Calibration and Measurement Guide

ShockLine™ MS46522A Series Value Vector Network Analyzer

MS46522A-010 VNA, 300 kHz to 8.5 GHz, 2-Port

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Symbols Used in Manuals

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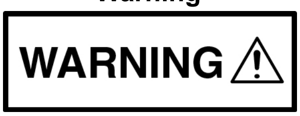
This indicates a risk from a very dangerous condition or procedure that could result in serious injury or death and possible loss related to equipment malfunction. Follow all precautions and procedures to minimize this risk.

Warning



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This indicates a risk from a hazardous procedure that could result in loss related to equipment malfunction. Follow all precautions and procedures to minimize this risk.

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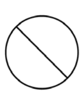
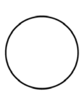
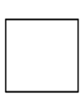


This indicates a prohibited operation. The prohibited operation is indicated symbolically in or near the barred circle.

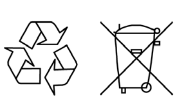


This indicates a compulsory safety precaution. The required operation is indicated symbolically in or near the circle.

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



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



These indicate that the marked part should be recycled.

For Safety

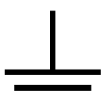
Warning

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

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

Warning

or



When supplying power to this equipment, connect the accessory 3-pin power cord to a 3-pin grounded power outlet. If a grounded 3-pin outlet is not available, use a conversion adapter and ground the green wire, or connect the frame ground on the rear panel of the equipment to ground. If power is supplied without grounding the equipment, there is a risk of receiving a severe or fatal electric shock.

Warning

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

Caution

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

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

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Chapter 8—Measurement Setup Requirements

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Chapter 10—Measurement - Sweep Types

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™ MS46522A Series Vector Network Analyzer (VNA) Systems 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

ShockLine™ MS46522A Series Vector Network Analyzers

The following ShockLine™ MS46522A Series Vector Network Analyzers documentation is available on the Anritsu internet and is provided on the user documentation USB Memory Device.

- MS46522A Series VNA Technical Data Sheet – 11410-00750
- MS46522A Series VNA Operation Manual – 10410-00330
- MS46522A Series VNA Measurement Guide – 10410-00331
- MS46522A Series VNA User Interface Reference Manual – 10410-00332
- MS46522A Series VNA Programming Manual – 10410-00333
- MS46522A Series VNA User Documentation – 2300-559-R

Calibration, Verification, and System Performance Verification

- 3653A Mechanical Calibration Kit Reference Manual – 10410-00278
- 3663-2 Verification Kit (for Type N Connectors) and 2300-527 Performance Verification Software (PVS) User Guide – 10410-00334
- 3663-2 Verification Kit and 2300-527 PVS Quick Start Guide – 10410-00335

1-4 Calibration Kits, Verification Kits, and Components

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

Calibration kits contain the precision components and tools required to calibrate the ShockLine™ MS46522A 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

Part Number	Name	Specifications	Connectors
Type N Connector Manual Calibration Kit			
3653A	Type N Calibration Kit	With fixed loads	Type N
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 2300-527 Performance Verification Software application and related documentation.	
Test Port Cables			
15NNF50-1.0B	Test port Cable, Flexible, Phase Stable	1.0 m	N(f) to N(m)
15NN50-1.0B	Test port Cable, Flexible, Phase Stable	1.0 m	N(m) to N(m)

1-5 SOLT 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/AUTOCAL utility menu (Figure 1-1) but user-defined kits can also be created using the parameters described above. If calibration kits from another manufacturer are used or to create a calibration kit, the following parameters are typically entered into one of the user-defined kits:

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

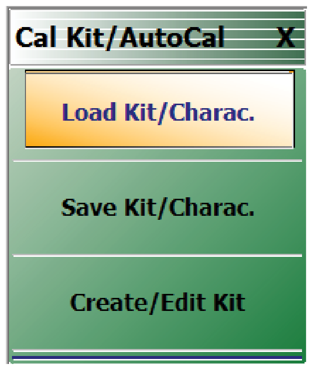


Figure 1-1. CAL KIT/AUTOCAL Utility Menu

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

1-6 Calibration Algorithms

The VectorStar MS4640B Series VNAs provide for the following calibration methods:

- Short-Open-Load-Through (SOLT) with Fixed or Sliding Load
- Short-Open-Load-Reciprocal (SOLR)
- Reciprocal or Unknown Through Method
- Line-Reflect-Line (LRL) / Line-Reflect-Match (LRM)

1-7 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 MS46522A Series VNAs. The choice between them is largely determined by the media used, the calibration standards available, and the desired accuracy/effort trade-off. Some of the choices to be made are:

- **Calibration Type**

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

- **Calibration Algorithm**

  How is the correction being accomplished?

Calibration Types

Table 1-2. MS46522A 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
SOLR, like above but with "Reciprocal" instead of "Through"	Like the above but when a good through is not available	Does not require well-defined through	Some accuracy degradation but slightly less definition, other disadvantages of parent cal
LRL (Line-Reflect-Line, also called TRL)	High performance coax, waveguide or on-wafer	Highest accuracy, minimal standard definition	Requires very good transmission lines, less redundancy so more care is required, band-limited
ALRM, advanced line-reflect-match, simplifies to: LRM (Line-Reflect-Match) or TRM (Through-Reflect-Match)	Relatively high performance	High accuracy, only one line length so easier to fixture/on-wafer, not band-limited usually	Requires load definition. Reflect standard setup may require care depending on load model used

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

Table 1-4. Calibration Types and Calibration Algorithms

VNA Mode	Type	SOLT	SOLR	LRL
2-Port Mode	Full 2 Port	YES	YES	YES
	Full 1 Port	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		–
	Frequency Response	YES		–

1-8 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 500 kHz on the MS46522A 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). Sweep time will be roughly proportional with the reciprocal of IFBW once below 100 kHz IFBW.

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

- **Power**

  Port power is somewhat less critical because of the excellent linearity of the MS46522A VNA receivers.

1-9 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, “MS46522A Calibration Types” on page 1-4).

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.

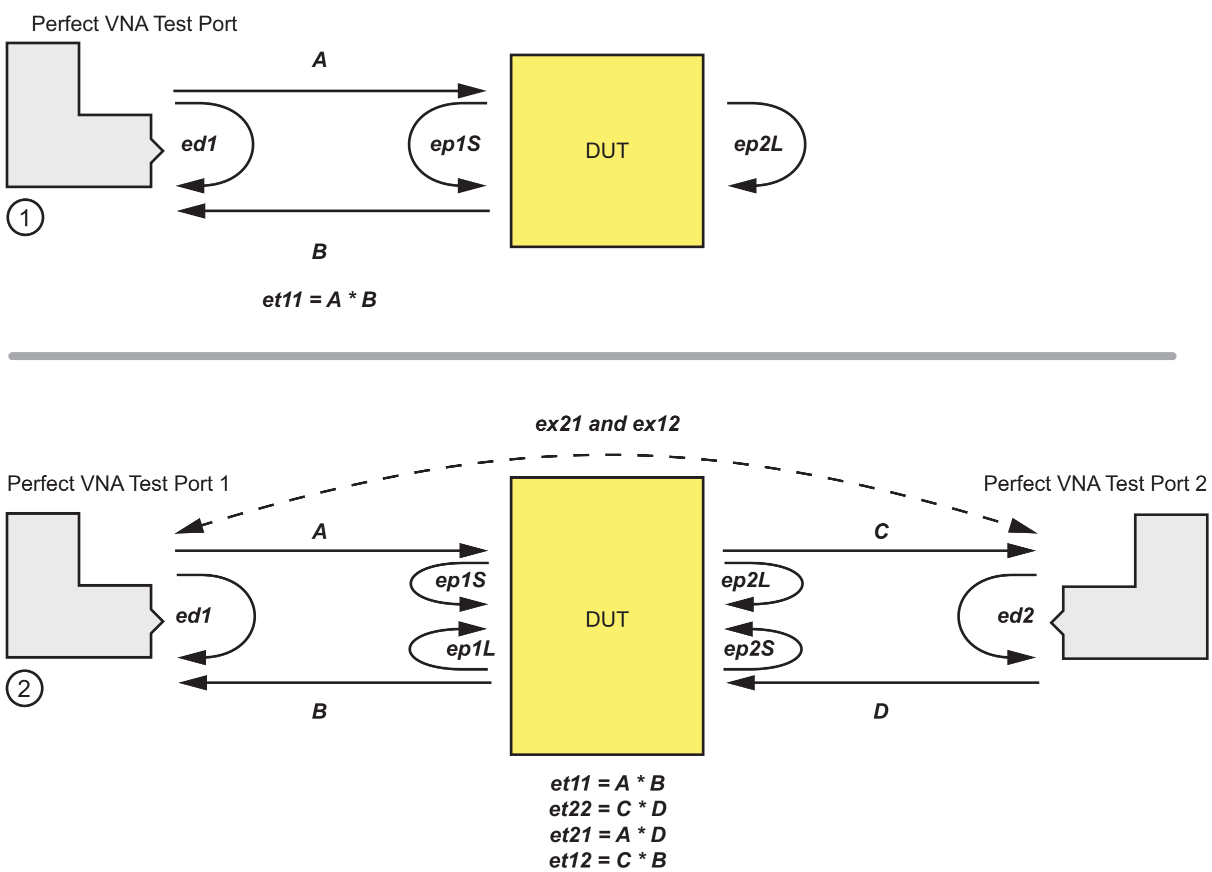
1 Path 2 Port (Forward or Reverse)

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 (≅ >10-20 dB insertion loss).

Frequency Response (Reflection Response and Transmission Frequency Response)

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

Each of these calibrations has an associated error model that describes what is being corrected. The error coefficients used fall into several categories that roughly describe the physical effect that they are responsible for correcting.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 1-7).



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

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

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

- **Directivity**

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

- **Source Match**

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

- **Load Match**

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

- **Reflection Tracking**

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

- **Transmission Tracking**

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

- **Isolation**

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

1-10 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:

$$
\begin{aligned}
v_{ph} &= \frac{c}{\sqrt{\varepsilon_r}} \\
&= \text{Phase velocity for coaxial and non-dispersive media}
\end{aligned}
$$

Eq. 1-1

Where:

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

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

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

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

Eq. 1-2

Where:

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

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

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

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

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

Eq. 1-3

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

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

Eq. 1-4

Where:

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

1-11 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.)

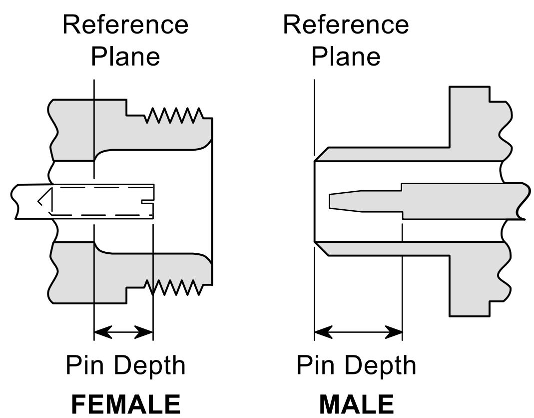
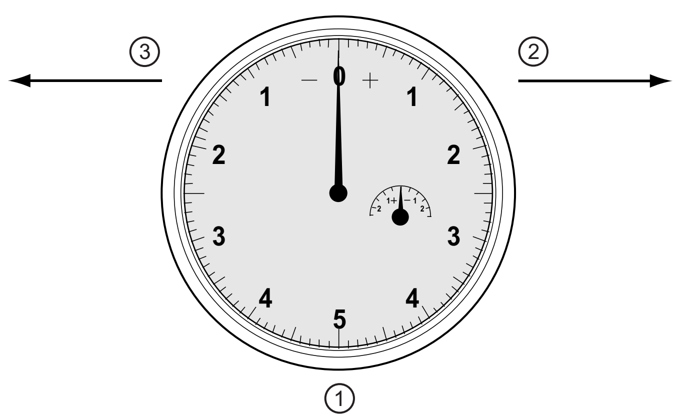


Figure 1-3. N Connector Pin Depth

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 1-12 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	+.0579 +.0697	+1.47 +1.77
7/16 Female	–.0697 –.0815	–1.77 –2.07
GPC-7	+0.000 –0.003	+0.000 –0.076
N Male	–0.207 –0.210	– 5.258 –5.334
N Female	+0.207 +0.204	+5.258 +5.182
WSMA Male (3.5 mm) WSMA Female (3.5 mm)	–0.0025 –0.0035	–0.0635 –0.0889
K Male (2.92 mm) K Female (2.92 mm)	+0.000 –0.0050	+0.000 –0.127
V Male (1.85 mm) V Female (1.85 mm)	+0.000 –0.0040	+0.000 –0.1016
W Male (1 mm) W Female (1 mm)	+0.000 –0.0020	+0.000[a] –0.0508

a. Anritsu does not offer a pin depth gauge for the W connector.

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.

1-12 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.

Note	**Teflon Tuning Washers:** 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.

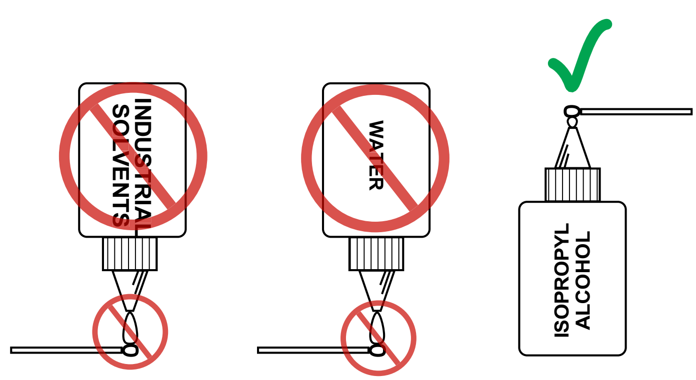


Figure 1-5. Isopropyl Alcohol Only

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.

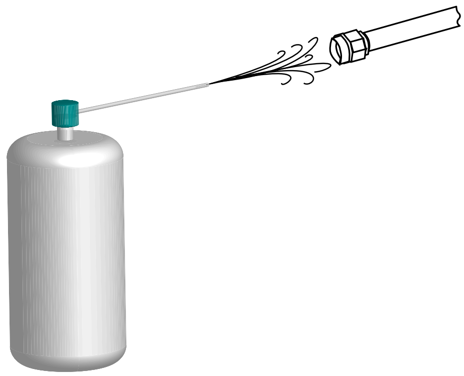


Figure 1-6. Low Pressure Compressed Air Cleaning

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.

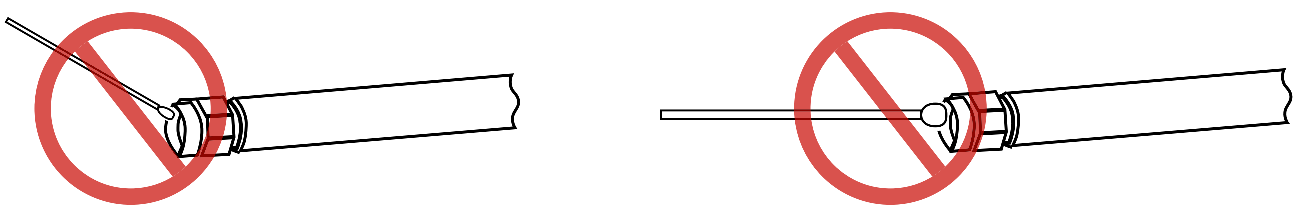


Figure 1-7. Avoid Angled or Large Swab

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.

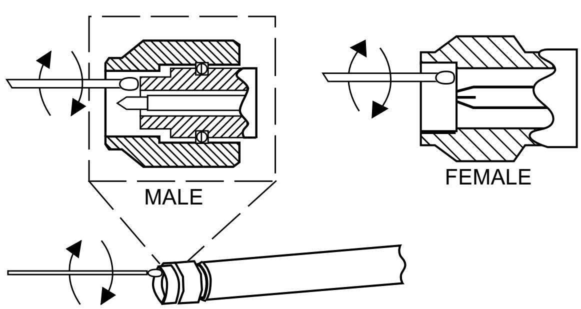


Figure 1-8. Cleaning Connector with Cotton Swabs

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

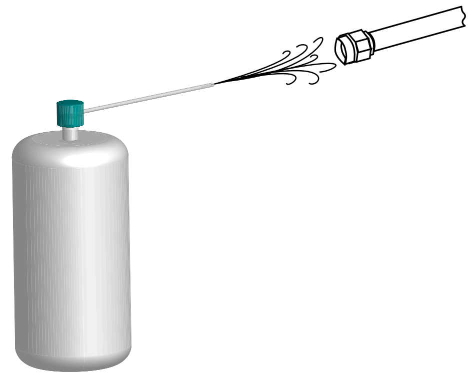


Figure 1-9. Compressed Air Drying

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

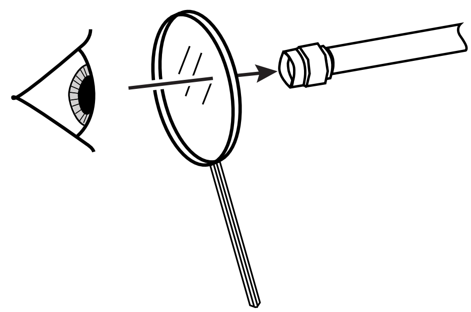


Figure 1-10. Final Inspection

Chapter 2 — SOLT/SOLR Calibration

2-1 SOLT/SOLT Introduction

This chapter describes calibration procedures using the SOLT/SOLR calibration algorithms. One of the more common calibration algorithms is based on Short-Open-Load-Thru. This is a defined-standards calibration meaning the behavior of all of the components is specified in advance via data or models.

Since the behaviors of all standards are known, by measuring them with the VNA we can define all of the error terms. The load behavior largely sets the directivity terms, the short and open together largely determine source match and reflection tracking and the thru largely determines transmission tracking and load match.

2-2 Definitions

Shorts

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

Opens

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

Loads

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

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

Thru

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

Reciprocal

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

2-3 Setup

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

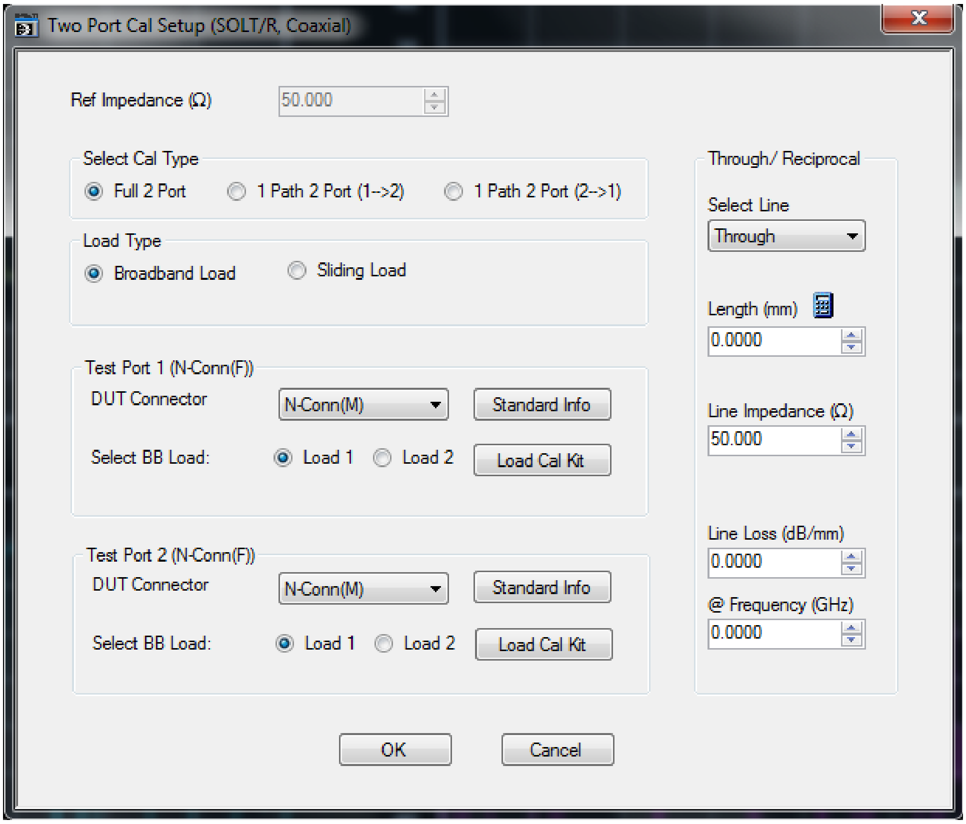


Figure 2-1. TWO PORT CAL SETUP (SOLT/R, COAXIAL) Dialog Box

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 standards information dialog for SOLT (and SOLR) is shown in Figure 2-2.

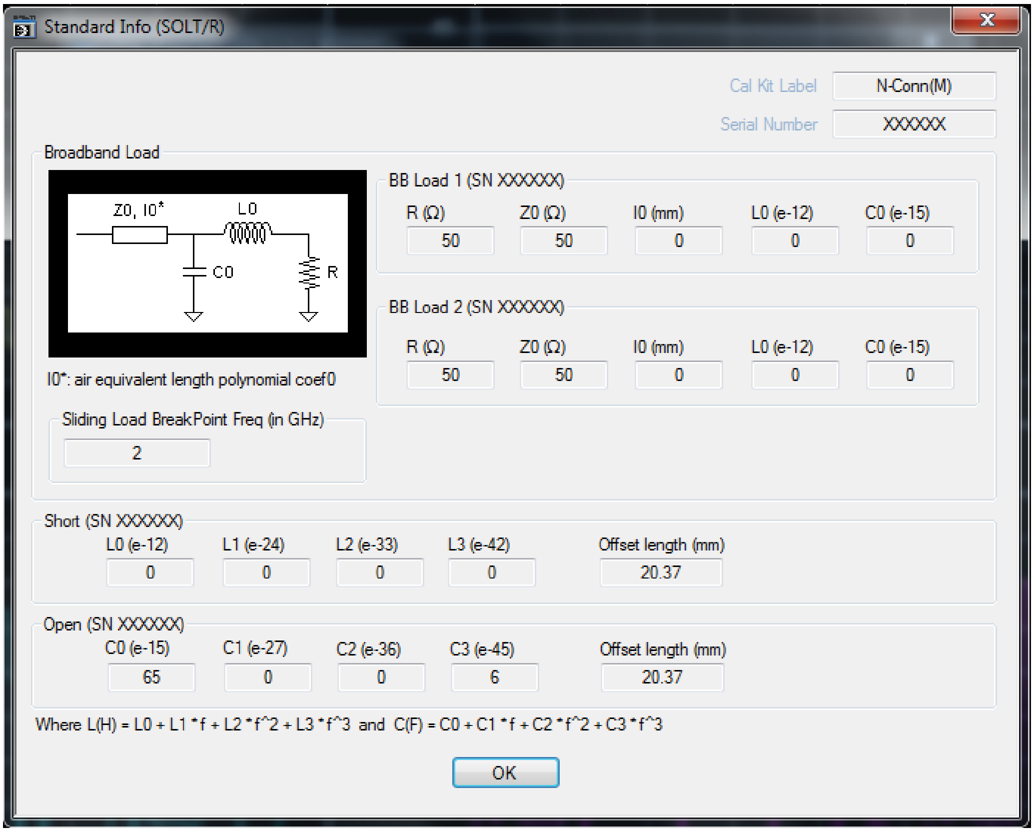


Figure 2-2. STANDARD INFO (SOLT/R) - V-Connectors (M)

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

Note	Reciprocal measurements (SOLR vs. SOLT) are covered in more detail in Chapter 11, “Reciprocal Measurements”.

2-4 SOLT/SOLR Calibration

The following example presumes an MS46522A 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 calibration will be performed although a number of other options are discussed along the way. The implications of these options are discussed in the calibration overview section.

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

Note	If a previous calibration exists, the Thru Update button will be active. See “Through (Thru) Update” on page 5-1 for more information.

3. Select Modify Cal Setup. The CAL SETUP menu appears. On this level, select a cal method of SOLT/SOLR and a line type of Coaxial.
4. Select Edit Cal Params; the TWO PORT CAL SETUP (SOLT/R, COAXIAL) dialog box appears which describes the calibration components:
   a. Reference impedance defaults to 50 ohms. 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. If a reciprocal network was being used instead of a through, use Reciprocal for the Select Line field and the length entered would serve as an estimate for root choice purposes.
   d. For **Port 1**, select a DUT connector of 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 3 — LRL/LRM Calibration

3-1 LRL/LRM Introduction

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

3-2 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) and ALRM (Advanced Line-Reflect-Match) calibrations have one of the lines above replaced with a match (or load). The load is modeled/characterized (or assumed perfect). Since only one line is involved, this calibration can work down to DC and up to very high frequencies (practically limited by the match knowledge/characterization). Variations allow one of the match measurements to be traded for a pair of additional reflect measurements (a second reflect standard is needed). Because of the requirement that the reflect standards be distinct, the calibration may become band limited.

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

Some parameters to keep in mind:

Line Lengths

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

Line Length Delta

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

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

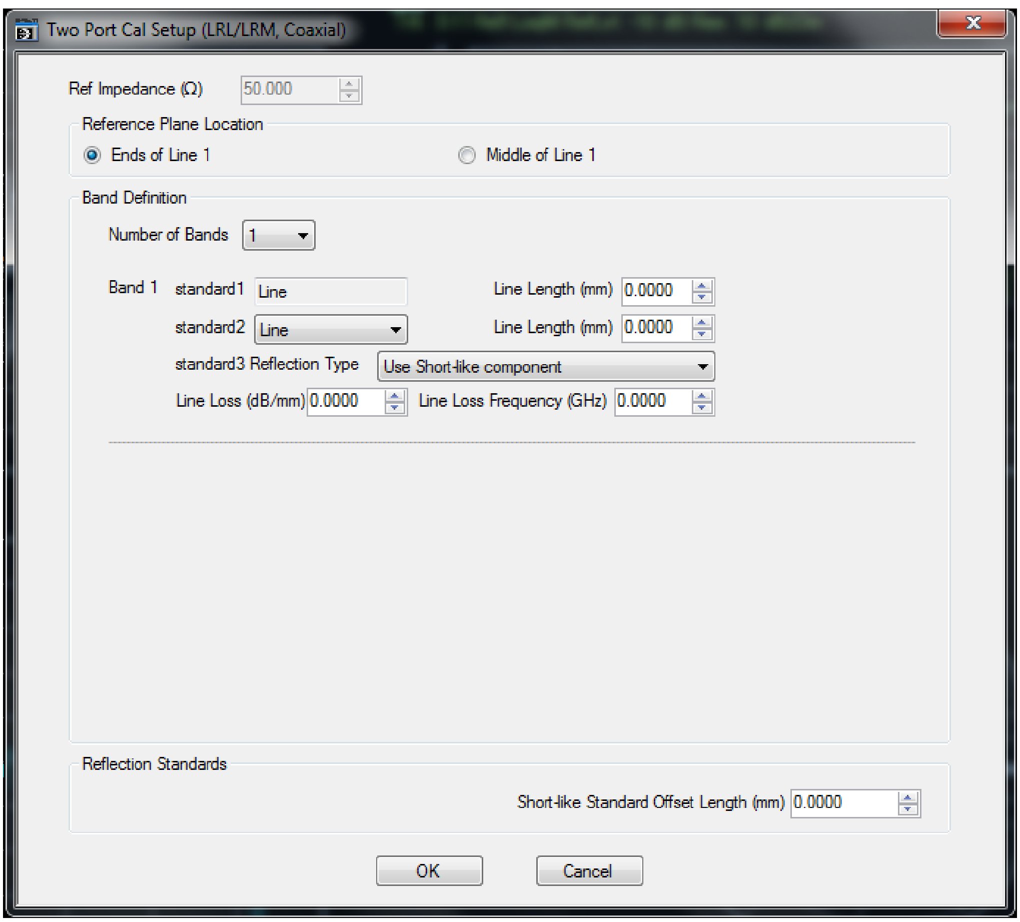
Eq. 3-1

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

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

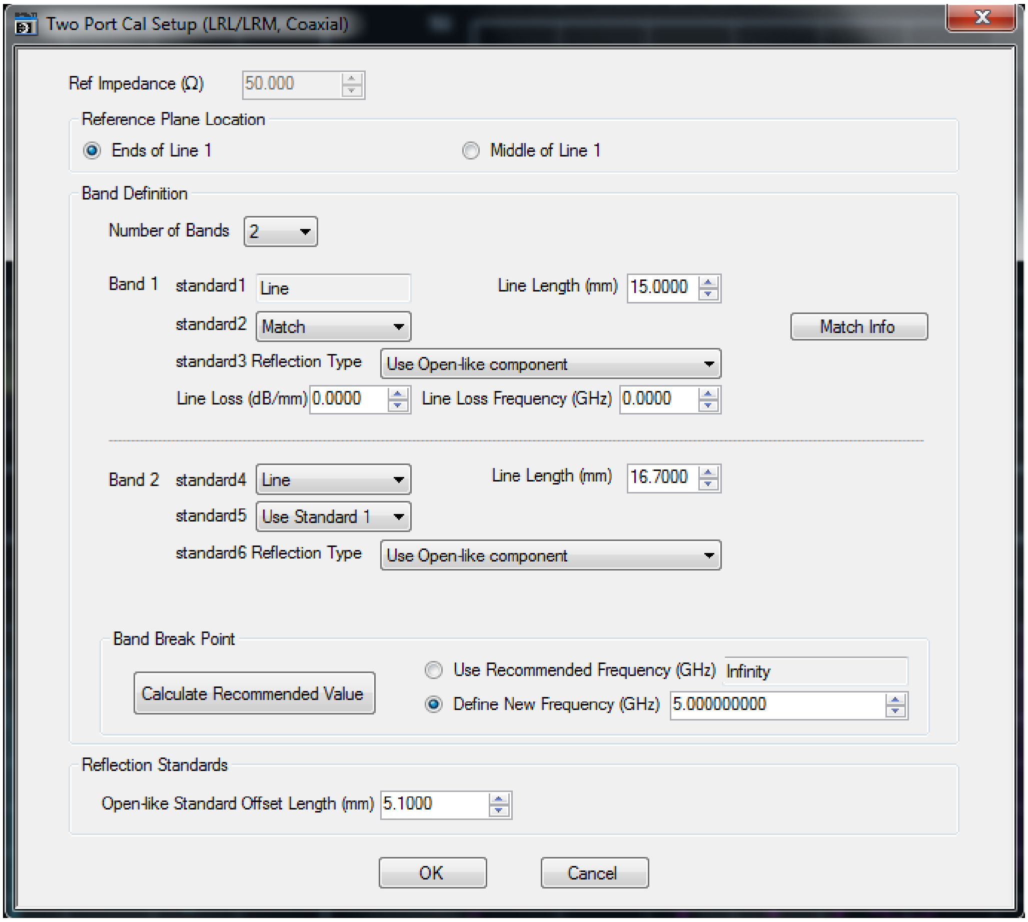
The setup dialog for LRL/LRM/ALRM is quite flexible with decisions made based on what standards are selected. Several examples are shown in the figures below.

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



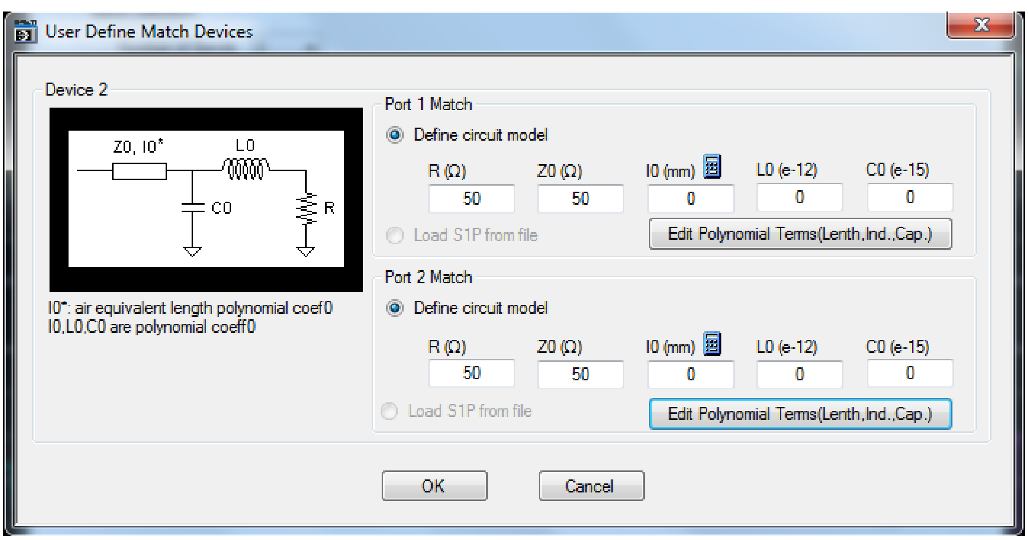
Typical parameters - One-Band LRL calibration

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



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

Figure 3-2. TWO PORT CAL SETUP (LRL/LRM, COAXIAL) Dialog Box



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

Figure 3-3. 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 ALRM methodology it is important that the reflect standards be distinct. More specifically, they must be distinct when rotated to the reference plane at the center of line 1. Since large offset lengths will lead to many more degeneracies, this double reflect option will generally be used when offset lengths are smaller (such as in on-wafer of fixtured calibrations).

Load Model/Characterization for ALRM

When a single reflect approach is taken within ALRM, it behaves like a classical LRM (see Figure 3-4). For slightly more advanced use, complete load models can be entered for the two matches independently. The same model as described for SOLT applies.

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

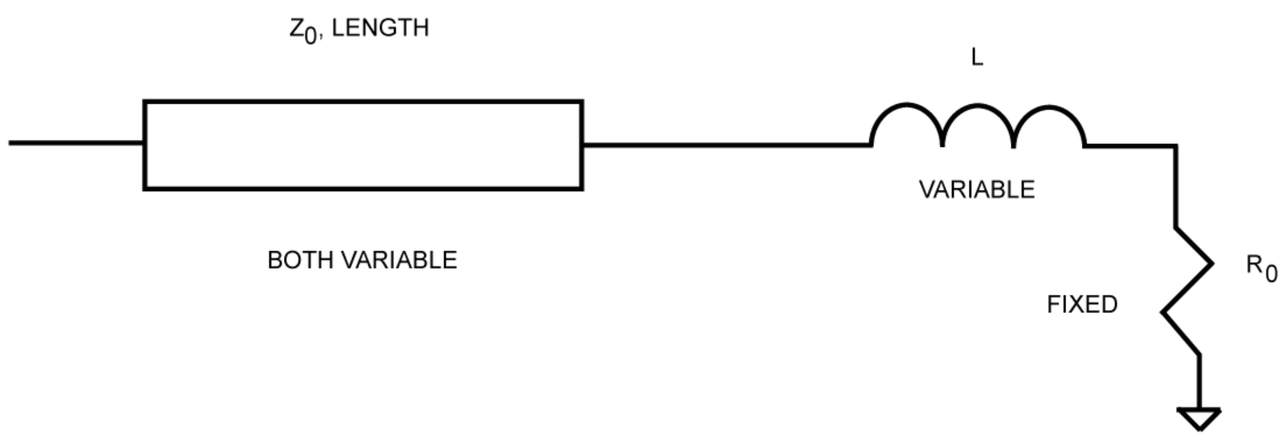
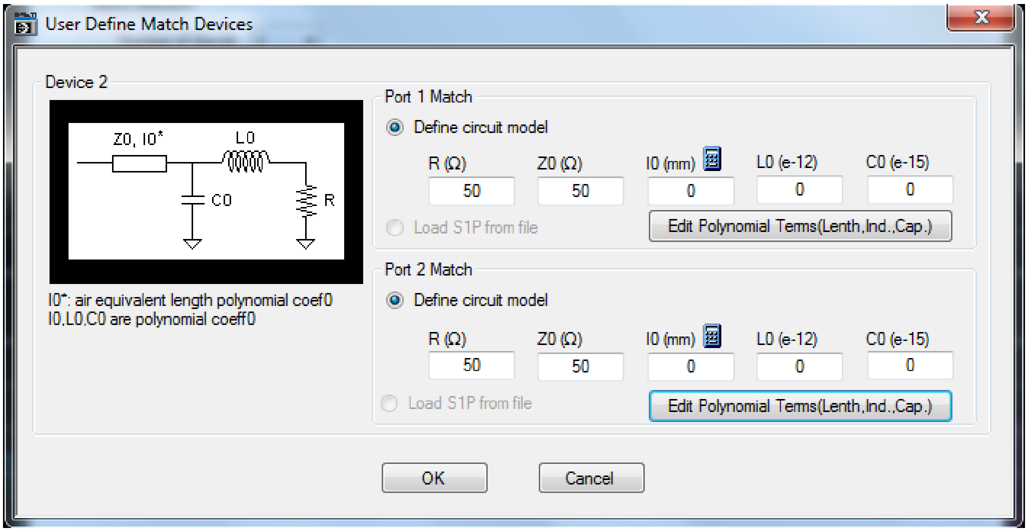


Figure 3-4. Load Model/Characterization for ALRM

The dialog box (Figure 3-5 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.



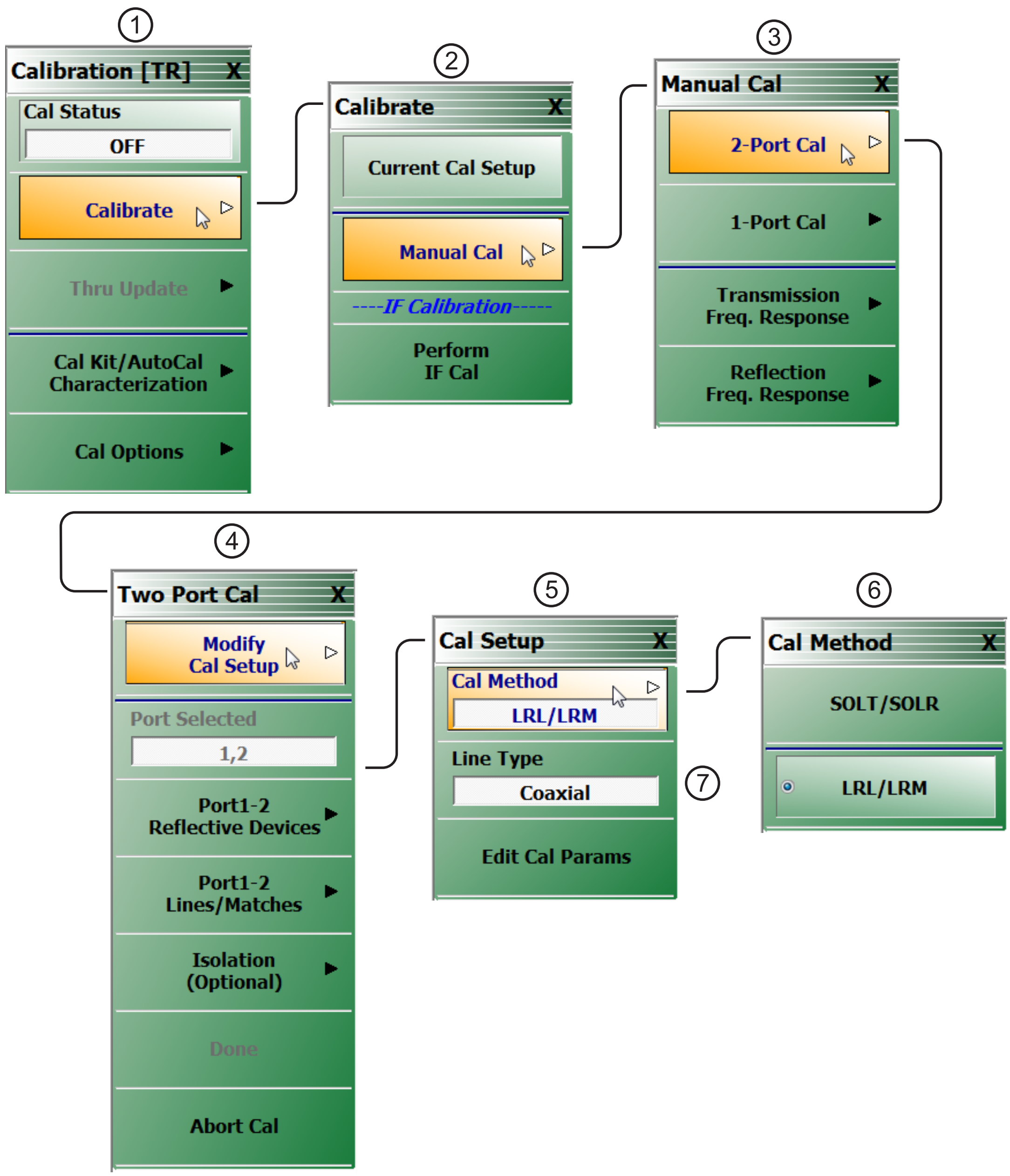
Typical parameters - Load Model Selection

Figure 3-5. ALRM MATCH DEVICES CALCULATED VALUES (BAND 1) Dialog Box

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

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

The following example presumes an MS46522A 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.



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 3-6. Calibration Menu Set for LRL/LRM Coaxial

Procedure

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

Note	If a previous cal exists, the Thru Update button will be active. See "Through (Thru) Update" on page 5-1 for more information.

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

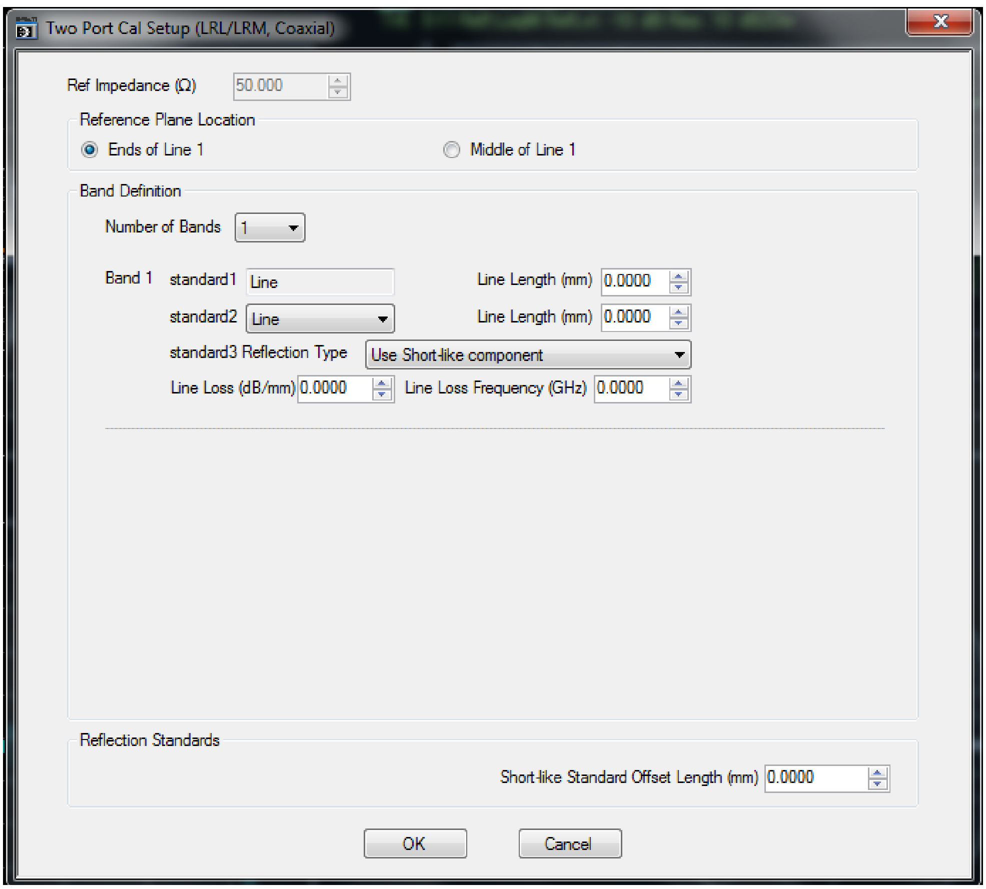


Figure 3-7. Calibration Setup Dialog - TWO PORT CAL SETUP (LRL/LRM, COAXIAL) Dialog Box

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.

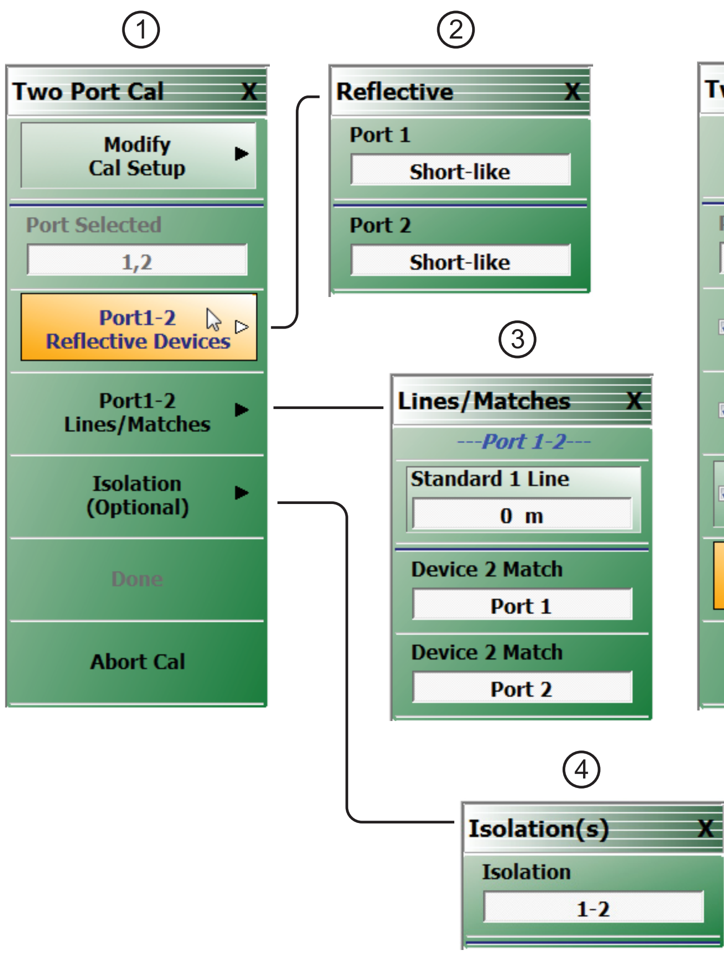
d. For this example, set Band 1 Device 1 to Line with a Line Length of 0 and Line Loss of 0 dB/mm. The reference frequency for the loss can be entered as 0. In general, this forces no loss scaling with frequency and the line loss value entered will be used at all frequencies.

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.



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

Figure 3-8. Two Port LRL/LRM Coaxial Calibration Procedure Menus

7. On the TWO PORT CAL menu (above in Figure 3-8 – #1), select the Port 1-2 Reflective Devices button and its linked REFLECTIVE menu (Figure 3-8 – #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 3-8 – #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 3-8 – #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 3-8 – #5), the Done button on the TWO PORT CAL menu is available. Click on Done. The focus returns to the CALIBRATION menu (at Figure 3-8 – #6) where the Cal Status button is set to ON.

3-4 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:

  `time delay (seconds) x 2.9978 x 108 (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.

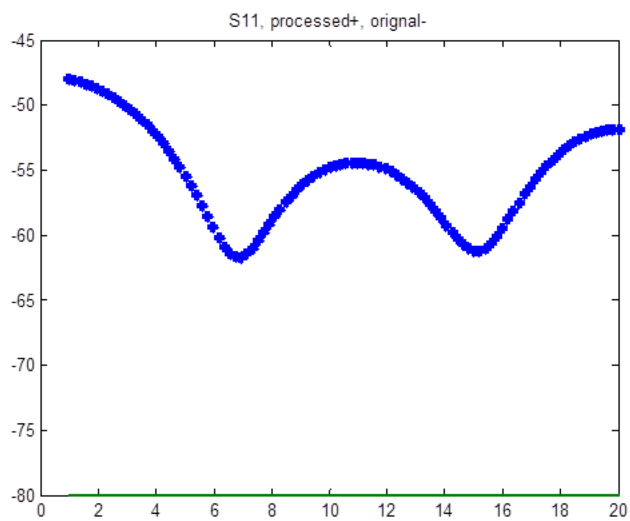


Figure 3-9. The effect of line impedance problems gets magnified as the line length delta approaches the theoretical band edges (the result for a high RL termination measurement when calibrated with unequal line impedances is shown here). This should be considered when deciding on the 2-band breakpoint 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 3-10 when there was a global 10 % impedance error on the LRL calibration lines and when the error was on only one line.

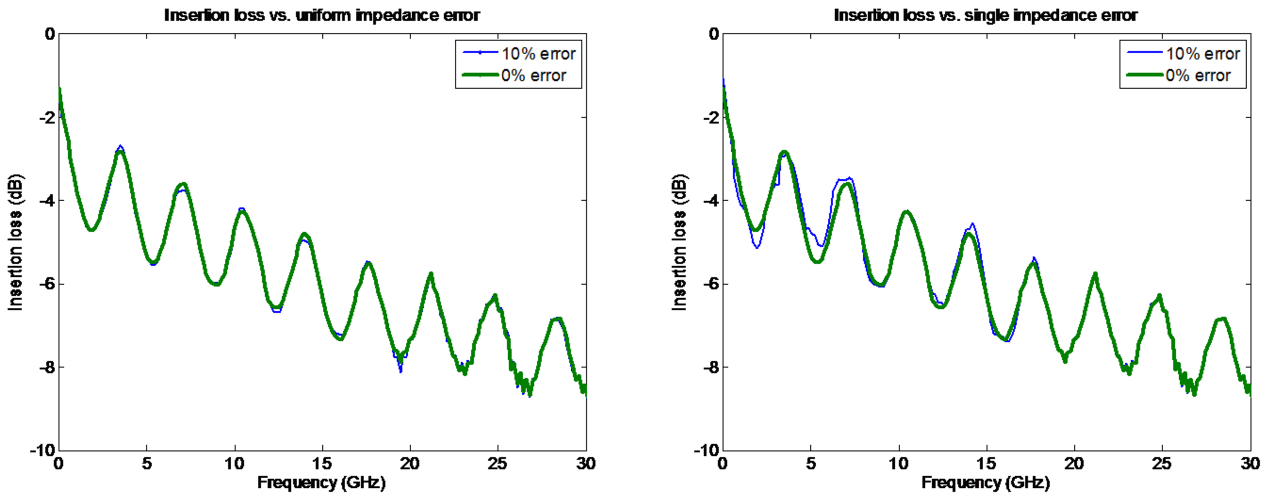


Figure 3-10. TRL/LRL is more sensitive to differences between the line impedances than to the absolute line impedance (although problems on that will shift the reference impedance of the calibration).

Chapter 4 — Adapter Removal Calibrations

4-1 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.

4-2 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 4-1 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 4-1 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.

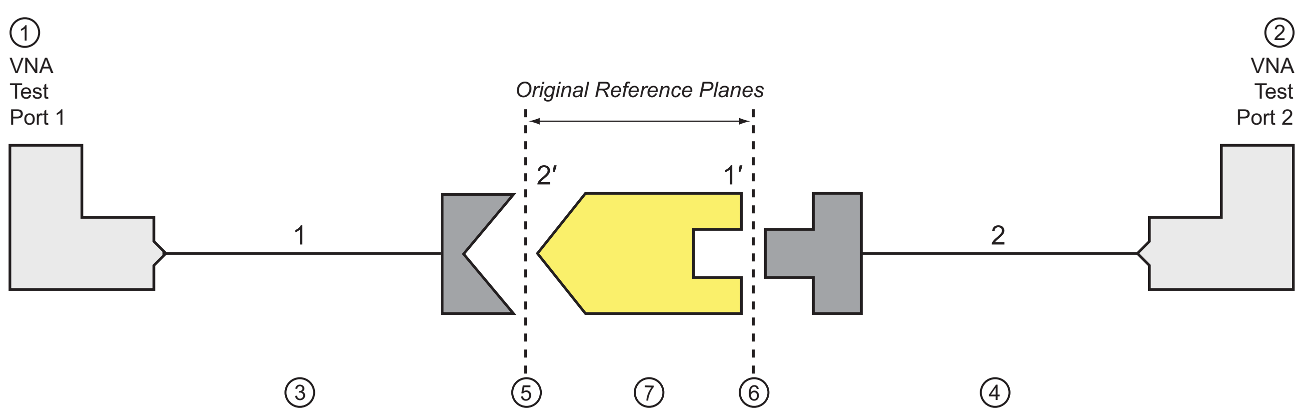


Figure 4-1. Adapter Removal Block Diagram

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

Figure 4-1. 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 4-2. 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.

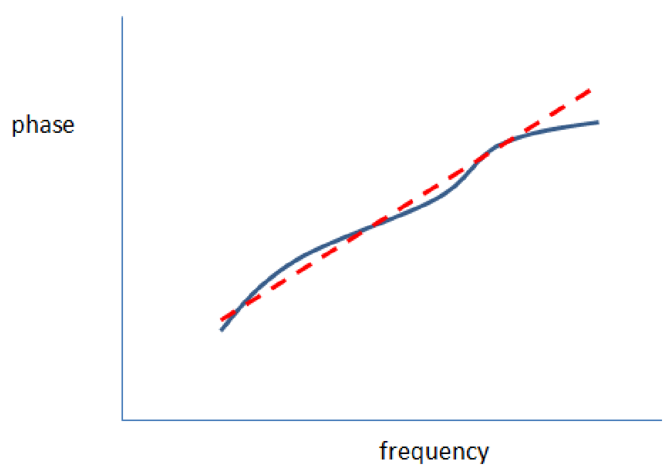


Figure 4-2. By entering 0 as the length estimate, the software calculates a length estimate for you. If the frequency step size is large relative to the electrical length of the setup, this may not be advisable.

In the upper half of Figure 4-3, 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.

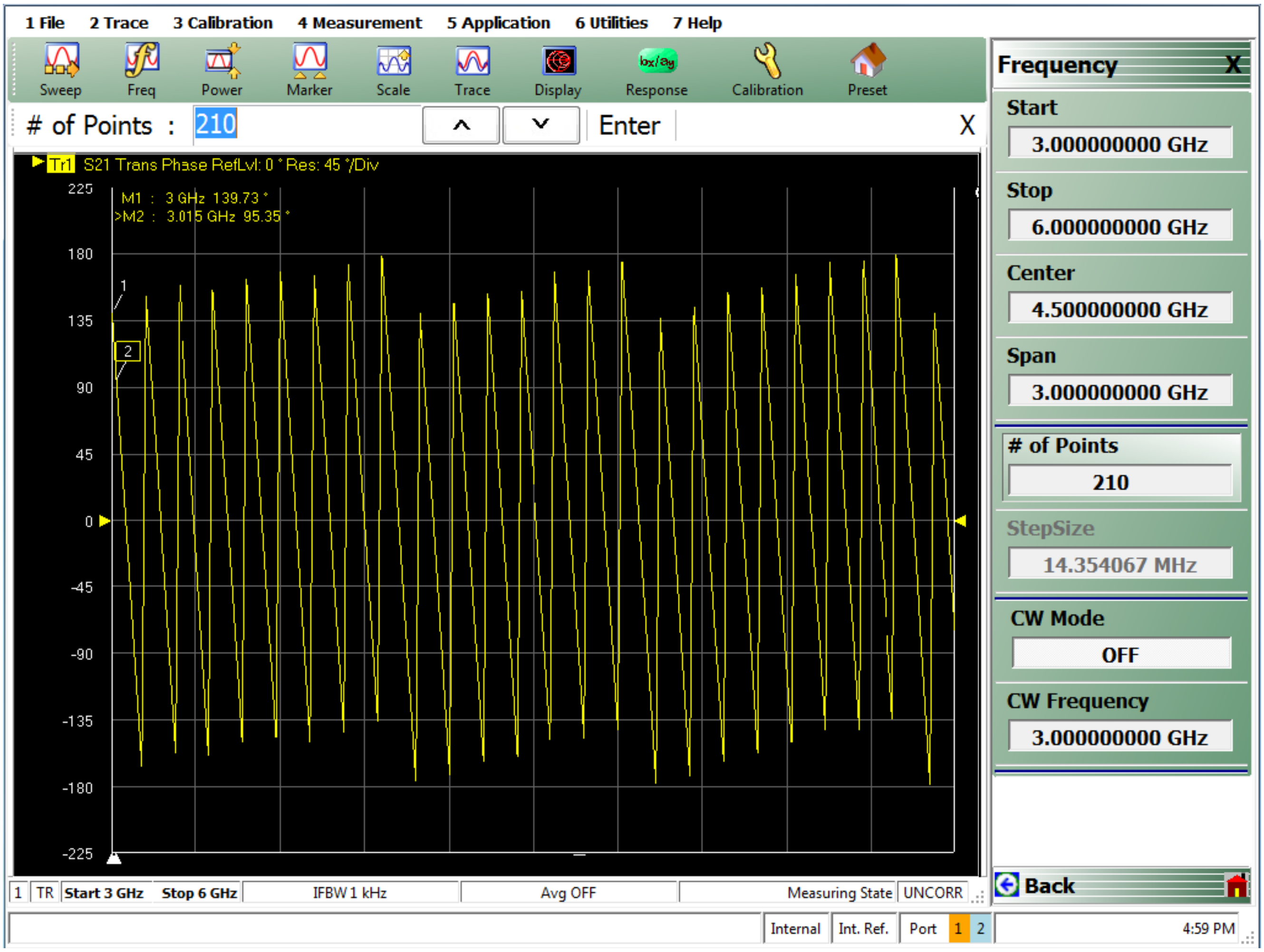


Figure 4-3. Uncalibrated phase plots from an example setup are shown here for two different step sizes. In the second case, the automatic length estimation may run into aliasing problems if much more length is added. (1 of 2)

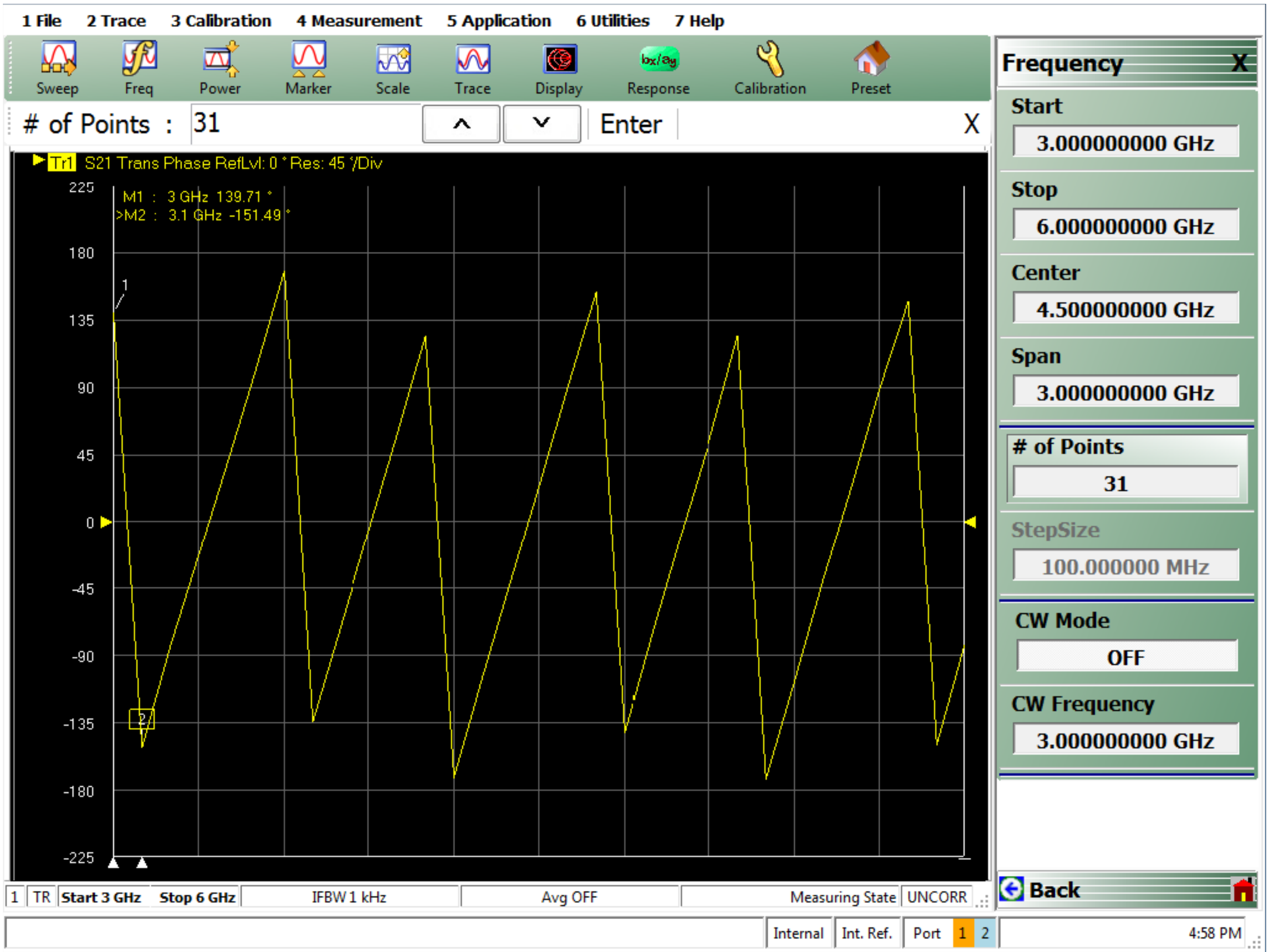


Figure 4-3. Uncalibrated phase plots from an example setup are shown here for two different step sizes. In the second case, the automatic length estimation may run into aliasing problems if much more length is added. (2 of 2)

4-3 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 4-4).

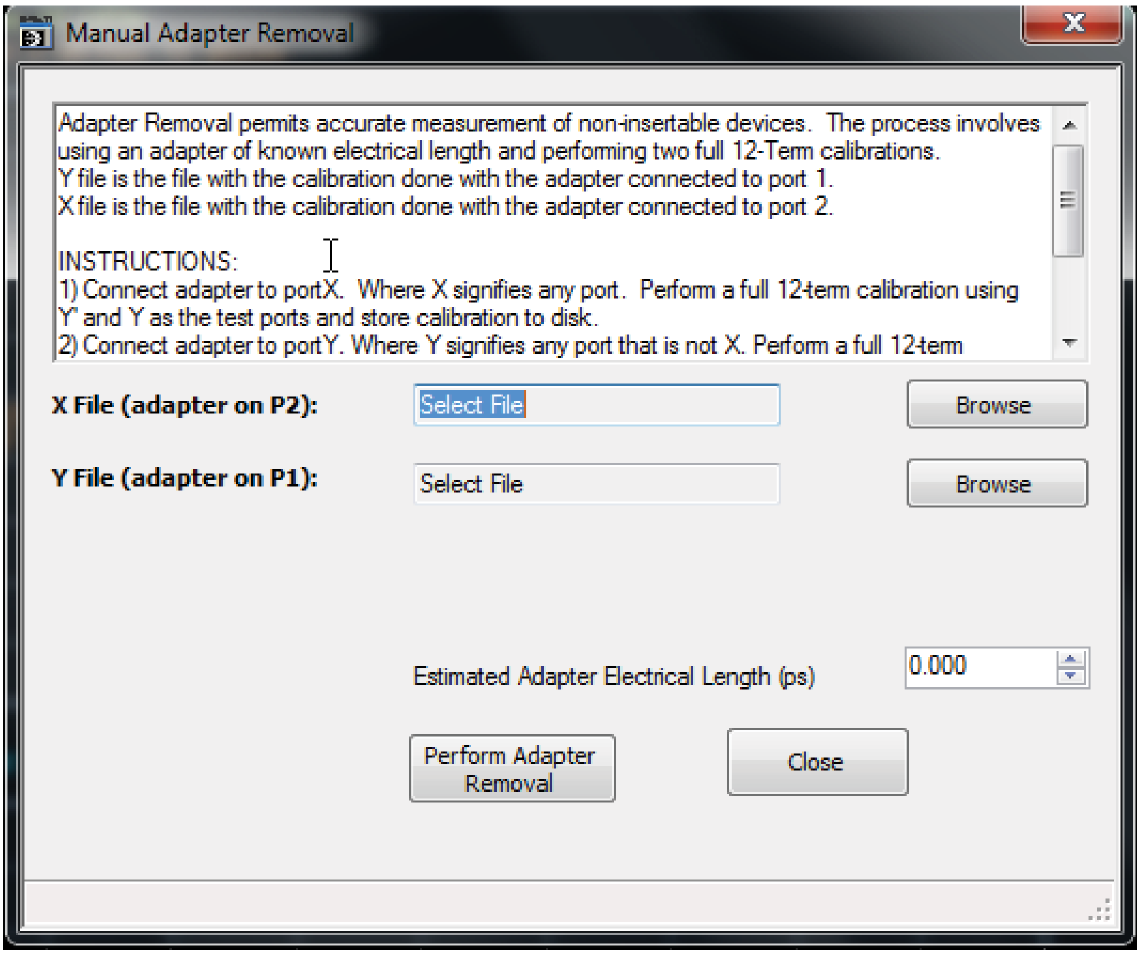


Figure 4-4. MANUAL ADAPTER REMOVAL Dialog Box - 2-Port VNAs

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:

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

Eq. 4-1

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 4-5).

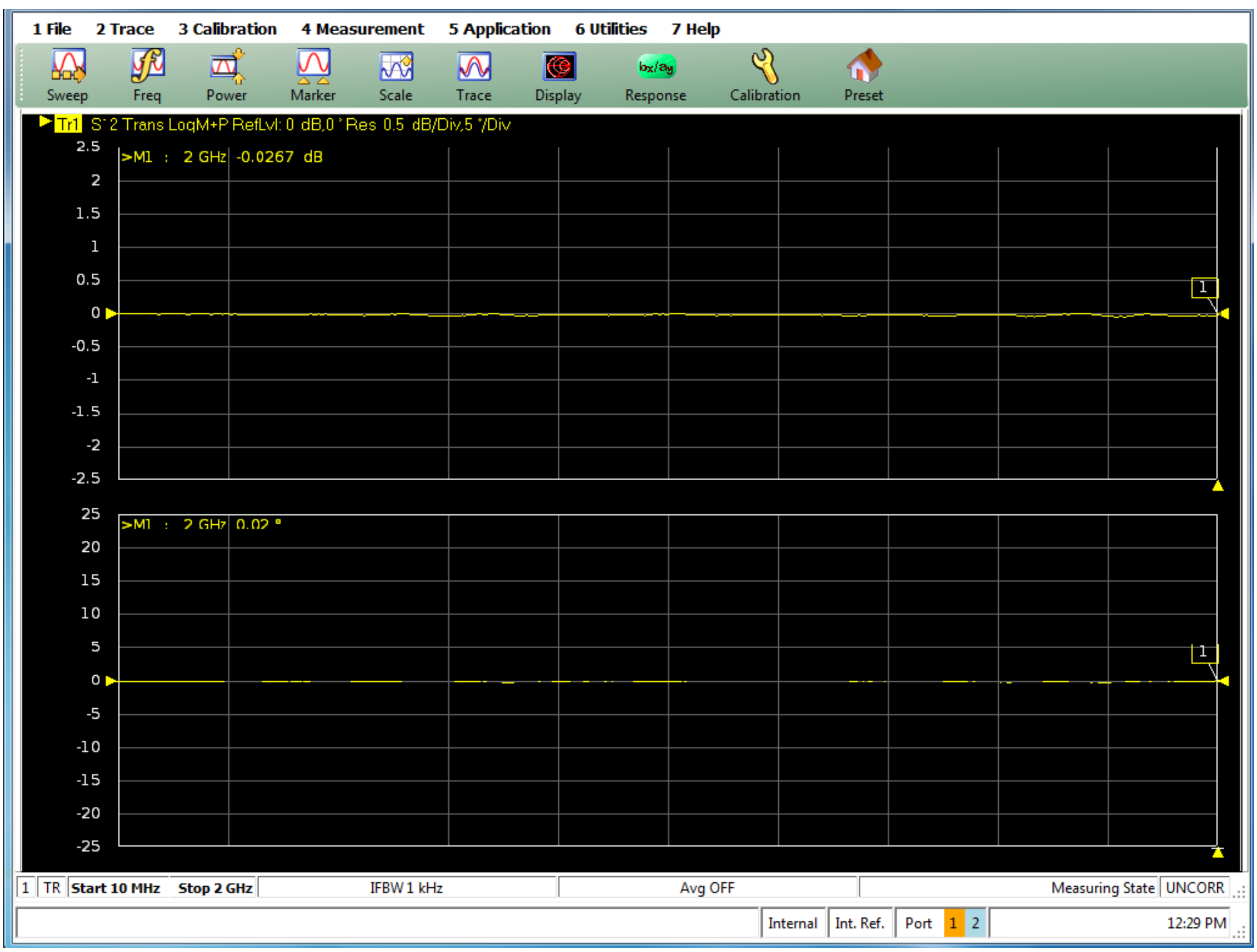


Figure 4-5. VNA Trace Display with Result of Adapter Removal

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.

4-4 Summary

Adapter removal is a 2-calibration technique for removing the effects of an adapter from a given calibration setup (e.g., when the DUT has one coax port and one different port, such as a waveguide port).

Chapter 5 — Other Calibration Procedures

5-1 Overview of Other Calibration Procedures

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

5-2 Through (Thru) Update

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

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

Like the thru step in other calibrations, the length of the line being used as well as its loss can be specified to ensure minimal disruption of the reference planes (see Figure 5-1). The entry methods for these parameters are the same as in the normal calibration procedures.

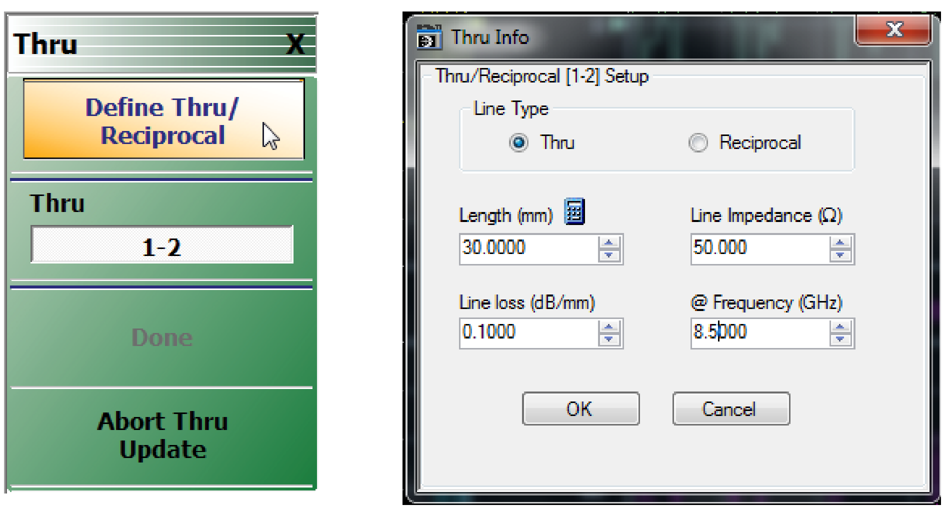
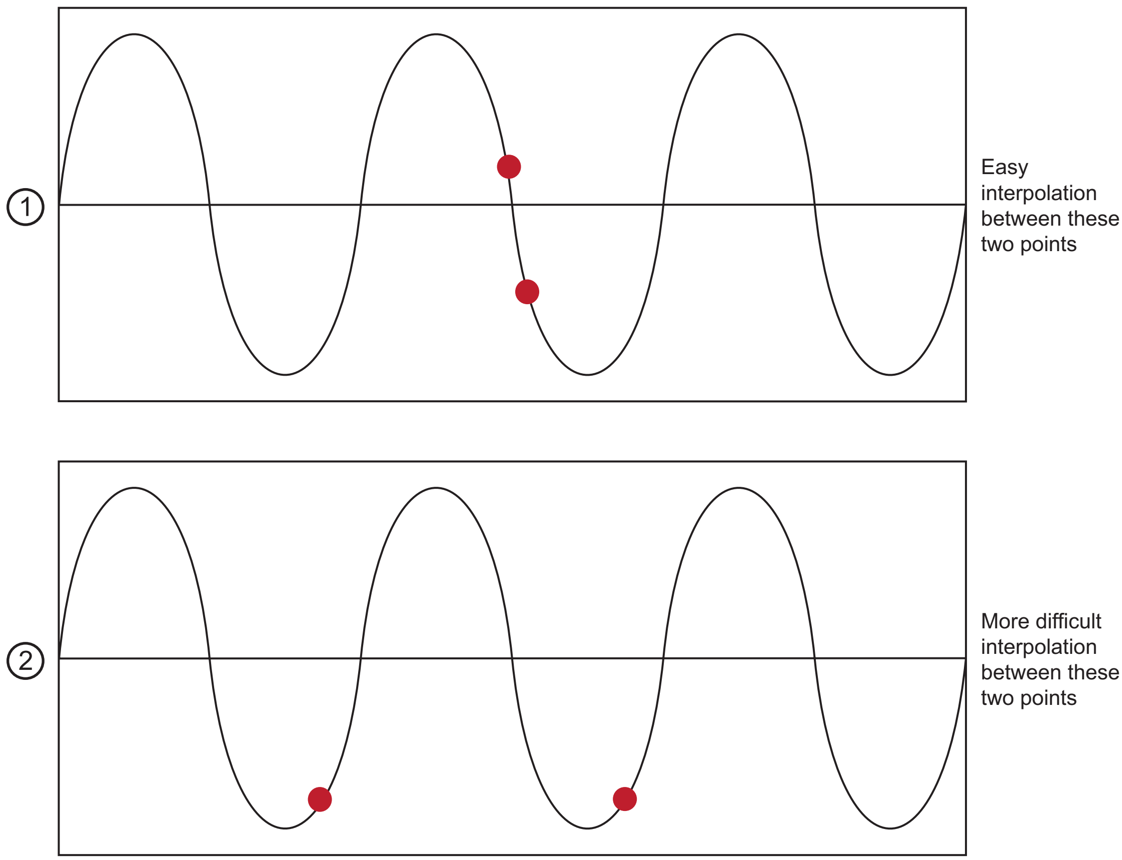


Figure 5-1. THRU UPDATE Setup Menu and THRU INFO Dialog

5-3 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 5-2).



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

Figure 5-2. 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 5-3.

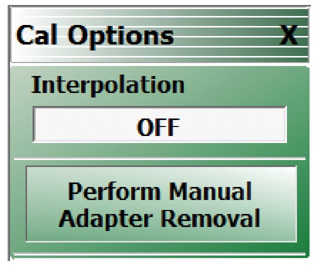


Figure 5-3. CAL OPTIONS Menu

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 5-4. 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.

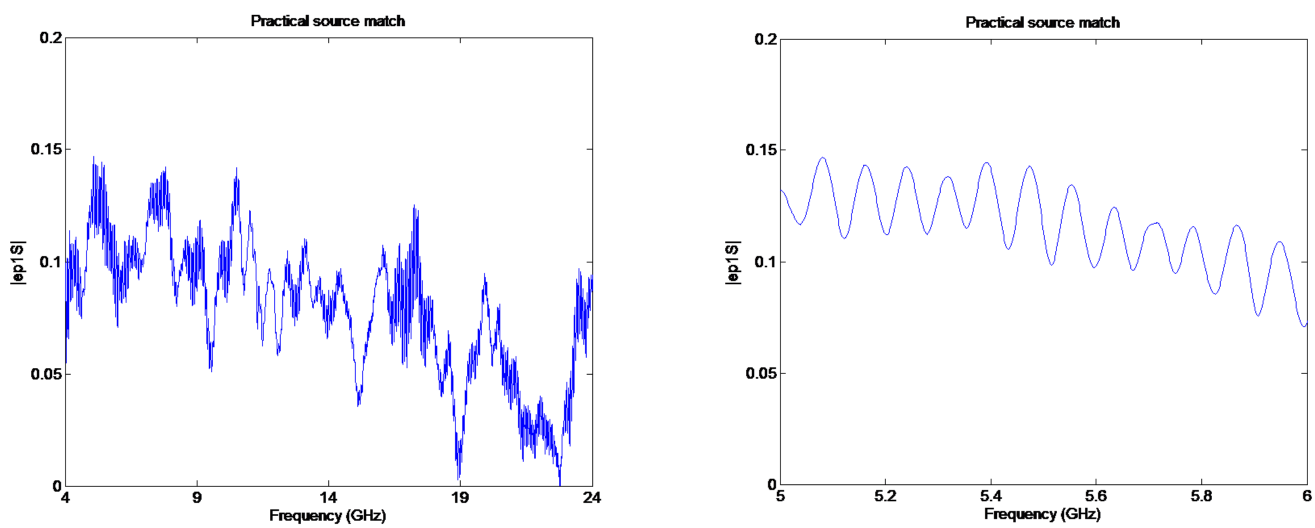


Figure 5-4. Large scale and zoomed-in source match variation over frequency.

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 5-5 (for a standard SOLT coaxial calibration).

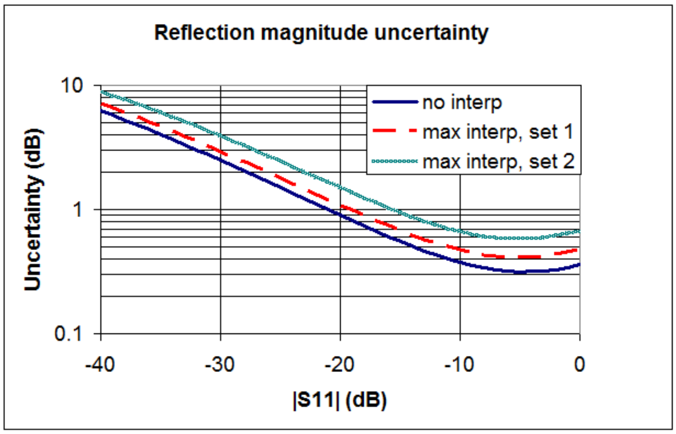


Figure 5-5. The uncertainty penalties possible with worst-case interpolation are shown here for some example setups.

As suggested above, one can get around this problem by increasing the frequency point density. In Figure 5-6, 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).

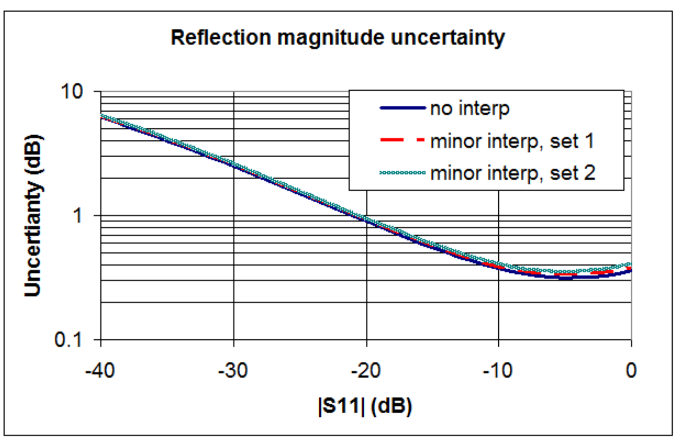


Figure 5-6. An increase in frequency point density can reduce interpolation effects in all setups as would be expected.

Chapter 6 — Calibration and Measurement Enhancements

6-1 Chapter Overview

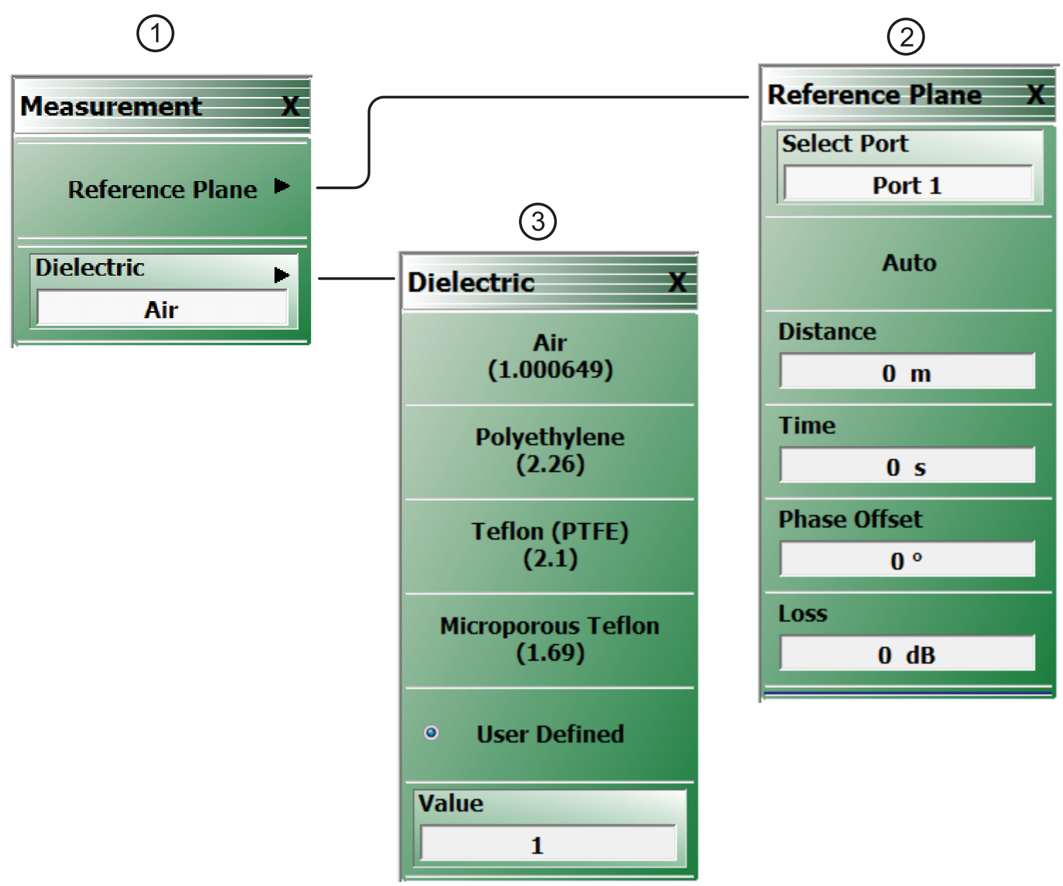
This chapter provides a description of functions that provide additional calibration, post-processing, and display options that increase the usefulness of the instrument data.

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.

- **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.

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 6-2, "REFERENCE PLANE Control Menu" on page 6-2). 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	3. DIELECTRIC menu.
2. REFERENCE PLANE menu	

Figure 6-1. MEASUREMENT Menus

6-2 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 6-2). 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.

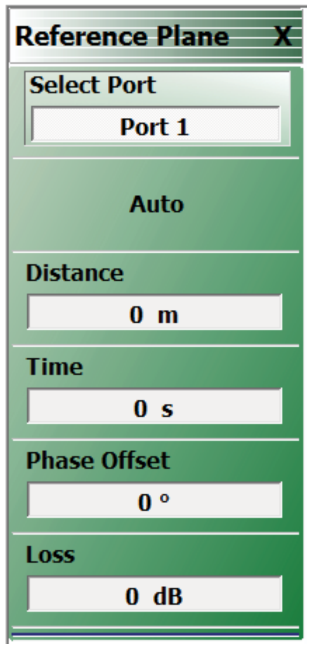
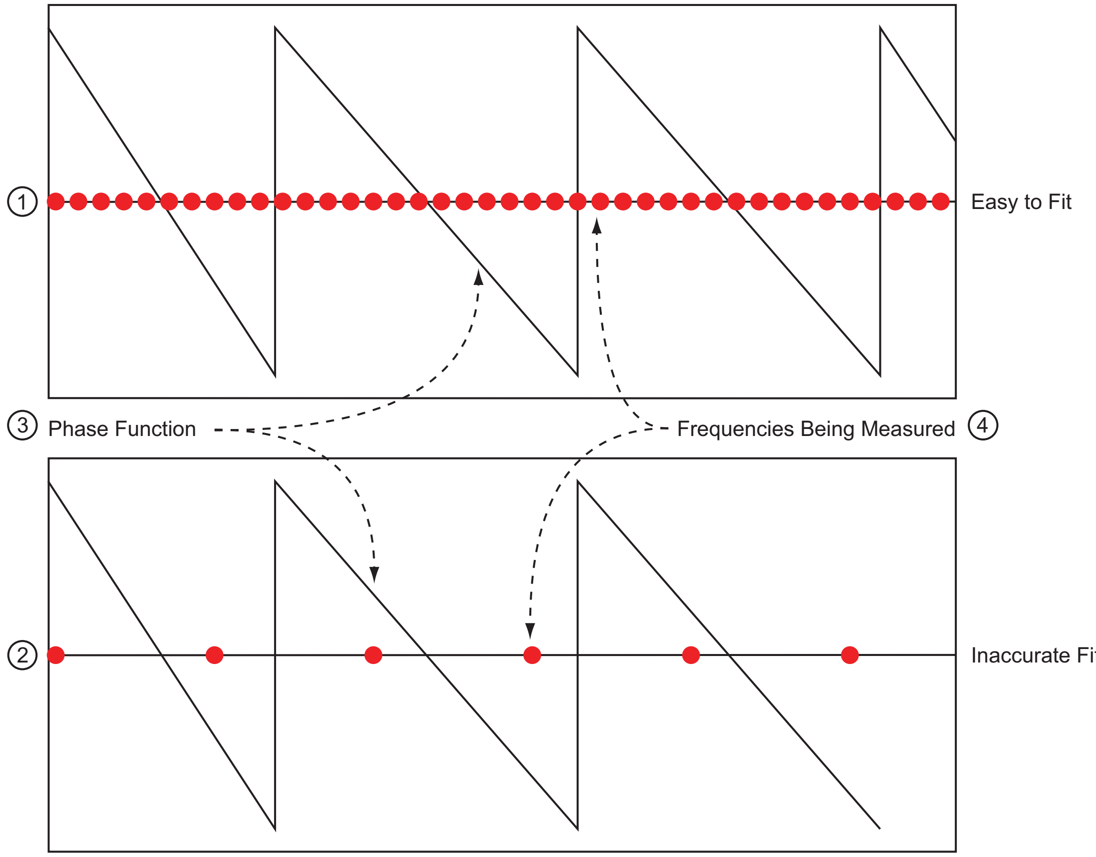


Figure 6-2. REFERENCE PLANE Control Menu

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 6-3 below). Increasing the frequency point density can help this problem.



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

Figure 6-3. 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.

Chapter 7 — Verification

7-1 Introduction to Verification

While there are many ways of verifying instrument performance, including the procedures described in the **ShockLine™ MS46522A 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:

- MS46522A Series VNA Operation Manual – 10410-00330
- 3653A Mechanical Calibration Kit Reference Manual – 10410-00278
- 3663-2 Verification Kit (for Type N Connectors) and 2300-527 Performance Verification Software (PVS) User Guide – 10410-00334
- 3663-2 Verification Kit and 2300-527 PVS Quick Start Guide – 10410-00335

See "Calibration Kits, Verification Kits, and Components" on page 1-2.

7-2 Basic Concepts

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

Hardware Level

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

Intermediate System Level

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

Comparison to Known Devices

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

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

Metric of Comparison

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

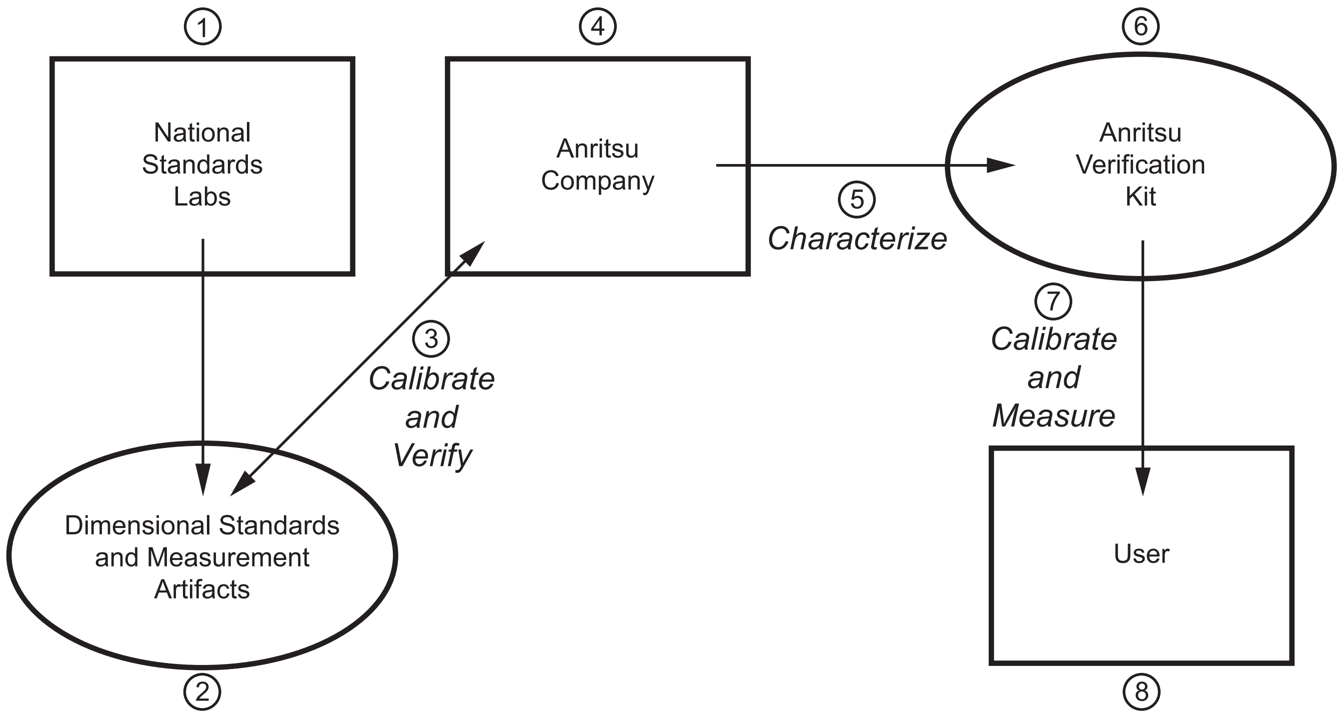
$$E_n = \frac{\left| S_{xy}^{char} - S_{xy}^{ver} \right|}{\sqrt{(U_{xy}^{char})^2 + (U_{xy}^{ver})^2}}$$

Eq. 7-1

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 7-1.



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

Figure 7-1. 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).

7-3 Verification Kit Components

The main verification kit for the ShockLine Series VNAs is that corresponding to N connectors:

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

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

- 3663-2 Verification Kit (for Type N Connectors) and 2300-527 Performance Verification Software (PVS) User Guide – 10410-00334
- 3663-2 Verification Kit and 2300-527 PVS Quick Start Guide – 10410-00335

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

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 7-2, “Regions of Parameter Coverage of Verification Kit Component” on page 7-5. 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 7-2 illustrates the regions of parameter coverage of the various verification kit components. The regions are not drawn to scale.

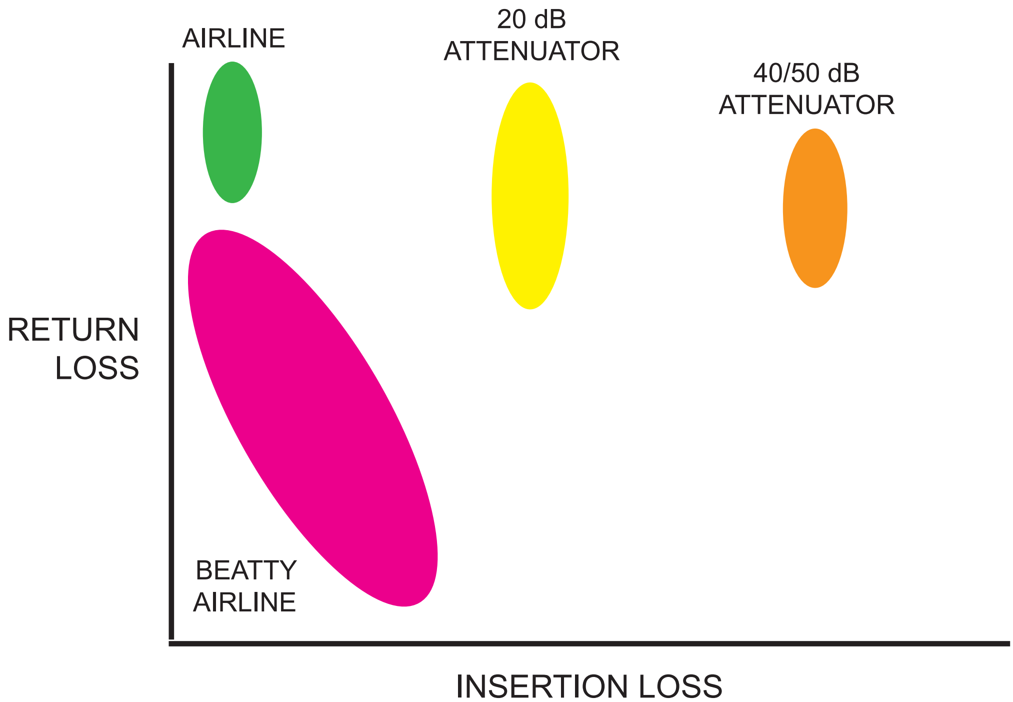


Figure 7-2. Regions of Parameter Coverage of Verification Kit Component

For the MS46522As, the verification comparison is valid for calibrations performed with the calibration kits listed under the verification kit:

- 3663-2 Type N Connector Verification Kit

  33653A Type N Manual Calibration Kit
- 3663-2 Verification Kit (for Type N Connectors) and 2300-527 Performance Verification Software (PVS) User Guide – 10410-00334
- 3663-2 Verification Kit and 2300-527 PVS Quick Start Guide – 10410-00335

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 MS46522A verification software does not support all of these.

7-4 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:

- 3663-2 Verification Kit (for Type N Connectors) and 2300-527 Performance Verification Software (PVS) User Guide – 10410-00334
- 3663-2 Verification Kit and 2300-527 PVS Quick Start Guide – 10410-00335

Chapter 8 — Measurement Setup Requirements

8-1 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 12 traces for MS46522A. 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.

8-2 Traces Introduction

The central concept in the MS46522A family that will enable the maximum functionality of the system is the trace.

Trace Concept

The trace is a concept that represents a data group. Twelve (12) traces are available on the MS46522A 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.

8-3 Traces General Concepts

The hierarchy of setups is illustrated in Figure 8-1. 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:

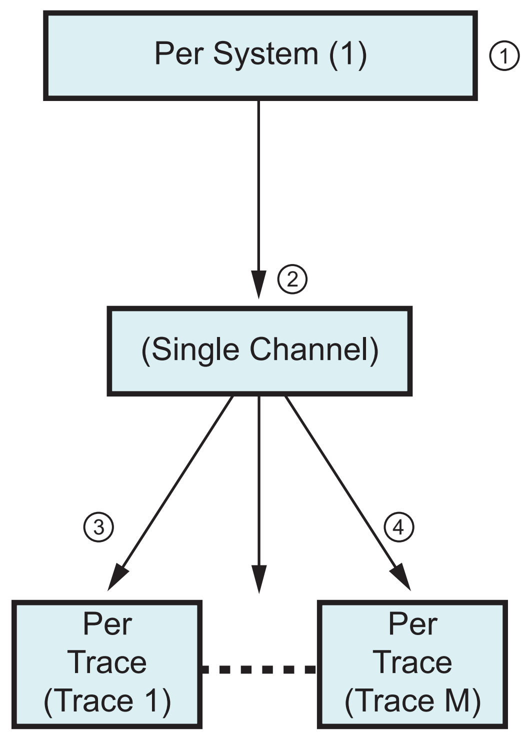
- Certain portions of the hold system and certain triggering functionality
- Cal kit files
- SnP and text file header/format setups
- Blank frequency display (security feature)
- Interface setup items (network config, touchscreen setup,...)

Per-System Variables

These variables are often per-system to prevent a setup scenario that could significantly shorten the life span of the hardware. In the case of hold and triggering, it also allows an entire measurement suite to be somewhat more easily controlled externally. Others fall more in the category of utilities that are somewhat per-system in nature. The hierarchy of system and trace setup information is shown below. M (the trace count) may always be up to 12 on MS46522A Family.

Per-Trace Variables

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



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

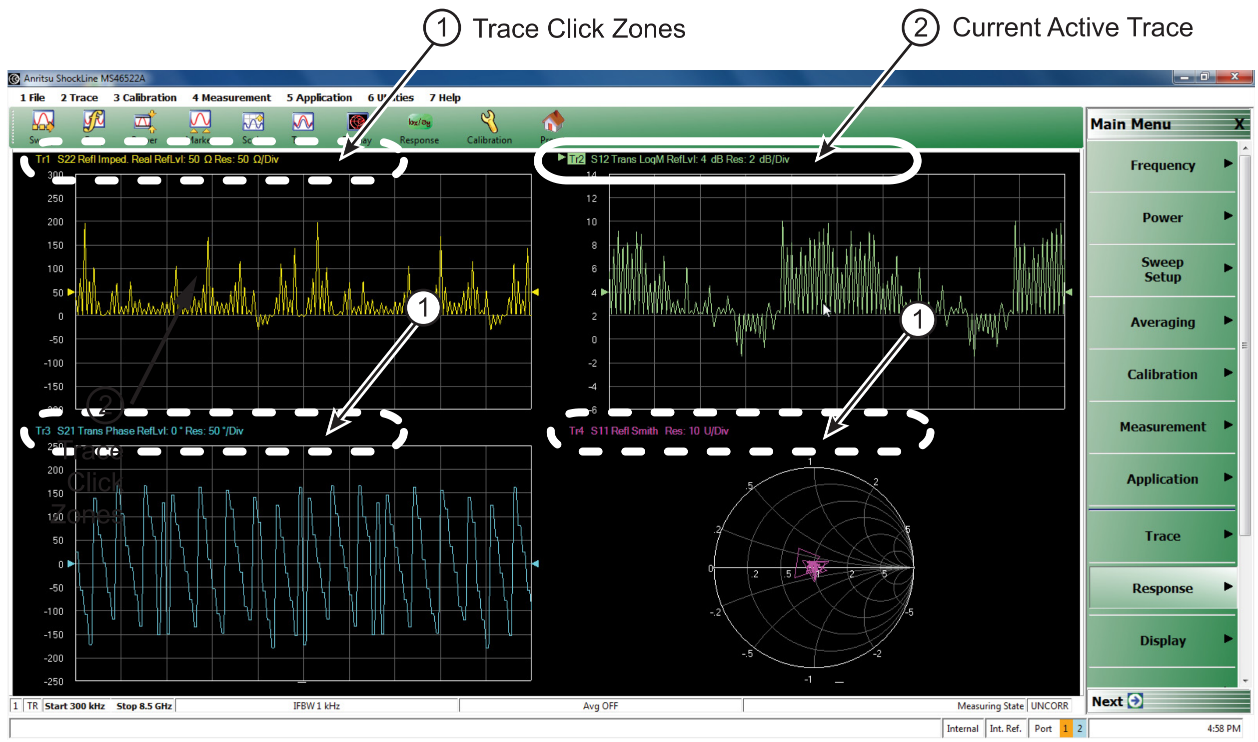
Figure 8-1. Setup Information Hierarchy

8-4 Traces

The number of traces displayed may be specified and one can rotate through the traces using Trace Next and Trace Previous. One can also make a trace active by clicking on its annotation line as suggested by Figure 8-2. The active trace is denoted by an inverse color field around the trace number (Tr2 in Figure 8-2).

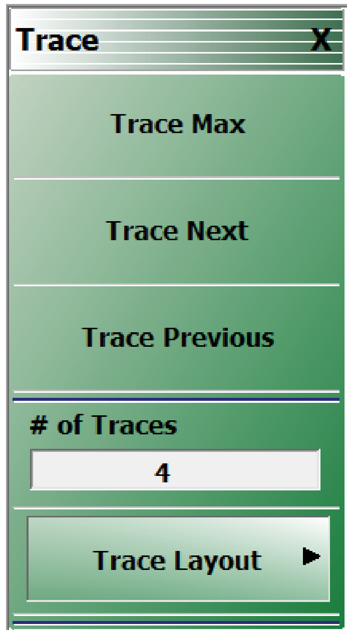
The Max function causes the trace (in this case) to occupy the full graph region of the screen. Also as with the Chan. Max, this button is a toggle. Double-clicking on the graph title area (ie. Tr1, Tr5, etc) of the active trace will have the same function as clicking on the Trace Max button. The main Trace menu showing these functions is shown in Figure 8-3.

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



1 – Trace activate click zones	2 – Current active trace

Figure 8-2. Trace Activate Click Zones



TRACE menu with four traces selected

Figure 8-3. TRACE Menu

There is a layout submenu for traces (see Figure 8-4). Here, however, one may have any number of traces on any graph configuration and the number of traces will not be coerced based on the layout choice. If the number of traces exceeds the number of graph areas selected in the layout, the traces will be overlaid in a sequential fashion that will minimize the number of overlays. Only certain numbers of graph areas (in the case of traces) are allowed that are semi-symmetric and blank areas in the graph area grid are allowed if the trace count is less than the graph count.

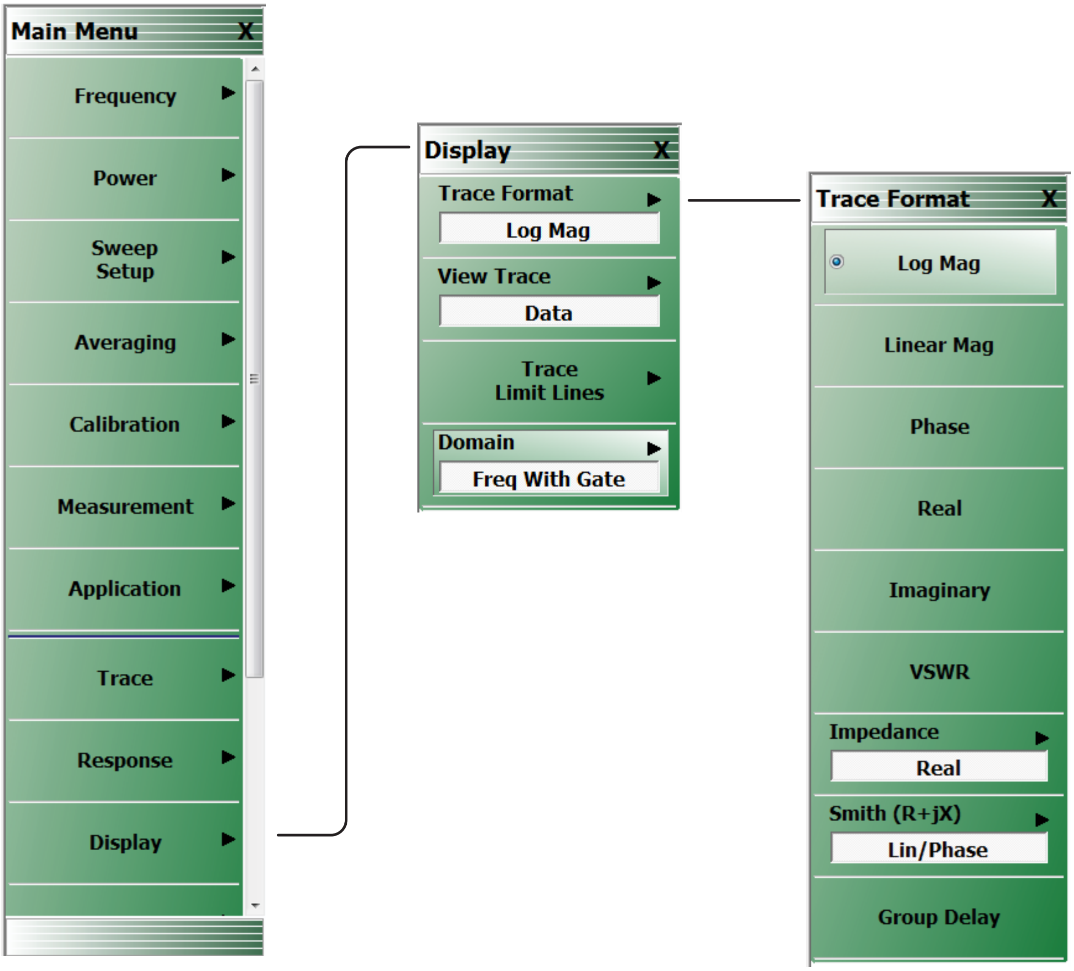


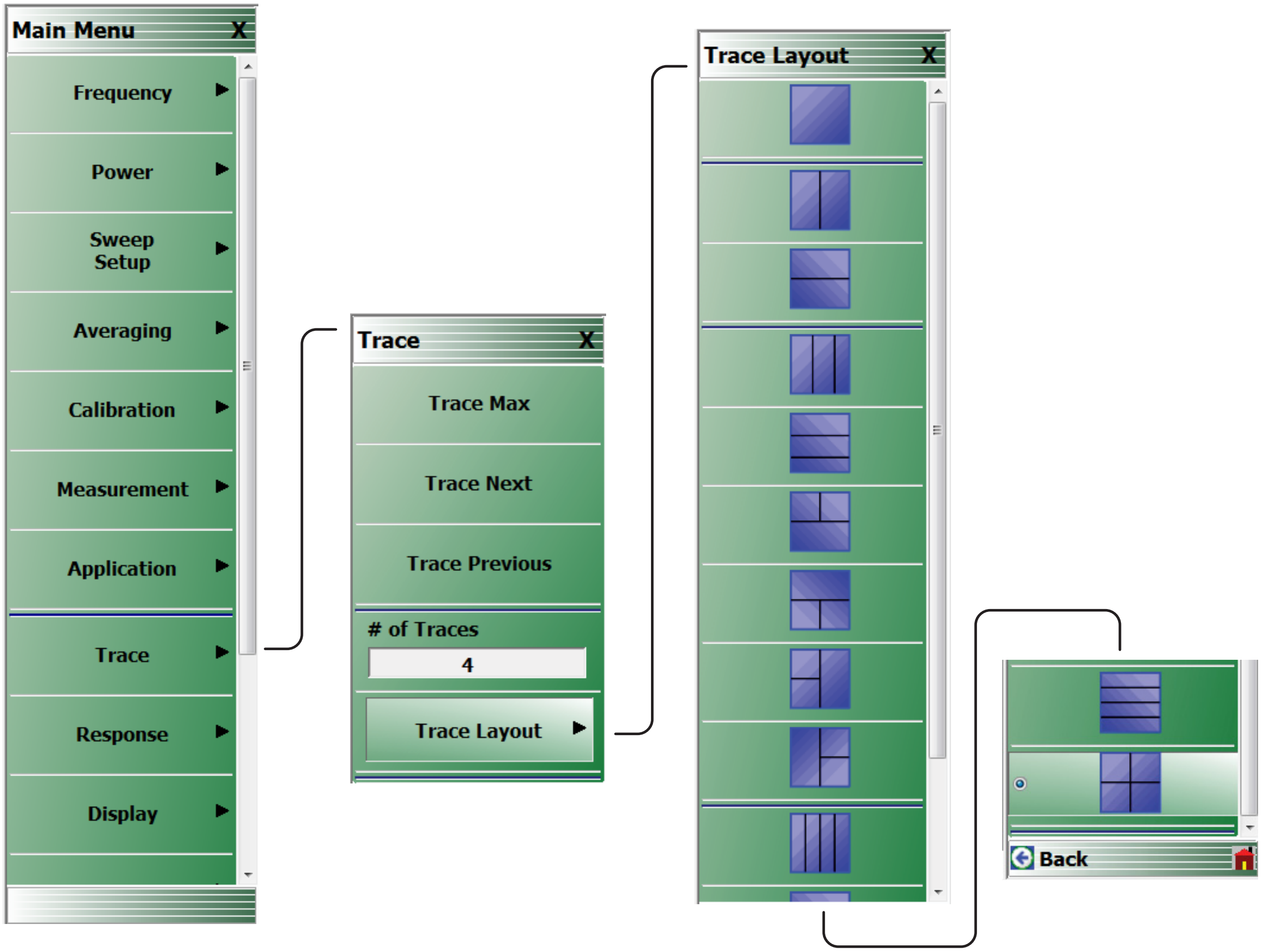
Figure 8-4. TRACE FORMAT Menu

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

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

Of course, a **12-way** overlay on the MSA46520 family can be arranged by activating 12 traces and selecting the single graph area (top of the trace layout menu).

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



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

Figure 8-5. TRACE LAYOUT Menu

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, un-ratioed parameter, ext. analog in)

Complex Trace Setup Example

A fairly complex trace setup example is shown in Figure 8-6 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 8-1. 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 8-1. Trace Labels and Annotations

<table>
<tr><th>Abbreviation</th><th>Definition</th></tr>
<tr><td>FGT</td><td>Frequency domain with time gating</td></tr>
<tr><td>TLP</td><td>Time domain low pass</td></tr>
<tr><td>TBP</td><td>Time domain bandpass</td></tr>
<tr><td>D&M</td><td>Data and memory</td></tr>
<tr><td>D/M</td><td rowspan="4">Data memory math</td></tr>
<tr><td>D+M</td></tr>
<tr><td>D-M</td></tr>
<tr><td>D-M</td></tr>
<tr><td>M</td><td>Memory</td></tr>
</table>

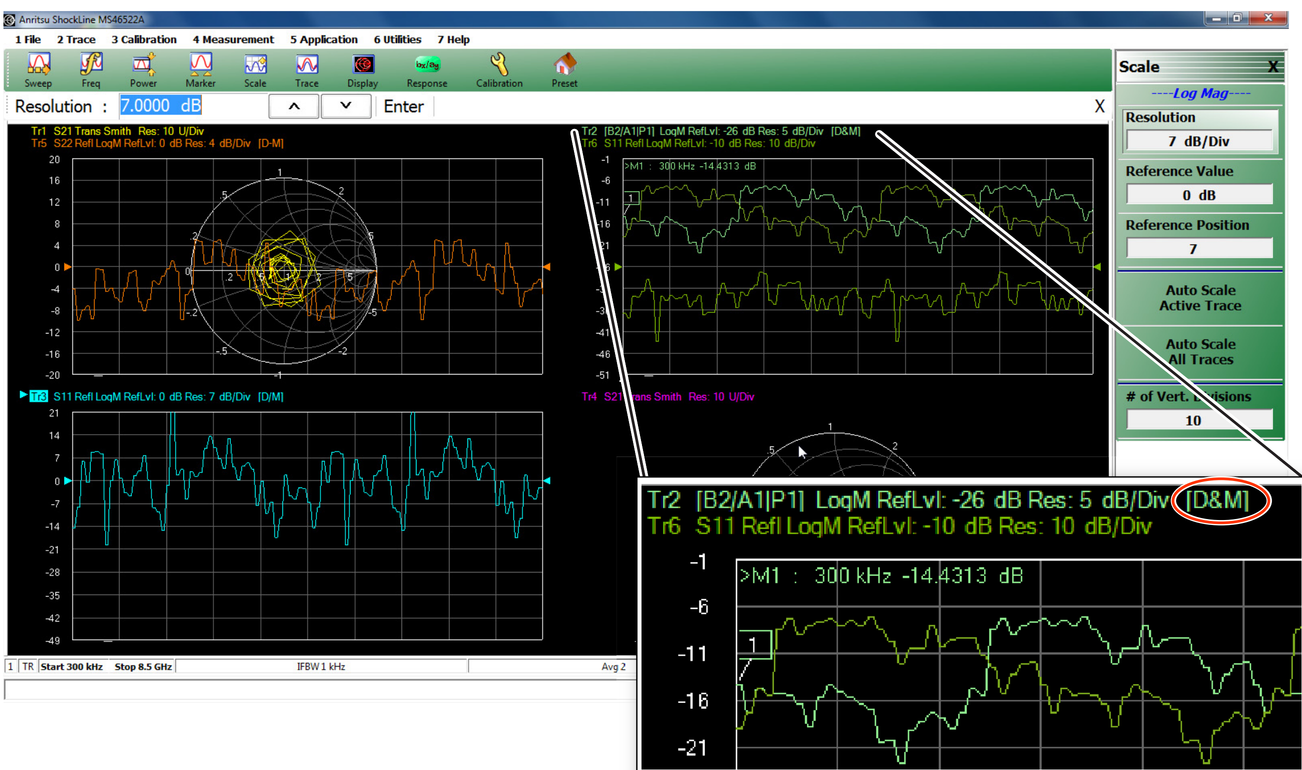


Figure 8-6. Multi-Trace Display with right-side SCALE menu

Figure 8-6 also illustrates an example of a function, auto scale in this case, available on per-trace and per-system levels.

8-5 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
- Averaging and smoothing. Functions and their effects on measurements

8-6 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 5 segments (upper and lower combined) per trace. The main limit line menu is shown in Figure 8-7.

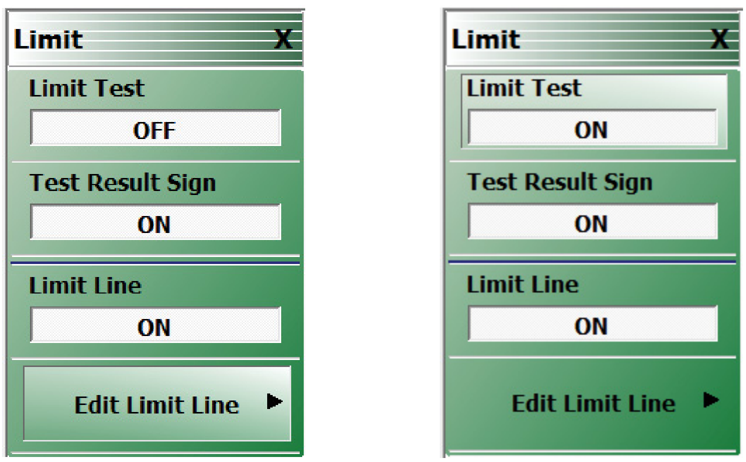


Figure 8-7. LIMIT Menu - Various Functions Toggled ON or OFF

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 8-10) 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.

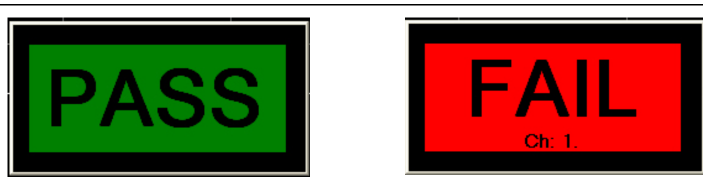


Figure 8-8. Pass and Fail Signs Configured by the LIMIT Menu

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 of Limit Lines

The editing of the limit lines is controlled on the one submenu and that is shown in Figure 8-9. 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

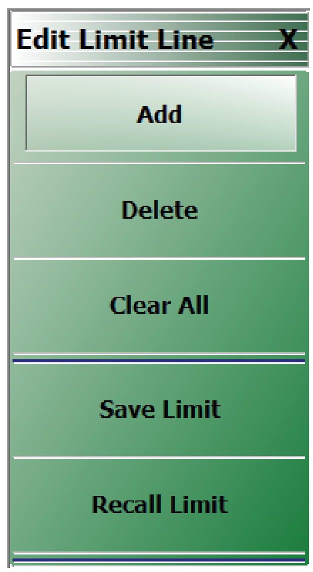


Figure 8-9. EDIT LIMIT LINE Menu

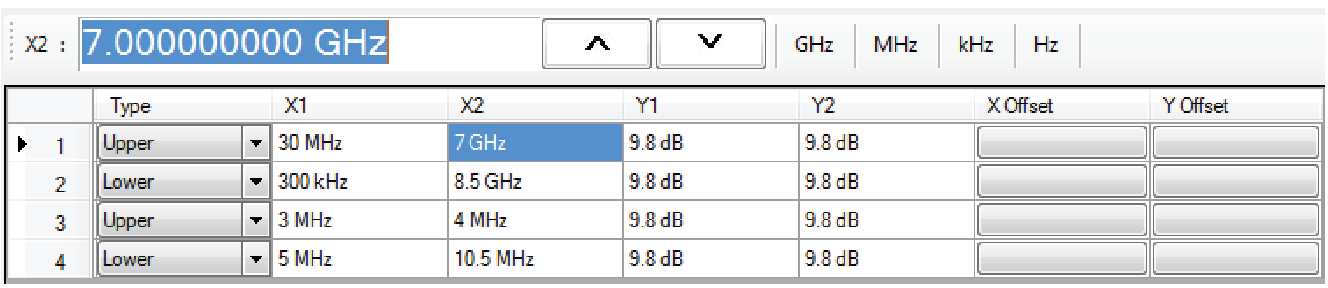
An example limit line table is shown in Figure 8-10 using two upper limit segments and two lower limit segments. For each segment, a number of things need to be entered: Upper or lower: Use the pull-down to indicate if it is an upper limit or lower limit. Another option on the pull-down is “off” to enable suspension that segment.

X1 and X2

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

Y1 and Y2

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



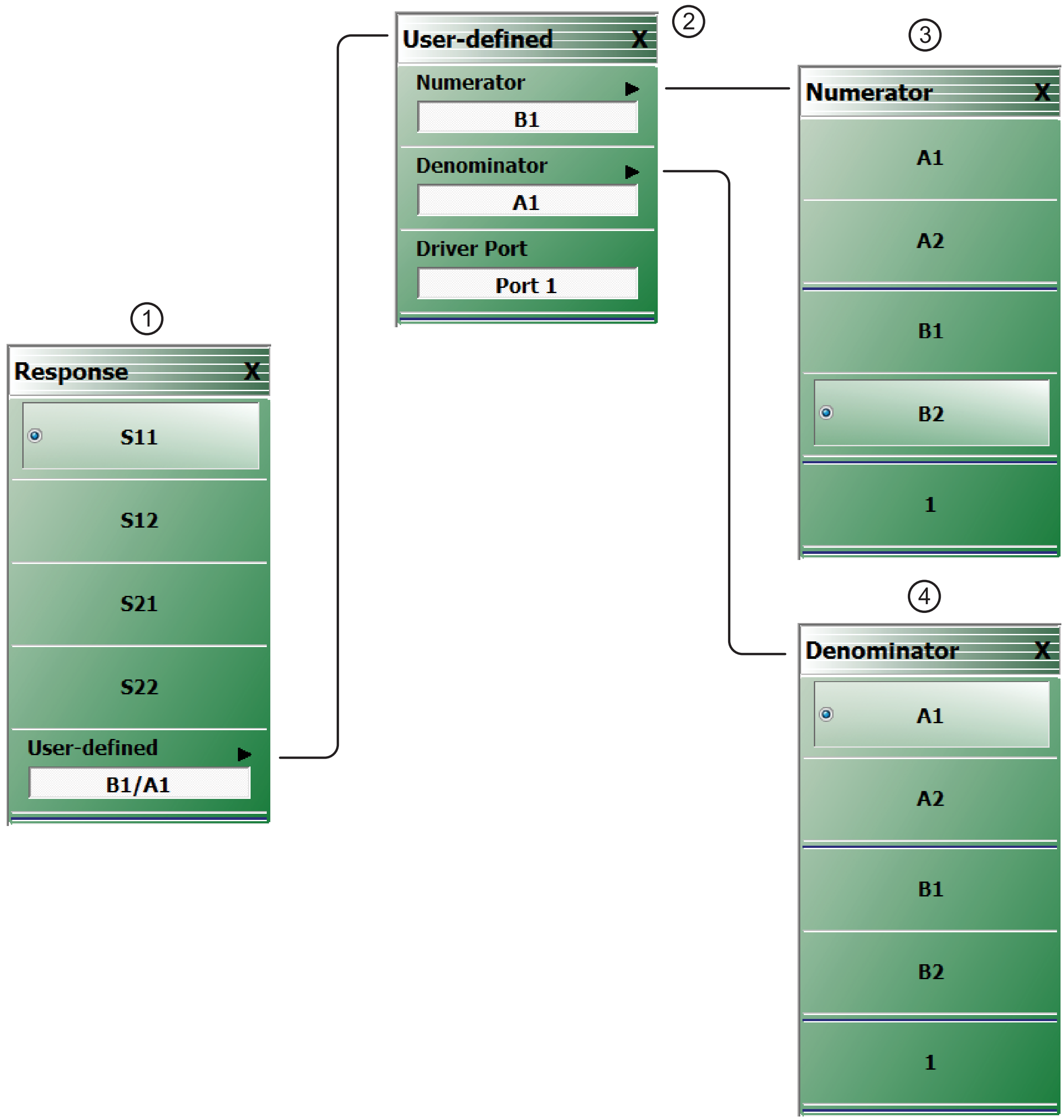
	Type	X1	X2	Y1	Y2	X Offset	Y Offset
1	Upper	30 MHz	7 GHz	9.8 dB	9.8 dB		
2	Lower	300 kHz	8.5 GHz	9.8 dB	9.8 dB		
3	Upper	3 MHz	4 MHz	9.8 dB	9.8 dB		
4	Lower	5 MHz	10.5 MHz	9.8 dB	9.8 dB		

Figure 8-10. 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.

Response Menu

These are selectable on the response menu as shown in Figure 8-11 on page 8-11 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.



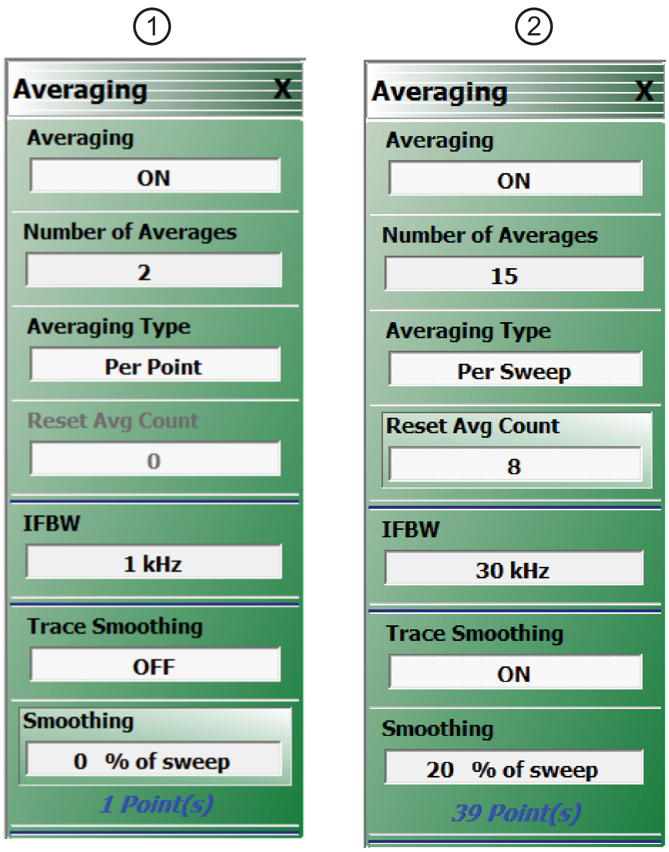
1 – RESPONSE menu	3 – NUMERATOR menu
2 – USER-DEFINED menu	4 – DENOMINATOR menu

Figure 8-11. RESPONSE Menu and Submenus

8-7 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 8-12 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 8-12. 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 500 kHz on the MS46522A. At lower IFBWs, additional per point averaging will have little effect.

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

Trace Smoothing

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

Averaging and Smoothing Conclusions

In time domain, averaging and IFBW apply to the basic frequency domain data. Smoothing applies to the time domain data.

Chapter 9 — Measurement - Time Domain (Option 002)

9-1 Chapter Overview

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

9-2 Introduction

The time domain option offers the ability to transform the native frequency domain data of the MS46522A 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 9-1 on page 9-1.

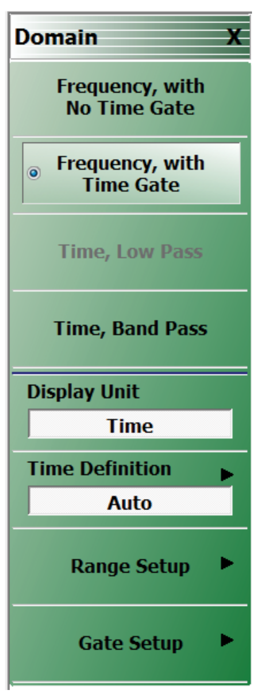


Figure 9-1. DOMAIN Menu - Top Level Domain Menu

9-3 Basic Time Domain Modes

The four basic modes of the Time Domain menu are:

- **Frequency With No Time Gate**

  This is the regular frequency sweep mode.

- **Frequency With Time Gate**

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

- **Time, Low Pass**

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

- **Time, Bandpass**

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

9-4 General Concepts

Chirp-Z Transform

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

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

Defects as Impulse Functions in the Time Domain

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

One-Way or Round Trip Time

One question that arises is whether the time (or distance) plotted represents a one-way or round trip time, particularly in the case of reflection measurements. The time definition menu, shown in Figure 9-2 on page 9-3, 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.

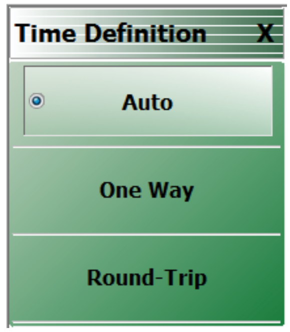


Figure 9-2. TIME DEFINITION Menu

9-5 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 9-3. 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.

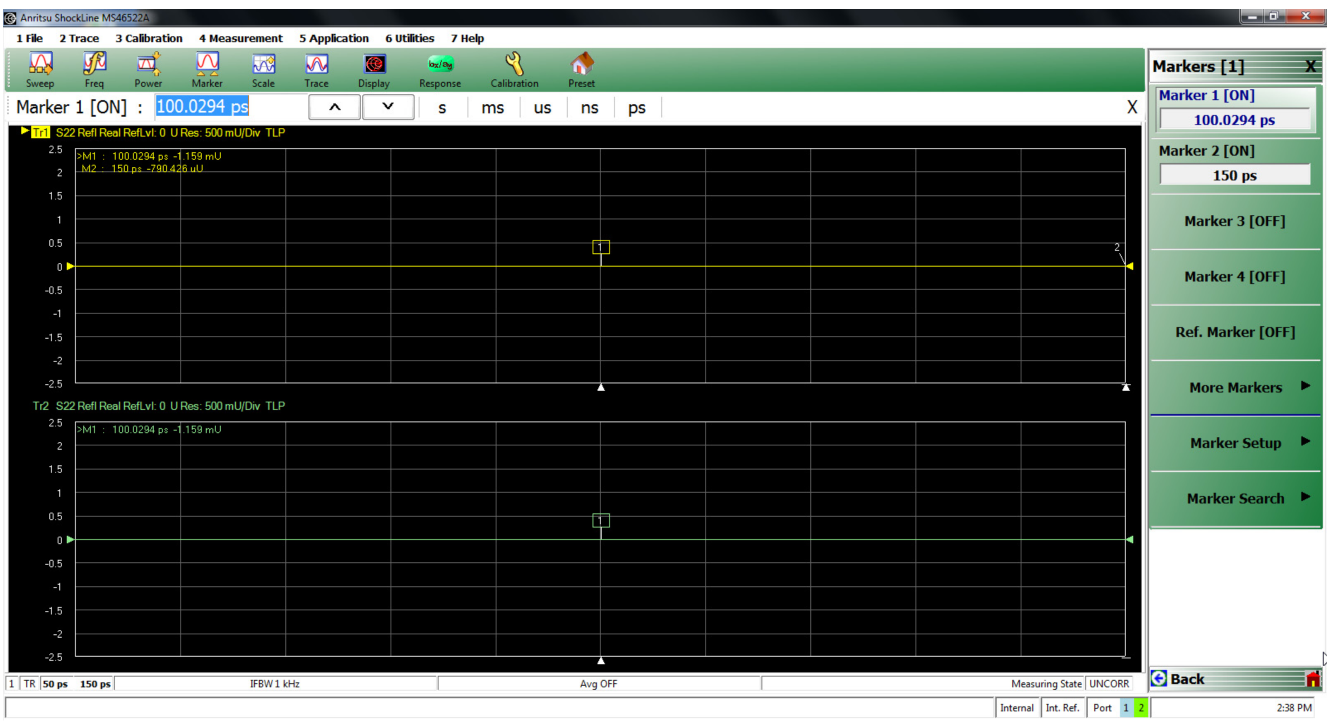


Figure 9-3. Example Low-pass Time Domain Plot

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 9-4. 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 9-1).

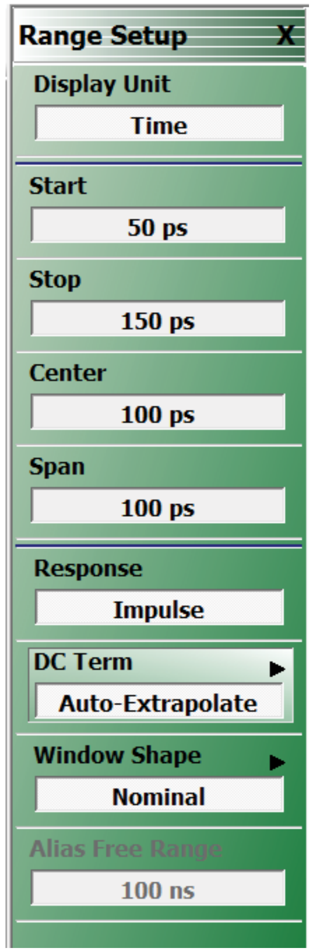


Figure 9-4. RANGE SETUP Menu - Time, Low Pass Domain

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 9-1) 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™ MS46522A-10 VNA cannot get all the way to DC, some additional information is needed to perform this integration. To see this consider:

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

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

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

Eq. 9-1

DC Term Menu

Since the DC value ends up being integrated from time 0 (zero), the value used here is quite important and the choices to compute this value are shown in Figure 9-5. The default choice is to allow the system to auto-extrapolate from existing frequency data to estimate the DC value.

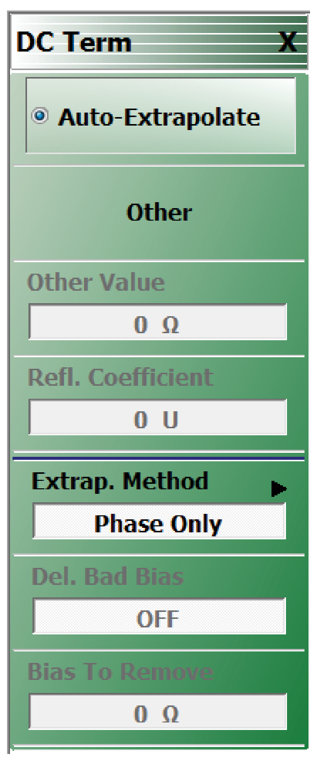


Figure 9-5. DC TERM Selection Menu

There are options on how the extrapolation is done, as shown in Figure 9-6.

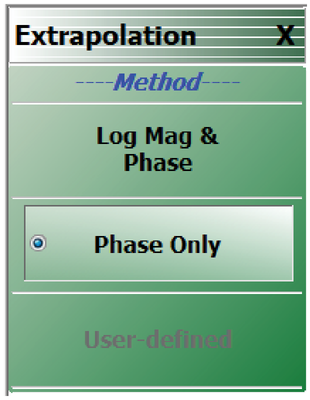


Figure 9-6. The DC Term EXTRAPOLATION Menu

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 9-7.

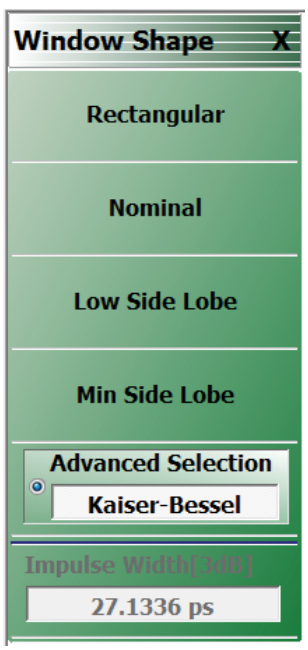


Figure 9-7. WINDOW SHAPE Menu

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 9-8. Here the same data appears with the four different window selections. For this plot, data was saved to TXT files and plotted externally.

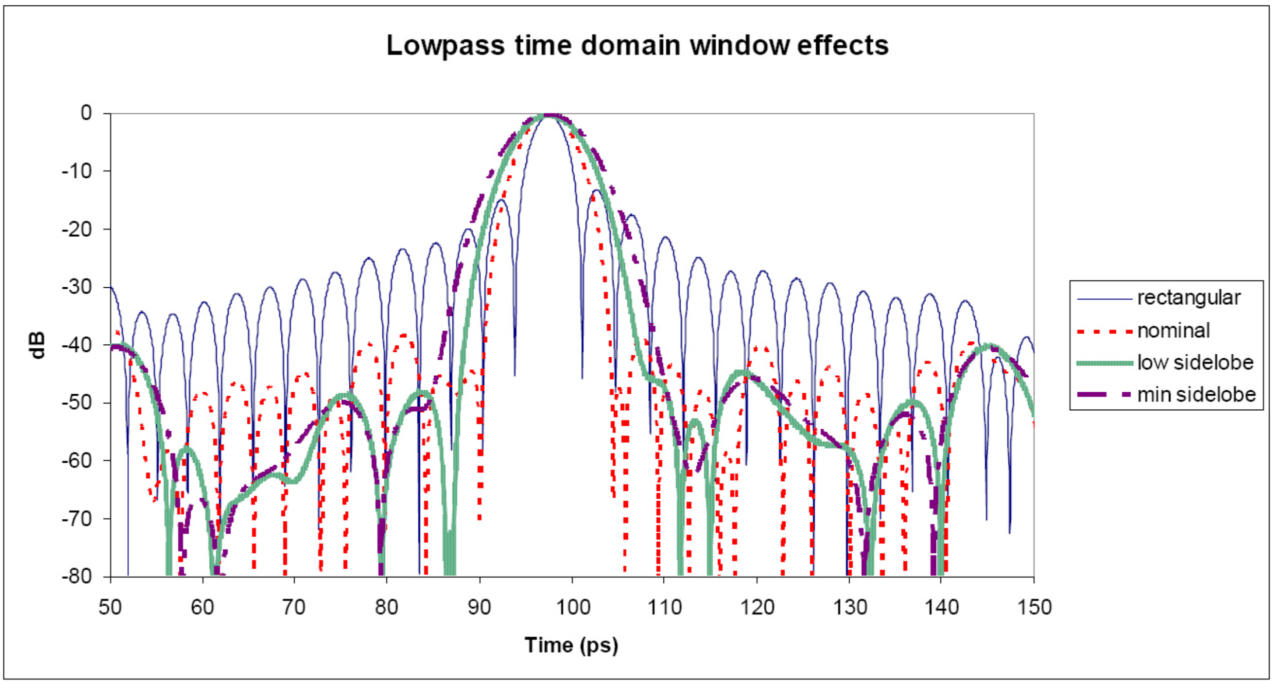


Figure 9-8. Effects of Window Shapes Plot

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

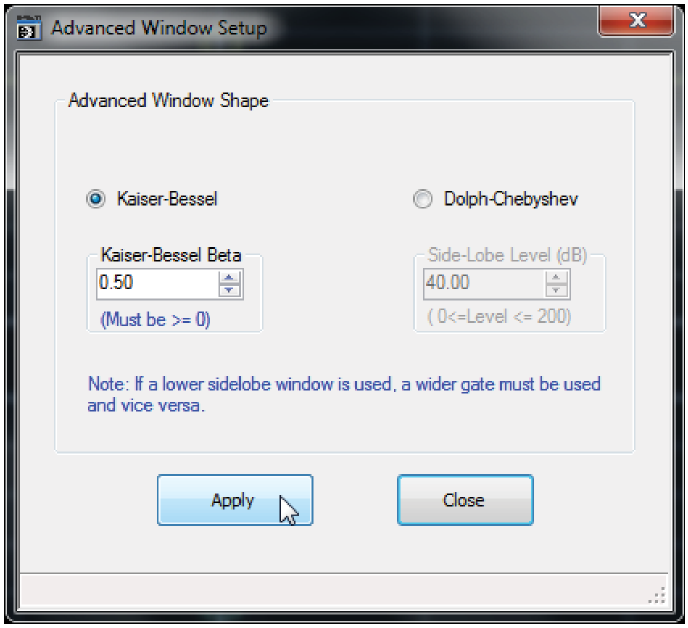


Figure 9-9. Advanced Window Setup Dialog

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 9-10 along with the rectangular window for comparison.

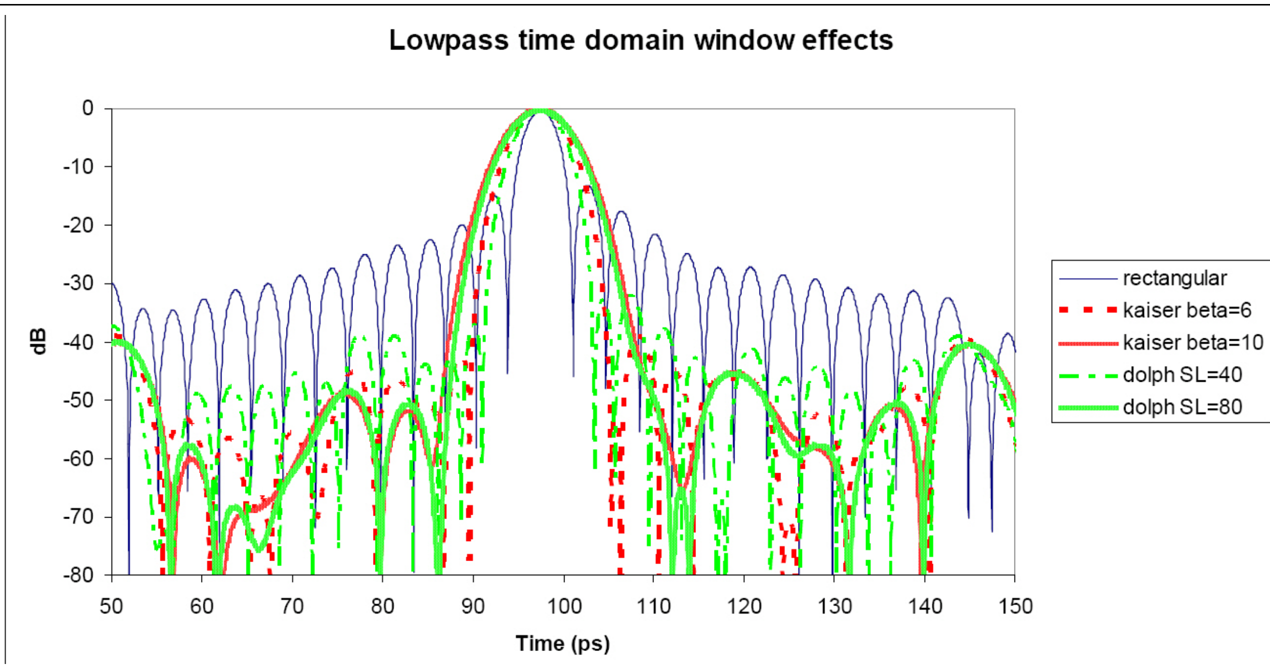


Figure 9-10. Effects of Window Shapes Plot with Advanced Windows Selection

The approximate relationship between these parameters and the main lobe width (null-to-null) is suggested in Figure 9-11. 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.

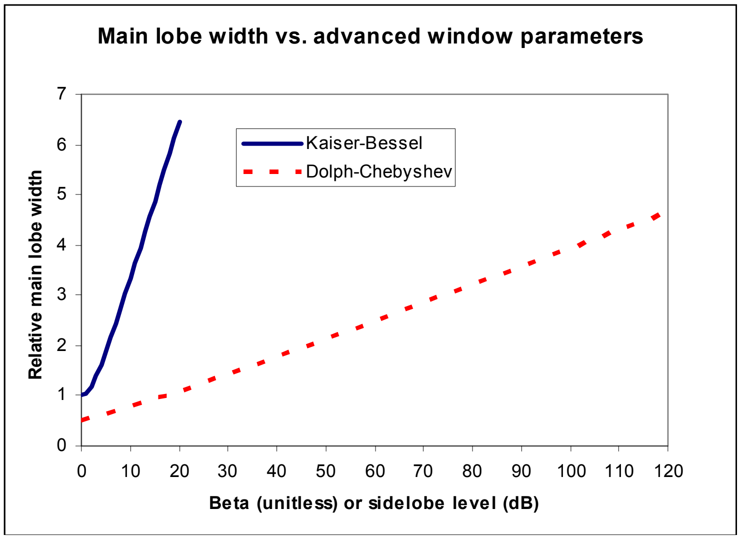


Figure 9-11. Comparison of Lobe Width vs. Window Parameters

9-6 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 9-12 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 9-2) is shown in Figure 9-17. 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.

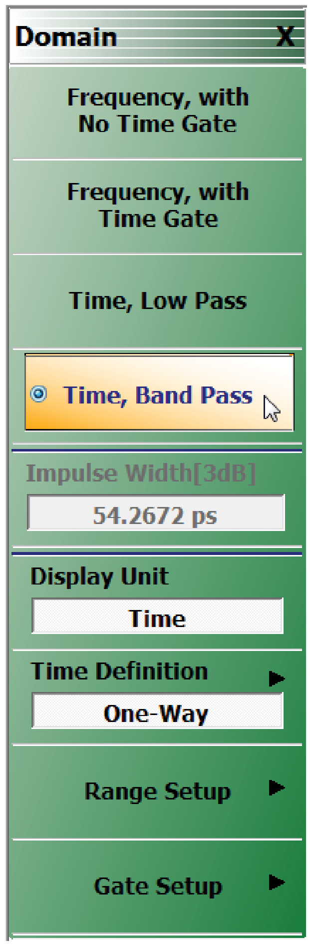


Figure 9-12. Top Level DOMAIN Menu - Time, Band Pass Selected

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.

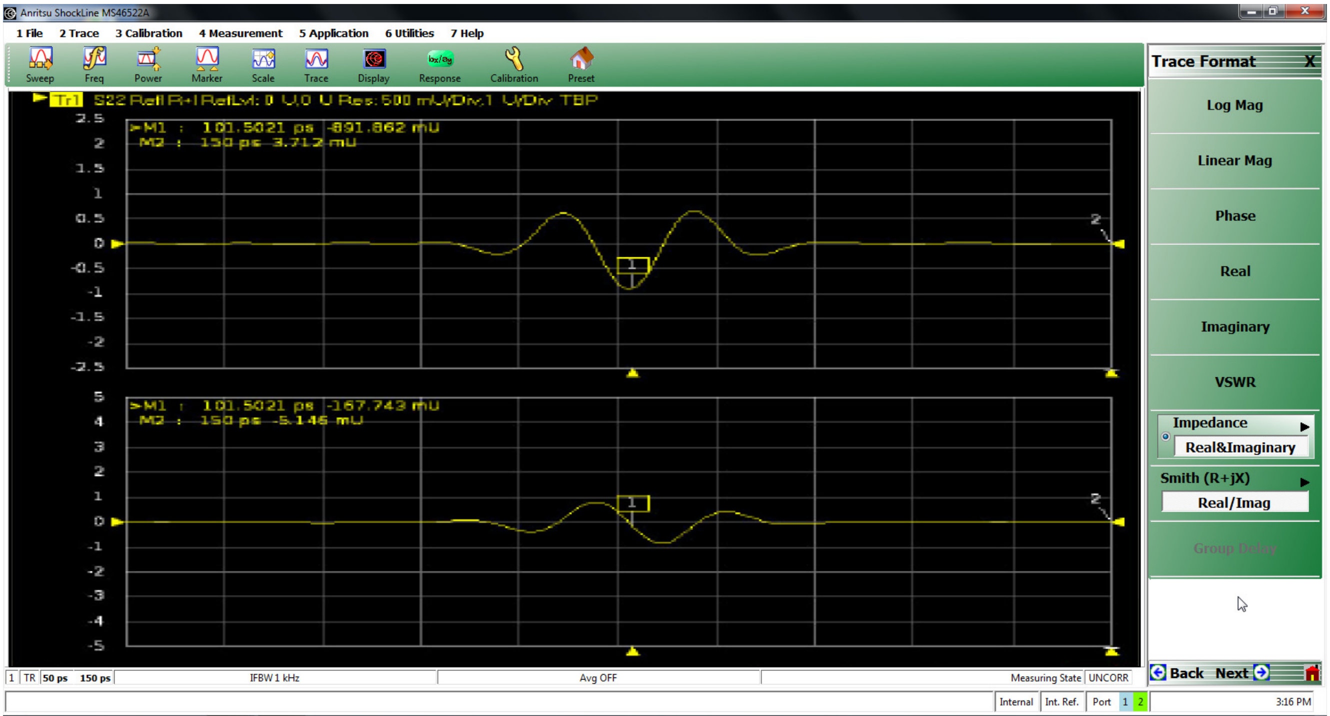


Figure 9-13. Example Band-pass Time Domain Plot

The range menu for bandpass mode is shown in Figure 9-14. The differences here are that the response choice and DC terms are gone since they do not apply to this mode, and a new item appears: Phasor Impulse.

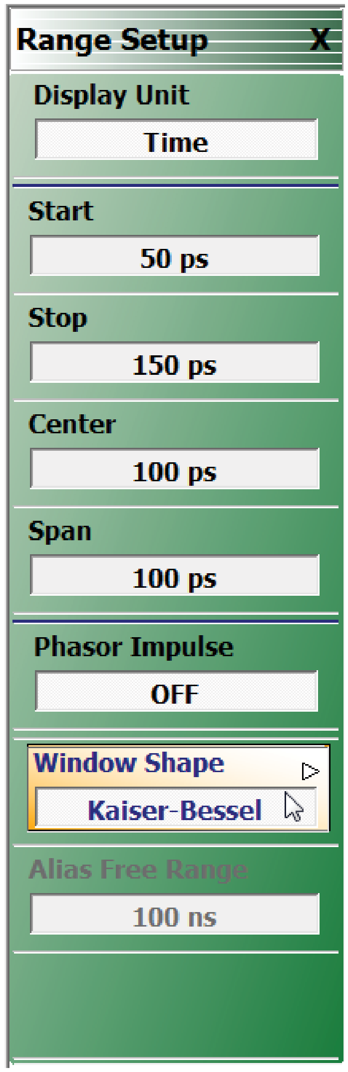


Figure 9-14. RANGE SETUP Menu for Bandpass Time Domain

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 9-15 and correspond to the measurement of Figure 9-13 on page 9-11, but expressed in log magnitude. Note the trade-off of side lobe height for main lobe width and that the lobe width is twice that for low pass (Figure 9-8 on page 9-7).

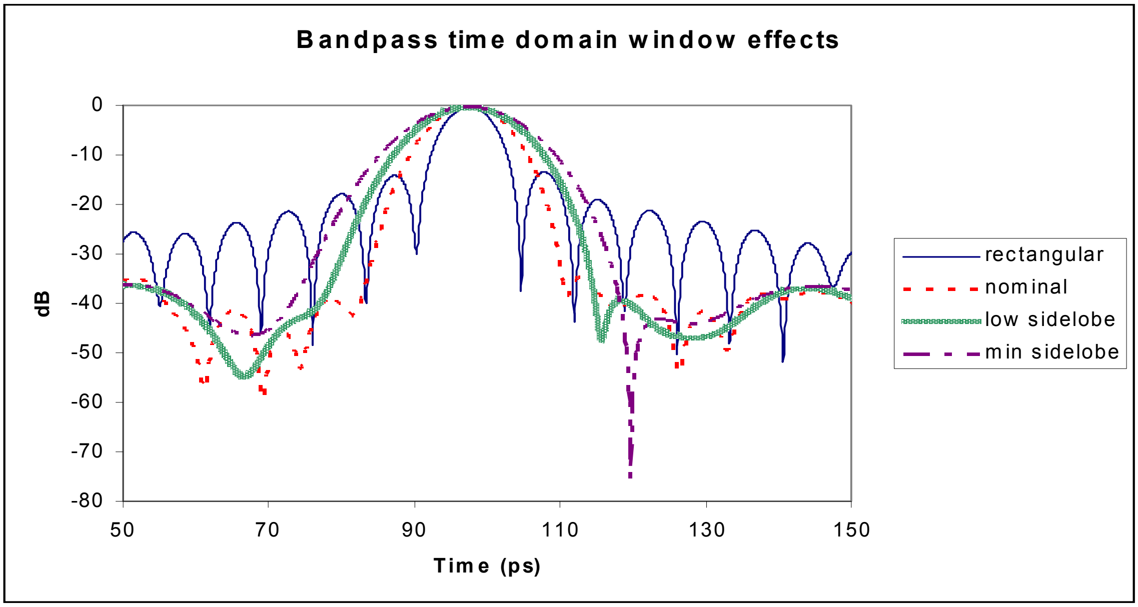


Figure 9-15. Window Effects in Bandpass Time Domain

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.

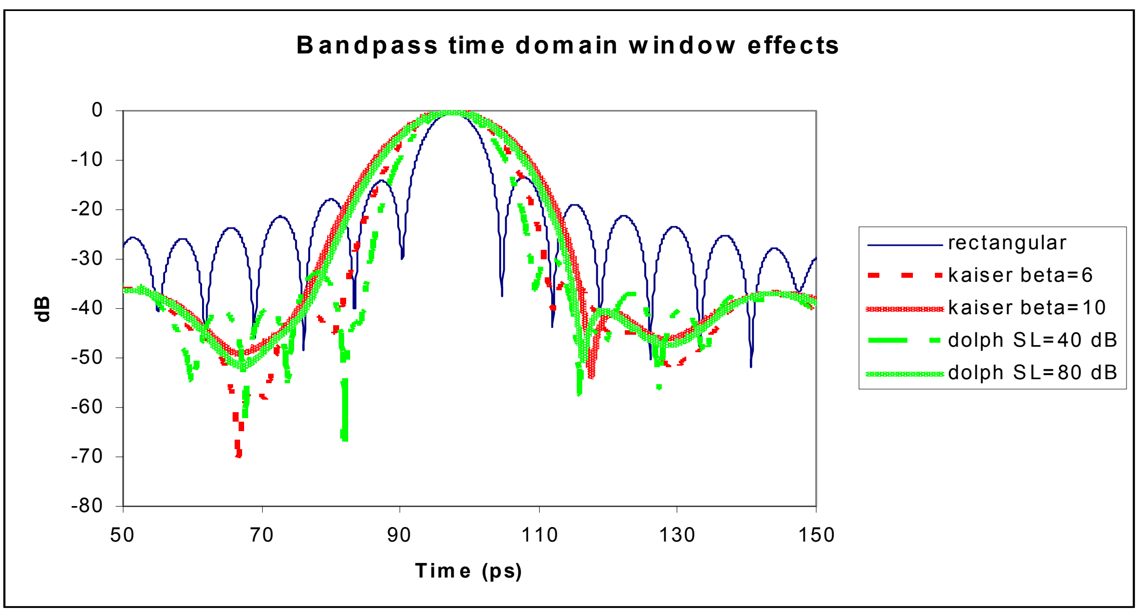


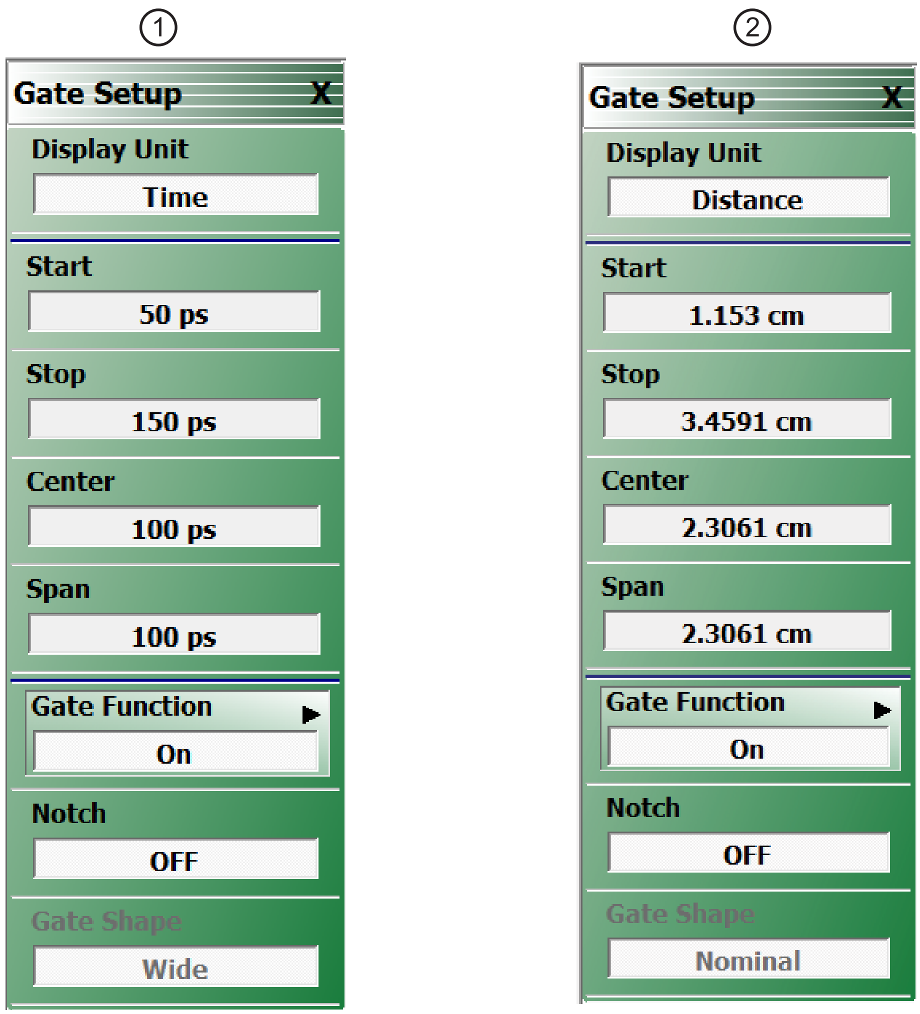
Figure 9-16. Window Effects in Bandpass Time Domain (advanced window types)

9-7 Gating

Both lowpass and bandpass work similarly with regards to gating. Gating is the process of selecting or deleting certain defects to study. This can be left in time domain but, more commonly, the gated results are fed back through the forward transform to get the frequency domain result corresponding to the modified defect scenario just created.

Gate Menu

The Gate menu looks much like the Range Menu. The Display Unit toggle button and Start, Stop, Center, and Span buttons (for the gate this time) control values as described in the sections above.



1. Time units (at left)	2. Distance units (at right)

Figure 9-17. 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 9-18.

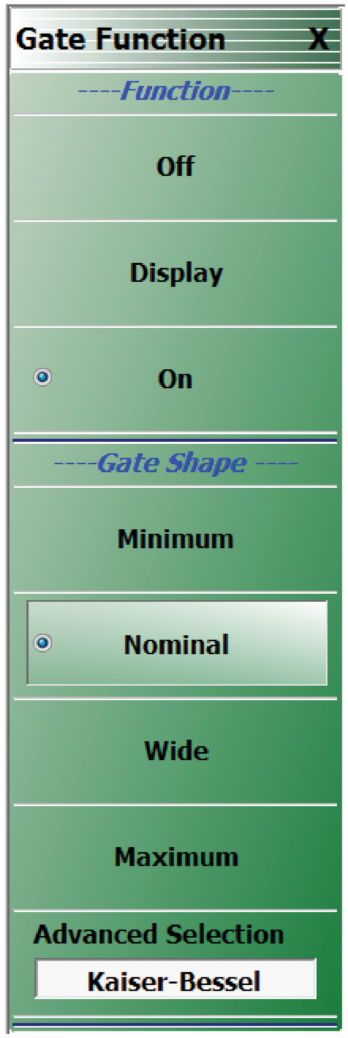


Figure 9-18. Gate Function Submenu

The default gate shape is nominal. By default, the gate is off. Selecting Display will allow the gate function to be drawn on screen (using the current graph type for the active trace). This can be helpful in visualizing what is being included in the gate. Turning gate on will apply the gate to the current time domain data.

The gate shape is analogous to the window selection. If the data was truncated with a sharp gate (minimum, akin to rectangular), maximum resolution in used determining the gate but ripple is introduced in the frequency domain. For more gradual gates, the resolution in separating defects decreases, but the size of the artifacts added to the frequency domain data decreases as well.

The window and gate shapes cannot be selected entirely independently since they interact through the transform. In particular, the use of a very sharp gate with a low side lobe window can lead to large errors. The allowed combinations are shown in the table below. If an invalid combination is selected, the variable not being currently modified will be changed to the nearest valid value.

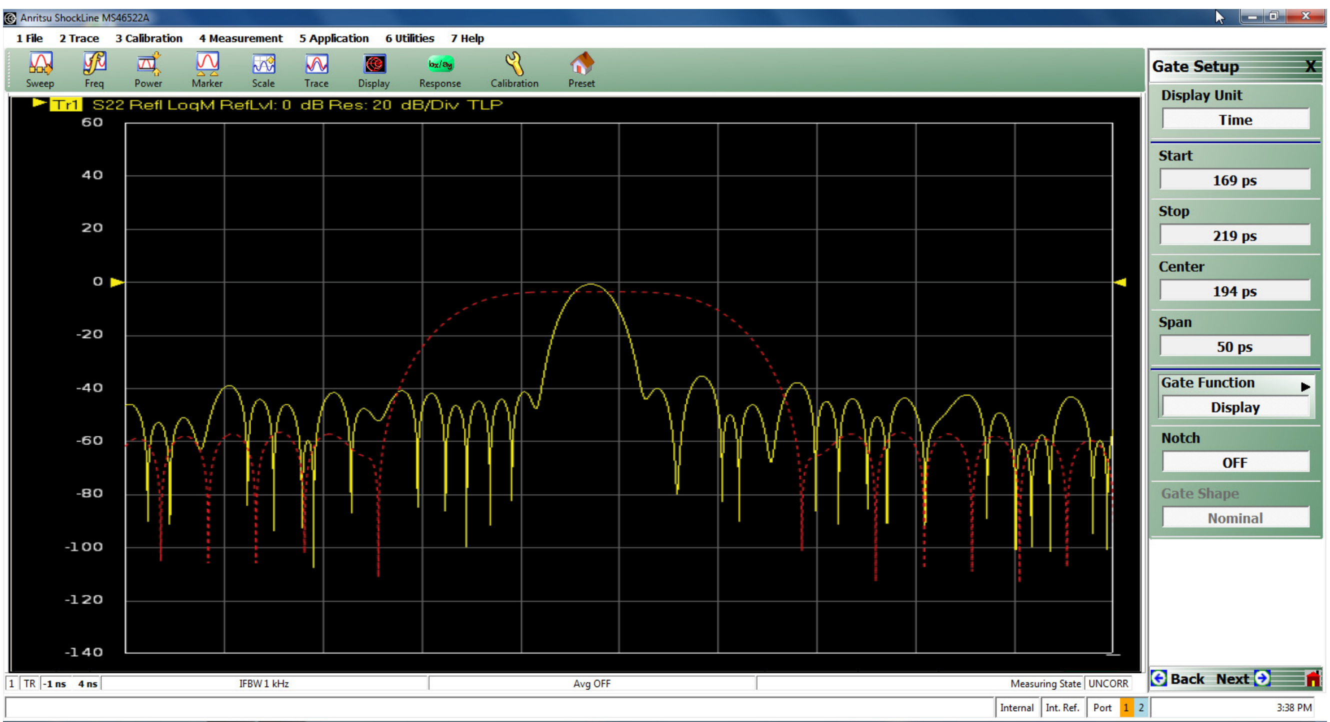
With the advanced gates and windows, selections are not precluded although substantial errors can result if values are chosen without caution. If a more aggressive window is chosen (larger beta or side-lobe level), then the gate must be wider (wide or maximum; larger beta or side-lobe level).

Table 9-1. 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 9-19, the gate is in display mode surrounding the desired reflection. Both gate and window are set to nominal in this case.



Gate is the red dashed line

Figure 9-19. Gate in Display Mode Example

Next the gate is turned to on. In Figure 9-20, the suppression of the time domain information outside of the gate area is seen.

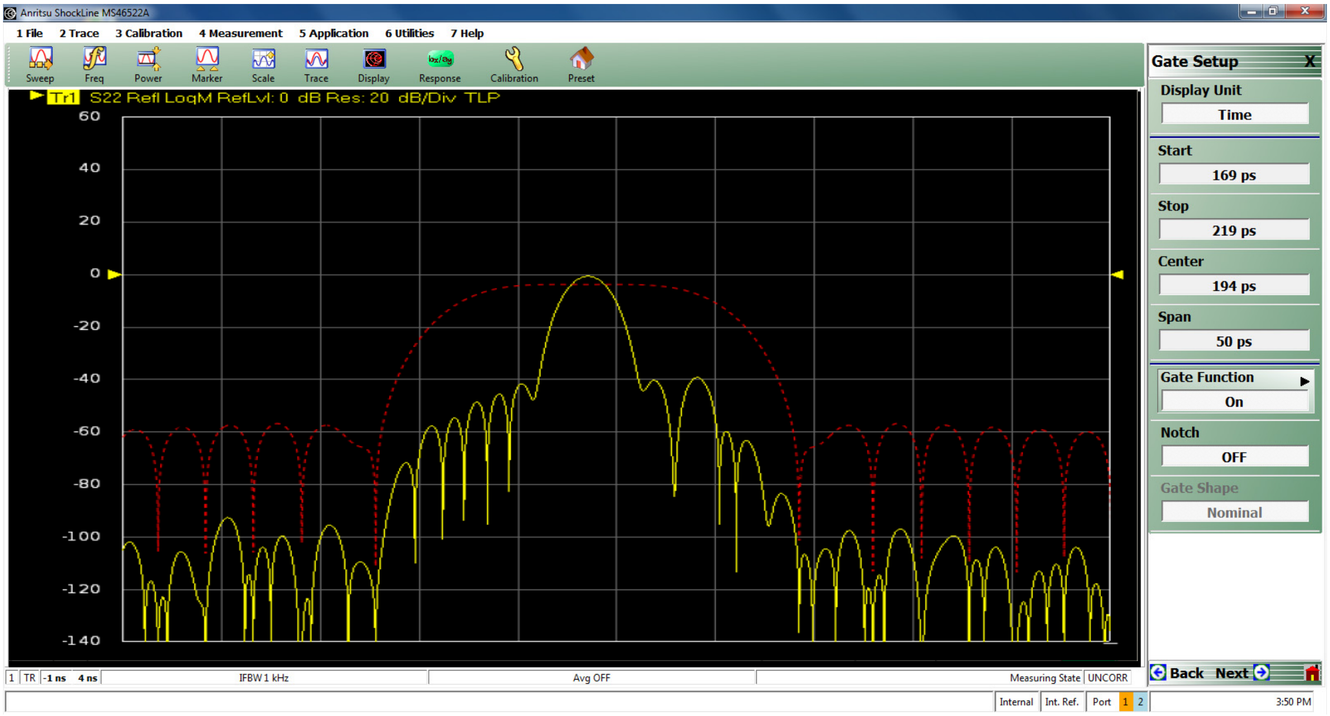


Figure 9-20. Gate Turned On Example

Finally, frequency with time gating is activated and the result is shown in Figure 9-21. 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.

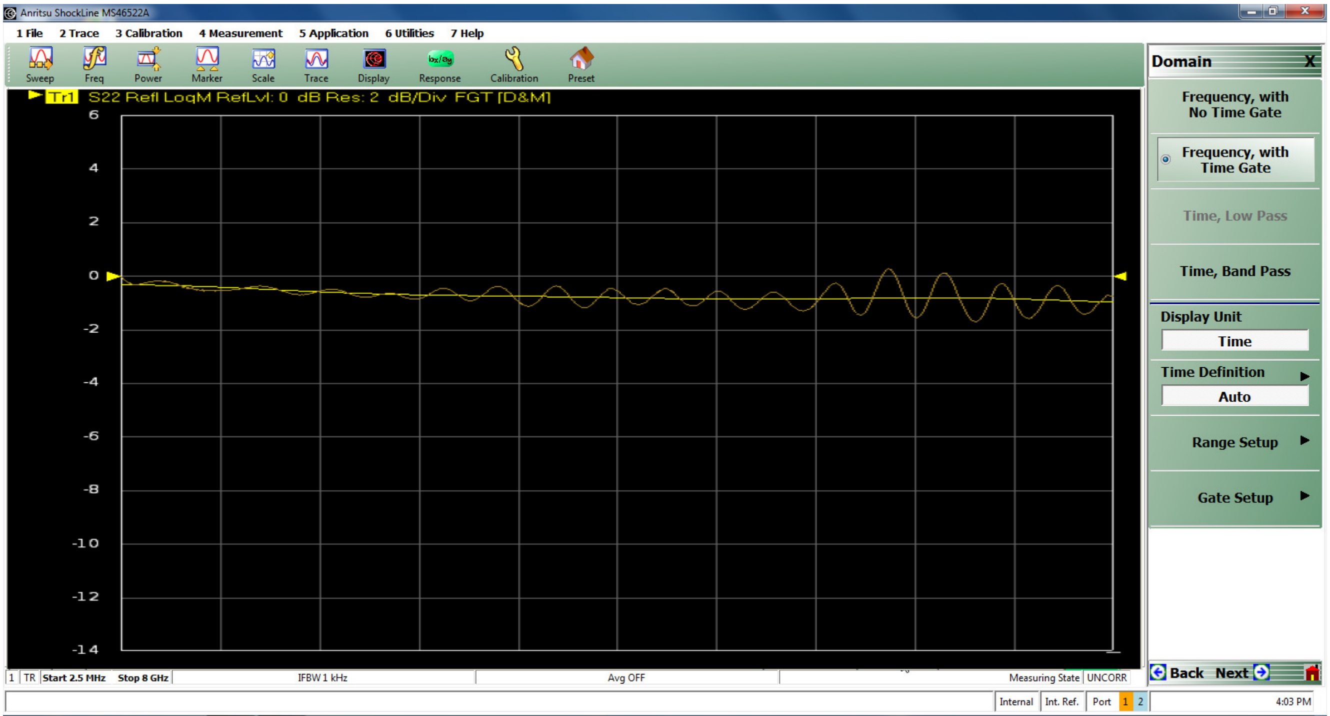


Figure 9-21. Frequency with Time Gating Example

Chapter 10 — Measurement - Sweep Types

10-1 Chapter Overview

This chapter covers the different sweep types available with the ShockLine™ MS46522A Series VNA to increase measurement functionality.

10-2 Introduction

A number of different sweep types are available within the MS4640B Series VNAs include

- Traditional frequency sweep (defined by a start frequency, a stop frequency and a number of points)
- Power sweep (frequency is constant and power is defined by a start value, a stop value, and a number of power points).
- Frequency-based segmented sweep (frequencies are defined individually or in sub-spans, that are monotonically increasing)
- Index-based segmented sweep (frequencies are defined individually or in sub-spans and can be in any order; all plotting is in terms of index rather than frequency because of the possible direction changes)

The setup complexities in regular frequency sweep and power sweep are minimal and will only be discussed briefly. The segmented sweep possibilities are considerably larger and some explanation will help in setting them up.

The SWEEP SETUP and SWEEP TYPES menus are shown in Figure 10-1

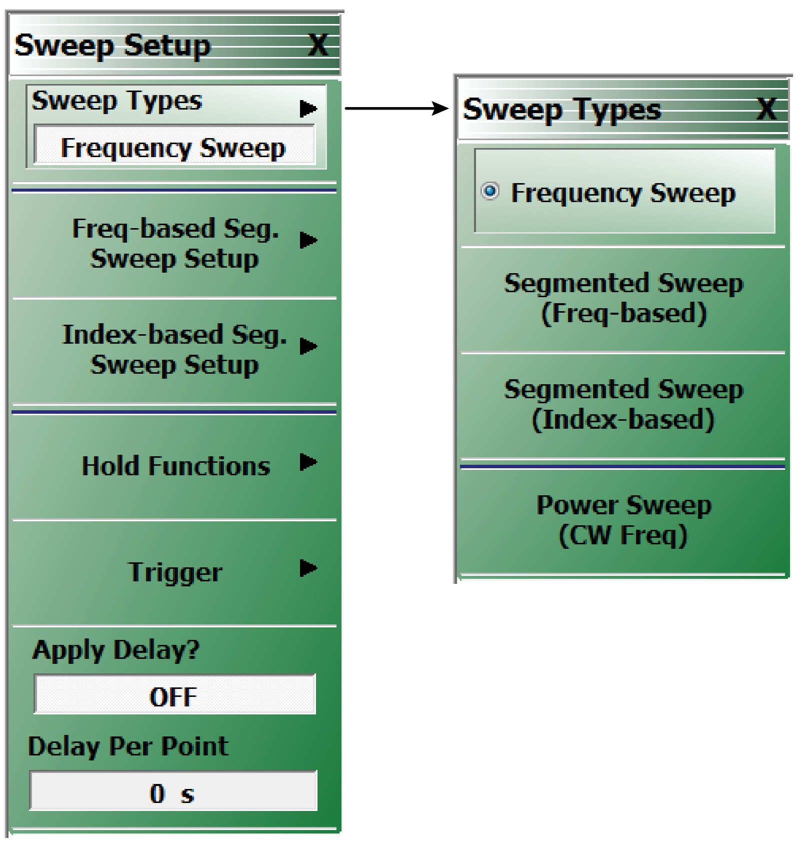


Figure 10-1. SWEEP SETUP Menu

10-3 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 20,001.

Power entry while in frequency sweep mode is accomplished through the Main Power Menu as shown in Figure 10-2.

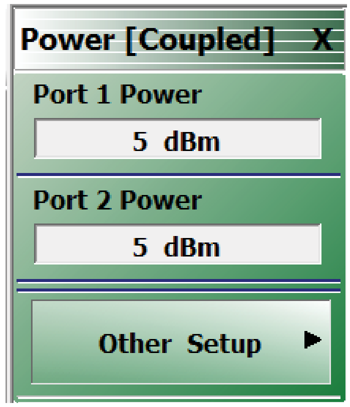
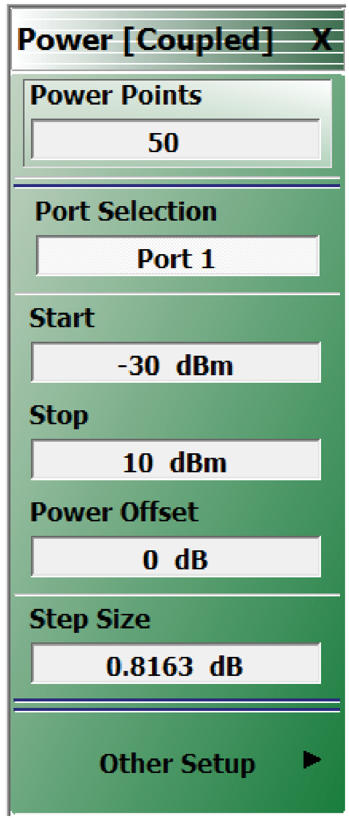


Figure 10-2. Main POWER Menu - Port 1 and Port 2 Coupled

10-4 Setting Up Power Sweeps

A power sweep is valuable for making power dependent semi-linear measurements. The frequency is set at a single CW value and the power range is specified in a way analogous to frequency sweeps as suggested by Figure 10-3.



Sweep Type set to Power Sweep (CW Freq)

Figure 10-3. Main Power Sweep Menu - POWER [COUPLE] Menu

As with the regular power control in frequency sweep, the power at the two ports may be coupled or uncoupled. This feature takes on new importance in power sweep in that the two ports may drive with completely different power ramps. The number of points in these two power sweeps must, however, be the same. As with all sweep types, different attenuator settings in different channels is not permitted to avoid potential attenuator damage in fast sweeping scenarios.

Power offset is an important entry for cases when an external preamplifier, large pad, or other network may be in use between the port and the DUT plane.

Some of the more detailed controls are on the power setup level of the power menu located on the POWER SETUP menu (see Figure 10-4). The coupling control and port selection (when uncoupled, duplicate of first level) is located here as is the single power selection items. This entry allows one to put the system in constant power (and constant frequency) and is often used for making DUT adjustments prior to full power sweep measurements.

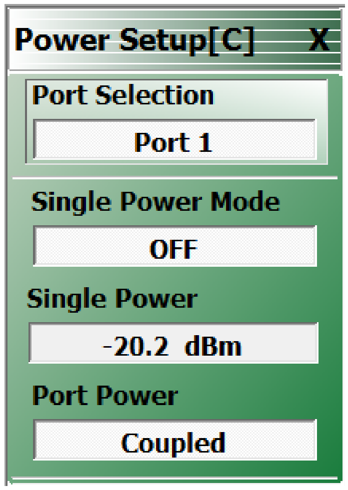


Figure 10-4. Second Level Power Sweep Setup Menu - POWER SETUP[C] Menu

10-5 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 10-5 and Figure 10-6. 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.

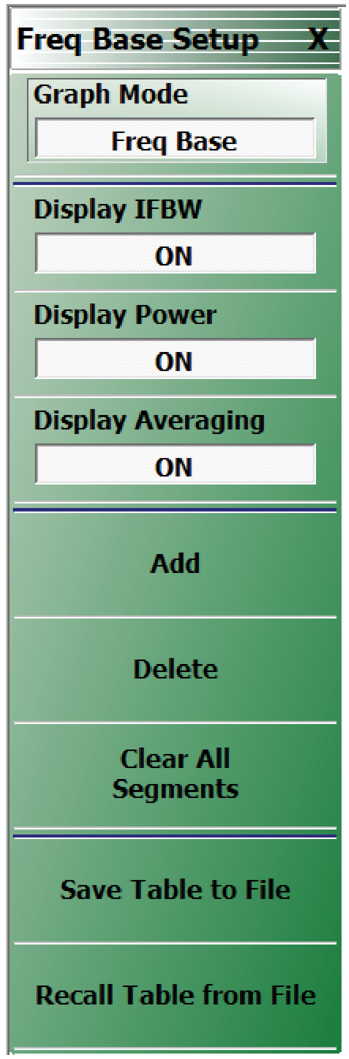


Figure 10-5. FREQ BASE SETUP (FREQUENCY-BASED SETUP) Menu

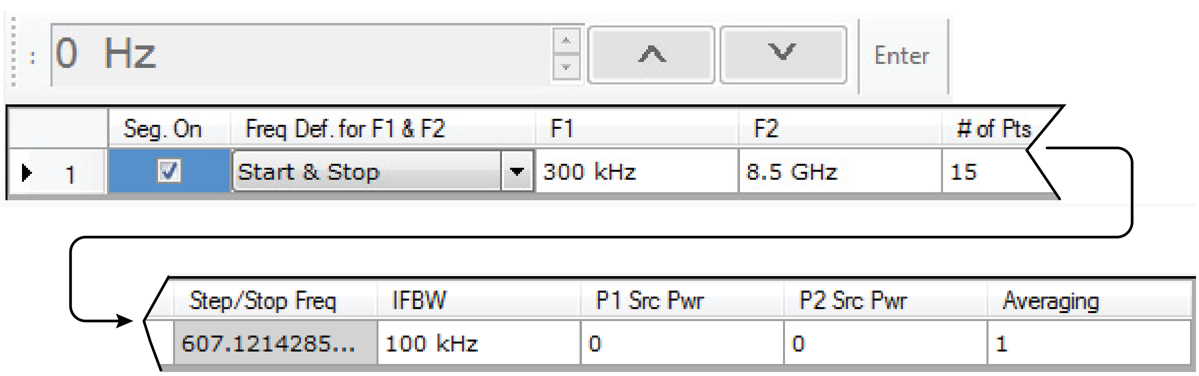


Figure 10-6. Tableau Entry Table for Frequency-based Segmented Sweep

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 10-7.

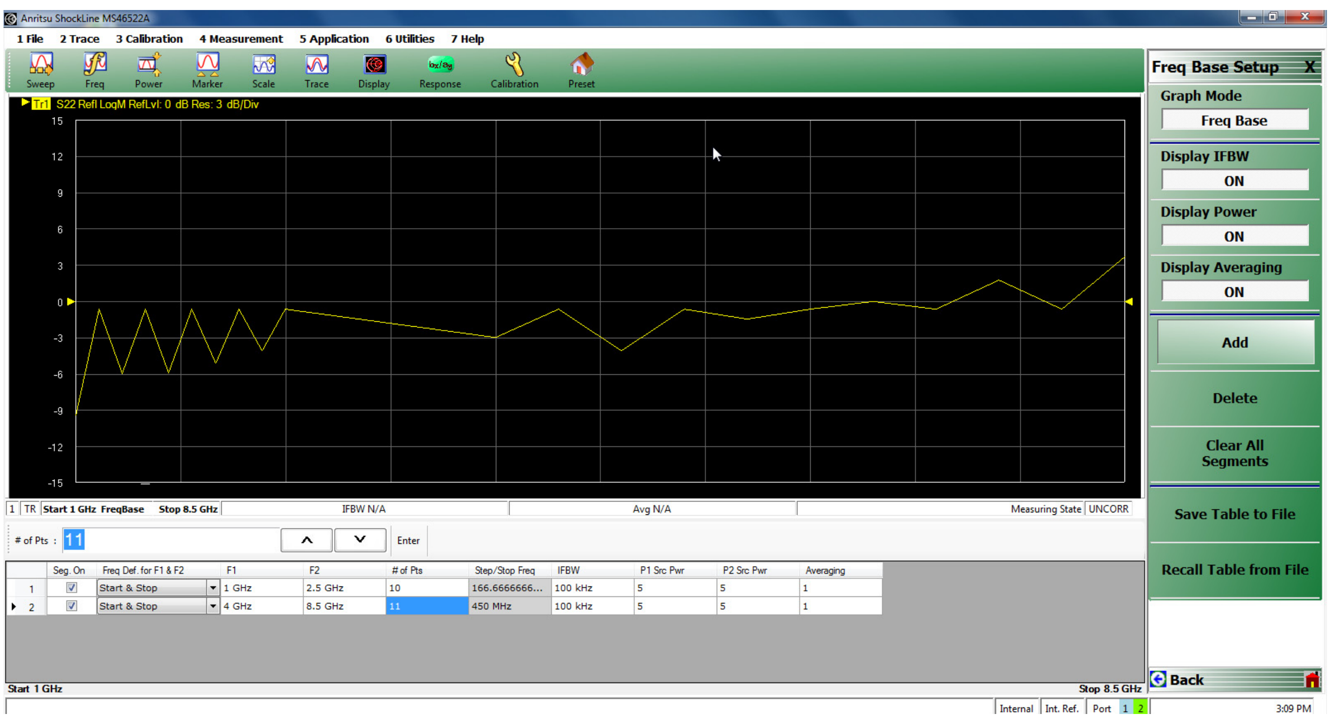
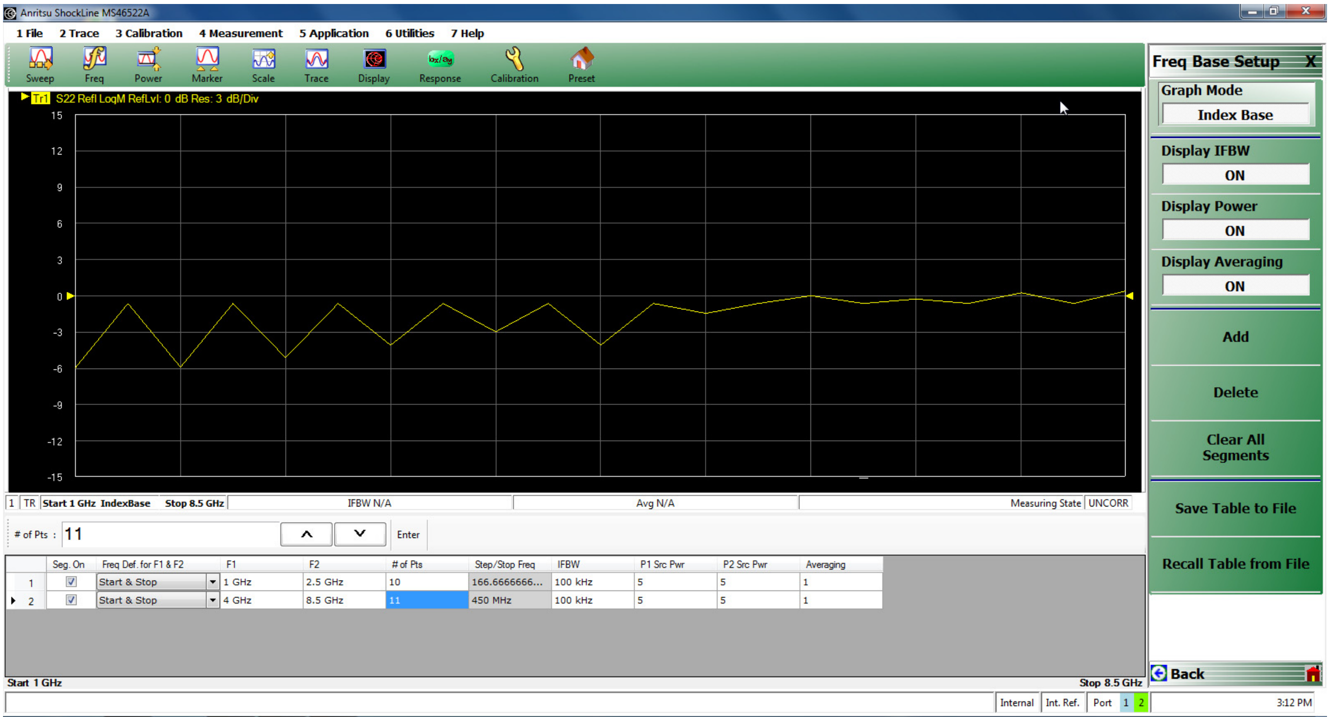


Figure 10-7. Frequency-Based Graph Mode

Since Segment 1 covers 1 GHz to 2.5 GHz and Segment 2 covers 2.5 GHz to 8.5 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 10-8 for the same setup as Figure 10-7. 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.



	Seg. On	Freq Def. for F1 & F2	F1	F2	# of Pts	Step/Stop Freq	IFBW	P1 Src Pwr	P2 Src Pwr	Averaging
1	☑	Start & Stop	1 GHz	2.5 GHz	10	166.6666666...	100 kHz	5	5	1
2	☑	Start & Stop	4 GHz	8.5 GHz	11	450 MHz	100 kHz	5	5	1

Figure 10-8. Index-Base Graph Mode

It is important to keep separate the concepts of frequency-based versus index-based for the graph mode (which only controls how things are plotted) and frequency-based versus index-based segmented sweep type (which determines how the points are swept by the instrument hardware).

10-6 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 10-9 and Figure 10-10.

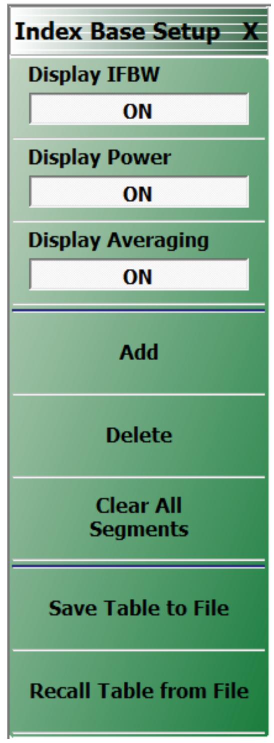
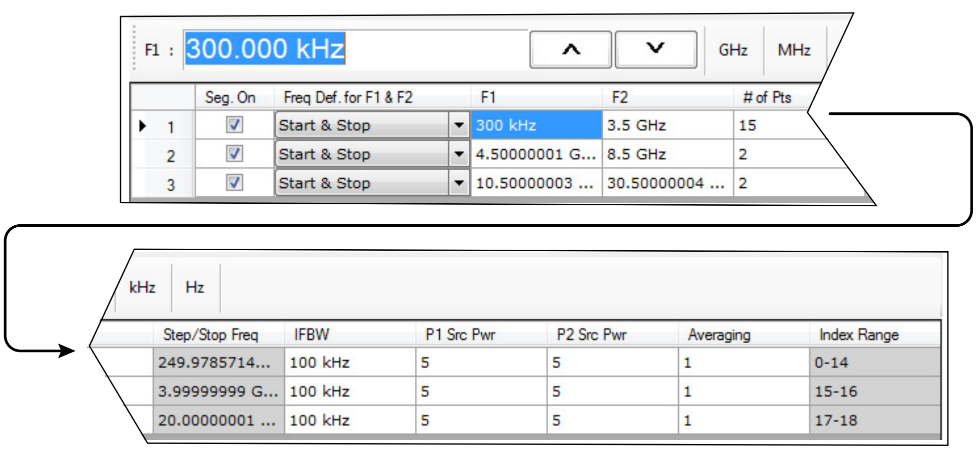


Figure 10-9. Main Menu for Index-based Segmented Sweep - INDEX BASE SETUP Menu

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



F1 : 300.000 kHz GHz MHz

	Seg. On	Freq Def. for F1 & F2	F1	F2	# of Pts
1	☑	Start & Stop	300 kHz	3.5 GHz	15
2	☑	Start & Stop	4.50000001 G...	8.5 GHz	2
3	☑	Start & Stop	10.50000003 ...	30.50000004 ...	2

kHz Hz

Step/Stop Freq	IFBW	P1 Src Pwr	P2 Src Pwr	Averaging	Index Range
249.9785714...	100 kHz	5	5	1	0-14
3.99999999 G...	100 kHz	5	5	1	15-16
20.00000001 ...	100 kHz	5	5	1	17-18

Figure 10-10. 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 11 — Reciprocal Measurements

11-1 Chapter Overview

This chapter describes the reciprocal concept (SOLR or unknown thru approach) measurements.

11-2 Introduction

The previously discussed SOLT and offset short calibration techniques all require a known “thru (or through)” as part of the full 2 port (or 1p-2p) calibration. The “thru” is really a defined transmission line having known length, known loss, and assumed perfect match (under most conditions). There are certain cases when this is not possible:

- Coaxial cal when the two ports are different connector types
- On-wafer when the “thru” is a meandering transmission line of imperfect match
- A calibration that must take place through a test set (coax or waveguide) with unknown (and highly frequency dependent) loss and match

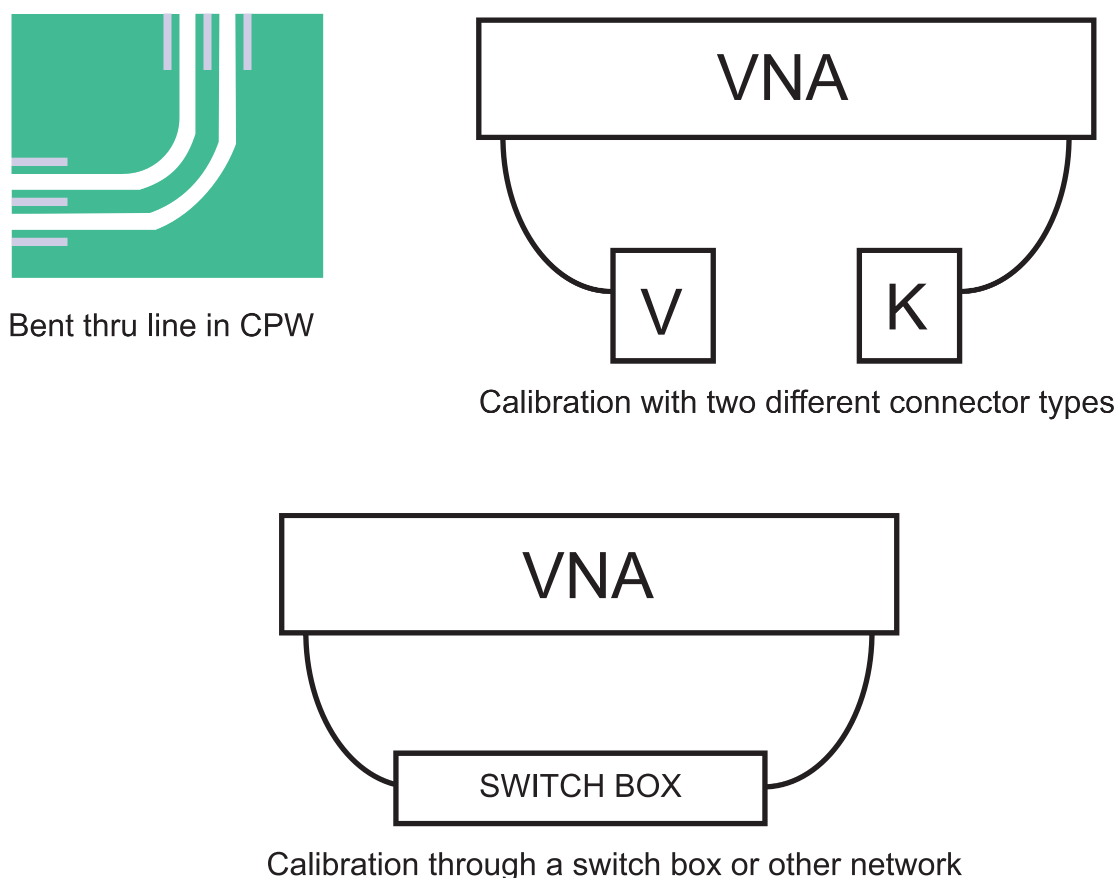


Figure 11-1. Illustration of SOLR or “Unknown Thru” Calibration

For these cases, and others when the “thru” cannot be very well-known, there is the Reciprocal option (also known as the unknown thru). In this case, the same reflect standards are used, but no assumption is made about the “thru” except that it be reciprocal (i.e., S21=S12; no assumption made about S11 and S22). In practice, there are some limits to this.

The technique borrows from the LRL family and uses some of the redundancy available with the fully-defined families to reduce knowledge needed about something (the thru in this case). The resulting cal will generally not be quite as accurate as the regular thru version if the thru met the conditions described above. It will, however, be better than using the regular thru version when the thru has unknown loss or match.

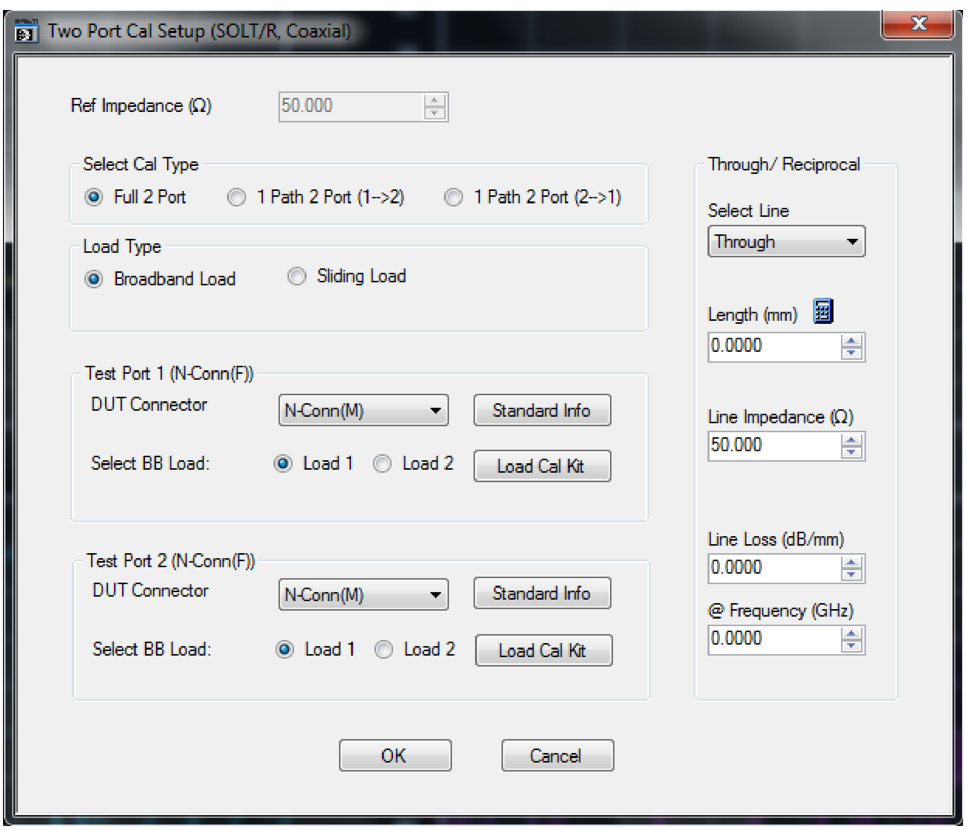
11-3 Line Length Estimate

A line length estimate (electrical delay or free space equivalent length) can be used to help with root choice, but this is not a critical parameter. Typically, one needs only to be within a half-wavelength of the correct length at the maximum desired calibration frequency. If one enters 0 for the length, the software will automatically estimate the length based on fitting-to-the-phase function at the lower part of the frequency range. Details are discussed in Chapter 4 related to automatic length estimation for adapter removal procedures and the same principles apply here. The only danger in auto length estimation is if the frequency step size is large relative to the electrical size of the setup. As discussed in Chapter 4, one can look at the phase of an uncalibrated transmission parameter in the setup to see how fast the phase is changing.

If the match of the reciprocal network is worse than –8 dB or the loss exceeds ~20 dB, the reciprocal treatment will start to degrade, but a calibration will still be possible. Since such a network is at the limits of de-embedding capability, there are few choices except to consider 1p-2p processing with scalar de-embedding.

11-4 SOLR Calibration

For SOLR, the “select line” field would be chosen as “reciprocal” instead of “through” and the length field would be the estimate of length for root choice that was discussed above (see Figure 11-2). Note that the same variants are possible for offset short and triple offset short calibrations.



Typical calibration setup dialog for SOLR (Short-Open-Load-Reflection)

Figure 11-2. TWO PORT CAL SETUP (SOLT/R, COAX) Dialog Box

11-5 Uncertainty and Sensitivity Considerations

With reciprocal methods, the usual determining question is *'how bad are the characteristics of a thru?'* in the environment in question. As suggested earlier, if the thru is good (RL~>25 dB and insertion loss known to within ~0.05 dB), then for most purposes, the defined thru methods will do better since there is a more explicit determination of load match. As the reciprocal device worsens in terms of insertion loss and match, the sensitivity of the calibration to small standards problems will increase because less and less information is available to the calibration. In this sense, sensitivity may be a more practical metric than best-obtainable uncertainty, which will be fairly similar in all cases.

When the available thru is poor, however, then the absolute defined thru uncertainty will be high. In one example, delay insertion loss deviation was plotted for two calibrations (SOLT and SOLR) where the only interconnect available had 8 to 15 dB return loss across the band. The SOLT measurement shows almost 0.7 dB deviation (on a low loss device) while the SOLR deviation was kept to < 0.2 dB as shown in Figure 11-3.

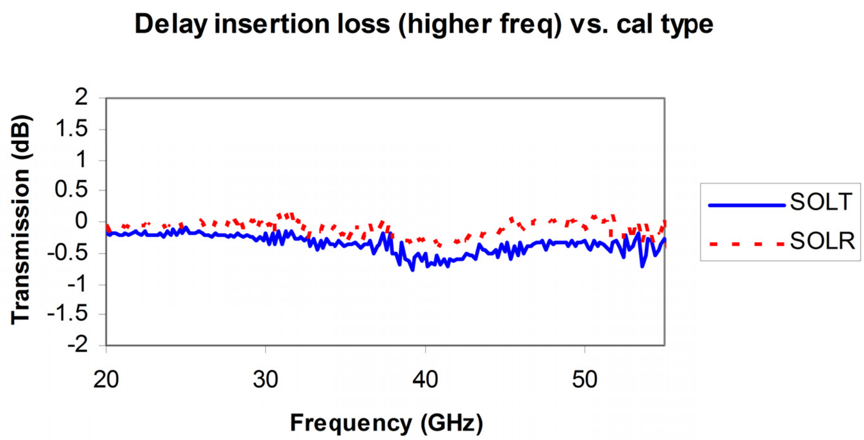


Figure 11-3. An example comparison (insertion loss deviation) is shown here between SOLT and SOLR when no good thru connection was available.

There are limits on the reciprocal network, as discussed above, and those will become most apparent when measuring reflection of well-matched, low insertion loss devices. The one mitigating factor is that if the media is complicated enough to require a reciprocal technique, there will be fewer well-matched, low insertion loss devices to be concerned about. The issue becomes one where the resolution on load match during calibration becomes limited by the reciprocal itself, so the correction for that term will become more sensitive.

As an example, consider the match measurement of a delay line where a problem was introduced on the open standard during the calibration. A series of different calibrations were done with different reciprocal devices (with different match levels). The resultant measurements are shown in Figure 11-4. For reciprocal elements with reasonable match (~< -20 dB), the measurements did not become distorted significantly by the open calibration error. At the -10 dB reciprocal match level, measurements below ~-20 dB were impacted. At the -6 dB reciprocal match level, even higher reflection measurements would have been distorted. A somewhat obvious guiding principle is that the reciprocal used for the calibration should not be worse (in terms of return loss or insertion loss) than the devices that will be measured with that resulting calibration.

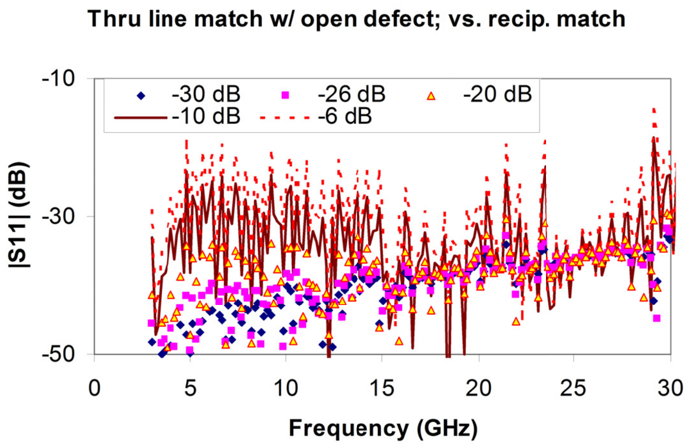


Figure 11-4. A plot of sensitivity of return loss measurements to a problem with one of the reflection standards is shown here for a variety of reciprocal devices used during the calibration.

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