



PicoVNA[®]

Vector Network Analyzers

PicoVNA 5 User's Guide

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Chapter 1

Safety

To prevent possible electrical shock, fire, personal injury, or damage to the product, carefully read this safety information before attempting to install or use the product. In addition, follow all generally accepted safety practices and procedures for working with and near electricity.

This instrument and accessories have been designed to meet the requirements of EN 61010-1 (Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory Use).

The following safety descriptions are found throughout this guide:

A **WARNING** identifies conditions or practices that could result in injury or death.

A **CAUTION** identifies conditions or practices that could result in damage to the product or equipment to which it is connected.



WARNING

The product is for professional use by trained and qualified technicians only. To prevent injury or death, use the product only as instructed and use only the accessories that have been supplied or recommended by Pico Technology. Protection provided by the product may be impaired if used in a manner not specified by the manufacturer.

1.1 Symbols

These safety and electrical symbols may appear on the product or in this guide.

Symbol	Description
	Earth (ground) terminal. This terminal can be used to make a measurement ground connection. It is NOT a safety or protective earth.
	Chassis terminal
	Possibility of electric shock
	CAUTION Appearance on the product indicates a need to read these safety instructions.
	Do not dispose of this product as unsorted municipal waste.

1.2 Maximum input/output ranges



WARNING

To prevent electric shock, do not attempt to measure or apply signal levels outside the specified maxima below.

The table below indicates the maximum voltage of the outputs and the overvoltage protection range for each input on the VNA and its calibration accessories. The overvoltage protection ranges are the maximum voltages that can be applied without damaging the instrument or accessory.

Instrument Connectors	Maximum operating voltage (output or input)	Overvoltage or overcurrent protection
Ports 1 and 2	+10 dBm (about 710 mV RMS)	+20 dBm (about 2.2 V RMS)
Bias tees 1 and 2	±15 V DC	250 mA
Trigger and reference in		±6 V pk
Trigger and reference out	0 V to +5 V	Do not apply a voltage
Calibration accessory connector/overvoltage protection	N/A	SOLT-AUTO Ports A/B, SOLT-PREM and SOLT-STD Ports = +20 dBm



WARNING

Signals exceeding the voltage limits in the table below are defined as “hazardous live” by EN 61010.

Signal voltage limits of EN61010		
±60 V DC	30 V AC RMS	±42.4 V pk max



WARNING

To prevent electric shock, take all necessary safety precautions when working on equipment where hazardous live voltages may be present.



WARNING

To avoid equipment damage and possible injury, do not operate the instrument or an accessory outside its rated supply voltages or environmental range.



CAUTION

Exceeding the overvoltage protection range on any connector can cause permanent damage to the instrument and other connected equipment. To prevent permanent damage, do not apply an input voltage to the trigger or reference output of the VNA.

1.3 Grounding



WARNING

The instrument or SOLT-AUTO E-Cal module's ground connection through the USB cable is for functional purposes only. The instrument does not have a protective safety ground.



WARNING

To prevent injury or death, or permanent damage to the instrument, never connect the ground of an input or output (chassis) to any electrical power source. To prevent personal injury or death, use a voltmeter to check that there is no significant AC or DC voltage between the instrument's ground and the point to which you intend to connect it.

**CAUTION**

To prevent signal degradation caused by poor grounding, always use the high-quality USB cable supplied with the instrument.

1.4 External connections

**WARNING**

To prevent injury or death, only use the power adaptor supplied with the instrument. This is approved for the voltage and plug configuration in your country.

1.4.1 Power supply options and ratings

Model name	USB connection	Ext DC power supply		
		Voltage	Current	Total power
PicoVNA 106	USB 2.0. Compatible with USB 3.0	12 to 15 V DC	1.85 A pk	22 W
PicoVNA 108				25 W
SOLT-AUTO-E-Cal module			N/A	

1.4.2 Containment of radio frequencies

**WARNING****Containment of radio frequencies**

The instrument contains a swept or CW radio frequency signal source (300 kHz to 6.02 GHz at +6 dBm max. for the PicoVNA 106, 300 kHz to 8.50 GHz at +6 dBm max. for the PicoVNA 108). The instrument and supplied accessories are designed to contain and not radiate (or be susceptible to) radio frequencies that could interfere with the operation of other equipment or radio control and communications. To prevent injury or death, connect only to appropriately specified connectors, cables, accessories and test devices, and do not connect to an antenna except within approved test facilities or under otherwise controlled conditions.

1.5 Environment

**WARNING**

This product is suitable for indoor or outdoor use, in dry locations only. The product's external mains power supply is for indoor use only.

**WARNING**

To prevent injury or death, do not use the VNA or an accessory in wet or damp conditions, or near explosive gas or vapor.

**CAUTION**

To prevent damage, always use and store your VNA or accessory in appropriate environments.

	Storage	Operating
Temperature	-20 to +50 °C	+5 to +40 °C
Humidity	20% to 80% RH (non-condensing)	
Altitude	2000 m	
Pollution degree	2	

**CAUTION**

Do not block the air vents at the back or underside of the instrument as overheating will cause damage.

Do not insert any objects through the air vents as internal interference will cause damage.

1.6 Care of the product

The product and accessories contain no user-serviceable parts. Repair, servicing and calibration require specialized test equipment and must only be performed by Pico Technology or an approved service provider. There may be a charge for these services unless covered by the Pico three-year warranty.

**WARNING**

To prevent injury or death, do not use the VNA or accessory if it appears to be damaged in any way, and stop use immediately if you are concerned by any abnormal behaviour.

**CAUTION**

Regularly inspect the instrument and all probes, connectors, cables and accessories before use for signs of damage or contamination.

To prevent damage to the device or connected equipment, do not tamper with or disassemble the instrument, case parts, connectors, or accessories.

When cleaning the product, use a soft cloth and a solution of mild soap or detergent in water, and do not allow liquids to enter the casing of the instrument or accessory.

Take care to avoid mechanical stress or tight bend radii for all connected leads, including all coaxial leads and connectors. Mishandling will cause deformation of sidewalls, and will degrade performance. In particular, note that test port leads should not be formed to tighter than 5 cm (2") bend radii.

To prevent measurement errors and extend the useful life of test leads and accessory connectors, ensure that liquid and particular contaminants cannot enter. Always fit the dust caps provided and use the correct torque when tightening. Pico recommends: 1 Nm (8.85 inch-lb) for supplied and all stainless steel connectors, or 0.452 Nm (4.0 inch-lb) when a brass or gold-plated connector is interfaced.

Chapter 2

Quick start guide

2.1 Software installation

2.1.1 Windows

1. Obtain the PicoVNA 5 software from www.picotech.com/downloads
2. Follow the instructions in the installer.
3. Once the software is installed, connect the PicoVNA instrument to the computer and open the software.

2.1.2 macOS

1. Obtain the PicoVNA 5 software from www.picotech.com/downloads.
Note that you will need to select the correct package: x86 or aarch64 depending on your hardware.
2. Follow the instructions in the installer.
3. Once the software is installed, connect the PicoVNA instrument to the computer and open the software.

2.1.3 Linux

PicoVNA 5 for Linux is 64-bit only. It is distributed as a self-extractable compressed tar archive that can be launched directly to install the software. The following list of distributions have been tested, although PicoVNA 5 is designed to work on any Linux distribution released within the last ten years:

- Debian 8 ("jessie") and later versions
- Ubuntu 18.04 (LTS) and later versions
- Linux Mint Cinnamon 21.1 (Vera) and later versions
- openSUSE Leap 15.0 and later versions
- Fedora 28 and later versions
- Arch Linux

2.1.3.1 Installation

PicoVNA 5 for Linux is distributed via a self-extracting archive. Follow these instructions in order to install the software:

1. Obtain the file `picovna.run` from www.picotech.com/downloads.
2. Open a terminal window to type commands.
3. Change directory in the terminal to the location where you downloaded the file in step 1. This is likely the `~/Downloads` directory, unless you specified a different directory when downloading the file or your web browser has a different default Downloads directory:

```
> cd ~/Downloads
```

4. Ensure the file `picovna.run` is executable. Type the following:

```
> chmod +x picovna.run
```

5. Run the installer, with sufficient permissions that it will be able to write to the `/opt/picovna` directory where the software will be installed:

```
> sudo ./picovna.run
```

PicoVNA 5 is now installed. You will need to open a new terminal window in order to start the software by typing:

```
> picovna
```

TIP!

The installation process adds a line to the current user's `.bashrc` file to ensure that the `/opt/picovna` directory is present in the `PATH` environment variable. If you do not use `bash` as your default shell, you will need to manually add `/opt/picovna` to `PATH`.

2.2 Setting the measurement parameters

The measurement span (in frequency or time) can be configured using the controls below each plot. An example of such a control is shown in Figure 2.1. Values can be input by typing, using the popup increment controls, or by hovering over the control and using the mouse scroll wheel.

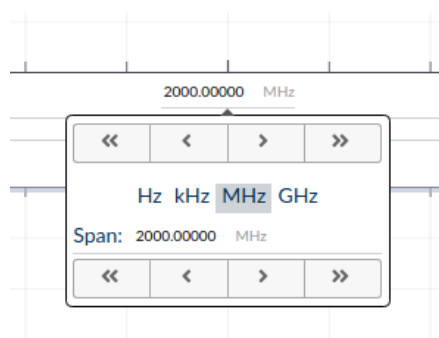


Figure 2.1: Measurement span controls.

The test signal power level is set using the popup control shown in Figure 2.2, which is part of the status/toolbar at the bottom of the main display window. The receiver bandwidth is set using the popup control shown in Figure 2.3. For more options, refer to Chapter 4.



Figure 2.2: Setting the test signal level, via the popup located below the main display.

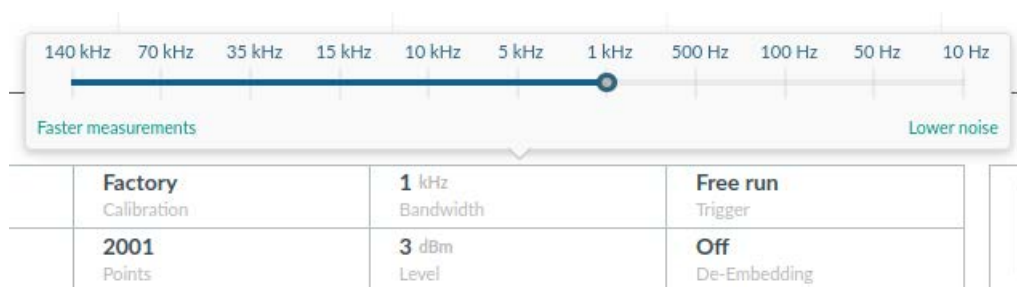


Figure 2.3: Setting the receiver bandwidth, via the popup located below the main display.

2.3 Setting up the display

The measurement parameters and plot types can be configured using the *axis options popup*, opened by clicking anywhere in the left half of the legend above the graph. The available options are shown in Figure 2.4. An additional axis (to display additional measurements on the same plot) can be added to each plot using the graph options menu, opened by clicking the button in the lower right of each plot. For more options, refer to Chapter 4.

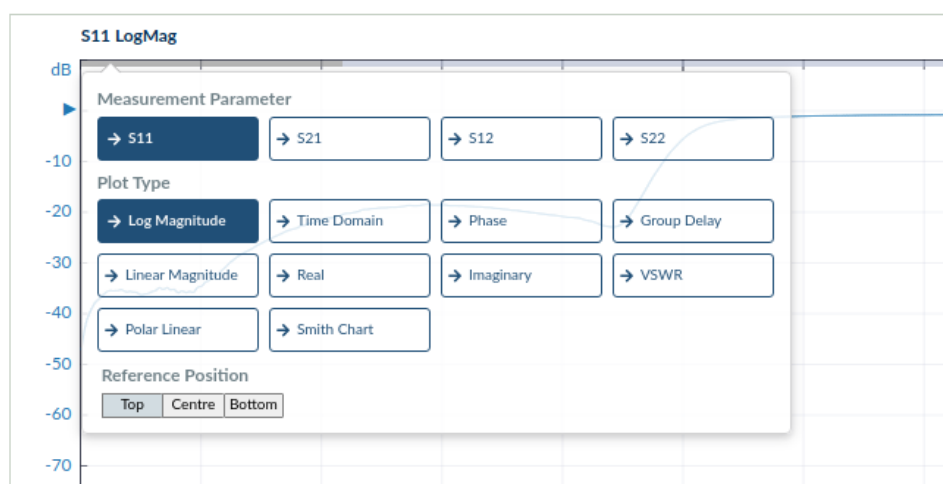


Figure 2.4: The axis options pop-up context menu, for configuring the measurement parameter and plot type of that axis.

2.4 Loading or performing a calibration

To perform a new calibration, click the “Calibration” button in the toolbar at the bottom of the main display window, then click “New Calibration” in the sidebar that appears and follow the on-screen instructions.

To recall a calibration that has been carried out previously, open the “Calibration” sidebar as above, click “My Calibrations” and then click “Load” next to the calibration to be recalled.

2.4.1 Calibration tips

The bandwidth setting used during calibration largely determines the available dynamic range during the measurement. The table below shows suggested bandwidth and power settings to use during calibration for different types of measurement.

Measurement	Calibration bandwidth	Calibration power	Comments
Fastest speed	10 kHz	+0 dBm	Set bandwidth to 140 kHz during measurement
Best accuracy and ≈ 100 dB dynamic range	100 Hz	-3 dBm	Leave bandwidth set to 100 Hz during measurement
General use, fast speed, ≈ 90 dB dynamic range	1 kHz	+0 dBm	Leave bandwidth set to 1 kHz during measurement
Best dynamic range	10 Hz	+6 dBm	Leave bandwidth set to 10 Hz during measurement. Refer to Section for tips on calibrating for the best dynamic range.

2.5 Running in demo mode

Demo mode can be used to explore and evaluate the user interface software with no instrument connected.

To enter demo mode, start the PicoVNA 5 software with no instrument connected. When the “Searching for devices” dialog appears, click on “Demo mode”. On the next screen, the software will offer a selection of demonstration measurements. When a demonstration measurement is selected, the software will enter demo mode.

Chapter 3

Vector network analyzer basics

A vector network analyzer (VNA) is used to measure the performance of circuits or networks such as amplifiers, filters, attenuators, cables and antennas. It does this by applying a test signal to the network to be tested, measuring the reflected and transmitted signals, and comparing them to the test signal. The VNA measures both the magnitude and phase of these signals.

3.1 Description

The PicoVNA 106 and 108 are PC-driven vector network analyzers (VNAs) capable of direct measurement of forward and reverse parameters. The main characteristics are as follows:

Model	PicoVNA 106	PicoVNA 108
Operating frequency range	300 kHz to 6 GHz	300 kHz to 8.5 GHz
Dynamic range	≤ 118 dB	≤ 124 dB
Frequency resolution	≤ 10 Hz	≤ 10 Hz

A simplified block diagram of the instrument is shown in Figure 3.1. Figures 3.2 and 3.3 show the front and rear panels of the PicoVNA 106 instrument respectively. Figures 3.4 and 3.5 show manual and automatic (E-Cal) calibration standards, that are used in the calibration process.

The instrument architecture is based on a four-receiver (Quad RX) arrangement using a bandwidth of up to 140 kHz. Couplers A and B are wideband RF bridge components that provide

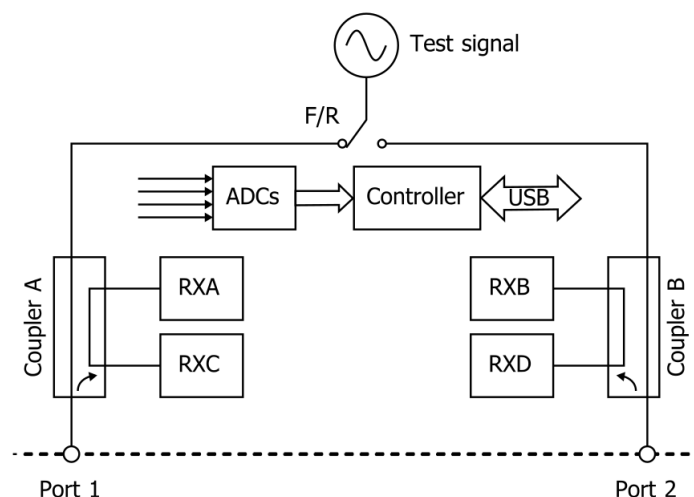


Figure 3.1: Simplified block diagram of the PicoVNA units.

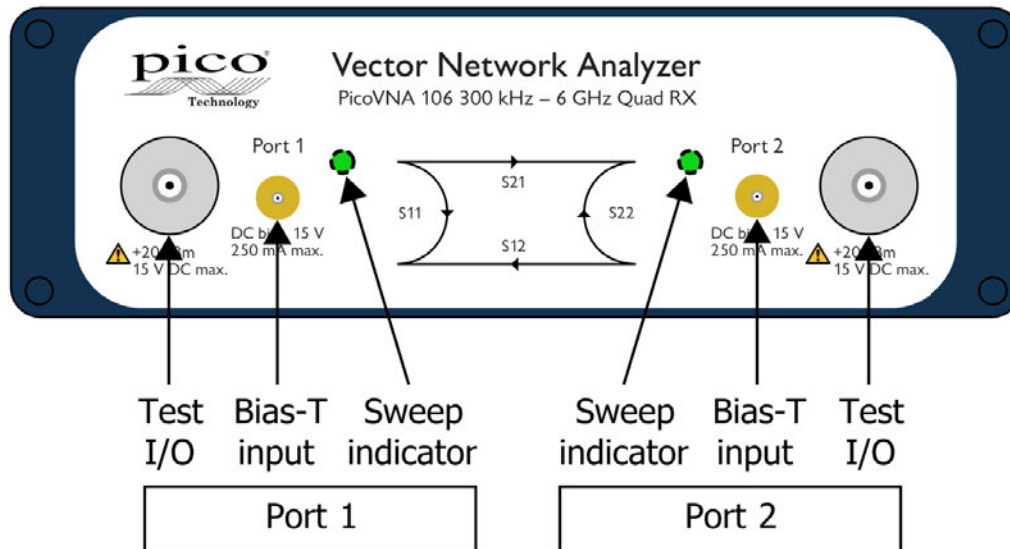


Figure 3.2: Front panel of the PicoVNA 106 (PicoVNA 108 is similar).

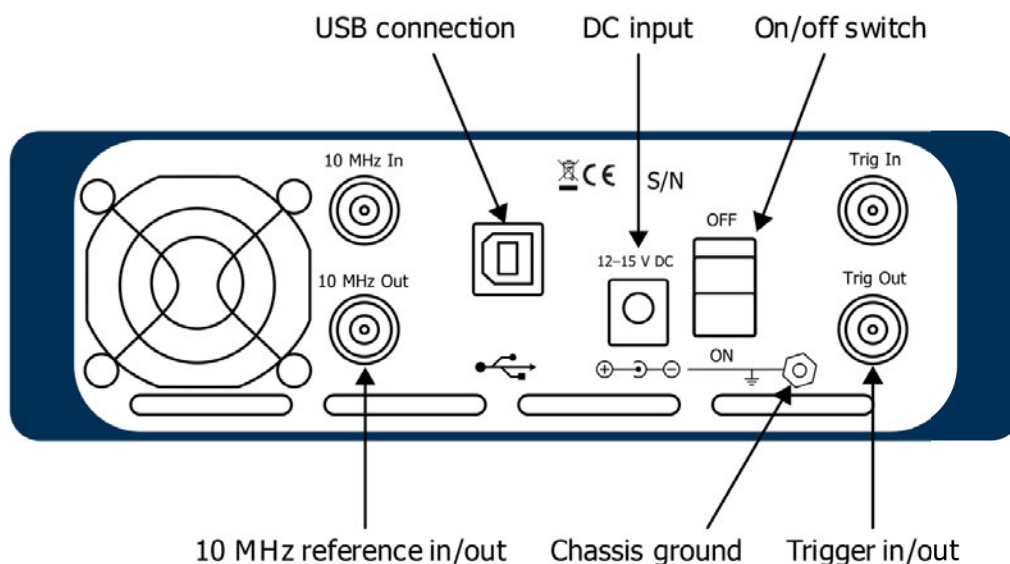


Figure 3.3: Back panel of the PicoVNA 106 (PicoVNA 108 is similar).

the necessary directivity in both directions. Signal detection is by means of analog-to-digital converters used to sample the IF signal. The sample data is processed by the embedded controller to yield the I and Q components. The detection system operates with an IF of 1.3 MHz and employs a patented circuit technique to yield fast speeds with very low trace noise.

The instrument's software runs on a personal computer or embedded controller and communication with the instrument is through a USB interface. The software running on the host computer carries out the mathematical processing and allows the display of measurement parameters in many forms, including:

- frequency domain
- time domain
- de-embedding utility

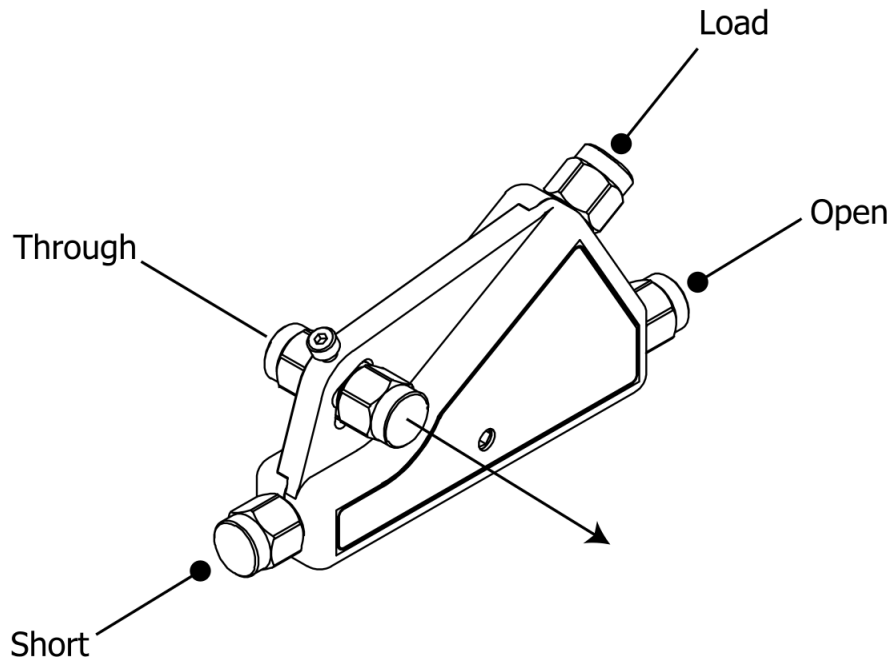


Figure 3.4: SOLT-STD-M/F and SOLT-PREM-M/F manual calibration standards.

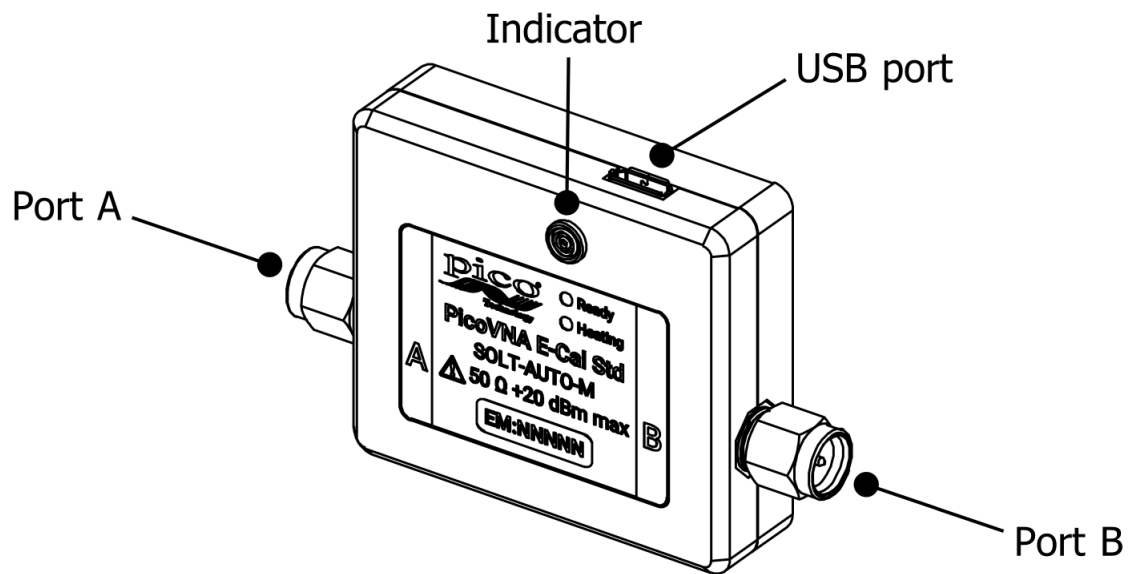


Figure 3.5: SOLT-AUTO-M/F automatic (E-Cal) calibration standards.

3.2 Structure of the VNA

The block diagram in Figure 3.6 describes the structure of a VNA and its connection to a DUT. The VNA consists of a tunable RF source, the output of which is split into two paths. The signal feeds to two couplers, and are then each measured by their respective reference receivers through power dividers. In the forward mode, the test signal is passed through a directional coupler or directional bridge before being applied to the DUT. The directional output of the coupler, which selects only signals reflected from the input of the DUT, is connected to the Port 1 receiver where the signal's magnitude and phase are measured. The rest of the signal (the portion that is not reflected from the input) passes through the DUT to the Port 2 receiver where its magnitude and phase are measured. The measurements at the Port 1 and Port 2 receivers are referenced to the measurements made by the Ref 1 and Ref 2 receivers so that any variations

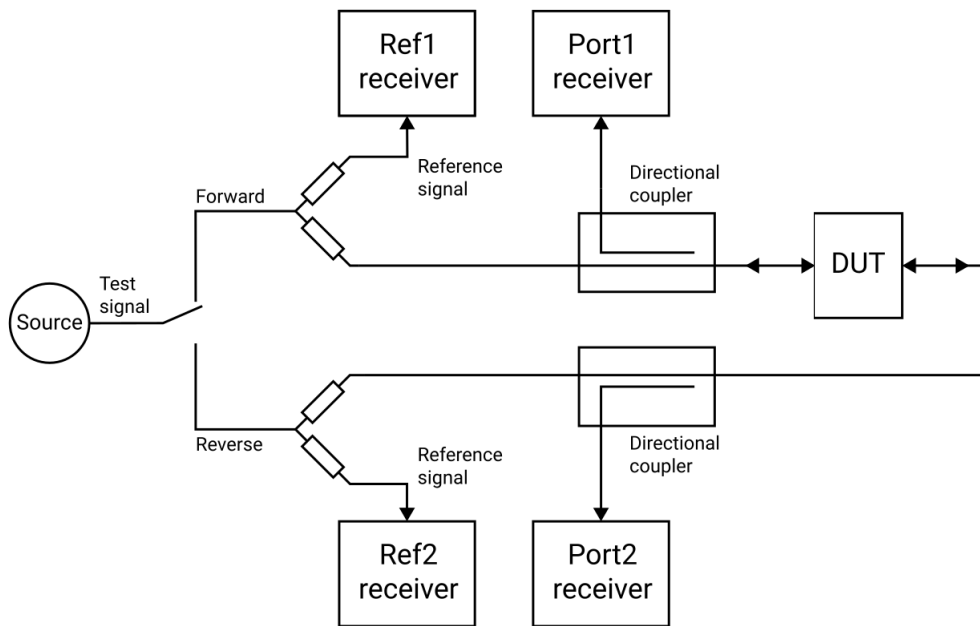


Figure 3.6: Simplified block diagram of the measurement system, showing the VNA and its connection to the DUT.

due to the source are removed. The Ref 1 and Ref 2 receivers also provide a reference for the measurement of phase.

In reverse mode, the test signal is applied to the output of the DUT, and the Port 2 receiver is used to measure the reflection from the output port of the DUT while the Port 1 receiver measures the reverse transmission through the DUT.

3.3 Introduction to measurement

VNAs have the capability to measure phase as well as magnitude. This is important for fully characterising a device or network, either for verifying performance or for generating models for design and simulation.

Knowledge of the phase of the reflection coefficient is particularly important for matching systems for maximum power transfer. For complex impedances the maximum power is transferred when the load impedance is the complex conjugate of the source impedance, as illustrated in Figure 3.7.

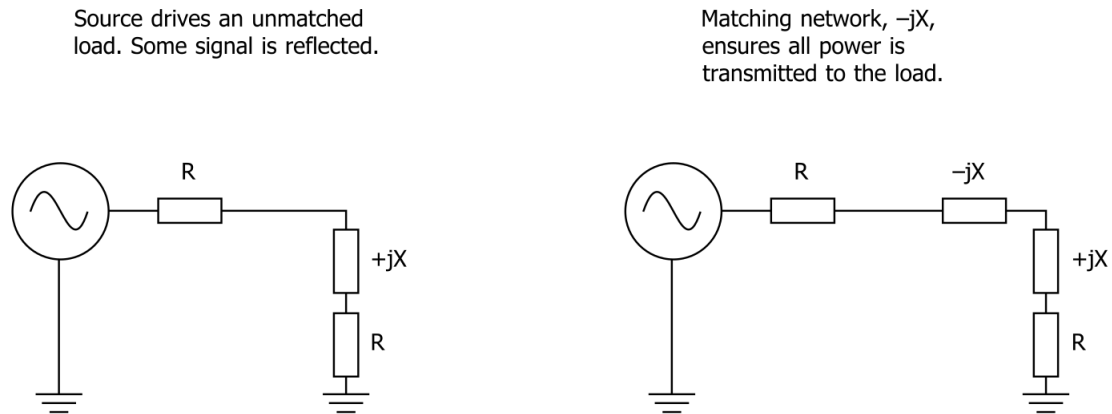


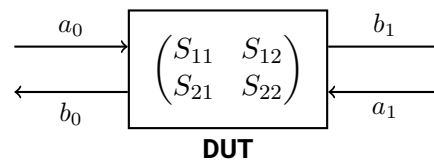
Figure 3.7: Matching a load for maximum power transfer.

Measurement of phase in resonators and other components is important in designing oscillators. In feedback oscillators, oscillation occurs when the phase shift round the loop is a multiple of 360° degrees and the gain is unity. It is important that these loop conditions are met as close as possible to the center frequency of the resonant element to ensure stable oscillation and good phase noise performance.

The ability to measure phase is also important for determining phase distortion in a network. Phase distortion can be important in both analog and digital systems. In digital transmission systems, where the constellation depends on both amplitude and phase, any distortion of phase can have serious effects on the errors detected.

3.4 S-parameters

A VNA characterises a DUT through measurement of its *scattering parameters* (*S*-parameters):



The complex-valued *S*-parameters are defined implicitly through the following relationship:

$$\begin{pmatrix} b_0 \\ b_1 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \end{pmatrix} \quad (3.1)$$

a_i , b_i and S_{ij} are functions of frequency ($\mathbb{R} \rightarrow \mathbb{C}$), that is $a_i = a_i(\omega)$, $b_i = b_i(\omega)$, $S_{ij} = S_{ij}(\omega)$. Hereon, this is not made explicit, but it is important to remember that all measurements of *S*-parameters and error terms must be made at all frequencies of interest.

If the DUT is linear and time-invariant, then $S_{ij}(\omega_1)$ is independent from $S_{ij}(\omega_2)$ (where $\omega_1 \neq \omega_2$).

Forward *S*-parameters are determined by measuring the magnitude and phase of the incident, reflected and transmitted signals with the output terminated with a load that is equal to the characteristic impedance of the test system, as shown in Figure 3.8.

Other parameters such as H, Y, T and Z parameters may all be deduced from the *S*-parameters if required. The reason for using *S*-parameters is that they can be easily measured over the range of frequencies of interest for RF. Other parameters require the measurement of currents and voltages, which is difficult at high frequencies. They may also require open circuits or short

circuits that can be difficult to achieve at high frequencies, and may also be damaging to the DUT or may cause oscillation.

Forward

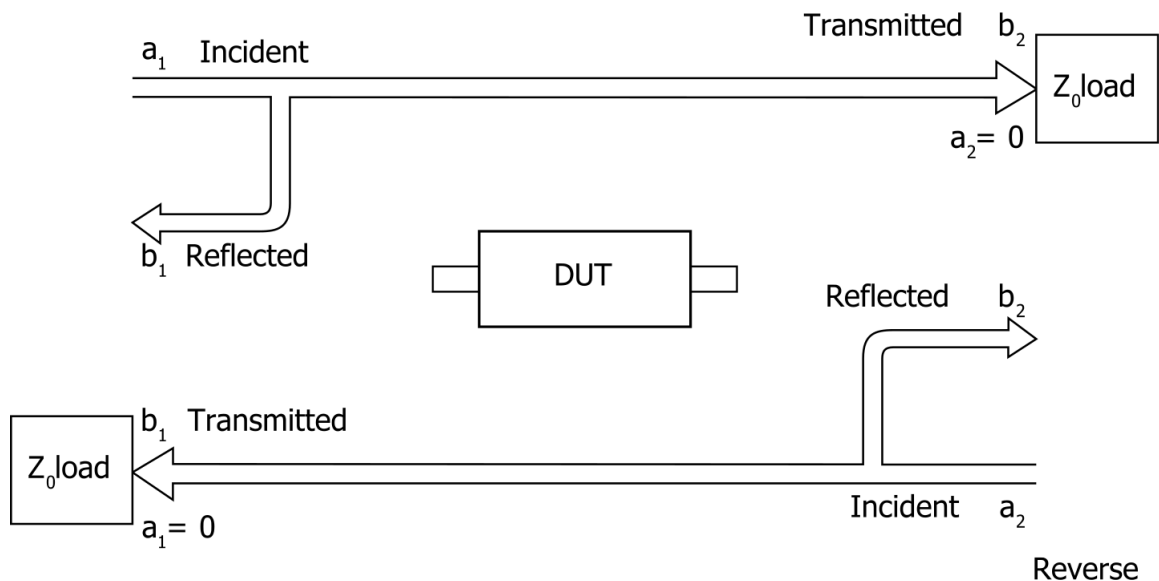


Figure 3.8: Definitions of the a and b waves considered when defining S -parameters.

3.5 Calibration and error correction

Before accurate measurements can be made, a process needs to be performed that will allow the VNA to correct measurement errors. Error correction may also be called *user calibration*, to distinguish it from the calibration process carried out by the manufacturer. However, it is often simply referred to as *calibration*, and for the purposes of this manual the word *calibration* will be used to refer to the process of error correction carried out by the user.

3.5.1 The importance of error correction

A VNA is able to make more accurate and precise measurements than any other generic measurement instrument. In part, this is due to the error correction that can be performed to eliminate certain systematic errors in the measurement process.

In addition to measuring the device under test as desired, the VNA measurements will also be affected by:

- the test fixture, including cables,
- connectors,
- imperfections in the equipment used,
- the change in response of the cables and connectors due to variations in temperature.

These sources of error are typically predictable and can be eliminated with a user calibration. Other sources of error, such as drift error and random errors, remain and mean that a user calibration must be performed each time accurate measurements are required.

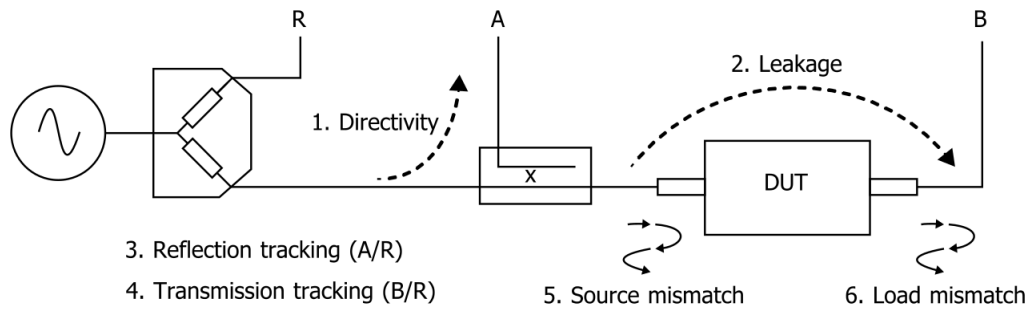


Figure 3.9: Six key sources of errors in the forward measurement. Another six sources exist in the reverse measurement (not shown).

3.5.2 Calibration procedure overview

In the calibration process, well-defined standards are measured and the results of these measurements are used to correct for imperfections in the hardware. The most common calibration method, SOLT (*short, open, load, thru*), uses four known standards: a short circuit, an open circuit, a load matched to the system impedance, and a through line. These standards are usually contained in a calibration kit and their characteristics are stored on the controlling PC in a Cal Kit definition file. Analyzers such as the PicoVNA 106 and 108 that have a full S-parameter test set can measure and correct all 12 systematic error terms shown in Figure 3.9.

3.6 Measurements

3.6.1 Group delay

Group delay is defined as the rate of change of phase, ϕ with frequency, ω :

$$\text{group delay} = \frac{d\phi}{d\omega} \quad (3.2)$$

In relatively non-dispersive components such as transmission lines, group delay is the transit time through the line. However, some components such as filters can exhibit negative group delays so care is needed when attaching an interpretation to group delay.

The PicoVNA 106 and 108 calculate the group delay by dividing the phase change between adjacent sweep points by the size of the sweep step. It is usual to apply some degree of trace smoothing to remove very rapidly changing perturbations from the trace. Care should be exercised to ensure that genuine sharp group delay variations are not masked by smoothing.

3.7 Time domain reflectometry (TDR) and time domain transmission (TDT)

Time domain reflectometry (TDR) is a useful technique for measuring the impedance of transmission lines and for determining the position of any discontinuities due to connectors or damage. The VNA can determine the time domain response to a step input from a broad band frequency sweep at harmonically related frequencies. An inverse Discrete Fourier Transform is performed on the reflected frequency data (S_{11}) to give the impulse response in the time domain.

The impulse response can then be integrated to give the step response. Reflected components of the step excitation show the type of discontinuity and the distance from the calibration plane.

A similar technique is used to derive a *Time Domain Transmission* (TDT) signal from the transmitted signal data (S_{21}). This can be used to measure the rise time of amplifiers, filters and other networks.

The following sections provide a more detailed exploration of TDR and TDT.

3.7.1 Background: traditional TDR

The traditional TDR consists of a step source and sampling oscilloscope, shown in Figure 3.10. A periodic step signal is generated and applied to a load. Depending on the value of the load, some of the signal may be reflected back to the source. The signals are measured in the time domain by the sampling oscilloscope. By measuring the ratio of the input voltage to the reflected voltage, the impedance of the load can be determined. Also, by observing the position in time when the reflections arrive, it is possible to determine the distance to the impedance discontinuities.

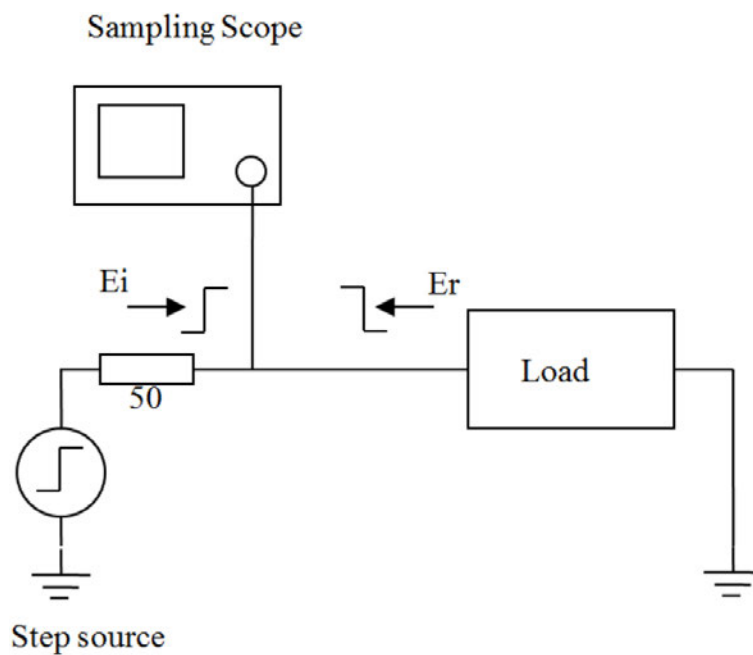


Figure 3.10: Traditional TDR setup

3.7.1.1 Example: shorted 50 ohm transmission line

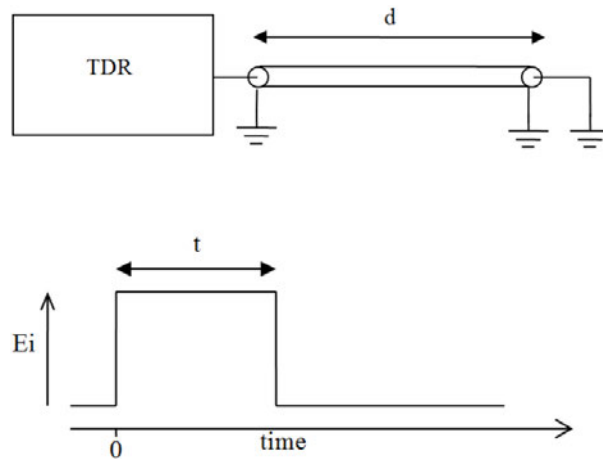


Figure 3.11: Simplified representation of the response of a shorted line

For a transmission line with a short circuit (see Figure 3.11), the incident signal sees the characteristic impedance of the line so the oscilloscope measured E_i . The incident signal travels along the line to the short circuit where it is reflected back 180° out of phase. This reflected wave travels back along the line cancelling out the incident wave until it is terminated by the impedance of the source. When the reflected signal reaches the scope, the signal measured by the scope goes to zero as the incident wave has been cancelled by the reflection. The result measured by the scope is a pulse of magnitude E_i and duration that corresponds to the time it takes the signal to pass down the line to the short and back again. If the velocity of the signal is known, the length of the line can be calculated using

$$d = \frac{t}{2}v \quad (3.3)$$

where v is the velocity of the signal in the transmission line, t is the measured pulse width and d is the length of the transmission line.

3.7.1.2 Example: open-circuited 50 ohm transmission line

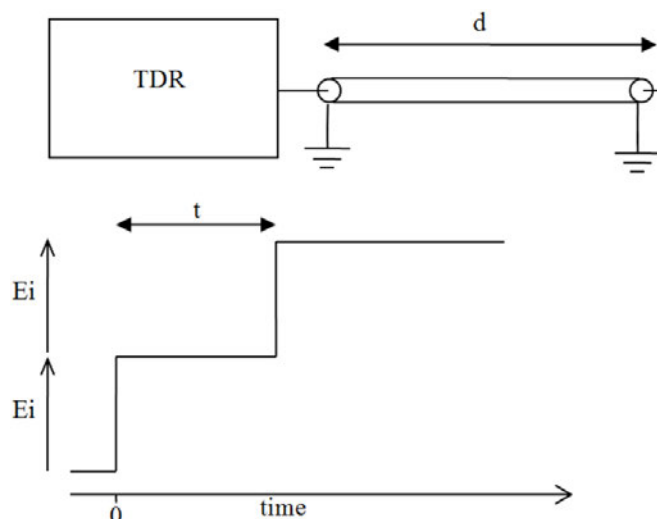


Figure 3.12: Simplified representation of the response of an open line

In the case of the open circuit transmission line (see Figure 3.12), the reflected signal is in phase with the incident signal, so the reflected signal combines with the incident signal to produce an output at the oscilloscope that is twice the incident signal. Again, the distance d can be calculated if the velocity of the signal is known.

3.7.1.3 Example: resistively terminated 50 ohm transmission line

$$\rho = \frac{E_r}{E_i} = \frac{R - 50}{R + 50}$$

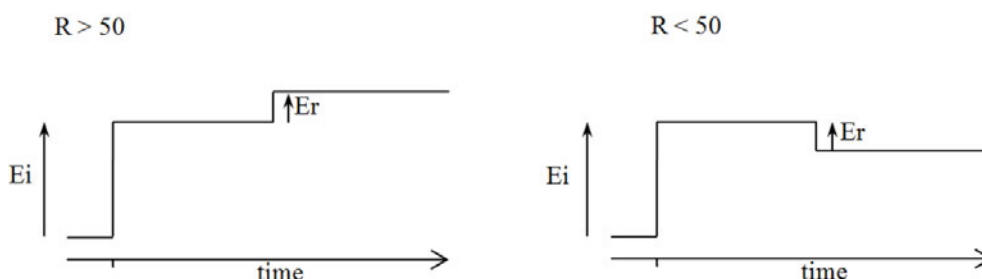


Figure 3.13: Simplified representation of the response of a resistively terminated line

3.7.1.4 Example: Reactive terminations and discontinuities

Reactive elements can also be determined by their response. Inductive terminations produce a positive pulse. Capacitive terminations produce a negative pulse.

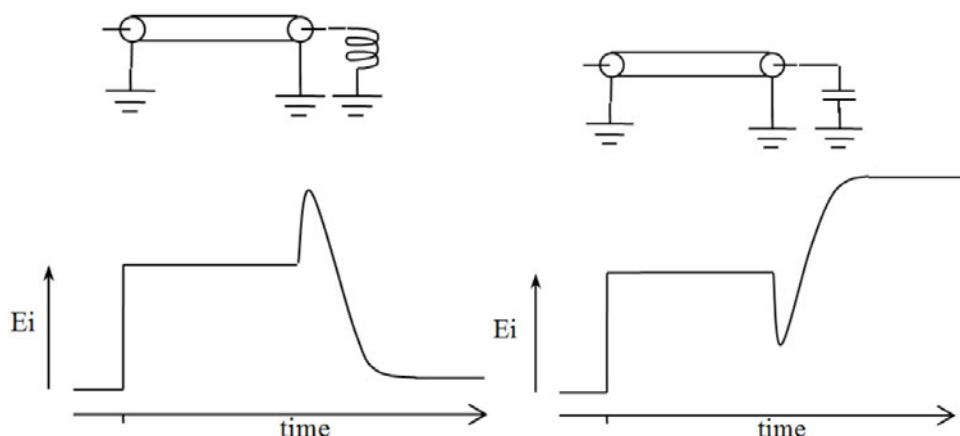


Figure 3.14: Simplified representation of the response of a reactively terminated line

Similarly, the position and type of a discontinuity in a cable, due to connectors or damage, can be determined. A positive pulse indicates a connector that is inductive or damage to a cable, such as removal of part of the outer screen. A negative-going pulse indicates a connector with too much capacitance or damage to the cable, such as being crushed.

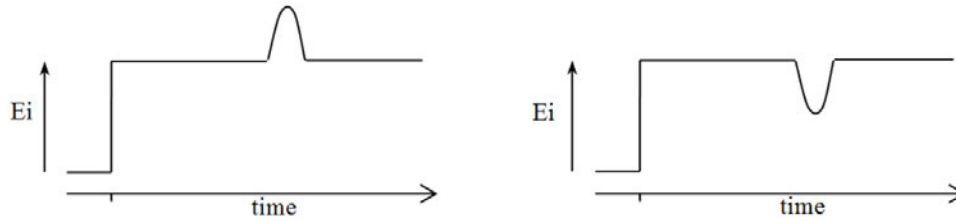


Figure 3.15: Simplified representation of the response of a line discontinuity

3.8 Time domain measurements from a vector network analyzer

An alternative to traditional TDR is where the time domain response is determined from the frequency domain using an Inverse Discrete Fourier Transform (IDFT). Several methods are available for extracting time domain information from the frequency domain. The main methods are *lowpass* and *bandpass*.

3.8.1 Lowpass method

The lowpass method can produce results that are similar to the traditional TDR measurements made with a time domain reflectometer using a step signal, and can also compute the response to an impulse. It provides both magnitude and phase information and gives the best time resolution. However, it requires that the circuit is DC-coupled.

The IDFT directly computes the impulse response of the DUT, which is integrated by PicoVNA 5 to determine the step response. In the step response mode, the trace is similar to that of a traditional TDR measurement, except there is no step at $t = 0$.

When the time domain response is derived from the frequency information, the value at $t = 0$ is the impedance of the transmission line or load immediately following the calibration plane. The value is referenced to $50\ \Omega$, the characteristic impedance of the system. For example, an open circuit would appear as a value of $+1$ unit relative to the reference value and a short circuit would appear as a value of -1 unit relative to the reference value (see Figures 3.11 – 3.12).

3.8.2 Range and resolution

There are two key parameters to consider when configuring a VNA for time domain measurements: *range* and *resolution*. The range, R , is the maximum time delay and hence the maximum cable length that can be measured. The resolution, Δt , is related to the minimum size of feature that can be resolved in the time domain step response.

If the number of measurement points are N , the measurement start frequency is f_L and the measurement stop frequency is f_H , the range (in seconds) in lowpass mode is given by

$$R = \frac{N - 1}{f_H - f_L} \quad (3.4)$$

The time domain span of the measurement will be from $-R/2$ to $R/2$.

The resolution is given by

$$\Delta t = \frac{1}{2f_H} \quad (3.5)$$

In bandpass mode, the resolution is half that given by Equation 3.5.

Some examples of ranges and resolutions achievable in lowpass mode are given in Table 3.1.

f_L (MHz)	f_H (MHz)	N	Range (ns)	Range (m)	Resolution (ps)
0.3	8 500	201	11.8	3.52	58.8
0.3	6 000	201	16.7	5.00	83.3
0.3	8 500	10 001	588	176	58.8
0.3	6 000	10 001	833	250	83.3
0.3	1 000	201	100	30.0	500
0.3	1 000	10 001	5000	1500	500

Table 3.1: Examples of ranges and resolutions achievable with the PicoVNA 106 and PicoVNA 108 instruments, in lowpass mode. The range calculation assumes that the propagation speed is equal to the speed of light, so ranges in practical transmission lines will be lower.

3.8.2.1 DC termination

No practical instrument can measure a response at a frequency of exactly 0 Hz. The VNA has a finite lower bound, such as 300 kHz. This means that some value must be assumed for the DC component in order to satisfy the requirements of the IDFT.

By default, the DC component is extrapolated from the low-frequency data to provide a phase reference. Alternatively, if the DC termination is known it can be entered manually.

3.8.3 Bandpass method

The bandpass method provides only magnitude information, so it is not possible to distinguish between inductive and capacitive reactances. Also, the time resolution is only half that of low-pass mode (described in Section 3.8.2).

3.8.4 Windowing

The VNA gathers data at a set of discrete frequencies, with a finite upper limit. The result of the sampled nature of the frequency domain data is to convolve the time domain response with the $\sin(t)/t$ function. This appears as ringing on both the displayed impulse response and the step response. To overcome this problem, a technique known as windowing can be applied to the frequency domain data before applying the IDFT.

The windowing function progressively reduces the data values to zero as the edge of the frequency band is approached, thus minimising the effect of the discontinuities. When the modified data is transformed, the ringing is reduced or removed depending on the selected windowing function. However, the windowing function reduces the bandwidth and so increases the width of the pulse in impulse response mode and slows the edge in step response mode. A balance must be made between the width of the pulse (or speed of the edge) and the amount of ringing to be able to determine closely-spaced discontinuities.

The PicoVNA 5 software allows you to choose between:

- *No window*, also known as the rectangular window. This is the default.
- *Hanning window*, also known as the raised cosine window.
- *Kaiser-Bessel* window. The order of the Kaiser-Bessel window is configurable.

Chapter 4

Basic operation

The PicoVNA 5 software allows you to program the measurement parameters and plot the measurement results in real time. The main window includes a status panel that displays information including calibration status, sweep status, sweep parameters, and trigger status.

4.1 The PicoVNA 5 main window

The PicoVNA 5 main window is shown in Figure 4.1. It is dominated by a large graphics area where the measurement results are plotted together with the readout of the markers. Any number of plots can be displayed simultaneously, limited by the resolution of the display monitor. The plots can be configured to display the desired measurements.

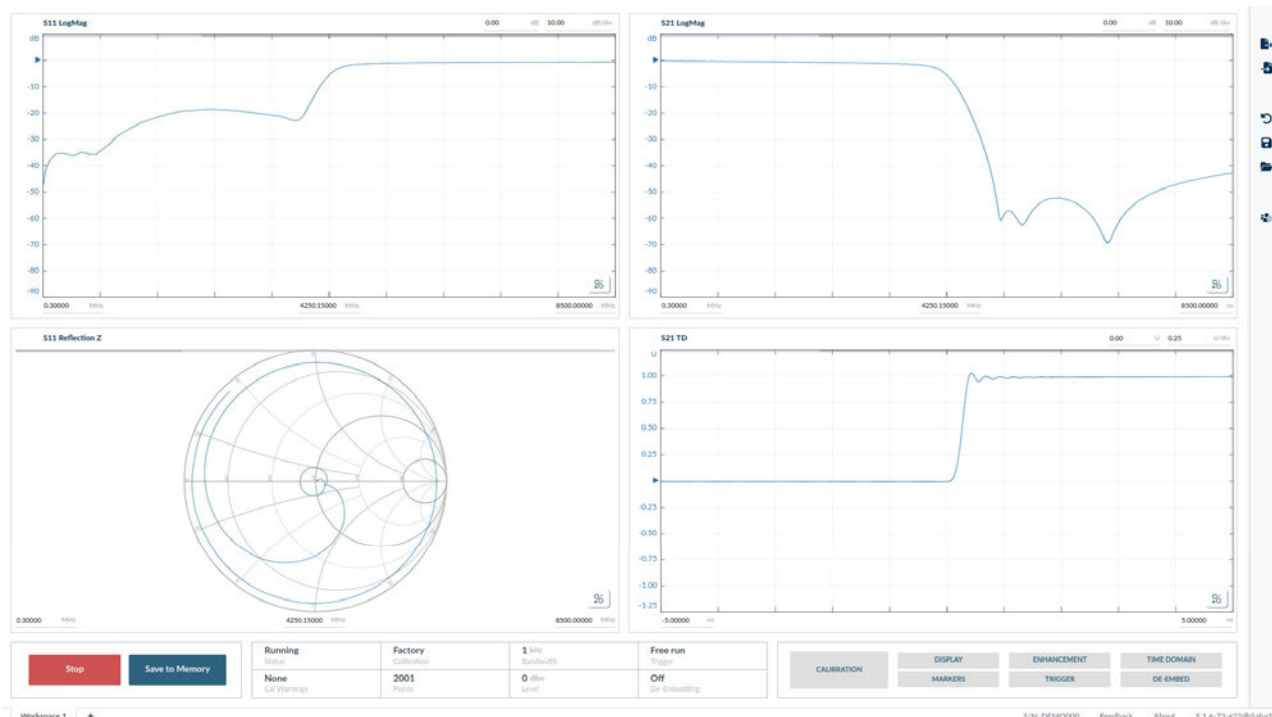


Figure 4.1: The PicoVNA 5 software main window.

The key components of the main window are described in the following sections.

4.2 Measurement start/stop

The measurement can be started and stopped using the button in the lower left of the main window. If the measurement is running (as shown in Figure 4.2), pressing the “Stop” button will stop the measurement. Otherwise, pressing the “Start” button will start the measurement.

The current status of the instrument is shown in the status bar at the bottom of the display window.

The spacebar key on the keyboard can also be used to start/stop the measurement.

Note that when the sweep is stopped, the test signal frequency is held at the frequency point at the time the stop command is received by the instrument. In the case of triggered sweep, by default, at the end of the sweep, the frequency is held at the last frequency point until the next sweep trigger event is received.



Figure 4.2: The start/stop button, and save to memory button.

4.3 Display setup

The measurements displayed on each plot can be configured using context menus associated with the plot (Section 4.3.2). The overall number and layout of plots displayed can be configured via the Display sidebar (Section 4.3.3).

4.3.1 Sidebars

A number of display options are controlled via sidebars, which allow measurement parameters to be changed as plots update alongside in real-time.

The sidebars can be opened by pressing the corresponding controls in the lower right of the main window. Sidebars can be closed either by clicking again on the corresponding controls in the lower right of the main window, or by pressing the X button in the top right of the sidebar.



Figure 4.3: An example of a sidebar: the time domain sidebar.

4.3.2 Configuring measurements per-plot

4.3.2.1 Per-plot axes

Each plot can display one or two axes. To add (or remove) a second axis to a plot, use the context menu in the lower right corner of each plot, shown in Figure 4.4.

TIP!

Using multiple axes on a single plot can be useful for comparing different measurement parameters or types of data (e.g. magnitude and phase data) on the same plot.

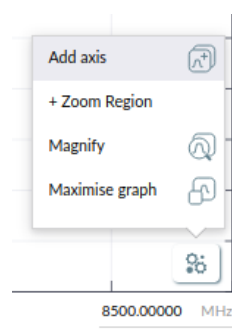


Figure 4.4: The button to add a second axis to a plot, in the lower right corner of the plot.

4.3.2.2 Per-axis measurements

To open the *axis options* context menu, click anywhere in the left half of the legend for the axis, above the graph. The measurement parameter displayed on the plot axis, and the plot type, can be configured via this pop-up context menu, shown in Figure 4.5.

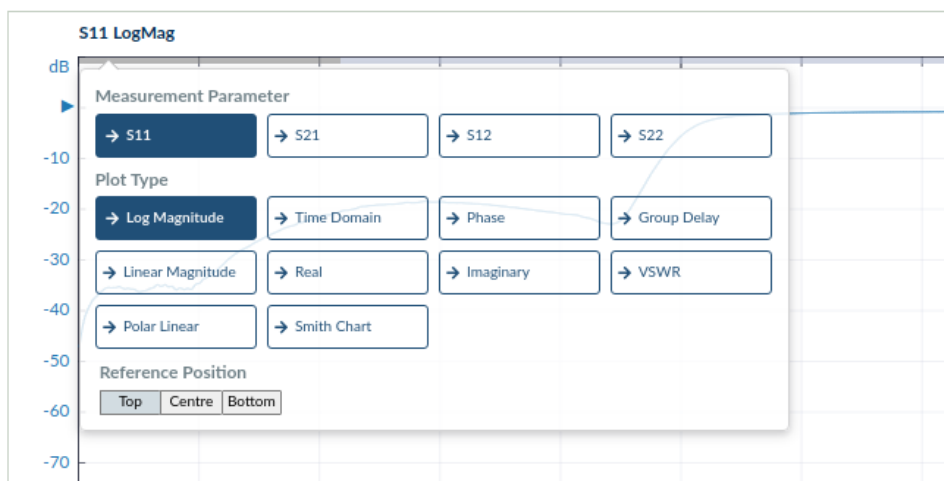


Figure 4.5: The axis options pop-up context menu, for configuring the measurement parameter and plot type of that axis.

4.3.2.3 Per-axis sensitivity, reference and reference position (offset)

The reference and sensitivity can be controlled using the inputs on the right side of each axis legend, shown in Figure 4.6.

Values can be typed directly into this field or, as with any numeric input field in the PicoVNA 5 software, clicking in the input field opens a context-sensitive popup with touch-friendly controls for incrementing or decrementing the input value. The unit of the input can also be set using this popup.

All numeric input fields in the PicoVNA 5 software support the value being incremented or decremented via the scroll wheel on the mouse. Hover the mouse over the input field, and scroll up or down to increment or decrement the value.



Figure 4.6: Controlling the reference and sensitivity.

The reference position can be set by clicking on and dragging the triangular reference position indicator up or down on the corresponding plot axis. The reference position indicator is shown in Figure 4.7.



Figure 4.7: Click and drag the reference position indicator to set the reference position.

4.3.3 Configuring the plot layout

The arrangement of plots in the main window can be configured using the Display sidebar.

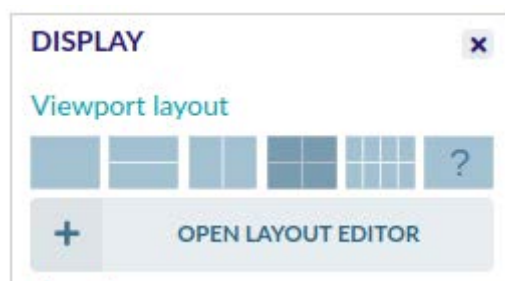


Figure 4.8: Options in the Display sidebar for configuration plot layout

The layout of plots can be updated at a single click by clicking on any of the standard layouts immediately under the “Viewport layout” title.

Alternatively, a custom layout may be applied by opening the layout editor, shown in Figure 4.9. Each existing plot can be moved or resized (relative to other plots) using the mouse. The main display window will update in real time as the plot layout is changed. New plots can be added using the “Add Graph” button in the lower right. To remove a plot, press the corresponding X button for that plot; you will not be asked for confirmation before the plot is removed.

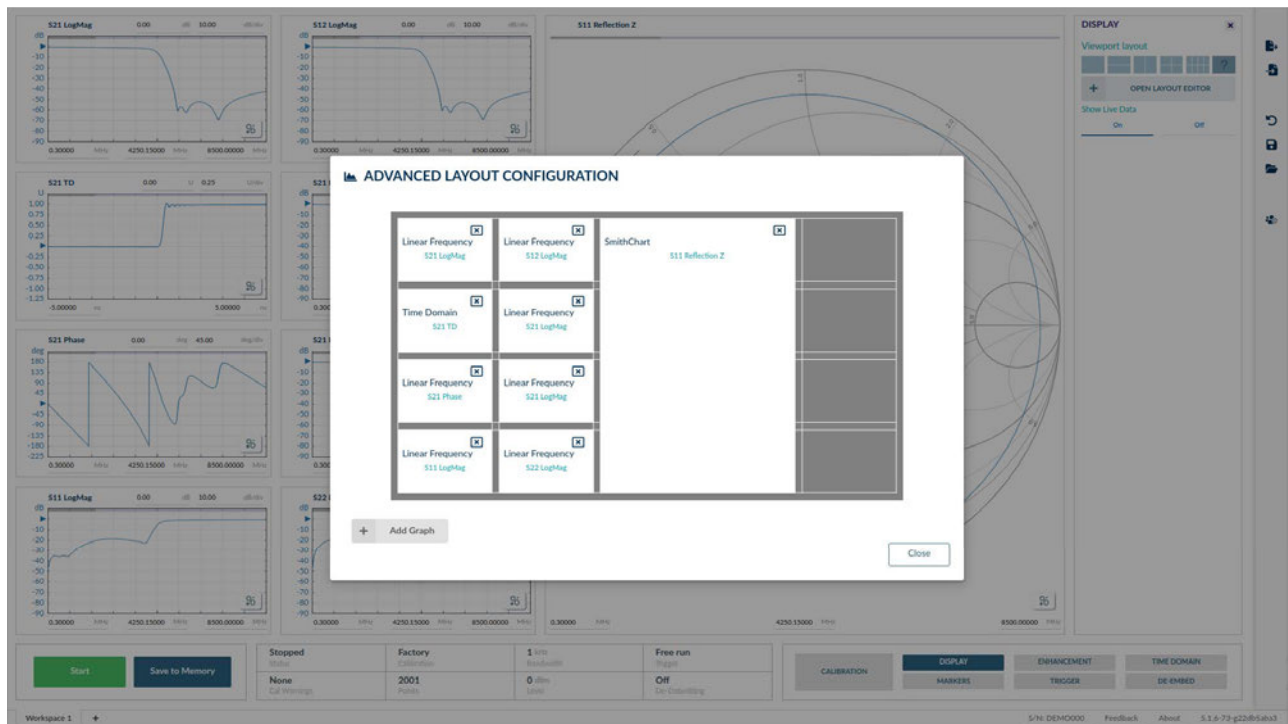


Figure 4.9: The advanced layout editor

4.3.4 Configuring the measurement span

For both frequency or time domain measurements, the measurement span can be adjusted using the input fields along the x -axis of each plot. As seen with the reference and sensitivity controls, values can be typed directly into these fields, the mouse scroll wheel can be used to increment/decrement the value, or the touch-friendly controls in the popup can be used.

For frequency domain measurements, both the centre frequency and the span can be adjusted using the popup under the central control.

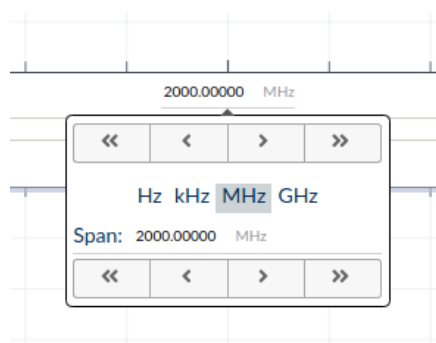


Figure 4.10: Measurement span controls.

4.4 Memory

PicoVNA 5 software supports an unlimited number of memory traces.

4.4.1 Creating a new memory trace

To save the current live trace to a memory trace, press the “Save to memory” button in the lower left corner of the main window.

4.4.2 Deleting a memory trace

Use the Display sidebar to delete memory traces. Click on the trash icon (highlighted in Figure 4.11) to delete the corresponding memory trace.

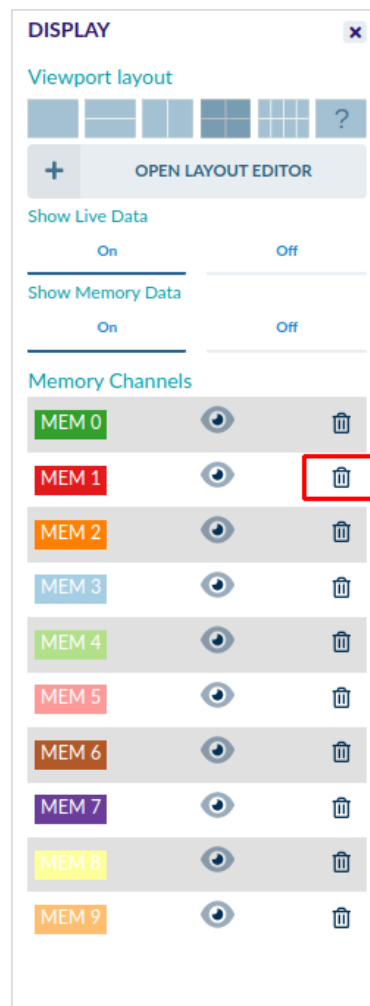


Figure 4.11: Deleting a memory trace

4.4.3 Global memory trace visibility

Use the Display sidebar to make memory traces visible or invisible on all plots simultaneously. The visibility of individual memory traces can be controlled using the “eye” icon highlighted in Figure 4.12.

The visibility of all memory traces can be toggled simultaneously using the control under the “Show Memory Data” title, also highlighted in Figure 4.12.

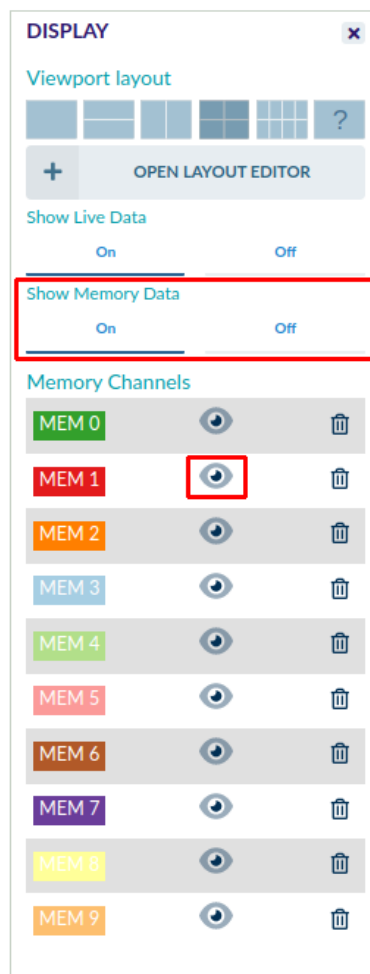


Figure 4.12: Memory trace global visibility controls

4.4.4 Per-plot memory trace visibility

The visibility of a memory trace can be set on individual plots using the buttons that appear in the plot's legend, shown in Figure 4.13. Click on the coloured button corresponding to a memory trace to toggle its visibility.

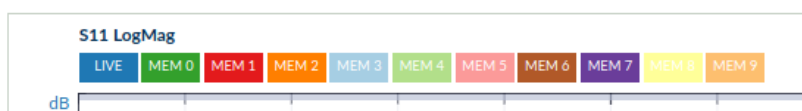


Figure 4.13: Per-plot memory trace visibility controls

4.4.5 Importing data from Touchstone files to memory traces

It can be useful to import previously-recorded data, or data from another source, to a memory trace for comparison purposes. To find the Import Data function (shown in Figure 4.14), hover the mouse over the pop-out panel at the right of the screen, and click on the "Import Data" menu item. One- or two-port data can be imported from Touchstone files (Touchstone v1 and v2 files are supported). The data will be imported to a new memory channel; one memory channel is created per data import.

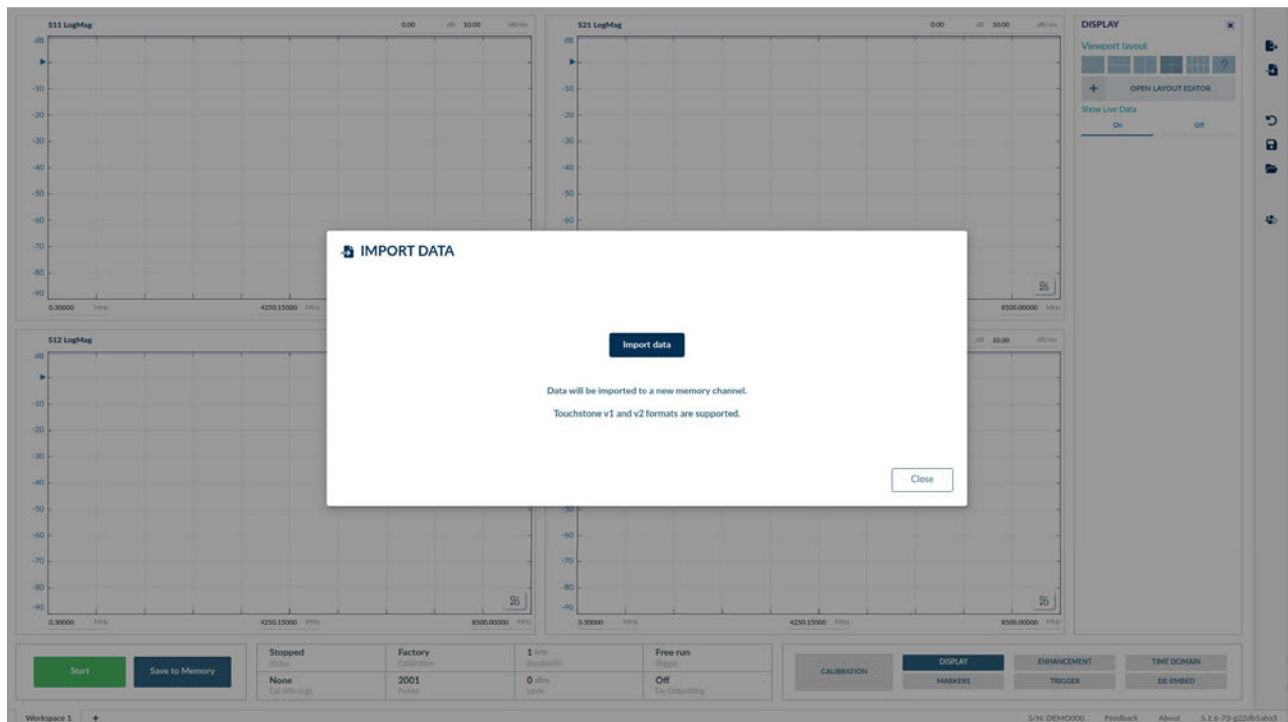


Figure 4.14: Per-plot memory trace visibility controls

4.5 Data markers and readouts

4.5.1 Trace cursor

Hovering over a trace with the mouse cursor will yield an on-plot readout for all traces at the frequency or time associated with the current mouse cursor position, as shown in Figure 4.15. On Smith charts or polar linear charts, a readout only appears on the trace closest to the mouse cursor.

The trace cursor can be useful when quickly inspecting a plot, although markers are often more useful for generating readouts at a precise frequency or set of frequencies.

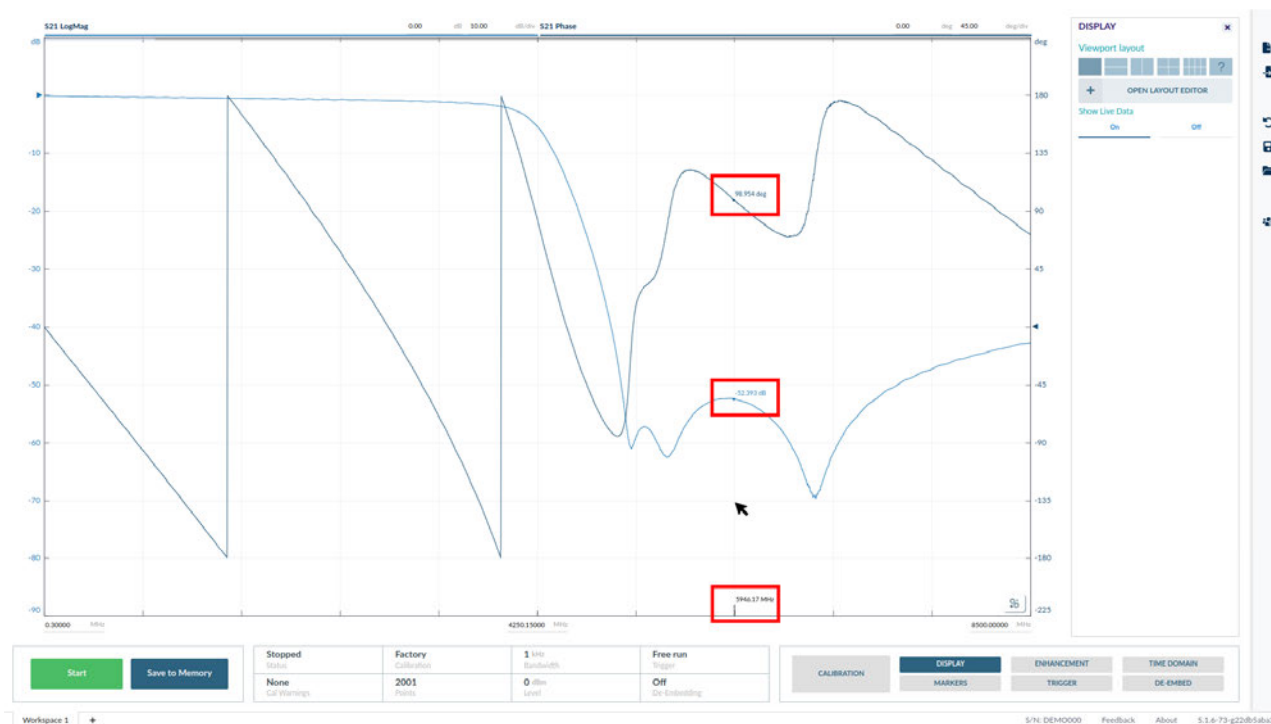


Figure 4.15: Hovering the mouse cursor over a trace yields an on-plot readout at the frequency or time associated with the current mouse cursor position.

4.5.2 Placing, editing and deleting markers

To place a marker on a trace, hover the mouse close to the trace, hold the “Control” key on the keyboard, and click the mouse. It is possible to add an unlimited number of markers and associated data readouts.

To set the frequency (or time) of the marker precisely, use the controls in the Markers sidebar (shown in Figure 4.16). A precise frequency (or time) for the marker can be set in the frequency (or time) input field, or its frequency (or time) can be incremented or decremented using the popup touch-friendly controls.

In order to edit a marker using the sidebar controls, that marker must first be selected. If a marker has just been placed, it will be the selected marker. To select any other marker for editing, either:

- use the left/right buttons in the markers sidebar,
- click on the marker itself (on a plot), or
- click the button associated with the marker in the readouts panel.

A marker is associated with a channel (live or specific memory channel) and S-parameter. The channel or S-parameter that the marker is associated with can be set using the markers sidebar.

In order to display a marker on other trace types from the trace type on which the marker was placed, a readout should be configured for the other new type. This is described in Section 4.5.3. The new readout can be configured in addition to the existing readout (in which case the marker will be visible on both the original and new trace type) or the new trace type can replace

the original trace type (in which case the marker will no longer be visible on the original trace type).

To delete a marker, use the “Delete marker” button. You will not be asked for confirmation before the marker is deleted.

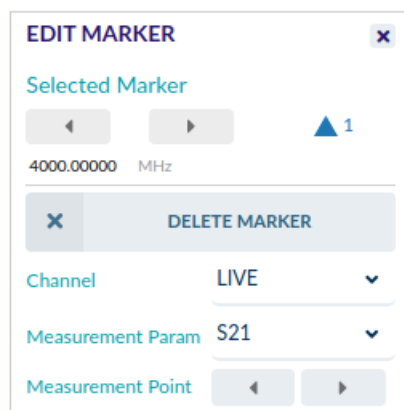


Figure 4.16: Use the markers sidebar to edit marker settings.

4.5.3 Marker readouts

Marker readouts are visible via the marker readouts panel, shown in Figure 4.17. To configure the readouts that are available for each marker, use the controls in the marker sidebar shown in Figure 4.18.

A marker can be placed at any frequency (or time). If the marker is placed between two measurement points, its readout will be interpolated using vector interpolation. The interpolation method used is the same method used to interpolate the on-plot trace data, and can be configured as described in Section 4.8.2.

If interpolation is undesirable and a marker needs to be placed exactly on a measurement point, the buttons associated with the “Measurement point” title in the markers sidebar can be used to move the marker to sit exactly on the next previous or next measurement point. This function is only available for frequency domain markers.



Figure 4.17: Highlights the marker readouts panel, here showing a selection of frequency domain and time domain marker readouts.

Readouts

Absolute

- ☒ Log Magnitude
- ☐ Magnitude
- ☒ Phase
- ☒ Real
- ☒ Imaginary
- ☐ Group Delay

Figure 4.18: Select which readouts appear for a given marker. A marker will be visible on any trace type for which it has a readout enabled.

4.5.4 Marker visibility

A marker is visible on any trace type for which it has a readout enabled.

To temporarily toggle the visibility of a marker and its associated readout, click on the filter controls at the top of the readout panel, shown in Figure 4.19. This can be useful for improving clarity when many markers and readouts are required.

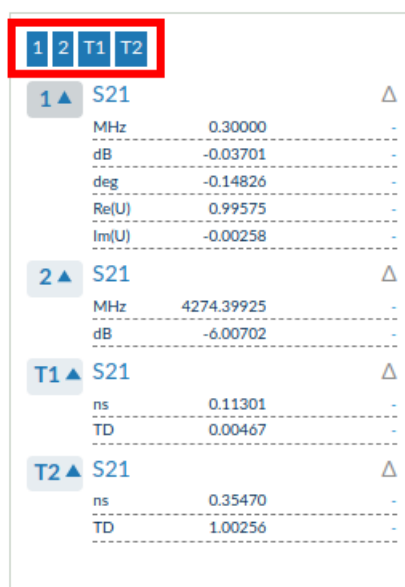


Figure 4.19: Reduce clutter by using the marker filter controls.

4.5.5 Marker groups and delta readouts

Marker groups enable measurements to be compared at different frequencies (or times) and across different channels (live and each memory channel) and different S-parameters. A marker group is created by converting one marker to a reference marker, and then adding other markers to the group.

The controls to convert a marker to a reference marker, and add other markers to the group, are found in the Markers sidebar and are highlighted in Figure 4.20.

Delta readouts are enabled by default when a group is created. They are displayed in the readouts panel alongside other readouts.

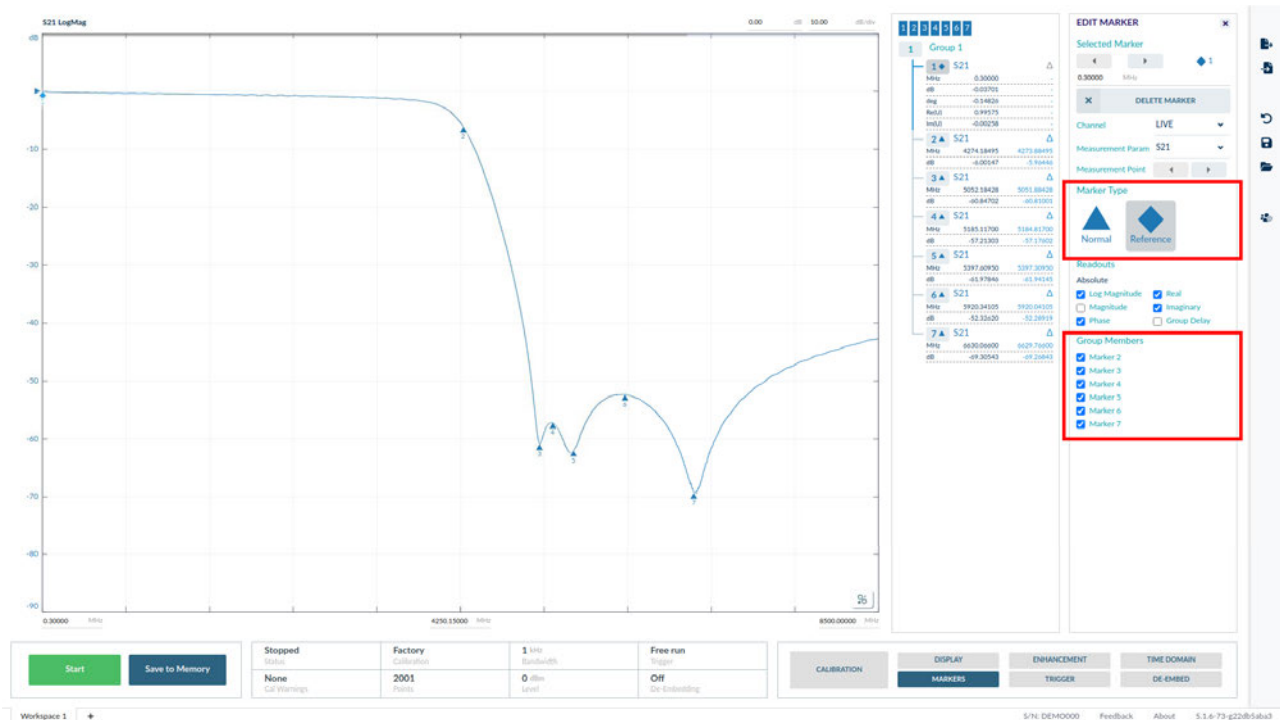


Figure 4.20: A marker group, with the controls for converting a marker to a reference marker and adding other markers to the associated group highlighted.

An unlimited number of marker groups can be created in the PicoVNA 5 software. Each new group is created by converting a marker to a reference marker, and then adding other markers to it.

There are no restrictions on which markers can be added to the group defined by a reference marker (other than every marker in the group must be from the same measurement domain: time or frequency). Markers can exist in multiple groups, and the reference marker for one group can be a member of another group.

Conceptually, there are three useful types of marker group:

- A *trace group*. The reference marker is placed on a trace and other markers in the group are placed along the same trace. This allows the trace value to be compared to itself at different frequencies (or times).
- A *frequency group (or time group)*. The reference marker is placed at a particular frequency (or time), and the value of several different traces is compared at that frequency (or time).
- A *parameter group*. The reference marker is placed on a trace and values are compared across the same trace or different traces for the same S-parameter.

The mechanism for creating each type of group is exactly the same, and PicoVNA 5 does not make a distinction between each kind of group.

Additional controls are made available by selecting a marker group (click on the button next to the group name in the readouts panel). These are shown in Figure 4.21. The additional controls allow delta readouts to be turned on/off, readout types to be enabled or disabled for all group members simultaneously, and (for empty groups) a button for fast creation of a frequency group.

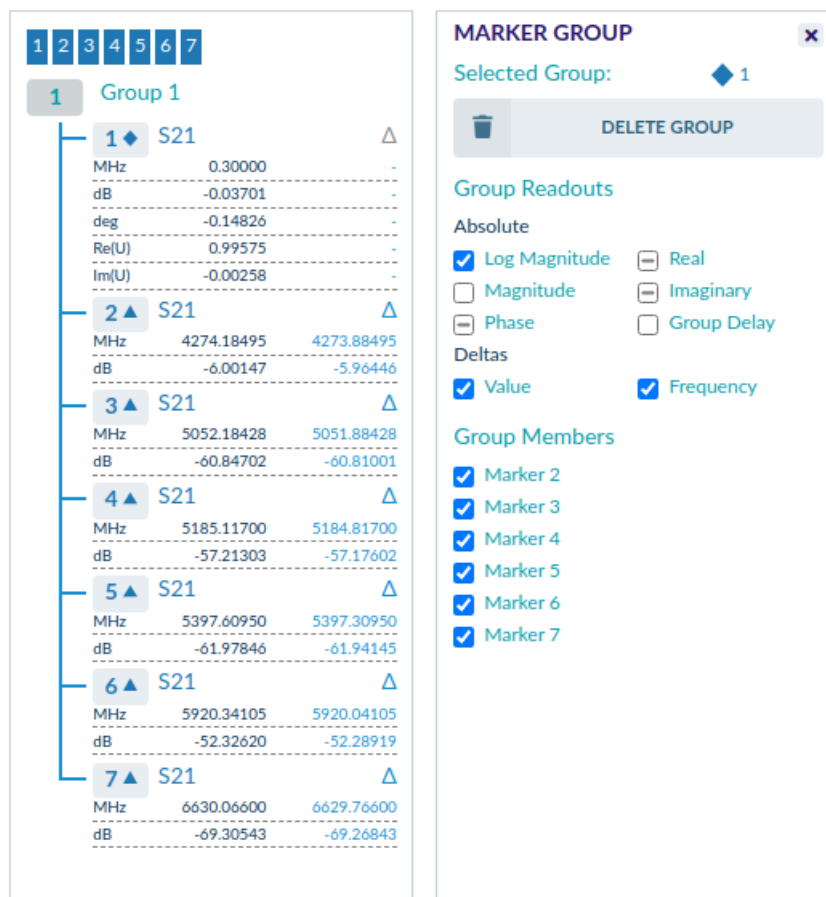


Figure 4.21: Additional controls for marker groups, accessed by selecting the marker group in the read-outs panel.

4.6 Measurement enhancement

The measurement enhancement options are displayed by opening the *Enhancement* sidebar. The options available are:

- Averaging on/off
- Number of averages
- Trace smoothing on/off
- Trace smoothing factor

4.7 Test signal level and receiver bandwidth

4.7.1 Test signal level

The test signal power level is set using the popup control shown in Figure 4.22. +3 dBm gives the best overall measurement accuracy. However, it may be necessary to reduce the test level, particularly when measuring active devices such as amplifiers. For maximum dynamic range, use the highest power setting.

For best measurement accuracy, it is always recommended that the calibration is carried out at the same test level that will be used for the measurement.

The range is +10 dBm to –20 dBm for the PicoVNA 108 and +6 dBm to –20 dBm for the PicoVNA 106, with a resolution of 0.1 dB.



Figure 4.22: Setting the test signal level, via the popup located below the main display.

4.7.2 Receiver measurement bandwidth

The receiver bandwidth is set using the popup control shown in Figure 4.23. The maximum sweep speed is achieved with the highest (140 kHz) bandwidth setting. On the other hand, the widest dynamic range (lowest noise floor) is achieved with the lowest value (10 Hz).

The bandwidth setting used during calibration determines the maximum dynamic range achievable during measurements. For example, if you need to carry out measurements over a dynamic range more than 90 dB, use a 500 Hz or less bandwidth setting during calibration.

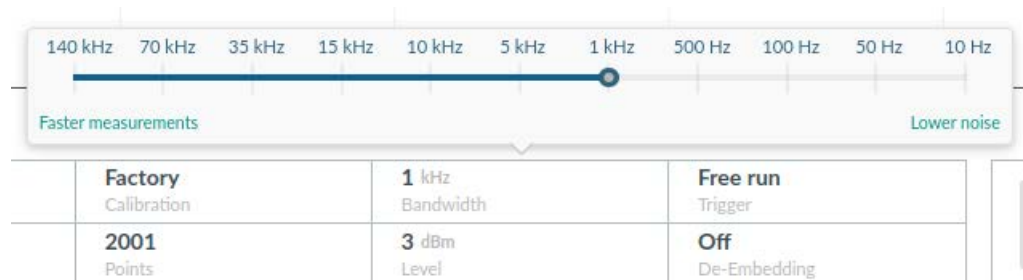


Figure 4.23: Setting the receiver bandwidth, via the popup located below the main display.

4.8 User preferences

To access user preferences, hover over the menu at the right of the screen and select “User Preferences”.

4.8.1 Display preferences

The options available are:

- *Marker size.* Can be used to render markers in a smaller or larger size on plots.
- *Sweep progress indicator size* Can be used to make the sweep progress indicator appear smaller or larger on plots.
- *Show phase axis in calibration.* When enabled, both log magnitude data and phase will be shown on calibration feedback graphs during manual calibrations.

4.8.2 Data preferences and interpolation options

PicoVNA 5 interpolates measurements using vector interpolation if the number of measurement points available is less than the width of the display viewport (in pixels), or if a marker is placed between measurement points. The best interpolation algorithm to use will depend on the DUT being measured, and no one interpolation algorithm is free of pathological cases. The data preferences modal enables the interpolation algorithm to be selected (or disabled) for each type of data series.

For almost all measurements, the default choice of interpolation algorithm will suffice. However, if unexpected artefacts are observed in measurements, then a different choice of interpolation algorithm should be tried, or interpolation should be disabled.

4.8.3 Privacy

If enabled, the developers of the PicoVNA 5 software find anonymised usage data very useful in improving future versions of the software. However, if you would prefer your anonymised usage data to not be shared with Pico, please uncheck the box.

4.9 Zoom

Zoom can be useful when the size or resolution of the display monitor is insufficient to see the required level of detail in measurements. The PicoVNA 5 software supports two kinds of zoom on all kinds of plots (including Smith charts and time domain plots): *magnify* and *span zoom*.

- *Magnify* is useful for short-term exploration of a detail in a measurement, or for placing markers with a fine-level of precision. It works in the same way as a traditional image zoom: simply making the selected area of the plot larger. At most one plot can be magnified at once.
- *Span zoom* allows a new plot (or plots) to be created that contain only a region of the time- or frequency-range of the original plot. In addition to controlling the span, the reference and sensitivity of the new plot (or plots) created can be modified independently of the original plot. The only limiting factors to the number of span zoom regions are the practical limit of the display monitor size on the number of plots that can be displayed, and the fact that span regions cannot overlap.

CAUTION!

Ensure the number of measurement points are sufficient to support the current zoom level. If you do not have a sufficient number of measurement points, you may find that you are viewing interpolation artefacts rather than real characteristics of the DUT. No interpolation scheme is free of pathological cases, and you may have to adjust the settings described in Section 4.8.2 to get best results from zoom.

4.9.1 Magnify

To magnify a plot, open the plot options menu for that plot by clicking on the button in the lower right corner of the plot and click magnify. To stop magnifying, press “Stop Magnify” at the top

right of the magnify output area. The controls to start and stop magnifying are shown in Figure 4.24.



Figure 4.24: Highlights the controls for starting and stopping the magnify feature.

4.9.2 Span zoom

A span zoom can be set up as follows:

1. Open the plot options menu for the plot to be zoomed, and press “+ Zoom Region”. The span will appear on all plots to which it relates.
2. Select the new region by clicking somewhere inside it, and adjust the span as desired. The selected span region will appear as shown in Figure 4.25.
3. Press the “+ Graph” button that hovers over the selected span region in order to create a new viewport to view the zoomed region. The available slots are enclosed in red in Figure 4.26.
4. Click in one of the available slots to create the new graph.
5. Rearrange existing plots and create any other zoom regions as desired by following the same procedure as in steps 1–4. An example of the final result, with two zoom regions created (following steps 1–4 twice), is shown in Figure 4.27.

Once plots have been created to view the output of span zoom, the reference and sensitivity of those plots can be adjusted independently from the original plot. The plot type of the new graphs can also be changed using the conventional axis controls described in Section 4.15, as shown in Figure 4.28 where the new plots have been changed to show phase.

A span region can be deleted by selecting it and pressing the “Delete” button. Any plots showing only that span region will also be removed.

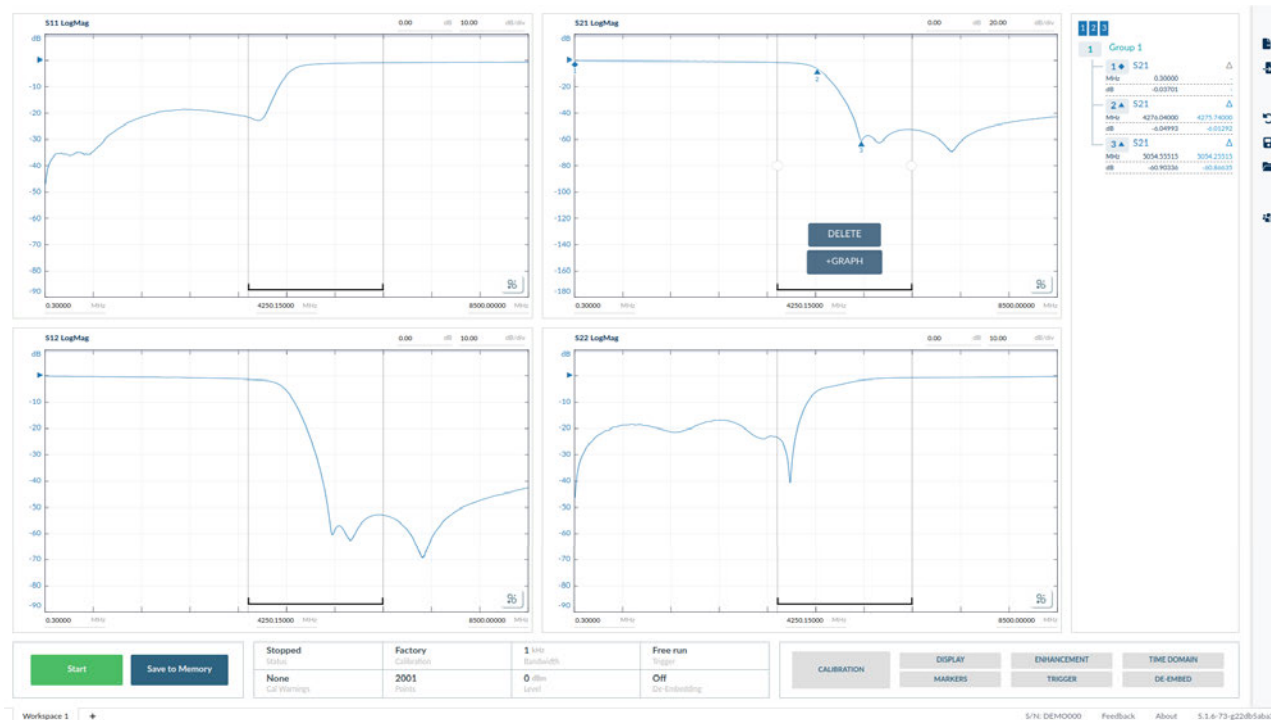


Figure 4.25: The span region is selected on the top right plot, and controls appear to either delete the selected region, or create a new plot to show the contents of that region.

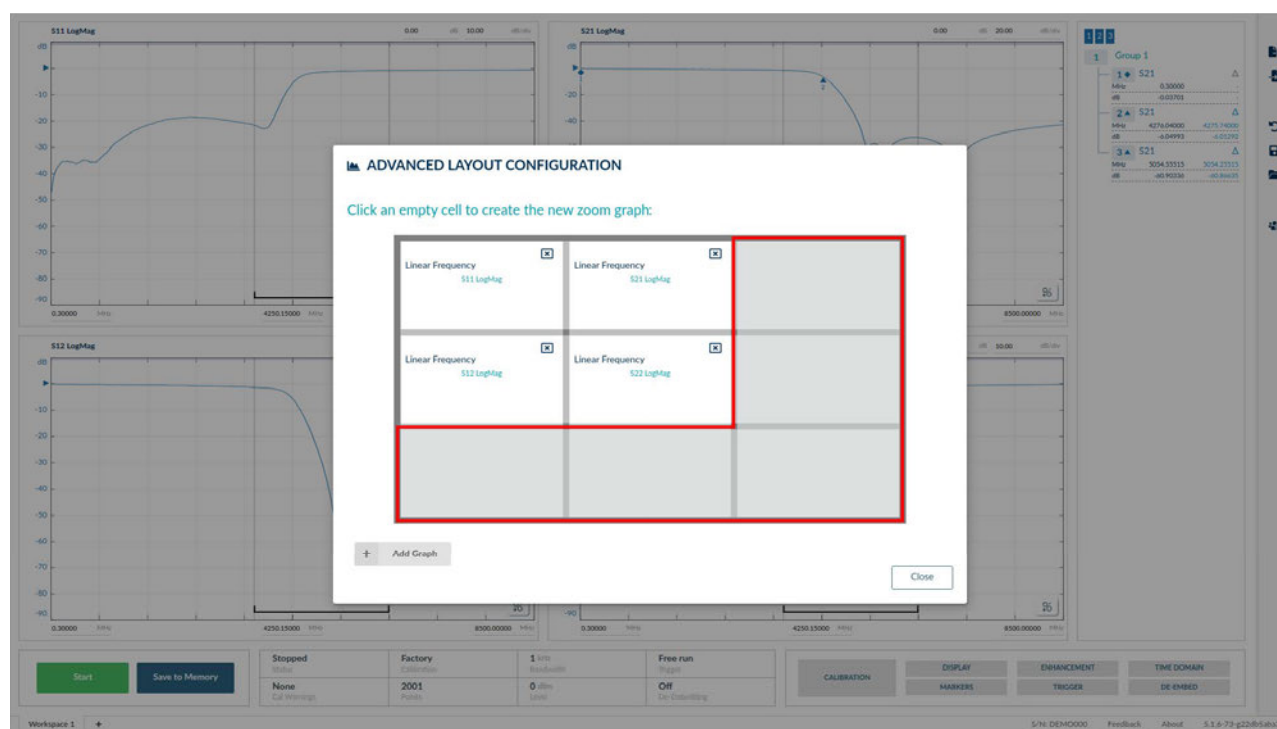


Figure 4.26: A new graph can be created in any of the available display slots (highlighted).

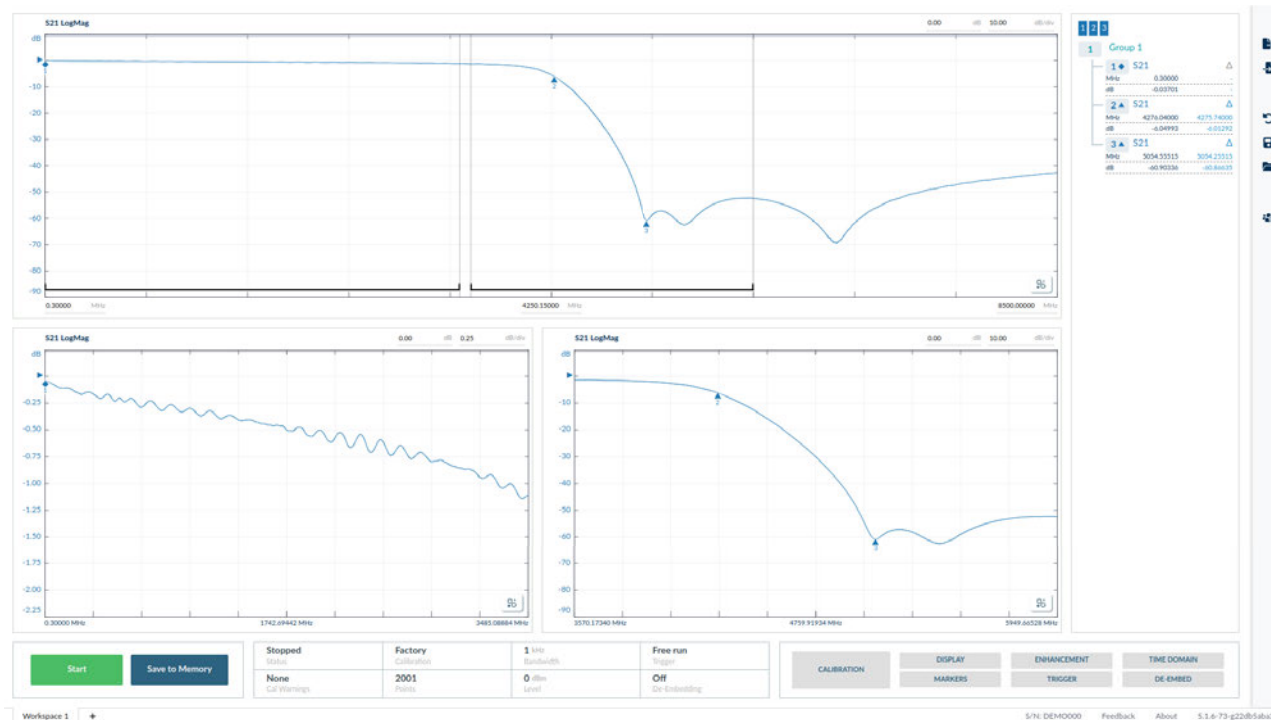


Figure 4.27: Two created span regions, showing both the pass band and transition band of a low-pass filter. The sensitivity has been adjusted in the lower left plot to inspect pass-band ripple.

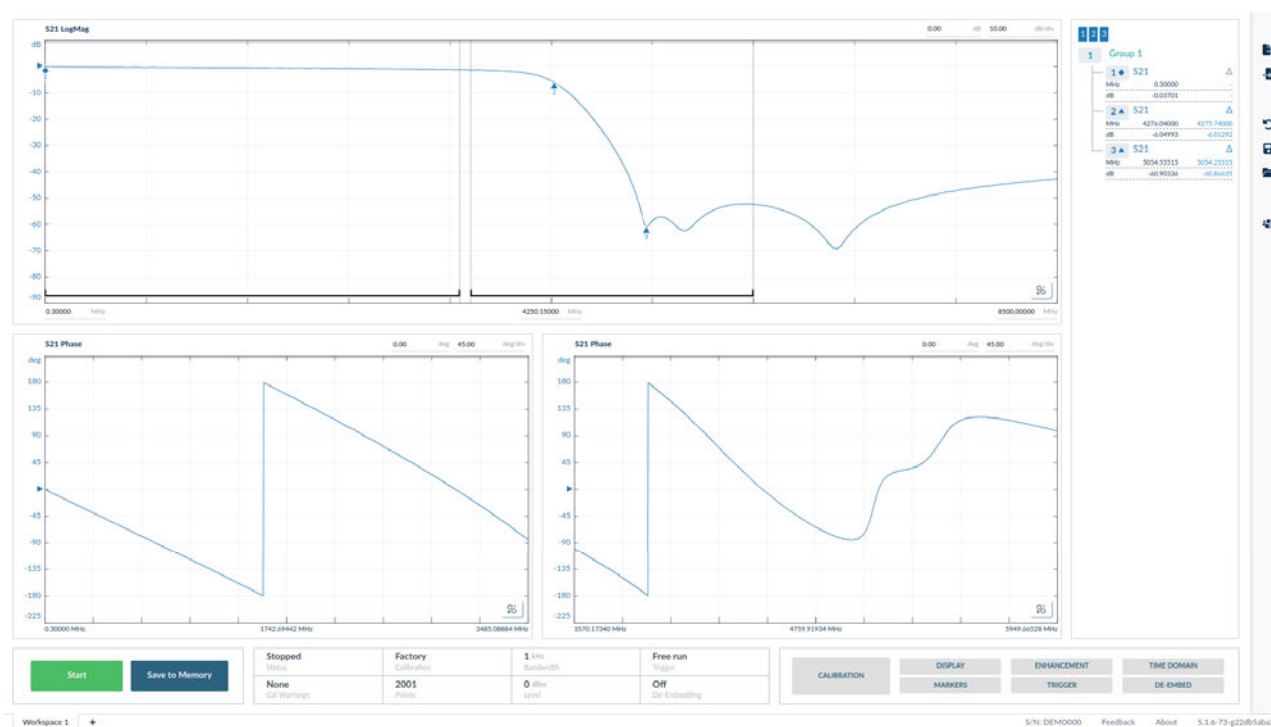


Figure 4.28: The plot type of the lower graphs can be changed to inspect the phase to be inspected in each of the span regions.

4.10 Workspaces

The PicoVNA 5 software supports a number of independent workspaces, each of which can have their own calibration, measurement parameters and display settings. This enables rapid switching between different measurement setups, for example if investigating different properties of a DUT or changing between test fixtures.

Workspaces are displayed as tabs at the bottom of the main display window, as in Figure 4.29. To create a new workspace, click the “+” button next to the list of tabs. To switch to a different workspace, click on the corresponding tab. To delete a workspace, right click on the tab and select “Delete” from the context menu; you will be asked to confirm the action as it is not possible to undo the deletion of a workspace.

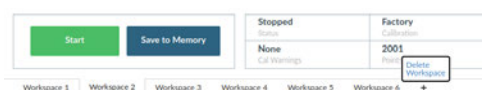


Figure 4.29: The tabbed workspace menu enables creating, switching and deleting workspaces.

4.10.1 Reset to factory default settings

Within a workspace, it is possible to reset the display, measurement parameters and calibration to the factory default settings. Hover over the menu at the right of the screen and select “Reset to factory default settings” to load the factory calibration and reset the display and measurement parameters. It is not possible to undo this action.

TIP! *Reset to factory default settings* can be useful on software startup, if it is undesirable to continue using recalled settings from the previous session.

4.10.2 Loading and saving settings, calibration and data

The active settings, calibration and data in a workspace can be saved to a file. They can be loaded into a workspace on any computer running the PicoVNA 5 software.

It is not possible to save multiple workspaces simultaneously; each workspace must be saved individually. However, the settings, calibration and data in all workspaces will be preserved when the software is closed, and automatically reloaded when it is started again provided the same instrument is connected when the software is restarted. To save the settings, calibration and data in the current workspace, hover over the menu at the right of the software and select “Save Session”.

To load a previously saved session, hover over the menu at the right of the software and select “Load Session”, choose which options to recall, and then press “Open File” to choose the file storing the session to recall. There are options to choose what to recall from the saved session file (any of: data, calibration, settings or all three), shown in Figure 4.30. It is also possible to choose whether to overwrite the current workspace, or recall the file to a new workspace.

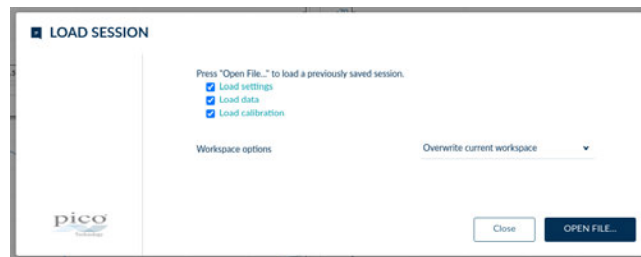


Figure 4.30: Options available when recalling a saved session.

4.11 Exporting measurement data

Measurement data can be exported to human- and machine-readable formats for processing in other software.

TIP! Data can be saved to Touchstone files and then loaded back into memory traces on a future occasion. This enables data to be compared to future or past measurements.

4.11.1 Touchstone

Hover over the menu at the right of the software, select “Export Data” and then “S-Parameters (.s2p)”. Enter the desired options in the modal dialog and finally press “Export Data” to export measurement data in Touchstone format. If multiple live and memory channels are selected for export, a zip file containing one Touchstone file for each channel will be saved.

4.11.2 CSV format

This option allows more data types to be exported than using the simple Touchstone option, and also allows multiple live and memory channels to be exported to a single file.

4.11.3 Raw a/b data

The test stimulus signal and received signal can be exported using this option. No calibration or other processing is applied.

4.12 Triggered Measurements

It is possible to synchronize each measurement sweep to an external trigger. Simply select the appropriate option in the Trigger sidebar and ensure that a trigger signal is connected to the instrument’s rear panel *Trigger* terminal.

The instrument supports either positive or negative edge trigger depending on the radio button selected on the main panel. The input impedance is 10 k Ω .

4.12.1 Manual trigger

When the *Manual* trigger option is selected, an additional *Trigger* button appears in the lower left of the main screen. The software waits until this button is pressed before starting a sweep, and runs one sweep at a time. Note that the *Start* button must have been pressed before the *Trigger* button is enabled, but no measurement will begin until *Trigger* is pressed.

TIP! Use the manual trigger to avoid continuous sweep, in applications where it is desirable to run one sweep at a time.

4.12.2 External trigger considerations

It is important to consider the maximum possible repetition rate of the external trigger. This rate is a function of factors such as the number of sweep points, bandwidth in use and crucially the speed of the host PC's operating system in allocating USB communication resources. If the trigger rate exceeds the maximum, the host PC may miss some trigger events.

Typically, the external trigger signal should occur 120 ms or more after the end of the previous sweep, but this will depend on the speed of the host PC.

4.13 Sweep trigger output

The rear panel *Trigger Output* terminal provides a 3 V logic output with the rising edge synchronised to the start of the measurement sweep. The signal goes to 0 V at the end of the sweep. The output resistance is about 500 Ω .

4.14 Measurements

4.14.1 Return loss

In order to carry out return loss measurements (S_{11}) the VNA must be calibrated using either the S_{11} , 12-term SOLT, 8-term SOLU or E-Cal methods (see Chapter 5). The device to be tested (DUT) is then connected to Port 1 of the VNA as indicated in Figure 4.31. *If the DUT can only be connected to the VNA using a cable, then the VNA should be calibrated at the end of the cable for best results.*

The measurement result can be displayed by selecting the S_{11} parameter on an appropriate display graph/axis as described in Section 4.15. Note that the measured phase is relative to the calibration reference plane as discussed in Chapter 5. The reference plane can be shifted at any time using the De-embed sidebar.

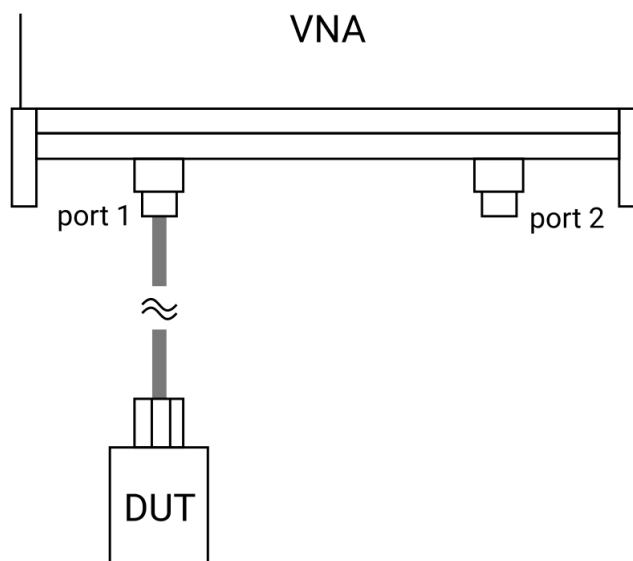


Figure 4.31: Connect the DUT to port 1 to carry out S_{11} measurements.

4.14.2 Insertion loss/gain

To carry out insertion loss measurements (S_{21}) the VNA must be calibrated with the test cables in place using the 12-term SOLT, 8-term SOLU or E-Cal methods (see Chapter 5). The device to be tested (DUT) is then connected between Ports 1 and 2 of the VNA as indicated in Figure 4.32.

For best results, the arrangement shown on the right hand side of Figure 4.32 should be used whenever possible. This will minimize repeatability/cable flexing errors associated with the connecting cables.

The measurement result can be displayed by selecting the S_{21} parameter on an appropriate display graph/axis as described in Section 4.15. Note that the measured phase is relative to the calibration reference plane as discussed in Section 6.1. The reference plane can be shifted at any time using the De-embed sidebar.

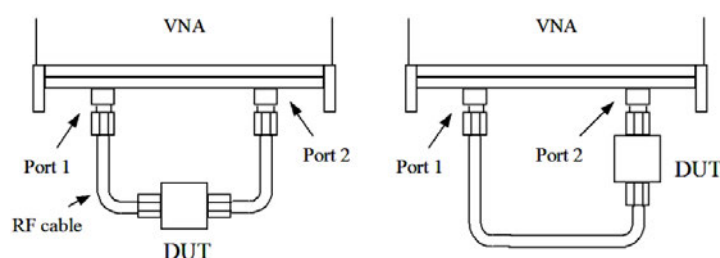


Figure 4.32: Connect the DUT between Ports 1 and 2 to carry out S_{21} measurements. For best results use the arrangement shown on the right.

4.14.3 Complete 2-port measurement

In order to measure all four S -parameters, a 12-term SOLT, 8-term SOLU or E-Calibration needs to be completed with the test cables in place (see Chapter 5). The arrangement shown on the right hand side of Figure 4.32 is likely to yield best results in terms of repeatability by virtue of using only one test cable, thus reducing the effect of errors due to cable flexing.

The measurement result can be displayed by configuring graphs and axes as described in Section 4.15. Note that the measured phase is relative to the calibration reference plane as discussed in Section 6.1. The reference plane can be shifted at any time using the De-embed sidebar.

Refer to Section 5.3 for guidance on achieving measurements with the largest dynamic range.

4.14.4 Time domain measurements

The time domain facility allows the display of the time domain response of a DUT. For example, time domain reflectometry (TDR) measurements can be made by first carrying out an S_{11} calibration. Similarly, time domain transmission (TDT) measurements can be made by first completing a 12-term SOLT, 8-term SOLU or E-Calibration. The time domain measurement can be displayed on an appropriate display graph/axis as described in Section 4.15.

In time domain mode, the plot markers display resistance values for S_{11} and S_{22} , as well as levels.

The time domain measurement can be configured using the time domain sidebar, shown in Figure 4.33. The available options are:

- *Mode*. This switches between low pass and band pass time domain mode.
- *Response*. This switches between displaying the step response and the impulse response. Note that only the impulse response is available in band pass mode as the DC term and phase information cannot be recovered.
- *x -axis scale*. This switches between displaying the x -axis labels and marker readouts in time or in distance.
- *Effective dielectric constant*. This specifies the effective dielectric constant of the medium, which is used in converting the x -axis labels and marker readouts between time and distance.
- *x -axis range: Reset to default*. This button resets the x -axis range to -5 ns to 50 ns (or equivalent distances).
- *x -axis range: Set to full*. This button sets the x -axis range to the maximum possible for the current frequency sweep settings, calculating the maximum range as described in Section 3.8.2.
- *Frequency sweep: Align frequency points*. By default, the PicoVNA 5 software interpolates frequency domain measurements in order to provide correctly-spaced inputs to the IDFT. This button sets the frequency sweep measurement points to be aligned to IDFT bin centres, so that no interpolation of measurement data is required (although this will cause the calibration to be interpolated, since the frequency sweep measurement points will no longer be aligned with the measurement points used during the calibration). For achieving the highest measurement accuracy, this button should be pressed before carrying out a calibration so that no interpolation of either the measurement data or calibration is required. Calibration for the highest accuracy in time domain instruments is discussed in 5.4.
- *DC termination*. Sets the DC termination (if known). Auto finds the DC termination through interpolation.

- *Window function*. Sets the window function to mitigate truncation effects, as described in Section 3.8.4.

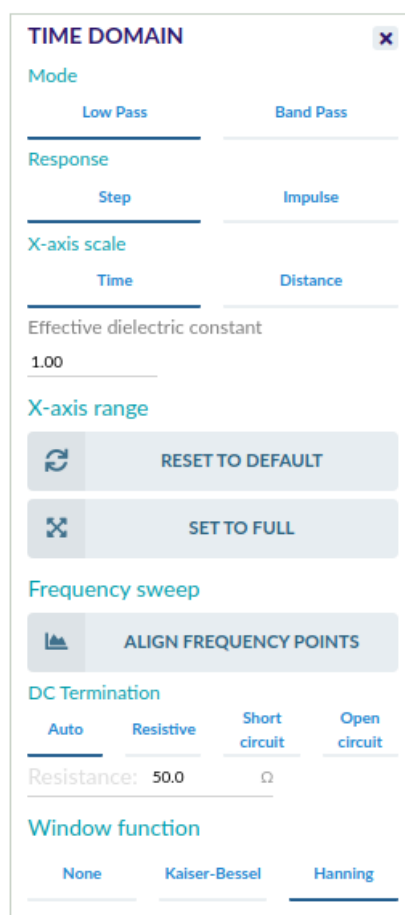


Figure 4.33: Time domain measurements can be configured using the time domain sidebar.

4.15 Reverse measurements on two-port devices

In order to measure the reverse parameters (S_{12} and S_{22}), it is necessary to complete a 12-term SOLT, 8-term SOLU or E-Calibration first. The other calibration options measure only forward parameters. After the 12-term SOLT, 8-term SOLU or E-Calibration has been completed, select the reverse parameter(s) to be required on any graph/axis (as described in Section) and start the measurement.

4.16 Powering active devices using the built-in bias-Ts

The PicoVNA 106 and PicoVNA 108 include two bias-Ts, which can be used to provide DC bias to the measurement ports 1 and 2. The bias-Ts are rated at 250 mA and can support DC voltages up to 15 V. The DC injection terminals are type SMB, male, and are located on the front panel. The facility can be used, for example, to provide DC bias to an active device being measured.



CAUTION

To avoid causing permanent damage to the internal biasing circuit, do not exceed the voltage and current ratings.

4.17 Exiting the software

When the PicoVNA 5 software is closed, all your workspaces will be saved, including the active calibrations, measurement settings and data traces. These will be reloaded when the software next starts and either saved at this point (following the procedure described in Section 4.10.2) or discarded by resetting to factory default settings (as described in Section 4.10.1).

Chapter 5

Calibration

The instrument must be calibrated before any measurements can be carried out. This is done by loading a previous calibration (using “My Calibrations”) or carrying out a fresh calibration.

5.1 Overview

Below is a summary of the calibration types supported by the PicoVNA 5 software, together with the standards required to complete each calibration. For best overall accuracy, particularly when measuring low isolation devices with poor return loss values, a 12-term calibration should be performed.

S₁₁ calibration

For reflection measurements of a 1-port DUT. Requires fixed SOLT standards: matched load, open, short. Supports measurements of S_{11} using 3-term error correction.

12-term SOLT calibration (insertable DUT)

For measurements of a 2-port insertable DUT. Requires fixed SOLT standards: 2x matched load (male and female), 2x open (male and female), 2x short (male and female), through cable (zero length). Supports measurements of S_{11} , S_{21} , S_{12} and S_{22} using 12-term error correction.

8-term SOLU calibration (non-insertable DUT)

Also known as an *unknown thru* calibration. Requires fixed SOLT standards: 1x matched load, 1x open, 1x short, 1x through adaptor (the only property required of the through adapter is that it is reciprocal, i.e. $S_{21} = S_{12}$). Supports measurements of S_{11} , S_{21} , S_{12} and S_{22} using 8-term error correction.

TRL calibration (insertable DUT)

TRL calibration requires the PicoVNA 108. Supports measurements of S_{11} , S_{21} , S_{12} and S_{22} using 12-term error correction.

The following standards are required:

- A short or open termination (reflection),
- One or two delay line standards (as required to cover the desired frequency range),
- A matched load (if measurements are required below the lowest frequency supported by either line standard),

- A zero-length through connection.

E-Calibration

An 8-term SOLU calibration, with automated measurements of the calibration standards. Requires the E-Cal SOLT kit. Supports measurements of S_{11} , S_{21} , S_{12} and S_{22} using 8-term error correction.

5.2 Calibration sequence

The sequence for carrying out a manual calibration is described by the following steps. The sequence for carrying out an E-Calibration differs only in steps 3–4.

TIP! For best results, ensure that the instrument is fully warmed up before carrying out a calibration.

5.2.1 Step 1: select the calibration type

First open the Calibration sidebar and select “New Calibration”. Then select the desired calibration type from the menu that appears and then press “Next”.

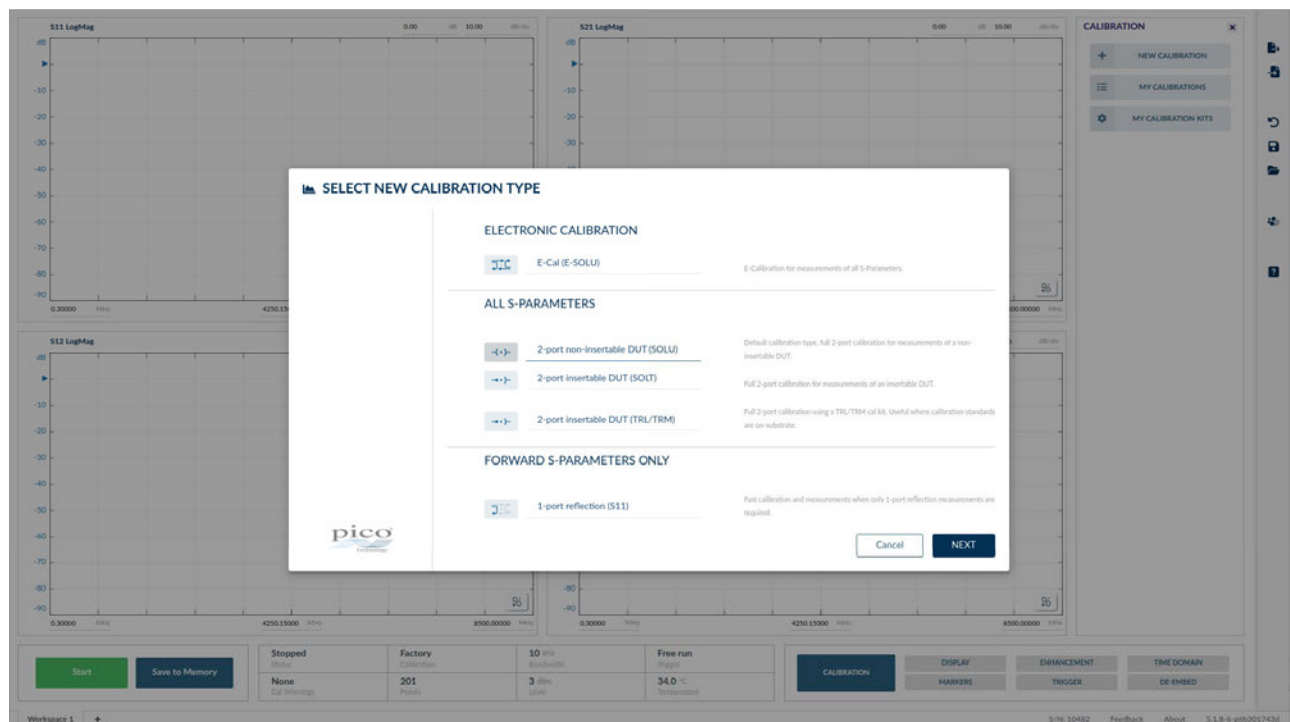


Figure 5.1: The first step when starting a new calibration: select the type of calibration to perform.

5.2.2 Step 2: set the sweep parameters

Next, select the measurement parameters for the new calibration. The frequency limits, receiver bandwidth, number of measurement points, and power level can be adjusted.

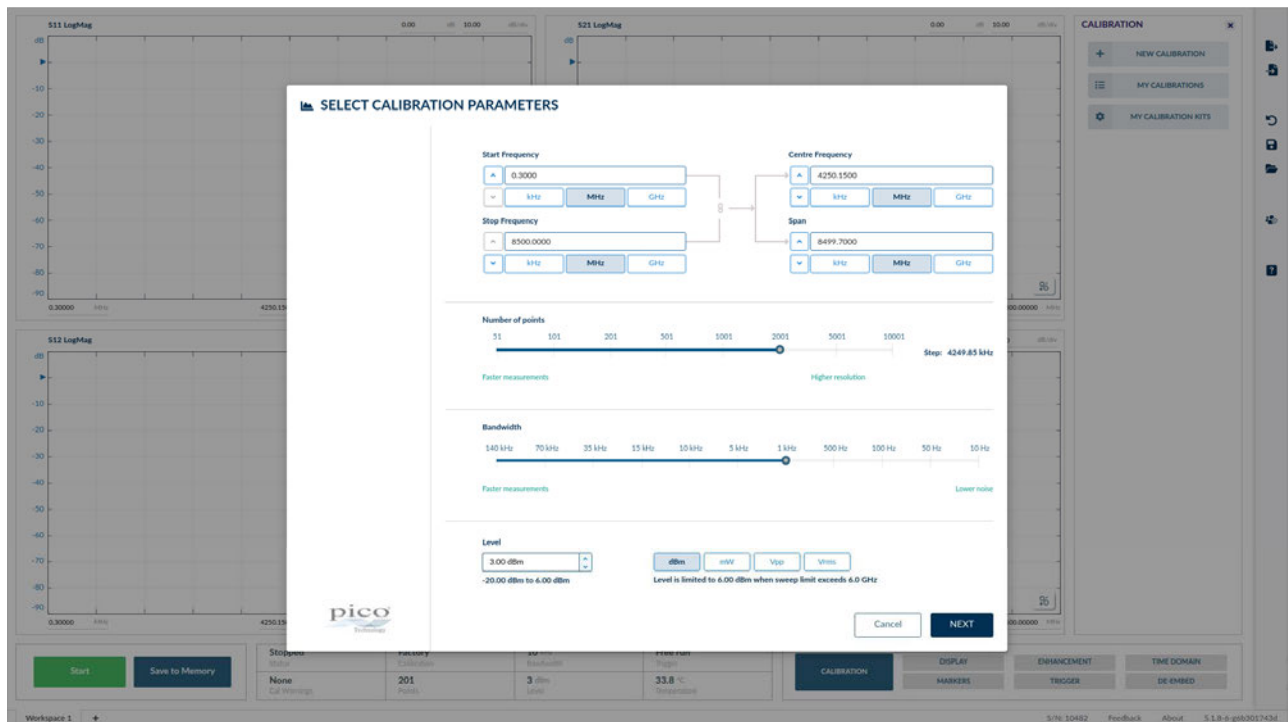


Figure 5.2: The second step when starting a new calibration: select the measurement parameters for the new calibration.

5.2.3 Step 3: select or import the calibration kits

Next, select the calibration kits to use. You will need to select either one or two calibration kits depending on the type of calibration.

You can select calibration kits that you have previously imported, or created using the calibration kit editor. Alternatively, you can import new calibration kits using the “Import Calibration Kit” button.

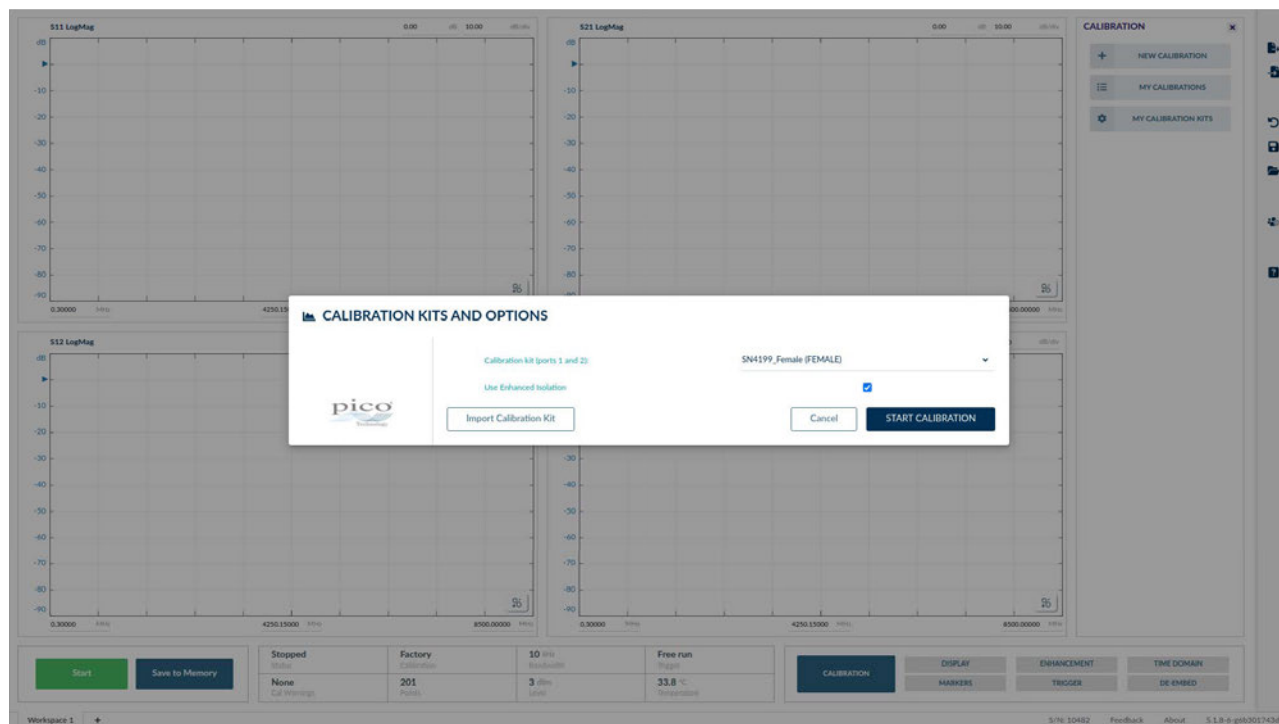


Figure 5.3: The third step when starting a new calibration: select or import calibration kits.

5.2.4 Step 4: carry out the calibration

Follow the instructions and steps in the wizard in order to carry out the calibration. The exact steps will depend on the type of calibration being performed.

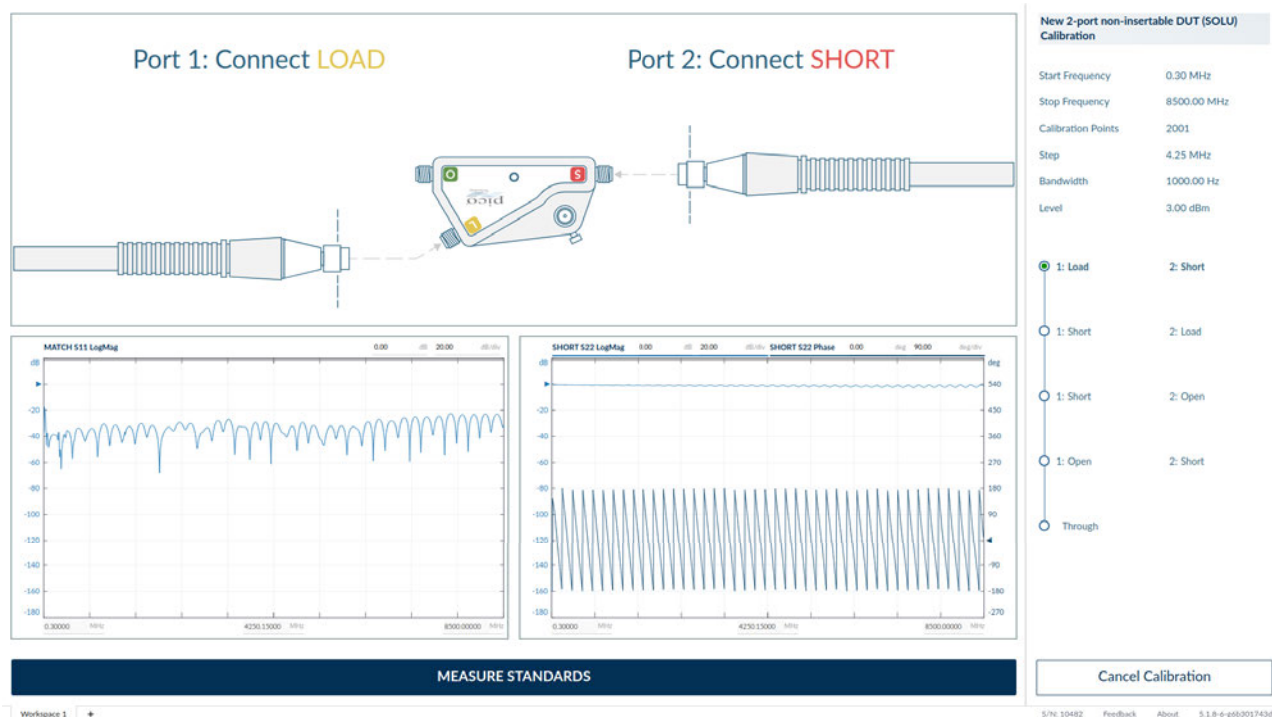


Figure 5.4: The calibration wizard: follow the instructions in the wizard in order to carry out the calibration.

5.2.5 Step 5: name and save the calibration

After completing all the calibration measurements required, you will be invited to name the calibration so that it can be identified in future. Click “Save and Continue” to save the calibration and apply it to the current workspace.

5.3 Calibration for best dynamic range – minimizing the effect of crosstalk

Instrument crosstalk is a limiting factor when making large dynamic range measurements. This is particularly the case at higher frequencies, say above 4 GHz. The reason is that some of the crosstalk is dependent on the loading at the test ports. Therefore, the isolation calibration process can only compensate it fully when the terminations are left unchanged from those used at the isolation calibration step.

5.3.1 Enhanced isolation calibration

The PicoVNA 106 and 108 provide an enhanced isolation calibration option. This method makes crosstalk measurements at the *short*, *open* and *load* calibration steps. In this way it attempts to more closely model the effect of port termination on the internal crosstalk components of the instrument.

To use enhanced isolation, make sure the “Enhanced isolation” checkbox is selected when starting the calibration sequence.

5.4 Calibrating for highest accuracy during time domain measurements

In lowpass time domain mode, a requirement is that the frequency domain samples are equally spaced between 0 Hz and the highest measurement frequency. When this condition is not satisfied, the PicoVNA 5 software will interpolate the frequency domain measurement data in order to provide the required inputs to the IDFT. However, depending on the nature of the DUT, it may be possible to achieve better measurement accuracy by performing the frequency domain measurements at the bin centres of the IDFT.

If the highest accuracy time domain measurements are desired, set up the measurement so that every measurement frequency is a multiple of the lowest (non-zero) measurement frequency. Equivalently, the lowest measurement frequency is equal to the step frequency. That is, all the measurement frequencies satisfy

$$f_{\text{Meas}} = k f_{\text{Step}} \quad (5.1)$$

for some $k > 0$.

Chapter 6

Advanced operation: Fixture removal and de-embedding

6.1 Reference-plane offset

The *reference plane extension* facility on the PicoVNA 106 and 108 allows the measurement reference plane to be shifted away from that set during calibration. This can be useful in removing the effect of interconnecting cables or microstrip lines from measurements. The instrument allows independent reference plane extensions on Port 1 and Port 2.

Reference plane extension in PicoVNA 5 will correct phase measurements. For more advanced correction, de-embedding should be used (described in Section 6.2).

Figure 6.1 illustrates a reference plane extension of $L1$ on Port 1 and $L2$ on Port 2. The figure shows explicitly how the Port 1 reference plane is shifted; the shift of the Port 2 reference plane is similar. In the PicoVNA 5 software $L1$ and $L2$ are entered using the de-embed sidebar, in the “Port 1 offset” and “Port 2 offset” fields respectively.

PicoVNA 5 accepts $L1$ and $L2$ as electrical lengths, in units of distance. If the reference plane extensions are known in terms of time, they can be converted using the formula

$$L = v_f \times c \times T \quad (6.1)$$

where L is the electrical length of the reference plane extension, T is the reference plane offset time, c is the speed of light, and v_f is the velocity factor of the medium.

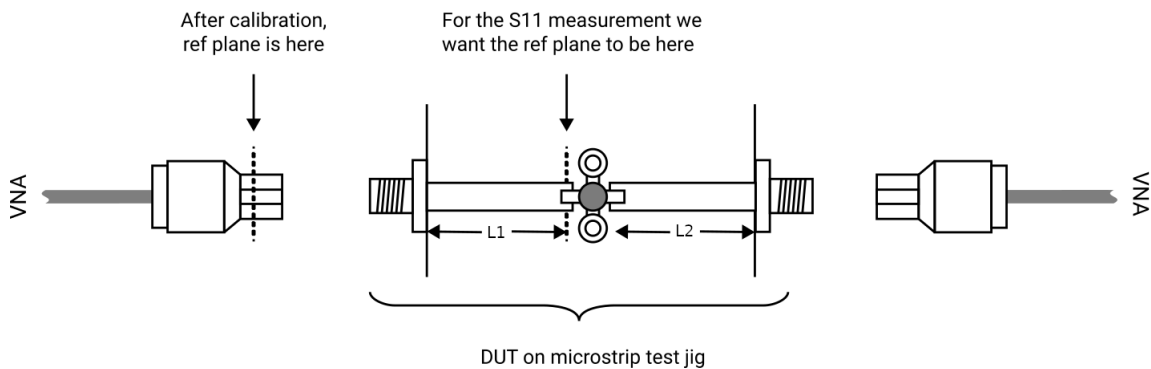


Figure 6.1: Correcting S_{11} , S_{21} , S_{12} and S_{22} phase measurement.

6.2 De-embedding arbitrary networks

A typical measurement jig, shown in Figure 6.2, includes input and output networks which introduce errors to the measured parameters of the device under test (DUT). For best measurement accuracy, these networks can be specified (in the form of Touchstone files) and PicoVNA 5 can remove the effect of these networks on the measurement using de-embedding.

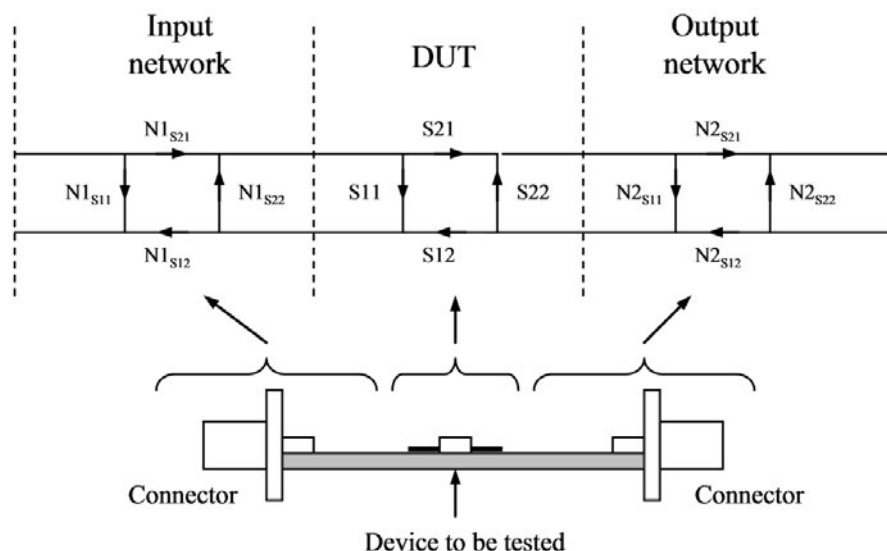


Figure 6.2: De-embedding allows the effects of the test jig's input and output networks to be removed.

The PicoVNA 106 and 108 allow you to specify Touchstone files (must be full 2-port data) for the input and output networks shown in Figure 6.2 so that the de-embedding takes place automatically. After first calibrating as usual, press the “Add Network” button under “Port 1 networks” or “Port 2 networks” to load the networks to de-embed on Port 1 or Port 2 respectively. To permanently remove the networks from de-embedding, use the delete button next to each network in the de-embedding sidebar.

The PicoVNA 5 software allows multiple networks to be de-embedded between each port and the DUT. If multiple networks are specified, the order in which they are applied is (A1..An are the networks to be de-embedded between Port 1 (P1) and the DUT, and B1..Bm are the networks to be de-embedded between Port 2 (P2) and the DUT):

$$P1 \leftrightarrow A1 \leftrightarrow A2 \leftrightarrow \dots \leftrightarrow An \leftrightarrow DUT \leftrightarrow Bm \leftrightarrow \dots \leftrightarrow B2 \leftrightarrow B1 \leftrightarrow P2$$

That is, network 1 is the closest network to each port, and the network with the highest index is closest to the DUT. These indices match the index of each network shown in the de-embed sidebar. If networks are loaded into the PicoVNA 5 software in the incorrect sequence, they can be re-ordered using the up/down buttons in the de-embed sidebar.

6.3 Turning de-embedding on and off

The de-embed sidebar allows de-embedding and reference plane offset to be toggled on and off for both live data and memory data separately. This can be useful for comparing the results of measurements with and without de-embedding and reference plane offset applied.

Chapter 7

Remote Control and APIs

There are three interfaces for programmatically controlling and retrieving data from the PicoVNA instrument:

1. API
2. SCPI
3. Binary data broadcasts (data retrieve only)

The API allows the PicoVNA instrument to be controlled directly, without running the PicoVNA 5 software. It is the most programmer-friendly way of controlling the PicoVNA instrument, with useful abstractions and clean syntax. The API is appropriate for system integrators who wish to distribute their own systems that encapsulate the PicoVNA instrument, without needing to also deploy the PicoVNA 5 software. Using the PicoVNA instrument via the API will maximise performance and minimise energy use on the host controller, so is also the most appropriate option for use in embedded systems. It is not possible to control the instrument via the API and the PicoVNA 5 software simultaneously.

SCPI allows the PicoVNA instrument to be controlled via the PicoVNA 5 software. The PicoVNA 5 software must be running in order to control the PicoVNA instrument via SCPI. SCPI control is most useful in applications where the instrument is being controlled together by both the PicoVNA 5 software and by an external user application. The syntax used for SCPI control will be familiar to users of other test and measurement equipment. SCPI control supports some more complex features of the PicoVNA 5 software that would not be appropriate in the API: for example, importing touchstone data to memory channels. The most simple example of an application where SCPI control is appropriate is: PicoVNA 5 can be used to load a calibration and configure the measurement, and then the external user application can perform the measurement and retrieve data. SCPI commands can also be typed by the user directly into a console, in order to control the application via interactive scripting.

Binary data broadcasts provide a simple way for other applications to extract data from the PicoVNA 5 software in real-time. No programming is required to configure these; data is broadcast using a binary protocol when a measurement is started via the PicoVNA 5 software. These are read-only, and they do not provide a programmatic way to configure measurements (which must be done either via the user interface of the PicoVNA 5 software or via SCPI).

7.1 API

Please refer to the separate API Programmer's Guide for documentation of the API.

7.2 SCPI

The PicoVNA 5 software listens for SCPI commands on TCP port 5025.

7.2.1 Example programs for SCPI control

7.2.1.1 Linux: Bash/netcat

On Linux, SCPI commands can be typed directly into a terminal prompt. For example, to start a single sweep from a terminal prompt running on the same host as the PicoVNA 5 software:

```
echo "*IDN?" | netcat localhost 5025
echo "INIT" | netcat localhost 5025
```

7.2.1.2 Python

We recommend using the `pyvisa` package for controlling the instrument via SCPI from Python. Ensure that the `pyvisa`, `pyvisa-py` and `zeroconf` packages are installed.

The following script will store the instrument ID in the variable `id` and then start a single sweep, when running on the same host as the PicoVNA 5 software:

```
import pyvisa

vna = rm.open_resource("TCPIP::127.0.0.1::5025::SOCKET")
vna.read_termination = '\n'
vna.write_termination = '\n'
id = vna.query('*IDN?')
vna.query('INIT')
```

7.2.1.3 MATLAB

The following script will store the instrument ID in the variable `id` and then start a single sweep from MATLAB running on the same host as the PicoVNA 5 software:

```
vnaInterface = tcpip('localhost', 5025);
fopen(vnaInterface);
id = query(vnaInterface, '*IDN?');
query(vnaInterface, 'INIT')
```

7.2.2 Key SCPI commands

HELP Get help about SCPI commands.

If you pass the name of a SCPI command to this command, detailed information about that command is given. If you give the name of a SCPI subtree, summary information about all commands in that SCPI subtree is given. If no argument is given, summary information is given for all commands.

INITiate Start a single sweep.

CALCulate<Ch>:DATA<MParam> <Type> Query the response values for a measurement parameter, for the live channel.

7.2.3 SCPI Command Reference

7.2.3.1 HELP

HELP [Command: STRING]

Get help about SCPI commands.

If you pass the name of a SCPI command to this command, detailed information about that command is given. If you give the name of a SCPI subtree, summary information about all commands in that SCPI subtree is given. If no argument is given, summary information is given for all commands.

Parameters

[Command: STRING] The name of the SCPI command, or subtree, to get help for.

7.2.3.2 :*IDN?:

*IDN?

Print a string identifying the device and associated software stack.

Returns a comma-separated string identifying the device connected and software version. The fields are: <vendor>,<instrument>,<instrument serial>,<picovna5 version> – <instrument firmware version>

To facilitate interoperability with other software, the value returned by this command may be modified using the SYSTem:IDENtify command.

Example of string returned

Pico Technology Ltd,PicoVNA-108,A0000.00000,5.2.4-0-0

7.2.3.3 :*OPC?:

*OPC?

Returns 1.

7.2.3.4 :*OPT?:

*OPT?

Print a string describing the optional hardware features present on the device.

At present, no such optional features exist, so this command just prints 1.

To facilitate interoperability with other software, the value returned by this command may be modified using the SYSTem:OPTions command.

7.2.3.5 :*RST:

*RST

Reset the device and workspaces.

Any ongoing measurement is stopped. Then:

- If a user reset file has been set using `SYSTem:PRESet:USER:NAME`, and user reset has been enabled using `SYSTem:PRESet:USER`, the current workspace is overwritten with what is stored in that file.
- If `SYSTem:PRESet:SCOPE` has been used to set the reset scope to apply to all workspaces, the same procedure is then performed on all other workspaces.

7.2.3.6 :*TRG:

*TRG

Send a manual trigger event to the device.

7.2.3.7 :ABORt:

ABORt

Stop all ongoing measurements.

7.2.3.8 :CALCulate<Ch>:AVERaging

`CALCulate:AVERaging <Average: BOOL>`

Change whether averaging is enabled.

Parameters

`<Average: BOOL>` Whether or not averaging should be enabled on this channel.

7.2.3.9 :CALCulate<Ch>:AVERaging:COUNT

`CALCulate:AVERaging:COUNT <NumAvgs: INT>`

Change the number of averages.

Parameters

`<NumAvgs: INT>` The new number of averages.

7.2.3.10 :CALCulate<Ch>:AVERaging:COUNT?:

```
CALCulate:AVERaging:COUNT?
```

Determine the current number of averages.

7.2.3.11 :CALCulate<Ch>:AVERaging?:

```
CALCulate:AVERaging?
```

Query if averaging is enabled.

7.2.3.12 :CALCulate<Ch>:DATA <MParam: (S11 | S21 | S12 | S22)> <Type: (LOGMAG | MAG | PHASe | TD | REAL | IMAGinary | GD | VSWR | POLARlinear)>:

```
CALCulate:DATA
  <MParam: (S11 | S21 | S12 | S22)>
  <Type: (LOGMAG | MAG | PHASe | TD | REAL | IMAGinary | GD | VSWR | POLARlinear)>
```

Query the response values for a measurement parameter, for the live channel.

This command will get you the data for one sparam in the requested format. The `FORMat:*` command can be used to select whether this command outputs ASCII data or raw floating point bytes, and which endianness/precision is used.

If you need multiple measurement parameters, simply run this command repeatedly.

If measurement is not in progress, this command will return immediately with the data for the most recent sweep.

If the most recent sweep was aborted early, this command will return the data that was collected during the partial sweep followed by as many NaNs as are needed to pad the result to the needed number of measurement points.

If continuous-mode sweeping was started from the UI, and then stopped, then this command will return the data corresponding to what the UI is showing (a mixture of data from two different sweeps).

If a sweep is in progress, this command will hang until it has finished so the data can be returned. If averaging is enabled, this command will wait for enough sweeps to have finished for the averaged data to be available, and return that.

A natural consequence of this behaviour is that you can perform measurements extremely straightforwardly, without having to think about concurrency unless you're intentionally doing exotic things with multiple SCPI connections:

```
# Start a sweep
INIT
```

```
# Get some data out. There will be a pause after running the first of these
# commands while we wait for measurement to finish. The latter 3 will return
# instantly.
```

```
CALC:DATA S11,LOGMAG
CALC:DATA S12,LOGMAG
CALC:DATA S21,LOGMAG
CALC:DATA S22,LOGMAG
```

NaN is represented by the string `nan` in ASCII mode. In binary mode, a non-signalling NaN is returned. The exact byte representation of this value depends on your hardware/OS, but it will certainly have all bits of the exponent set and at least one bit of the fraction set. That is: it's an IEEE754-compliant NaN, but whether or not it triggers your hardware's FP exception mechanism is subject to the whims of the C++ standard library on your platform (and whether it supports quiet NaNs at all).

You may open a second SCPI connection and send an ABORT command to unblock a SCPI connection that is waiting for this command to complete. This will result in the same partial data semantics as described above. This may be useful if you discover a defect in the measurement configuration or DUT and wish to start again without having to wait. Alternatively, you may drop the SCPI connection, reconnect, and then send ABORT.

Parameters

Measurement parameter you want data for:

```
<MParam: (S11 | S21 | S12 | S22)>
S11:
S21:
S12:
S22:
```

The data you want:

```
<Type: (LOGMAG | MAG | PHASe | TD | REAL | IMAGinary | GD | VSWR | POLARlinear)>
LOGMAG: Log-magnitude data (dB)
MAG: Linear magnitude
PHASe: Phase (degrees)
TD: Time Domain
REAL:
IMAGinary:
GD: Group Delay.
VSWR:
POLARlinear: Outputs the real and imaginary parts of each measurement point,
               in order.
```

Note that for group delay, Note that the first value will always be NaN, because group delay cannot be computed for the first measurement point.

7.2.3.13 :CALCulate<Ch>:DATA:STIMulus?

```
CALCulate<Ch>:DATA:STIMulus?
```

Output the stimulus values for the given sweep segment.

7.2.3.14 :CALCulate<Ch>:SMOothing

```
CALCulate:SMOothing <Smooth: BOOL>
```

Change whether smoothing is enabled.

Parameters

<Smooth: BOOL> Whether or not smoothing should be enabled on this channel.

7.2.3.15 :CALCulate<Ch>:SMOothing:FACTOR

CALCulate:SMOothing:FACTOR <Smoothing: DOUBLE>

Change the smoothing factor.

Parameters

<Smoothing: DOUBLE> The new smoothing factor.

7.2.3.16 :CALCulate<Ch>:SMOothing:FACTOR?

CALCulate:SMOothing:FACTOR?

Determine the smoothing factor.

7.2.3.17 :CALCulate<Ch>:SMOothing?:

CALCulate:SMOothing?

Query if smoothing is enabled.

7.2.3.18 :CHANnel<Ch>:COPY

CHANnel<Ch>:COPY [MemChanID: INT]

Save a channel to a memory channel.

If no parameters are given, the channel is saved to a new memory channel and its ID is printed.

If you give an ID of a memory channel, it will be overwritten or created.

Afterwards, the new channel can be assigned a friendly name using CONFigure:CHANnel:NAME.

Parameters

[MemChanID: INT] The ID of the memory channel to write.

7.2.3.19 :CHANnel<Ch>:MEMory:CATalog:COUNt?:

CHANnel:MEMory:CATalog:COUNt?

Print the number of existing memory channels.

7.2.3.20 :CHANnel<Ch>:MEMory:CATalog?:

CHANnel:MEMory:CATalog?

Print the names and ID of all memory channels that exist.

7.2.3.21 :CHANnel<Ch>:MEMory:DElete

CHANnel:MEMory:DElete <MemChanID: INT>

Delete the memory channel with the given ID.

Parameters

<MemChanID: INT> The ID of the memory channel to delete.

7.2.3.22 :CHANnel<Ch>:MEMory:DElete:ALL:

CHANnel:MEMory:DElete:ALL

Delete all memory channels.

7.2.3.23 :CONFigure:CHANnel<Ch> <OnOff: BOOL>:

Create the identified channel (ON) or delete it (OFF).

7.2.3.24 :CONFigure:CHANnel<Ch> <OnOff: BOOL>:CATalog?:

Print a list of all channel names and IDs.

7.2.3.25 :CONFigure:CHANnel<Ch> <OnOff: BOOL>:NAME <Name: STRING>:

Associate a new name with the given channel ID.

7.2.3.26 :CONFigure:CHANnel<Ch> <OnOff: BOOL>:NAME <Name: STRING>:ID? <Name: STRING>:

Get the ID of the channel associated with the given name, if any.

7.2.3.27 :CONFigure:CHANnel<Ch> <OnOff: BOOL>:NAME?:

Returns the name associated with the specified channel ID, if any.

7.2.3.28 :CONFigure:DEEmbed:POFFSet <Port: INT> <Offset: DOUBLE>:

Change the port offset for a given port.

7.2.3.29 :CONFigure:DEEmbed:POFFSet? <Port: INT>:

Query the port offset for a given port.

7.2.3.30 :DISPlay:LAYout <LayoutMode: (LINEup | STACK | GRID)>:

Change how diagrams are arranged on the screen.

7.2.3.31 :DISPlay:LAYout <LayoutMode: (LINEup | STACK | GRID)>:GRID <Rows: INT> <Columns: INT>:

Change the size of the layout grid used by GRID mode.

7.2.3.32 :FORMat <Format: (ASCIi | REAL)> [Length: INT]:

Set the format of data output from SCPI's CALCULATE:DATA commands.

7.2.3.33 :FORMat <Format: (ASCIi | REAL)> [Length: INT]:BORDER <Border: (BIG | LITTLE)>:

Set whether big or little endian is used when doing binary data output.

7.2.3.34 :HELP [Command: STRING]:

Get help about SCPI commands

7.2.3.35 :INITiate:

Start sweeping the specified channel

7.2.3.36 :INITiate:ALL:

Start a single sweep in all channels.

7.2.3.37 :INITiate:CONTinuous: <Cont: BOOL>:

Set the continuousness of measurements on this channel.

7.2.3.38 :INITiate:CONTinuous: <Cont: BOOL>:ALL:

Change the continuous measurement setting for all channels at once.

7.2.3.39 :INITiate:CONTInuous: <Cont: BOOL>:ALL?:

Returns true iff at least one channel is set to measure continuously.

7.2.3.40 :INITiate:CONTInuous?:

Query if measurements on this channel will operate continuously.

7.2.3.41 :INSTrument:NSElect:

Change the active channel.

7.2.3.42 :INSTrument:PORT:COUNt?:

Determine how many ports the attached VNA has.

7.2.3.43 :MARKer<M> <Channel: STRING> <SeriesType: (LOGMAG | LINMAG | PHASe | TD | REal | IMag | GD | VSWR | POLARlinear | SMITH)> <SParam: (S11 | S12 | S21 | S22)>:

Create a marker, or move it between channels/plots/sparams.

7.2.3.44 :MARKer<M>:DELETE

Delete a marker.

7.2.3.45 :MARKer<M>:Query <Type: (LOGMAG | LINMAG | PHASe | TD | REal | IMag | GD | VSWR)>:

Extract some interesting value at the point this marker is associated with.

7.2.3.46 :MARKer<M>:READOUT <Type: (LOGMAG | LINMAG | PHASe | TD | REal | IMag | GD | VSWR)> <State: BOOL>:

Configure the readouts shown in the UI for this marker.

7.2.3.47 :MARKer<M>:READOUT:AOFF:

Disable all readouts from this marker in the UI.

7.2.3.48 :MARKer<M>:READOUT? <Type: (LOGMAG | LINMAG | PHASe | TD | REal | IMag | GD | VSWR)> <State: BOOL>:

Query the readouts shown in the UI for this marker.

7.2.3.49 :MARKer<M>:TYPE <Visible: (REFerence | NORmal)>:

Change the type of a marker (reference or normal).

7.2.3.50 :MARKer<M>:TYPE?:

Determine if a marker is a reference marker or not.

7.2.3.51 :MARKer<M>:VISible <Visible: BOOL>:

Temporarily hide or show a marker.

7.2.3.52 :MARKer<M>:VISible?:

Determine if a marker has been hidden.

7.2.3.53 :MARKer<M>:X <X: DOUBLE>:

Set the X-value associated with the marker.

7.2.3.54 :MARKer<M>:X?:

Get the X-value associated with the marker.

7.2.3.55 :SENSe:BANDwidth <Bandwidth: DOUBLE>

SENSe:BANDwidth <Bandwidth: DOUBLE>

Change the bandwidth of the sweep.

Parameters

<Bandwidth: DOUBLE> The new bandwidth.

7.2.3.56 :SENSe:BANDwidth?

Query the bandwidth of the sweep.

7.2.3.57 :SENSe:FREQuency:START <StartFreq: DOUBLE>

Change the start frequency of the sweep.

7.2.3.58 :SENSe:FREQuency:START?

Query the start frequency of the sweep.

7.2.3.59 :SENSe:FREQuency:STOP <StopFreq: DOUBLE>

Change the end frequency of the sweep.

7.2.3.60 :SENSe:FREQuency:STOP?

Query the end frequency of the sweep.

7.2.3.61 :SENSe:LEVel <PowerLevel: DOUBLE>

Change the power level of the sweep.

7.2.3.62 :SENSe:LEVel?

Query the power level of the sweep.

7.2.3.63 :SENSe:SWEep:POINts <PointCount: INT>

Change the point count of the sweep.

7.2.3.64 :SENSe:SWEep:POINts?

Query the point count of the sweep.

7.2.3.65 :SENSe:SWEep:STEP <FreqStep: DOUBLE>

Change the frequency step of the sweep.

7.2.3.66 :SENSe:SWEep:STEP?

Query the frequency step of the sweep.

7.3 Binary data broadcasts (data retrieve only)

Magnitude/angle data updates from the device are broadcast via a custom binary protocol. No programming is required to configure these, so binary data broadcasts provide a simple way for other applications to extract data from the PicoVNA 5 software in real-time.

Data is broadcast by a server accepting connections on TCP port 13375.

The data stream is broadcast in the following format:

```
uint8      format
uint16     numActiveChannels
uint64     sweepStartFrequencyMilliHz
uint64     sweepStopFrequencyMilliHz
uint64     numSweepPoints
uint64     updateFirstSweepIndex
uint64     updateLastSweepIndex
for i in 1..numChannelsActive
    uint8    txPortNumber
    uint8    rxPortNumber
    double   sparamMag[updateLastSweepIndex - updateFirstSweepIndex + 1]
    double   sparamAngle[updateLastSweepIndex - updateFirstSweepIndex + 1]
```

There are no guarantees on the timing of data updates, other than that a data update will certainly be generated at the end of each complete frequency sweep (i.e. there will always be an update when `updateLastSweepIndex = numSweepPoints - 1`). Otherwise, updates are generated roughly every 50 milliseconds.

`updateFirstSweepIndex` and `updateLastSweepIndex` range from 0 to `numSweepPoints - 1`.

All data is sent using little-endian byte order. The magnitude and angle data points are in IEEE-754 double-precision format. Angles are measured in radians.

If a sweep is in progress when a client connects on port 13375, the sweep will be stopped. The sweep may be restarted using the user interface, or via remote control (SCPI). This guarantees that `updateFirstSweepIndex` will be 0 in the first update that any binary data client receives.



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