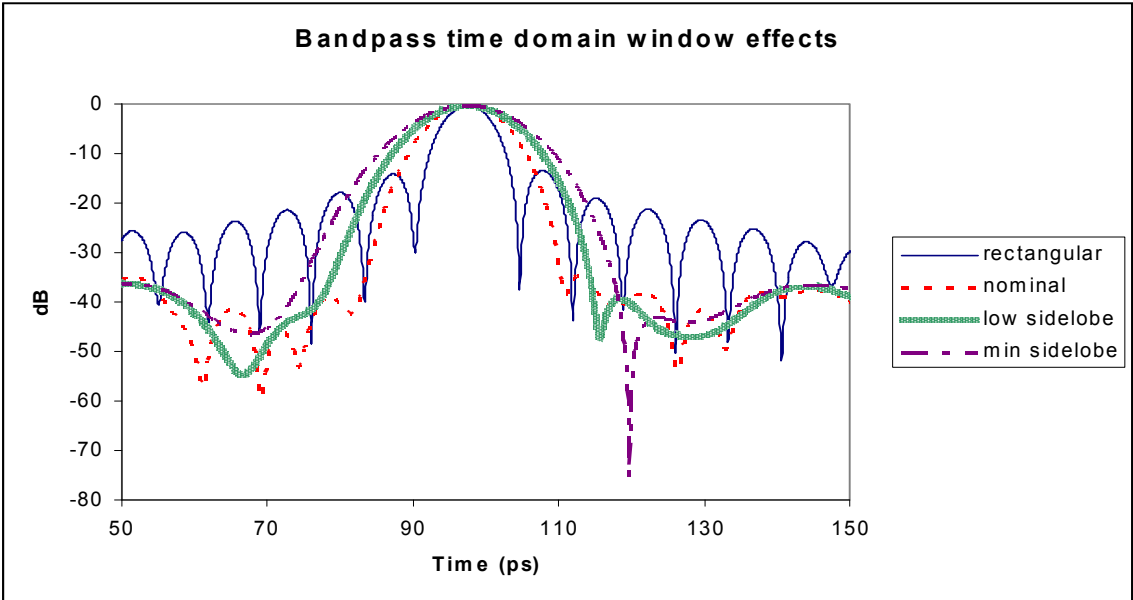


Figure 12-15.Window Effects in Bandpass Time Domain

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.

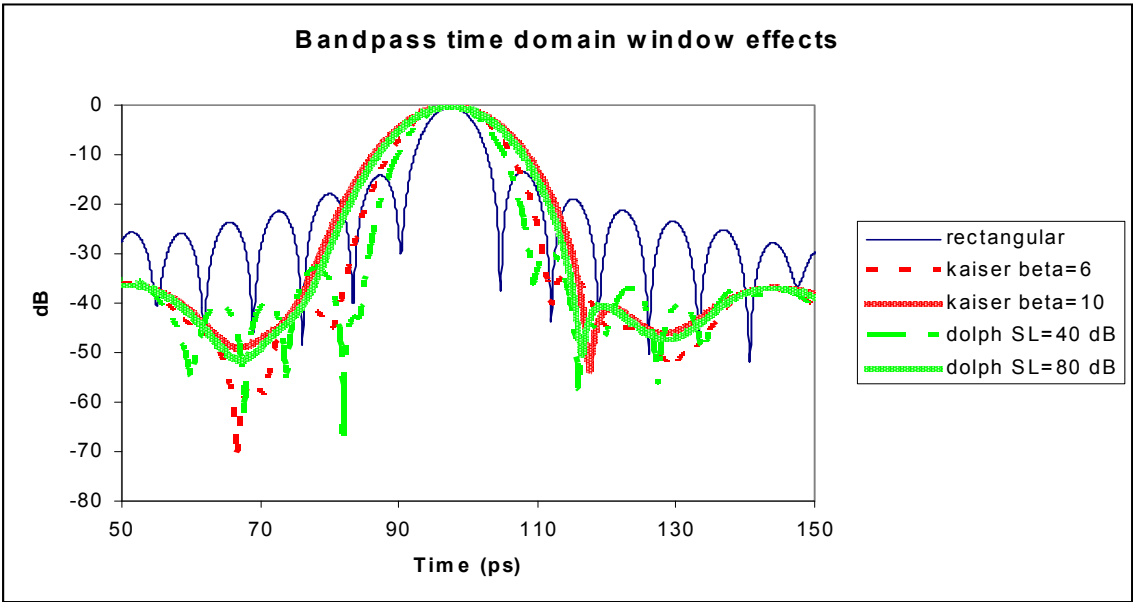


Figure 12-16.Window Effects in Bandpass Time Domain (advanced window types)

12-7 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.

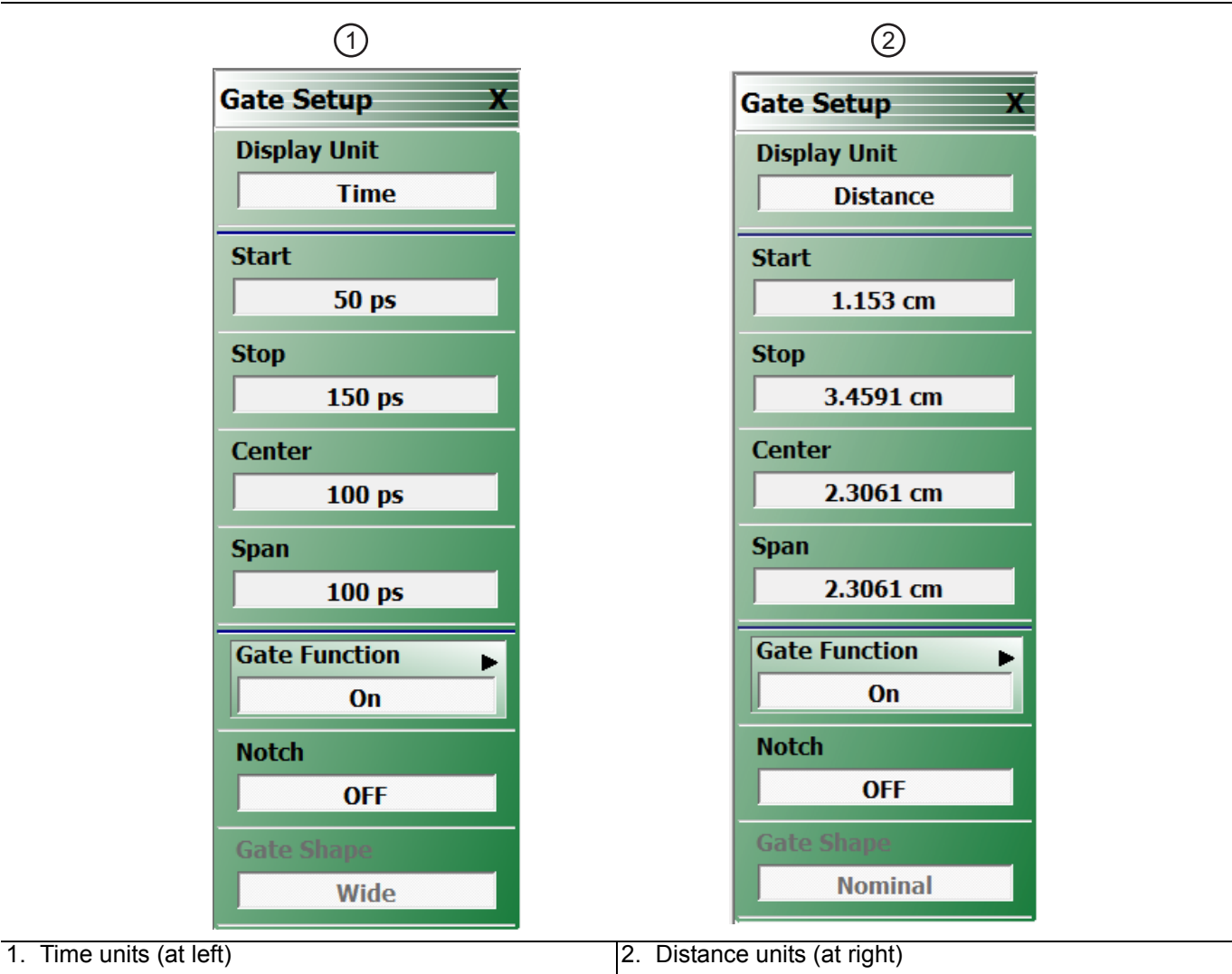


Figure 12-17. GATE SETUP Menu

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 12-18](#).

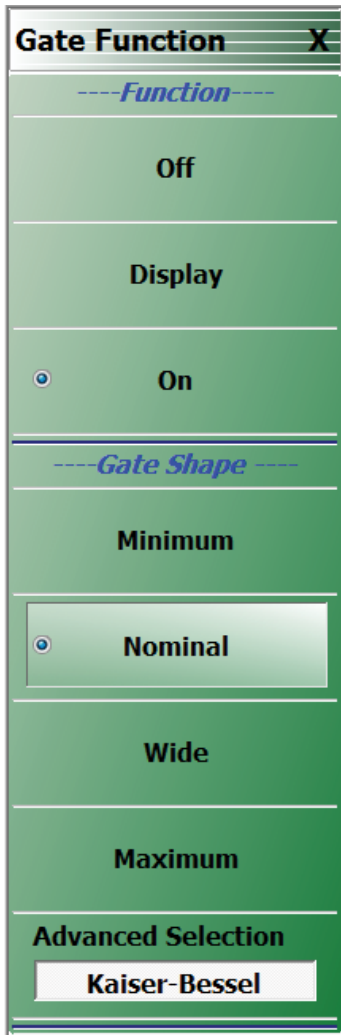


Figure 12-18. Gate Function Submenu

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 is 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.

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).

Table 12-1. 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

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 12-19](#), the gate is in display mode surrounding the desired reflection. Both gate and window are set to nominal in this case.

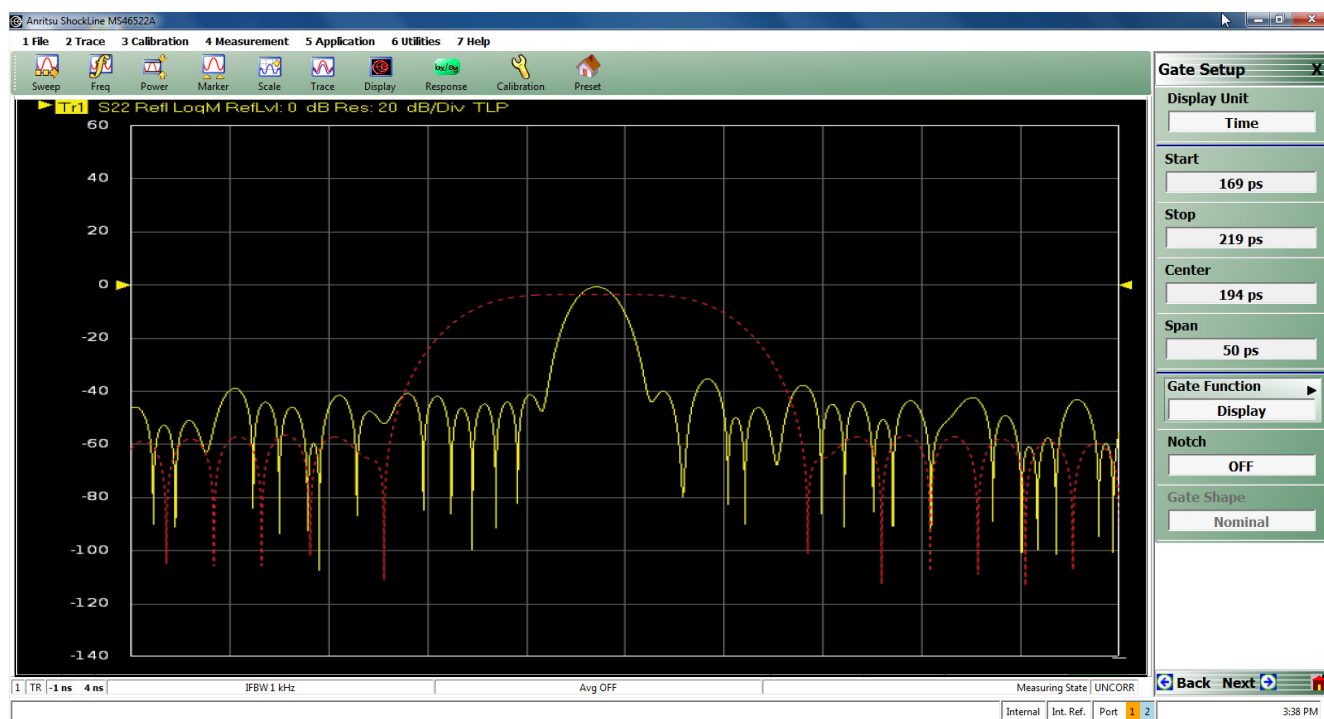


Figure 12-19. Gate in Display Mode Example

Next the gate is turned to on. In [Figure 12-20](#), the suppression of the time domain information outside of the gate area is seen.

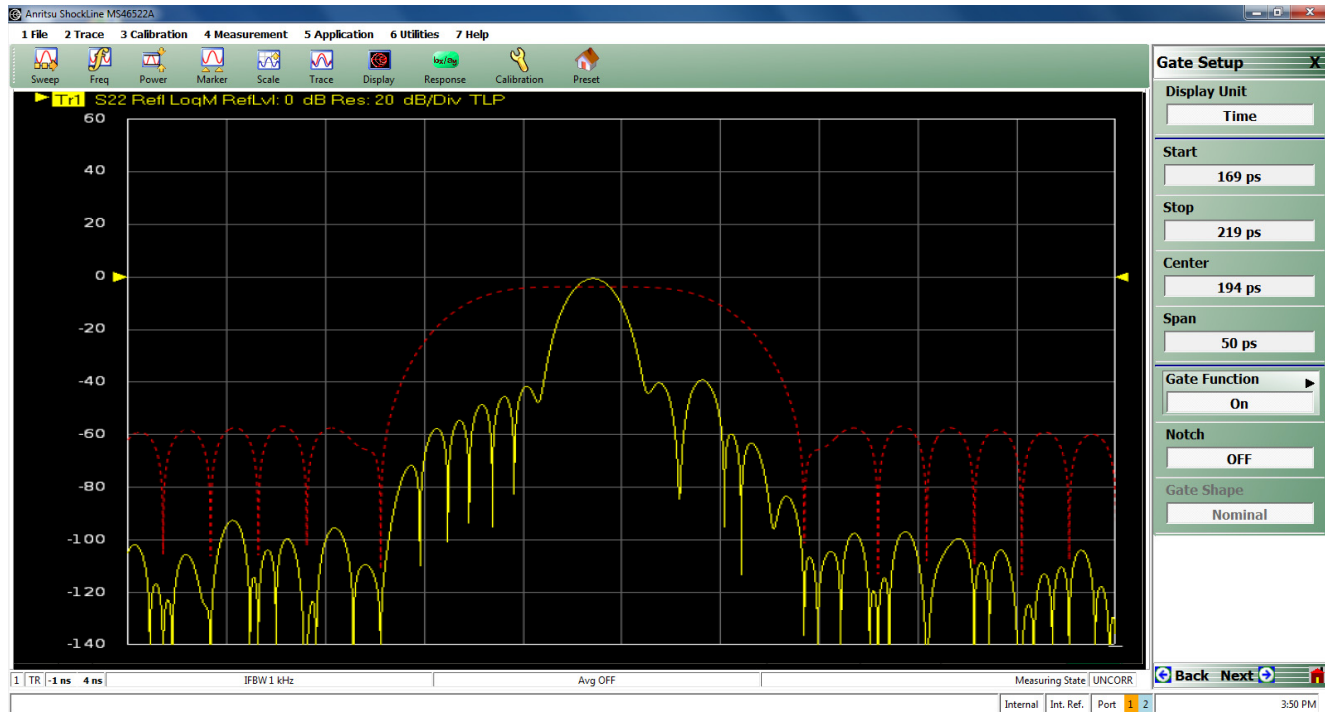


Figure 12-20. Gate Turned On Example

Finally, frequency with time gating is activated and the result is shown in Figure 12-21. 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.

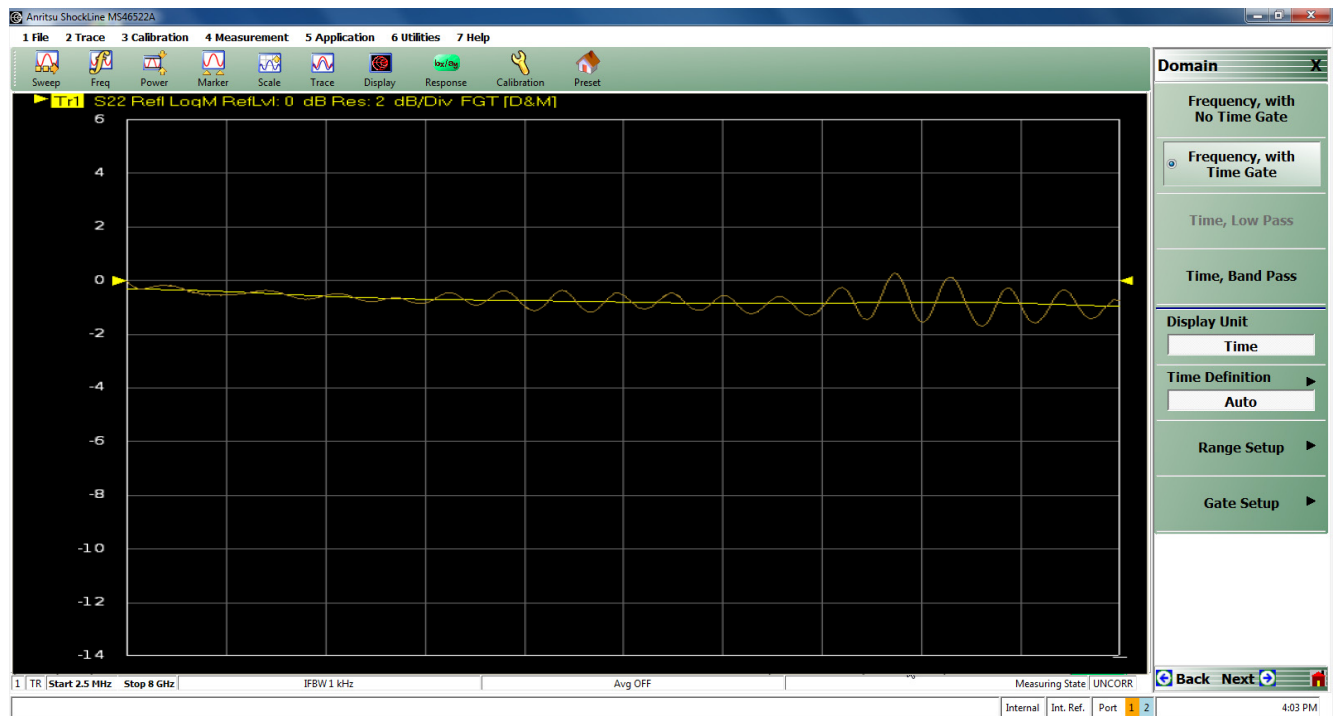


Figure 12-21. Frequency with Time Gating Example

Other Frequency-with-time-gate Calculation Items

Questions are sometimes asked about the details of the gating process and the subject of uncertainty in the final result. The latter topic is addressed in the next section. In terms of the process itself, the basic concept is simple enough: a particular functional form (to exclude or include certain portions) is applied to the time domain data before it is returned to the frequency domain. As the time domain data is theoretically of infinite extent, the limited data roster forces some truncation to happen by default so even with an infinitely wide gate, the process is not conservative.

To get around this problem, a calibration signal (a single, synthetic tone) is applied to the current window/gate setup to generate a set of correction factors. Normally this does not introduce any significant errors. If the gate is very narrow (in the sense of approaching $1/BW$), there is an additional issue in that the equivalent frequency domain convolution starts trying to interact more with frequencies outside of the sweep range. In the extreme case, this results in distorted final result, particularly at the extreme frequencies. To improve these results, the gate processing is done on a synthetically larger frequency range (using modeled extrapolation) to minimize out-of-range convolution effects. It is still advisable that the gate not be any narrower than a few resolution intervals.

A second type of question that often arises is on how to use and interpret FGT results on transmission parameters. Suppose one had a device in a fixture, one might think that one could de-embed transmission by simply placing a gate around the appropriate place. Unfortunately, it is not quite that simple. Consider the time domain representation of an impulse traveling through our fixture + DUT assembly.

In the time domain sense, an impulse is incident from the left and, at the first interface, some is reflected and some is transmitted. The transmitted impulse then sees the output plane of the DUT and again, some is reflected and some is transmitted. The transmitted impulse (labeled 'A' in Figure 12-22) goes to the receiver and this is the first response observed in the time domain transmission measurement.

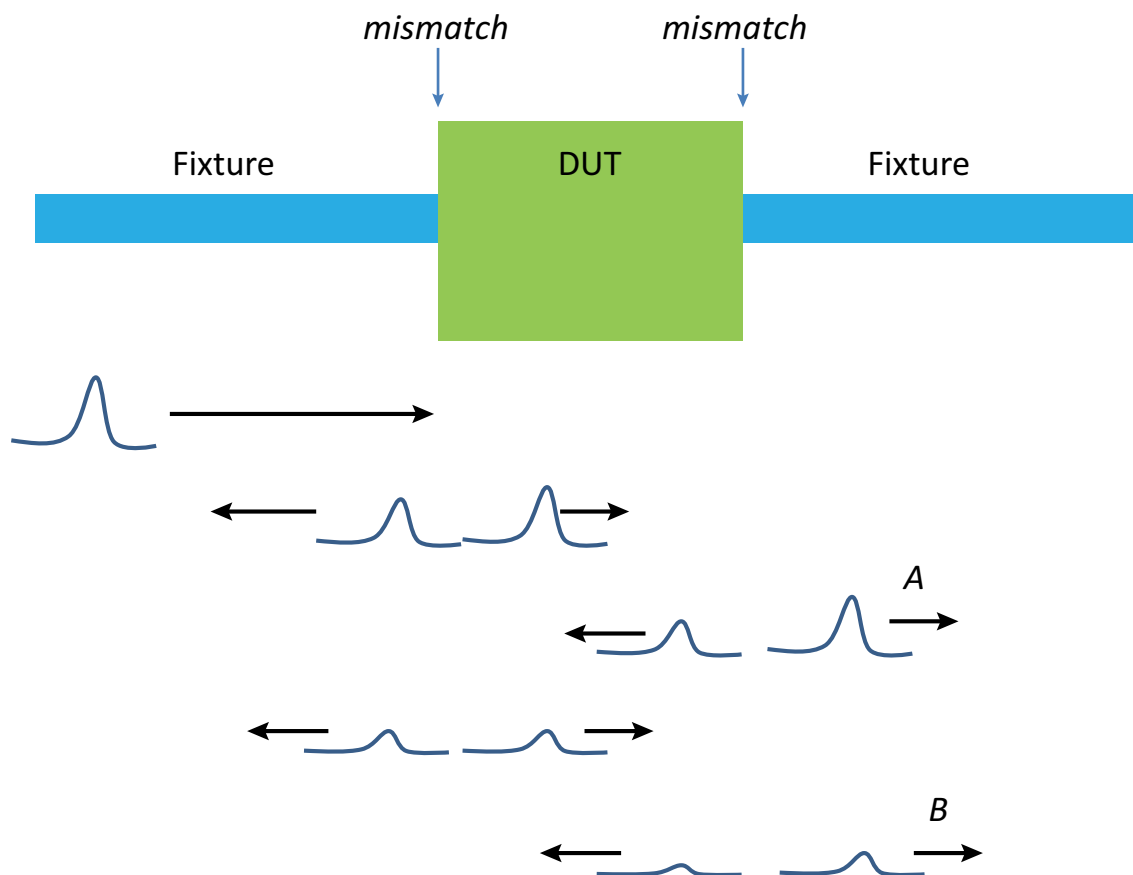


Figure 12-22. Illustration of Gating Effect on Pulse Re-reflections

If one follows the remaining pulse energy, there is an internally reflected impulse in the DUT that again emerges towards the receiver (labeled *B*). There may be additional re-reflections that contribute depending on the loss and reflection levels. Now if one places a gate around 'A', one will remove the contribution of re-reflections and this may reduce the ripple in the FGT response. This is not complete de-embedding, however, since 'A' includes loss effects of the fixture as well as any incident mismatch. Those effects were not removed by this gating process. For that fuller level of correction, more traditional de-embedding steps usually need to be followed.

Saving Gated Results

As usual, .txt and .csv formats (along with the graphical formats) can be used to save post-processed results. Many users also wish to save gated results in the .sNp file formats but this is not enabled by default to avoid confusion on what the S-parameters represent. This can be turned on using a control at the bottom of the sNp setup menu as shown below.

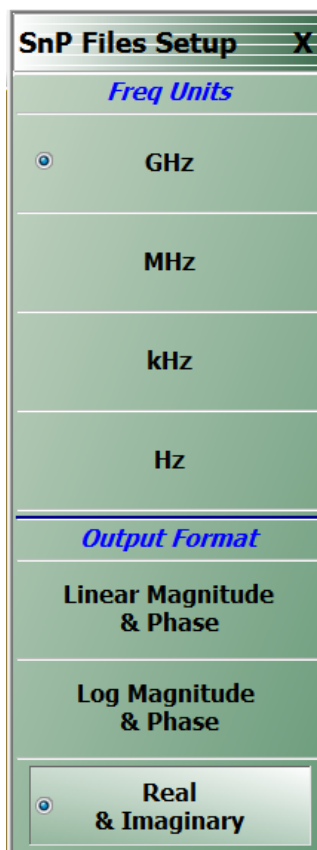


Figure 12-23. SnP Files Setup Menu

As might be expected, there is some potential for confusion on which gate is applied to which parameter. The following rules are employed:

- If gating is applied on no traces on the current channel, only ungated .sNp data will be saved.
- If gating is applied on at least one trace and the save gated button described above is ON, gated data will be saved for all parameters (that are part of the current .sNp save request). In this case:
 - If all parameters of the .sNp are setup as gated in the current channel, those parameter-specific gate parameters will be used. The data from the last processed run will be used for the save.
 - If not all parameters are setup as gated, the gate parameters of the first gated trace of the same parameter type (transmission/reflection) will be used. If such a trace does not exist, the gate parameters of the first gated trace will be used. If a trace does not exist for the required parameter, its measurement will be taken from the buffer (if a calibrated parameter) or a measurement re-triggered (if not a calibrated parameter but part of the sNp save definition).
- If gating is applied to the .sNp file, a comment line (! GATING applied) will be added to the header of the file.

Chapter 13 — Measurement - Sweep Types

13-1 Chapter Overview

This chapter covers the sweep type available with the ShockLine™ MS46122A/B and MS46322A/B Series VNA to increase measurement functionality.

13-2 Introduction

A single sweep type is available within the MS46122A/B and MS46322A/B Series VNAs.

- Traditional frequency sweep (defined by a start frequency, a stop frequency and a number of points)

The SWEEP SETUP menu is shown in [Figure 13-1](#)

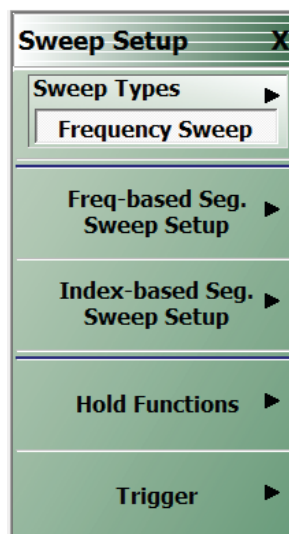


Figure 13-1. SWEEP SETUP Menu

13-3 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 16,001.

Power entry while in frequency sweep mode is accomplished through the POWER [COUPLED] menu shown in [Figure 13-2](#).

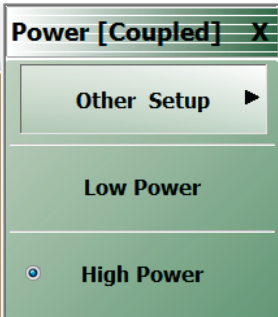


Figure 13-2. POWER [COUPLED] Menu

13-4 Maximum and Minimum Power Settings

For all configurations, the maximum power setting for:

MS46122A, MS46322A

- -3 dBm

MS46122B and MS46322B:

- +5 dBm (1MHz to 8 GHz)
- -3 dBm (>8 GHz to 43.5 GHz)

A summary of the power settings is in [Table 13-1](#) below.

Table 13-1. Summary of Maximum and Minimum Power Levels

VNA	Power Level	Power Setting	Output Power (Typical)
MS46122A/B-010 MS46122A/B-020 MS46122A/B-040	Maximum Power	High	-3 dBm
MS46322A/B-010 MS46322A/B-020 MS46322A/B-040	Minimum Power	Low	-20 dBm

Other Setup

This Selection opens the Min. Port Power dialog. (See description of dialog below) When Sweep Type is Segmented (Frequency or Indexed), this capability is not available and the button is deactivated and grayed out.

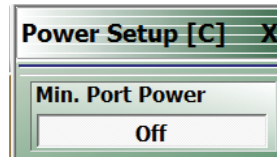


Figure 13-3. Power Setup Menu

Min. Port Power Dialog

This dialog has one button for on/off control of minimum power on the ports. When set On, the VNA will use the lowest output power it can achieve. (This is not the same as the Low Power setting, which simply applies the normal Low Power setting in sweeps.

13-5 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

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 13-4 and Figure 13-5. 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 13-4. FREQ BASE SETUP (FREQUENCY-BASED SETUP) Menu

# of Pts : 2		<div>^</div> <div>v</div>		Enter						
	Seg. On	Freq Def. for F1 & F2	F1	F2	# of Pts	Step/Stop Freq	IFBW	Src Power [Coupled]	Averaging	
▶ 1	<input checked="" type="checkbox"/>	Start & Step Size	9.999992 MHz	13.5 GHz	2	13.50999999...	100 kHz	Low	2	
2	<input checked="" type="checkbox"/>	Start & Stop	21.09999829...	30 GHz	2	8.900001701 ...	100 kHz	Low	3	
3	<input checked="" type="checkbox"/>	Start & Stop	30.00000000...	30.00013 GHz	50	2.653040816...	100 kHz	Low	3	

Figure 13-5. 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 13-6.



Figure 13-6. 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 13-7](#) for the same setup as [Figure 13-6](#). 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.

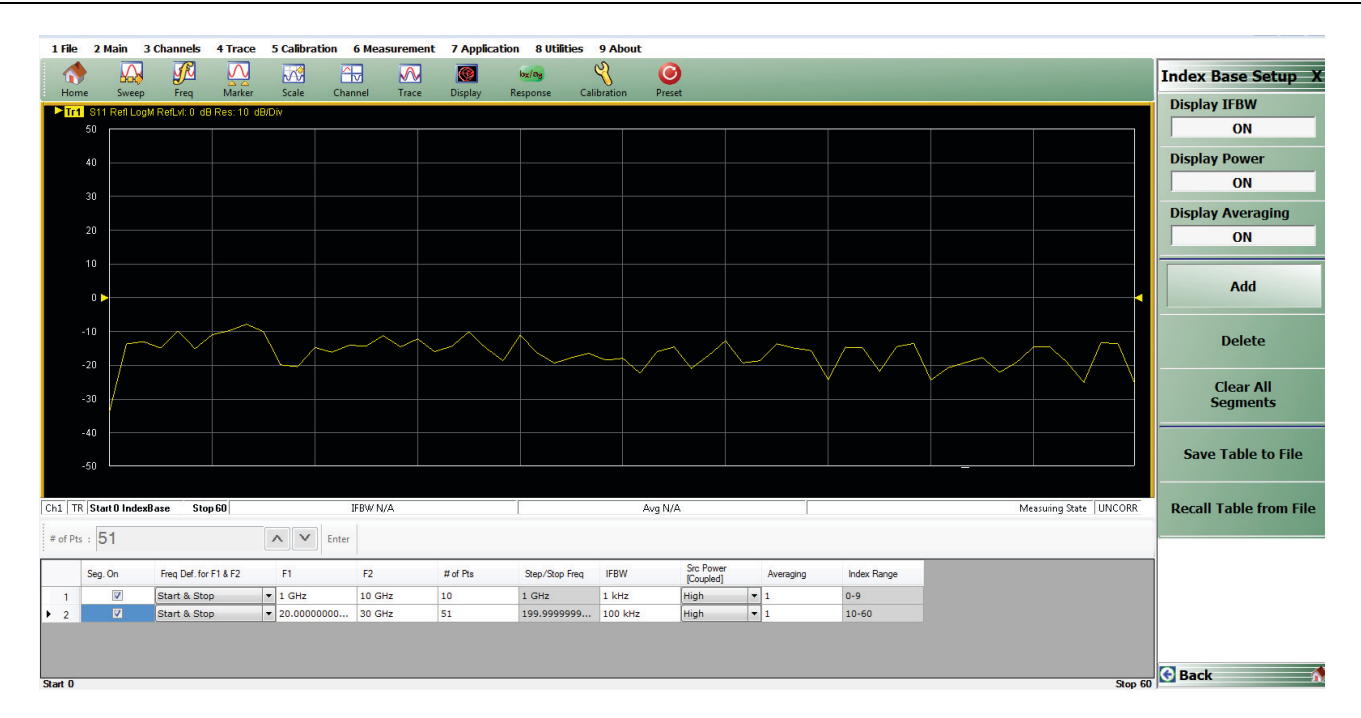


Figure 13-7. Index-Base Graph Mode

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).

13-6 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 13-8](#) and [Figure 13-9](#).

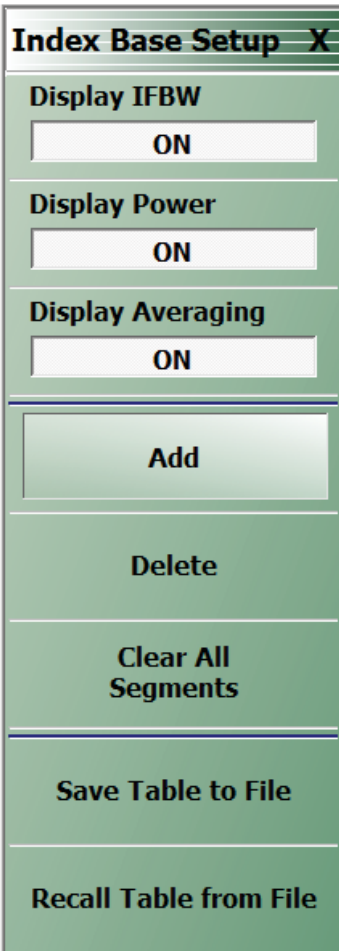


Figure 13-8. Main Menu for Index-based Segmented Sweep - INDEX BASE SETUP Menu

All plotting in this sweep type is based on the point index, which is listed in the last column of the table below.

Ch1	TR	Start 0 IndexBase	Stop 67	IFBW N/A				Avg N/A			
F2 :		10.000000000	<div>^</div> <div>v</div>	GHz	MHz	kHz	Hz				
	Seg. On	Freq Def. for F1 & F2	F1	F2	# of Pts	Step/Stop Freq	IFBW	Src Power [Coupled]	Averaging	Index Range	
▶ 1	<input checked="" type="checkbox"/>	Start & Stop	10 MHz	10 GHz	15	713.5714285...	100 kHz	High	1	0-14	
2	<input checked="" type="checkbox"/>	Start & Stop	25 GHz	26 GHz	51	20 MHz	100 kHz	High	1	15-65	
3	<input checked="" type="checkbox"/>	Start & Stop	6 GHz	27 GHz	2	21 GHz	100 kHz	High	1	66-67	

Figure 13-9. 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.

Chapter 14 — E/O and O/E Converter Measurements

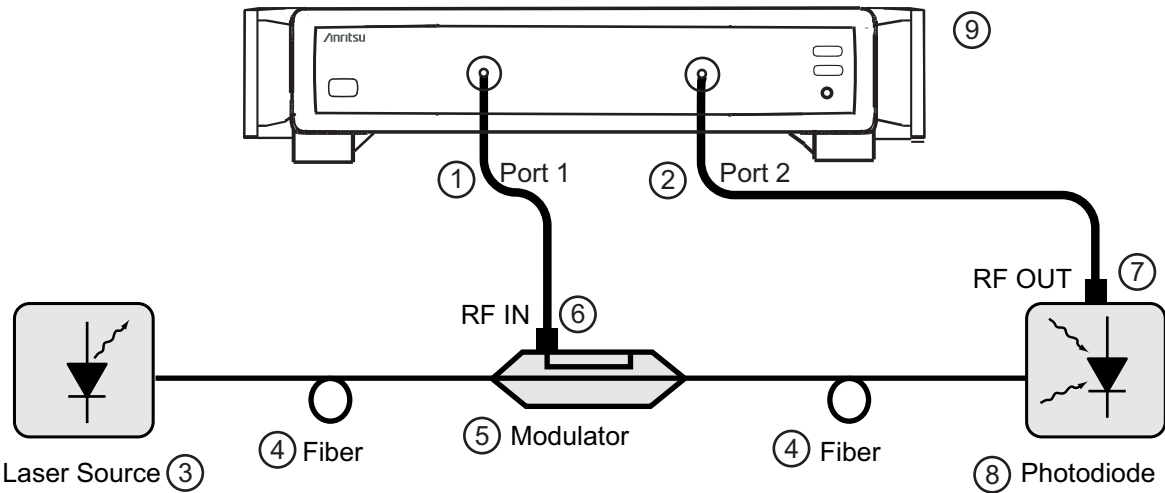
NEW CHAPTER

14-1 Chapter Overview

As fiber and free-space optical communication bandwidths increase, the need for very high speed optical modulators and detectors has also increased. The frequency response characterization of these **electrical-to-optical** (E/O, modulators sometimes integrated with lasers) and **optical-to-electrical** (O/E, detectors and receivers) converters can be important in terms of such parameters as bandwidth, flatness and phase linearity. The ShockLine Series VNA have a number of measurement utilities to facilitate this kind of analysis and, coupled with the MN4765X O/E calibration module or some other calibration device, some level of measurement traceability is possible. This chapter will discuss some of the measurements of interest, setup considerations, possible measurement performance, and examples of execution procedures.

14-2 Introduction and Background

Conceptually, the job of the optical modulator is to place a microwave signal as modulation onto an optical carrier. Similarly, the job of the photodetector or receiver is to recover that modulation and regenerate the microwave signal. For a VNA-based measurement, both directions of conversion are required so that the processing can occur in the microwave or modulation signal domain. The result is a setup like that shown in Figure 14-1. The optical carrier is generated (usually) by a coherent laser source (which may be integrated with the modulator), modulation is applied, and then the modulation is recovered. Optical fiber is shown as the media in Figure 14-1 but it could be some other optical guiding medium or free-space in some cases. The VNA acts as a microwave stimulus (Port 1 in the figure) and receiver (Port 2 in the figure). Three and four port cases are also possible, involving multiple converters or differential ones, which will be discussed later in this chapter.



Index	Description	Index	Description
1	VNA Port 1	6	Modulator RF IN
2	VNA Port 2	7	Photodiode RF OUT
3	Laser Source	8	Photodiode
4	Fiber	9	MS46122A/B or MS46322A/B VNA
5	Modulator		

Figure 14-1. A general 2-port E/O or O/E measurement setup is shown here. In some cases, the laser and modulator may be one assembly. The photodiode may be integrated with amplifiers or other components into a photoreceiver.

Since the measurements results will be classed as normal S-parameters, one may wonder how these relate to the actual optical behaviors of the components. In some sense, they all become relative because the conversion between domains introduces dependencies on optical laser power, optical path losses (usually small) and other absolute shifts. Thus the real measure of conversion is essentially a responsivity slope between the optical and electrical domains as illustrated in Figure 14-2.

The S-parameters that appear on the instrument display for an O/E or an E/O component then represent a relative responsivity measure (in both magnitude and phase). Often, the frequency response of this quantity is of interest as that determines bandwidth and magnitude vs. frequency plot gives this information. The phase linearity and group delay are both ways of looking at the deviation from a purely linear phase function that can be an important assessment of potential phase-related modulation distortion. Return loss of the component may also be of interest but that is a purely microwave measurement.

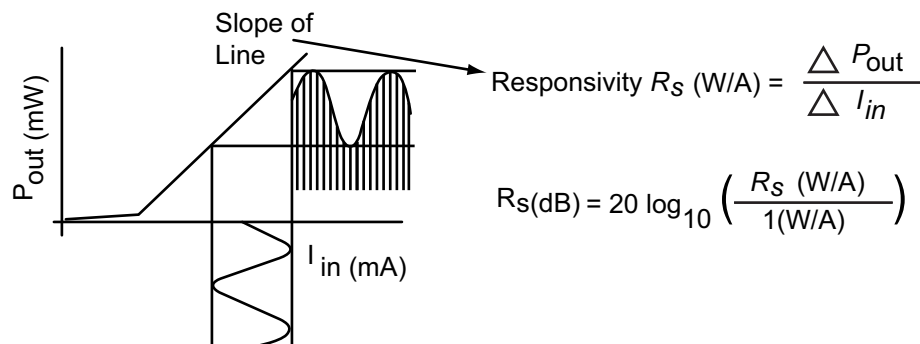


Figure 14-2. The concept of responsivity is shown here. The conversion parameters of the O/E and E/O devices measured with the VNA are essentially measures of responsivity.

A next question may be how the measurements are conducted. The starting point is a two-port VNA calibration as has been discussed in earlier chapters of this measurement guide. This calibration establishes reference planes at the microwave ports of the optical devices as shown in [Figure 14-3 on page 14-4](#) (often coaxial ports but could be waveguide, in a fixture, etc.).

The next step is the use of an O/E calibration device such as the MN4765X. That particular model is a wide bandwidth photodetector housed in a thermally controlled module with carefully designed bias circuitry. This module is characterized at a traceable facility using electro-optic sampling techniques (or references derived from that) so its frequency response (in magnitude and phase) is well-known with established uncertainties (e.g., [1] -[2]).

If such a calibration device is the detector in [Figure 14-1](#), then its effects can be de-embedded (see the embedding/de-embedding sections of [Chapter 9](#) in this guide for more general information) since those behaviors are known. This then moves the reference plane to the optical side of the photodiode/calibration detector as shown in [Figure 14-3](#). Now a measurement of S21 will describe the loss and phase of the modulator alone (plus some effect of the fiber which will be discussed). This frequency response (magnitude and phase) gives the required performance information discussed earlier when combined with the microwave reflection measurement (S11 in the diagram) of the modulator RF port that comes for 'free' with the calibrated VNA measurement.

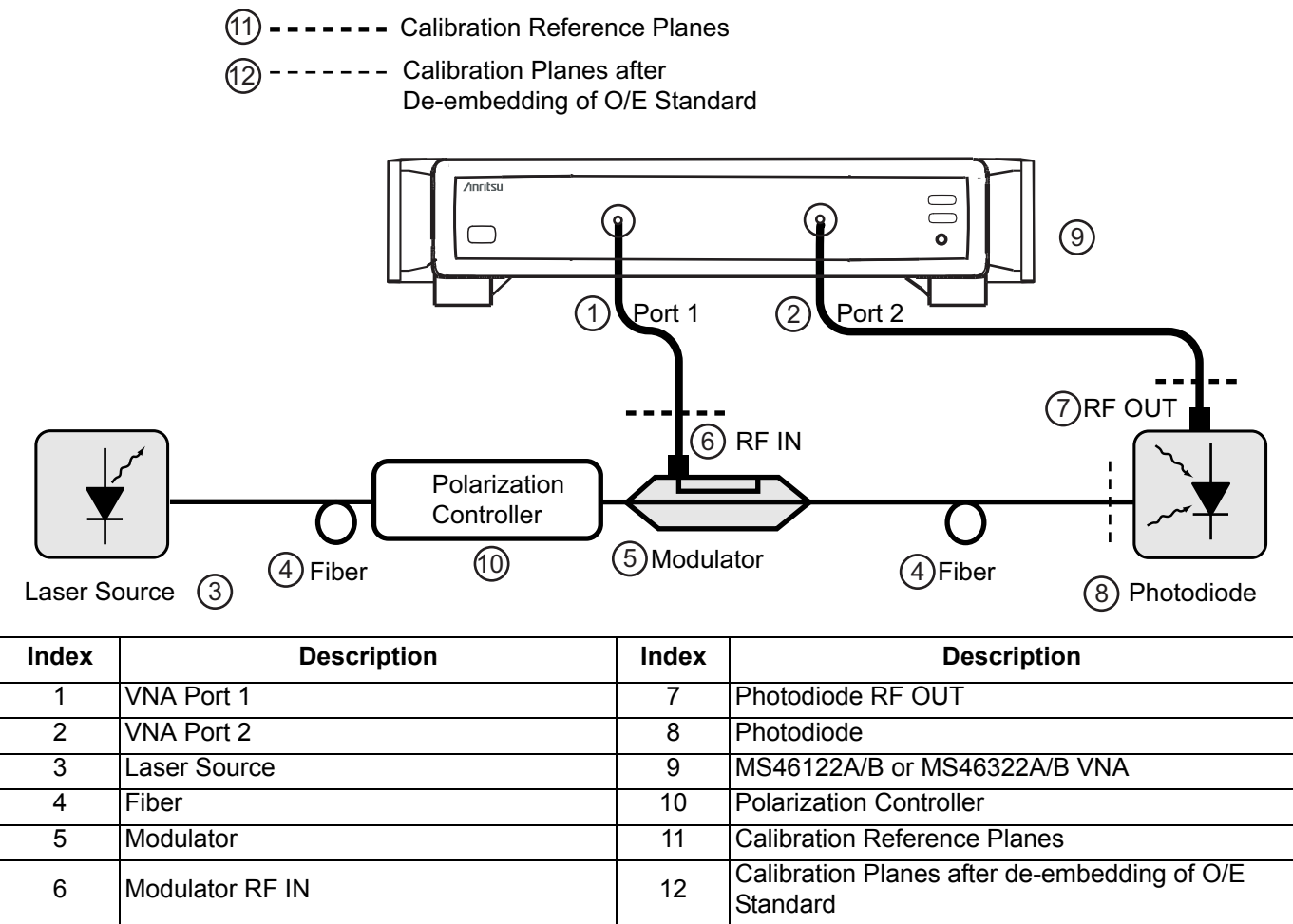


Figure 14-3. Reference plane placement is shown here. A calibration is done in coax, waveguide, or some other electrical media and the de-embedding function, via the O/E-E/O measurement utility, of the VNA are used together with optical data to move a reference plane into the optical domain.

The MS46122A/B and MS46322A/B have a maximum frequency of 43.5 GHz. The following example is primarily for explanatory purposes. An example plot of the conversion response of a 50 GHz photodetector is shown in [Figure 14-4](#). From the magnitude response, the 3-dB bandwidth is indeed around 50 GHz but the roll-off is sufficiently slow that this device is commonly used beyond 65 GHz.

Device Response

The device response is shown in the figure's below, but the linear portion has not been removed. The group delay plot (derivative of phase with respect to frequency) is often a more convenient way of looking at the phase behavior. Towards 50 GHz, there are some deviations from flat group delay (equivalent to deviations from linear phase) that are not surprising in view of the device's bandwidth. If being used as a characterization device, these deviations are not important since they can be well-characterized (to beyond 65 GHz in this case).

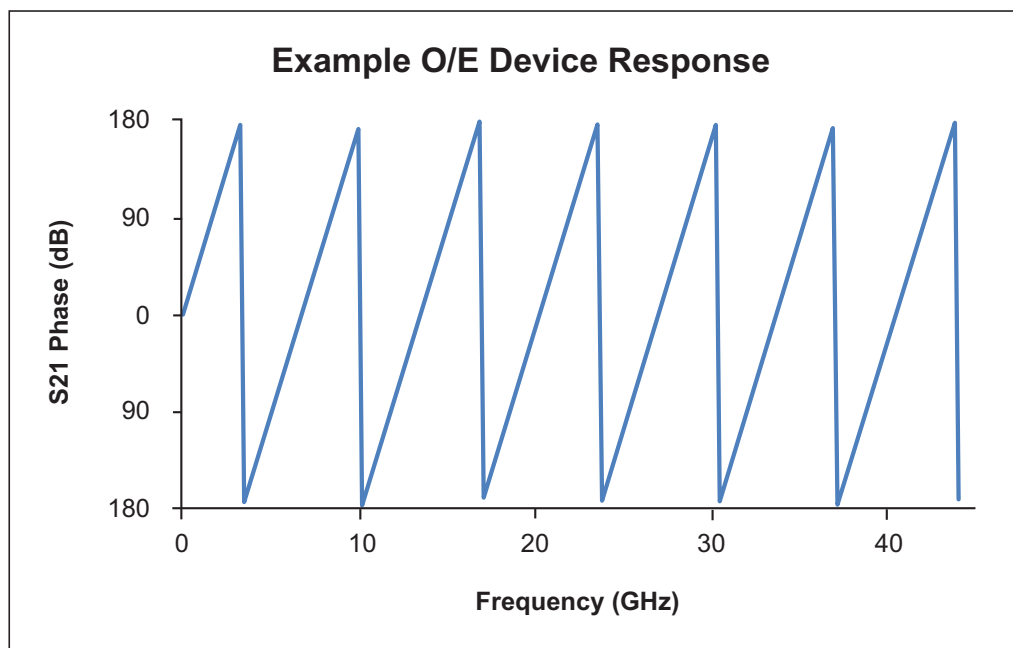
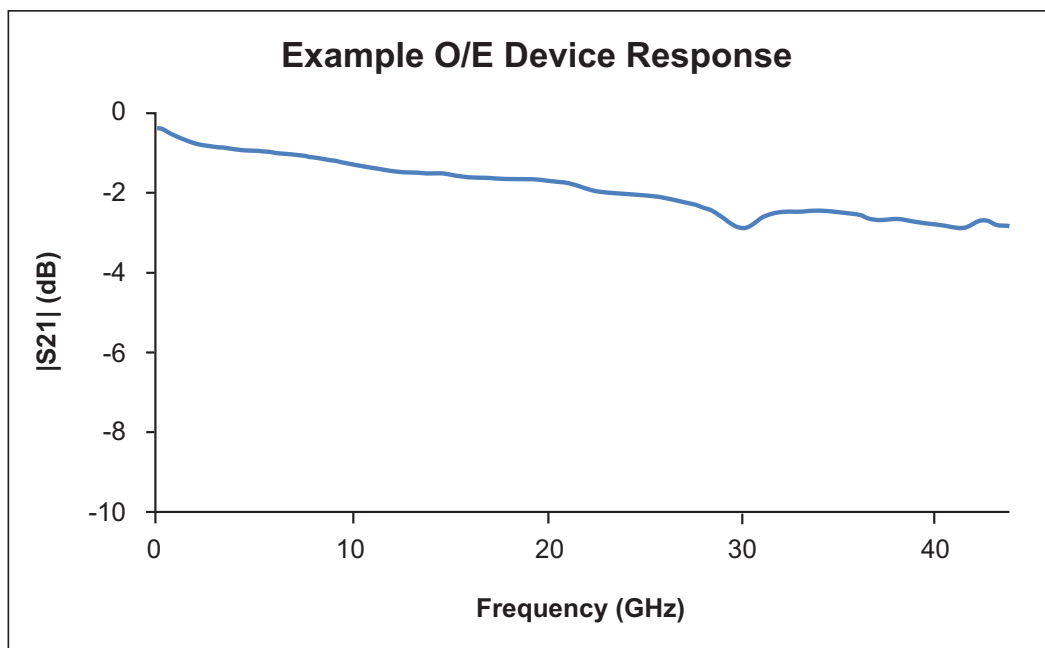


Figure 14-4. The characteristics of an example O/E device are shown here.

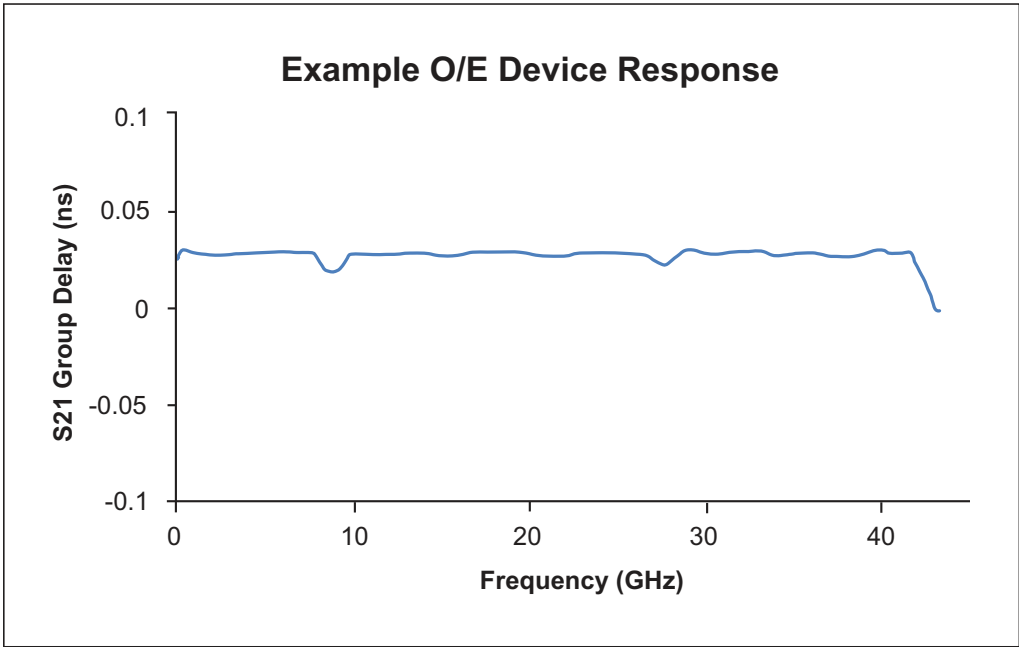


Figure 14-4. (Continued)The characteristics of an example O/E device are shown here.

If one now wanted to measure a different O/E device (not a calibration module), one could then insert that detector into the setup of [Figure 14-3 on page 14-4](#) and instead now de-embed the modulator response that was just found. In this case, because it is a second level de-embed, there may be some elevation of uncertainties that will be discussed. One could also obtain an E/O calibration device and use that instead in a one-step process.

The de-embedding (or sequential de-embedding) steps form the basis of this O/E-E/O measurement utility. The key points are controlling traceability and uncertainties throughout the process when multiple devices are being used, to control match so minimal additional artifacts are introduced, and to not try to de-embed what cannot be de-embedded. This last point is important in that inner-plane (optical) match is not known and the transmission path is unilateral anyway, so there are no multiple reflections within the DUT assembly to remove.

Measurements/(O/E-E/O) menu

All of these measurement aids are available under the O/E-E/O button on the Measurements menu. As might have been guessed from the previous discussion, these approaches naturally separate based on whether the target is an O/E device (e.g., detector or receiver) or an E/O device (e.g, modulator). The menu selections, as shown in [Figure 14-3](#) delineate that choice.

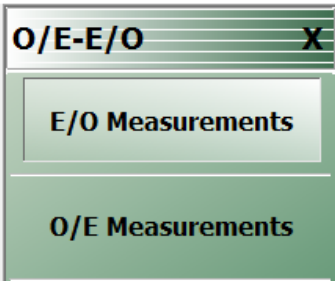


Figure 14-5. Under the Measurements/(O/E-E/O) menu are the two selections based on which type of device is to be solved for.

14-3 Measurement Setups and Considerations

It is not the intent of this chapter to fully cover the optical setup details. However, some common issues and concerns will be discussed. More general information of fiber optic measurement setups can be found elsewhere (e.g., [3]-[4]).

Optical linearity

The linearity of the characterized photodiode directly affects the accuracy of the measurement and the optical input power at which RF photocurrent will remain linear is important. One way to check that the measurement path is still linear is to normalize the S21 plot against itself and increase the optical power to see if there is a gross sensitivity. For example, set the optical laser power to 4 or 5 dBm with the setup like that of [Figure 14-1](#). Store the resulting S21 to memory (under the Display/View Trace menu) and then view DataMemMath (data divided by memory). Now increase the laser power in 1 dB steps until some compression is seen in the normalized plot on the scale of 2 dB/div. At that point, decrease the optical power level until it is out of compression. Make sure that the maximum DC current for the photodiode is not exceeded.

Laser power and photodetector bias sequencing

Always make sure the photodiode is biased properly before turning the laser on. Improper bias or no bias can degrade photodiode performance and can also result in damage. Instructions on handling and biasing of the photodiode are shipped with the characterized photodiode accessory. Always observe ESD precautions as these devices are very sensitive to static discharge.

Optical fiber lengths

The measurement setup will typically require optical fibers to interconnect optical components with different connectors. For example, a modulator with an FC/PC connector at the output will require an optical patch cord to adapt to the FC/APC connector on the input of the characterized photodiode accessory. Optical fibers have negligible frequency dependent loss over microwave modulation bandwidths. Thus, adding short lengths of optical patch cords to the setup does not affect the accuracy of transfer function measurements. To avoid certain polarization-related issues, it is recommended to keep the patch cord length under 10 m.

Modulator Bias Control

Lithium niobate modulators are generally biased using a modulator bias controller (MBC) to control the operating point of the modulator. When biased in quadrature, the input RF signal linearly modulates the optical carrier. Note that when an MBC is applied, it must be designed for small signal operation. The default power from the Port 1 test port is -10 dBm. This level results in a modulation depth of $<10\%$ for many commercially available modulators. If a different model VNA or a different option configuration is being used, it may be required to drop the VNA power level from the default setting to ensure that the modulator is operating linearly. Different technology modulators may have different linearity limits so it may be required to consult the manufacturer of that device.

A DC power supply can be used in place of an MBC. However, the stability of the measurement may be degraded due to drift in the modulator's bias point.

Connector care

It is important to establish proper cleaning procedures when connecting fiber optic devices together. Fiber optic cores are made of glass and can easily be scratched or chipped if care is not taken. The connectors found on the MN4765X are of the FC/APC type. APC (Angled Physical Contact) is chosen to help minimize back-reflection. The 8° angle at the end-face of the APC connector has an optical return loss of better than 50 dB. DFB lasers require large amounts of reflection isolation to function properly. The optical return loss from a common PC connector can 30 dB or worse, depending upon the polish and cleanliness of the connector.

The following are some tips to help ensure quality connections:

- Always clean connectors after every connection.
- Use a fiber optic scope often to ensure there are no defects on the connector end face that can cause damage to other connectors.
- Use insertable patch cords for expensive devices that require many connections.
- Always use a cloth that is free of fiberglass to clean the connectors. If necessary, use alcohol to remove stubborn dirt and oil. Thoroughly remove any alcohol residue before reconnecting.
- Avoid using any oils for connecting two cables together. Oils are messy and very difficult to clean up.
- Optical connectors do not need torque. Some connections are better when the two fibers are barely touching. Tightening the connector too much will result in higher insertion loss, more reflection, and in some cases damage to the connector.
- Always observe proper mating to APC connectors. Connecting APC to PC connectors will damage the connectors.

14-4 Example 2-port Procedures

With the physical setup described, the next task is really how to interface with the measurement utilities. Consider first the case of a 2-port E/O measurement where one has a characterized O/E device (such as the MN4765X). The dialog for this measurement is shown in [Figure 14-7 on page 14-10](#) (the system automatically detects if it is a 4-port configuration in which case one of the later dialogs would be displayed instead). One choice that has to be made is the port configuration. The default is to have the E/O device connected to port 1 of the VNA but this can be changed.

Navigation to 2-Port E/O Measurement Dialog Box

Main | Measurement | MEASUREMENT | O/E-E/O | E/O Measurements

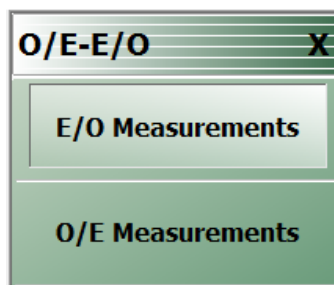


Figure 14-6. O/E-E/O Measurement Menu

The other major requirement is a 2-port VNA calibration. This dialog assumes that the calibration has already been done with the desired method, frequency range, etc. and saved (using **Save Setup** under the **File** menu) as a .chx file. Most of the setup parameters are obvious:

- **Frequency Range and Number of Points** (dictated by the bandwidth of the DUT among other test requirements)
- **Power Level** (this depends on the linear drive range of the modulator as discussed above and the maximum available power of the VNA, which varies with options. Generally, the higher the better within those limits for best signal-to-noise ratio)
- **IF Bandwidth and Averaging** (trade-off between measurement time and trace noise. Generally 10-100 Hz IFBW is recommended for very wideband devices since the conversion losses tend to be high and the signal-to-noise ratio is stressed). Averaging can be added for additional trace noise reduction but there is a point of diminishing returns beyond about 10 sweep-by-sweep averages or if IFBW/(pt-by-pt averages) falls below 1 Hz.
- **Calibration Method** The only requirement is that the calibration contain a transmission path that match the E/O → O/E path (anything beyond that is acceptable). Some of the choices are:

E/O Port = 1

Forward transmission tracking (1 → 2)
 1 path – 2 port forward (1 → 2)
 Full 2 port calibration

E/O port= 2

Reverse transmission tracking (2 → 1)
 1 path – 2 port reverse (2 → 1)
 Full 2 port calibration

Any calibration algorithm can be used as appropriate.

Assuming this setup file is now available, it can be loaded in the dialog of [Figure 14-7](#) as can the O/E characterization file (in a .s2p file format). Note the **Swap ports** checkbox availability near the characterization portion of the dialog box. It is always assumed that the dominant path in the characterization file is the S21 parameter. If the file was constructed differently (e.g., S12 was the measurement path for the calibration device), then selecting the checkbox will force the instrument to reorder the ports in the file before processing.

When **Done** is selected on this dialog, the de-embedding is applied and the resultant calibration left on the system includes the shifted reference plane as suggested by [Figure 14-3 on page 14-4](#). This state can be saved as a new setup file (again using the **Save Setup** command under the **File** menu) if desired. Note that to go back to the non-de-embedded state, one can recall the old setup file that was just loaded in the dialog box. At this point, one can make measurements of any number of E/O devices and save the results using any of the usual techniques.

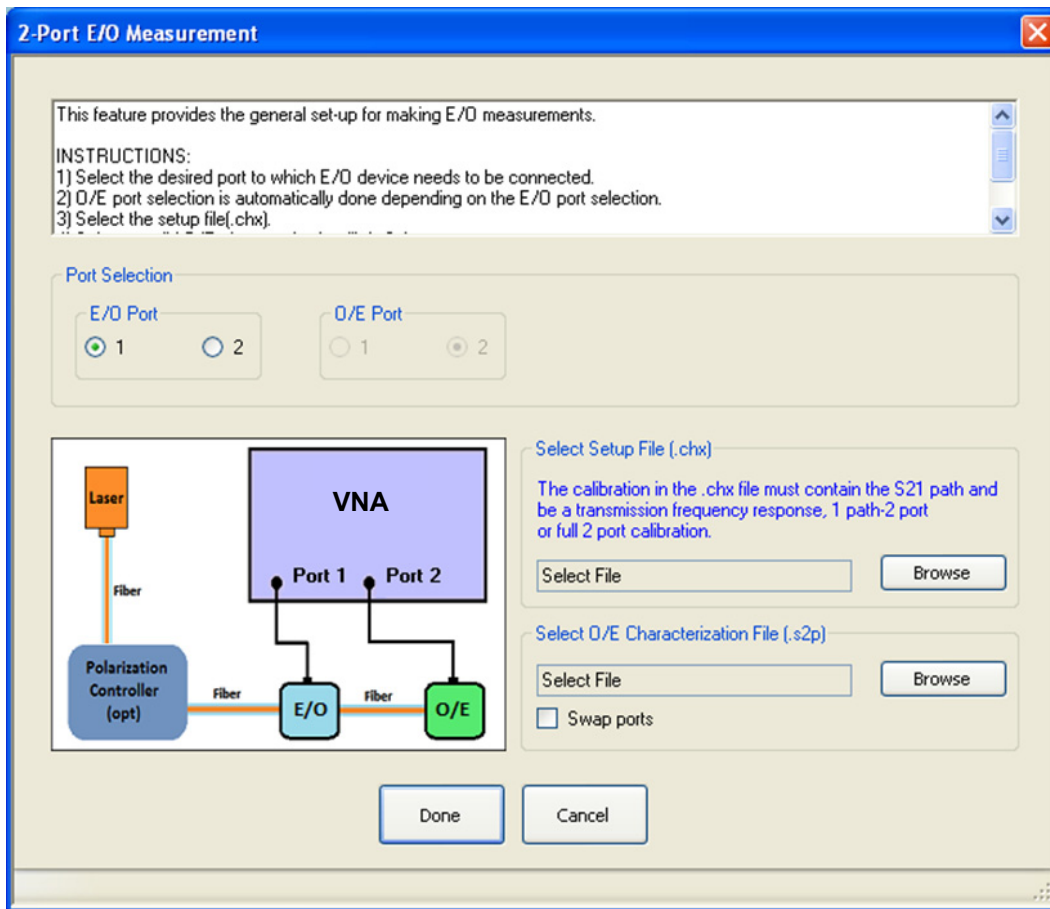


Figure 14-7. The dialog for 2-port E/O measurements is shown here.

The O/E measurement setup is quite similar and that dialog is shown in [Figure 14-7](#). The difference, of course, is that an E/O characterization file must now exist. One can generate it using the previous procedure and saving the measurement result as a .s2p file or one may already have a characterization file for the E/O device. If this is not the case, a shortcut is provided to help generate an E/O characterization file with less work. This path is triggered with the **Go Measure E/O** button which will bring up the sub-dialog of [Figure 14-9](#).

Assuming one has an O/E calibration device (such as the MN4765X), this **Go Measure** feature allows one to load that photodetector characterization file and use the setup file found on the main E/O dialog to do a quick measurement of the modulator (or assembly). The sub-dialog also has a field to save this new E/O characterization file. When completed, one can go back to the previous dialog and select **Done**. The resultant setup will now have the **Port 1** reference plane moved to after the modulator so one can now measure any number of new O/E devices. Again, the final setup (with shifted reference planes) can be saved as can any new measurement data of the O/E devices.

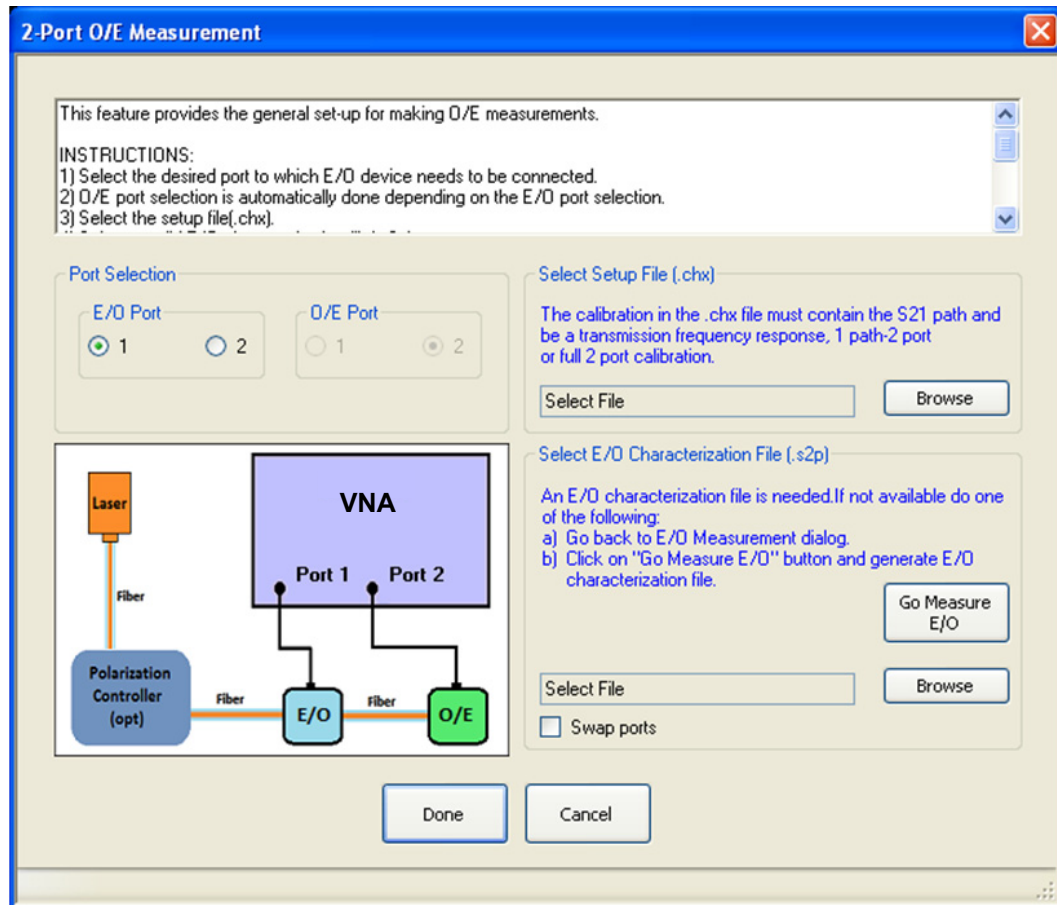


Figure 14-8. The dialog for 2-port O/E measurements is shown here.

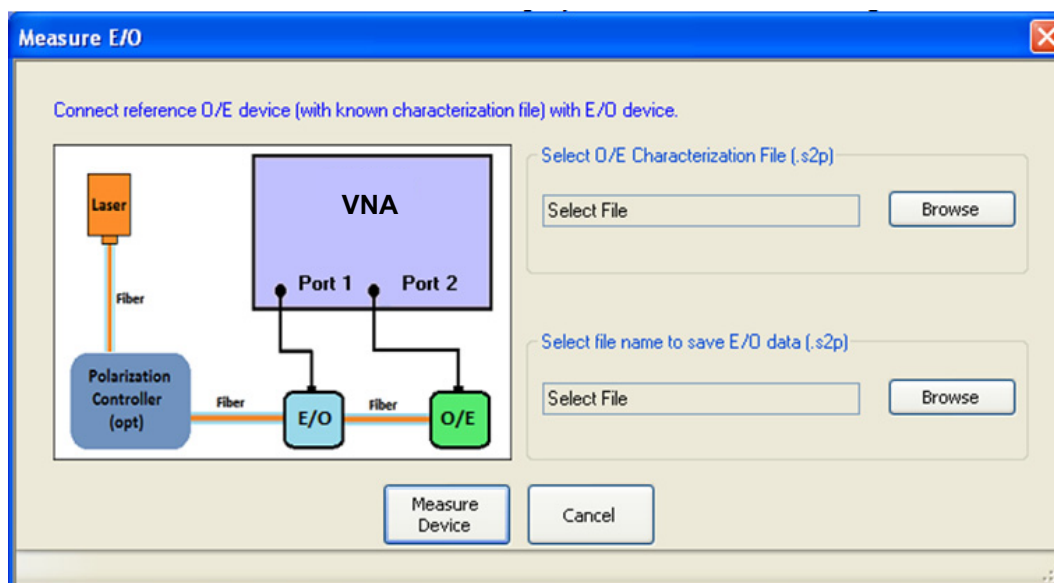


Figure 14-9. When measuring O/E devices, the characteristics of the E/O device must be known. If a file does not already exist, this dialog can help in doing the intermediate measurement with the help of a calibration O/E device such as the MN4765X.

Example

As an example, consider the following setup:

- 2 GHz to 40 GHz, 10 Hz IFBW, power –20 dBm, no averaging.
- A full two-port SOLT/SOLR calibration is performed using a 3652A Calibration Kit.
- The resulting setup file is saved as setup.chx. This setup file will include all of the above parameters including the calibration data.
- The optical assembly is hooked up with the modulator-under-test connected to Port 1 and an MN4765X O/E calibration module connected to Port 2 of the VNA. The laser is powered up after setting up bias control on the modulator and applying bias to the MN4765X (and, of course, connecting the fiber).
- The E/O measurement utility is invoked using the default port assignment, loading the .chx setup file and loading the characterization file of the MN4765X. Upon selecting **Done** on the dialog, the resulting S21 measurement reflects the conversion behavior of the modulator and is shown in [Figure 14-10](#). In this case, there is about 10 dB of roll-off over the bandwidth of the measurement.

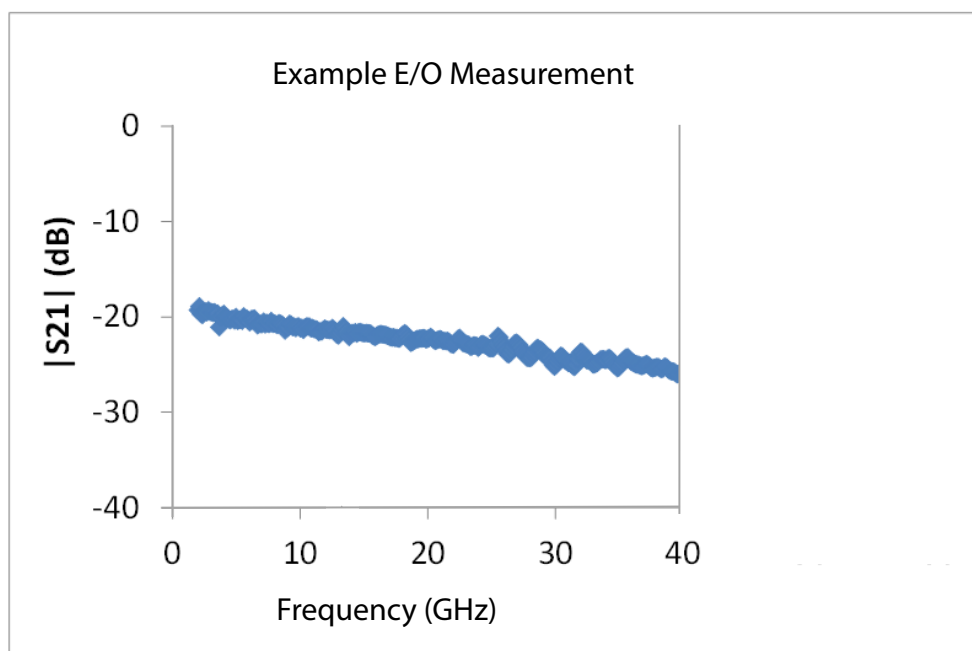


Figure 14-10. The results of an example 2-port E/O measurement are shown here using the procedure discussed in the text.

14-5 Uncertainties

In the measurements just described, the uncertainty can be broken into two broad categories:

1. Uncertainty associated with the characterization of the calibration device (such as the MN4765X)
2. Uncertainty in the measurement with the DUT

Typically the user will purchase a characterized photodiode and receive a data file describing that device's transfer function. There is some uncertainty associated with that data based on the characterization technique.

There are different levels of characterization possible. A direct characterization using such optical techniques as electro-optic sampling (e.g., [1]) or the heterodyne method (e.g., [2]) would be termed 1st tier. It is outside the scope of this note to go into detail on these characterization techniques but they are discussed in the references and elsewhere in the literature. These 1st tier characterizations are typically performed at National Metrology Institutes (NMIs, such as NIST or NPL) or large private laboratories.

A 2nd tier standard is characterized by a laboratory based on a 1st tier standard. It would be generated using a process similar to the techniques discussed here but under carefully controlled conditions (bias, temperature, wavelength, etc.) using a 1st tier standard as the characterization device. This 2nd tier device is much more commonly available (the MN4765X is an example) and the uncertainties for a 2nd tier standard will be used in later calculations. The uncertainty penalty in going to 2nd tier device is typically small (on the order of 0.1 dB additional).

When measuring the DUT, there is an uncertainty associated just with the VNA measurement which is discussed elsewhere (e.g., [5]). Since the characterized photodiode response is then de-embedded, the characterization uncertainty must be combined with the VNA measurement uncertainty to obtain an overall value. In the case of an O/E measurement, there are actually two user measurements involved (one with a modulator and the characterized photodiode and one with that modulator and the DUT) so an additional uncertainty must also be included (note the distinction between this second level de-embed and a 2nd-tier calibration device). Typically these uncertainties are all added on a root-sum-square basis since the measurements are assumed to be dominated by uncorrelated quantities.

Before proceeding to some uncertainty values, it may be useful to examine dependencies. On the VNA side, S21 uncertainty is typically quite low for medium power levels but will deviate at high signal levels (receiver compression, not an issue in these measurements) and at low signal levels (effects of the receiver noise floor). Thus the overall uncertainty will be a function of detector output signal level (getting worse as the signal level gets closer to the noise floor). Results can be improved by using higher RF drive levels (keeping all devices linear) and high optical power levels (same caveat). The RF match of the modulator and photodiode will also influence uncertainties to some degree (at all signal levels) but the dependence is relatively weak as long as return loss is better than a few dB.

On the optical side, there is little high level signal dependence as long as the devices are operating linearly. The characterized photodiodes are usually chosen to be very linear over wide power ranges to keep this from being an issue. The characterized detectors typically also have very weak wavelength dependencies; usually less than a few hundredths of a dB over 40 nm. When using a modulator as a transfer standard (as in an O/E measurement), however, it is important that the same wavelength be used in the different measurements with that modulator since much greater wavelength sensitivity usually exists in that component (although this will vary with technology). The use of different VNAs and/or calibration kits may result in slightly different values. Characterization uncertainties of the MN4765X O/E calibration device were used for the standard part of the model. Optical system drift is included in the error model but it is assumed that all components are mechanically and thermally stable. Connector repeatability is also included in the model but all connectors are assumed to be in very good condition. The results are shown with an independent variable of photodiode output power and plotted for both magnitude and phase for the two different types of measurements. Frequency is used as a parameter. While the results for a two port measurement are shown here, there are normally no significant deviations in going to four port structures.

14-6 Summary

The E/O and O/E measurement utilities have been discussed in this chapter. This utility is essentially an advanced de-embedding tool allowing one to remove the effects of one optical conversion device to learn the properties of the other. There are a large number of configuration choices, particularly in the four port cases, but the measurement principle is the same: use a good VNA calibration to characterize the converting pair and then de-embed the effects of a calibrated/characterized device to analyze the DUT. Signal-to-noise ratio is often a limiting uncertainty factor so it is important to carefully choose drive levels (as high as possible without being nonlinear), IF bandwidth, and averaging in order to optimize the measurements.

14-7 References

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Chapter 15 — Maximum Efficiency Analysis (MEA) Measurements

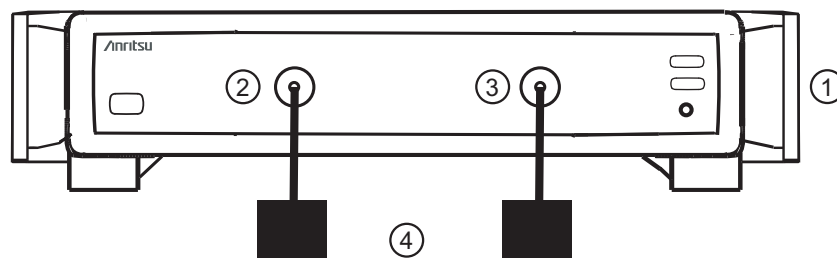
15-1 Overview

The ability to accurately measure maximum efficiency and the kQ product for Wireless Power Transfer (WPT) systems is becoming very important. Anritsu, in collaboration with Toyohashi University of Technology have provided a measurement system that evaluates the product of the WPT coupling coefficient and quality factor. This kQ product is mathematically related to the maximum efficiency of the WPT and both can be shown in real time.

More and more devices are becoming disconnected from cables as wireless power transfer continues to become a dominant technology. This chapter will discuss some of the measurements of interest, setup considerations, and examples of execution procedures.

15-2 Introduction

The VNA acts as a wireless power transfers system that transfers electromagnetic power from one VNA port to the other VNA port via Transmit/Receive elements.



1. ShockLine MS46122A/B or MS46322A/B VNA

2. VNA Port 1

3. VNA Port 2

4. Transmit/Receive Elements

Figure 15-1. 2-Port MEA Measurement Setup

A general 2-port MEA measurement setup is shown in [Figure 15-1](#). The Transmit/Receiver elements are not limited to coils or antennas and can be a device that moves electromagnetic energy.

Software Setup for Maximum Efficiency Analysis

ShockLine software provides a simple interface to setup parameters for Maximum Efficiency Analysis. The initial parameter that must be setup is the Response type. The Response type is not an S parameter but a Z parameter that is mathematically manipulated to provide key parameters for measuring a WPT system. The correct response for this measurement Max Efficiency as shown in [Figure 15-2](#).

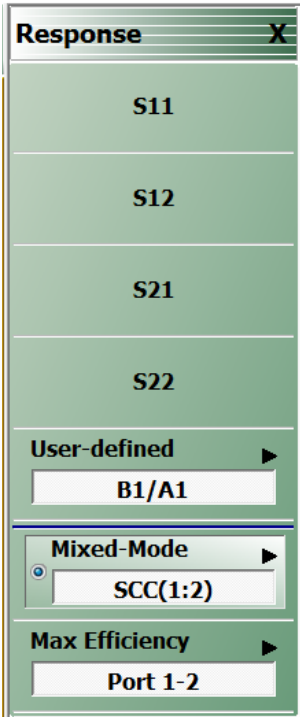


Figure 15-2. Response Menu with Max Efficiency for WPT

When the Response type has been set to Max Efficiency, ShockLine software enables a set of hidden menus that allows the user to access kQ product and maximum efficiency buttons. This menu is accessible via the ShockLine customized toolbar or through the Main menu function. The Display menu with enabled Maximum Efficiency Analysis display option is shown in [Figure 15-3](#).

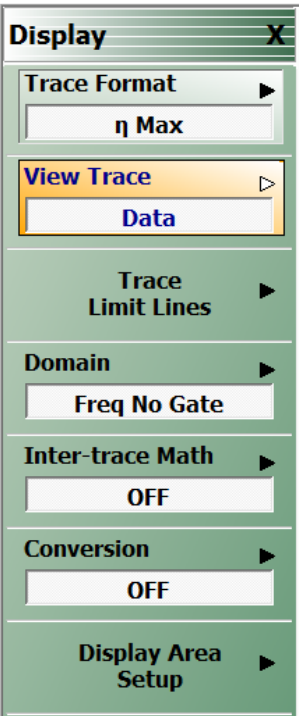


Figure 15-3. Maximum Efficiency Analysis Display

The Display type will be limited to η Max (Maximum Efficiency), kQ or both. The user may want to see one format, the other or both and the measurement data is real time. See the Trace Format options for MEA in [Figure 15-4](#)

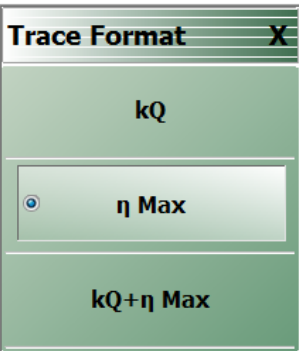


Figure 15-4. Trace Format Menu

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