VNA Control 5 Users' Manual

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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 VNA Control 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 VNA Control 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

VNA Control 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 VNA Control 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
   ```

VNA Control 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.

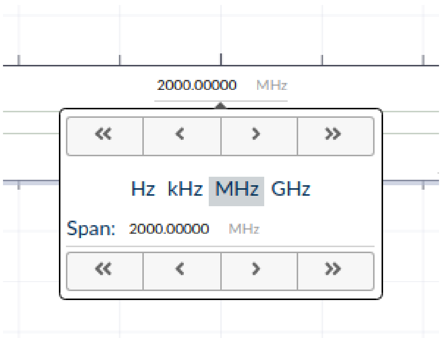


Figure 2.1: Measurement span controls.

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.

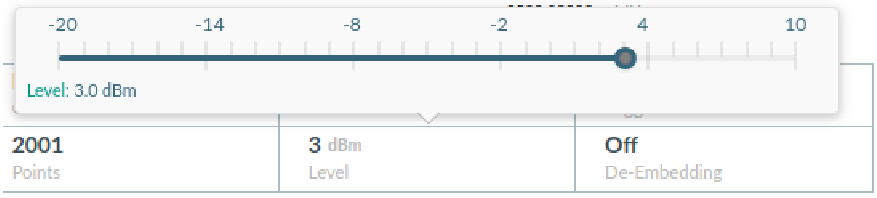


Figure 2.2: Setting the test signal level, via the popup located below the main display.

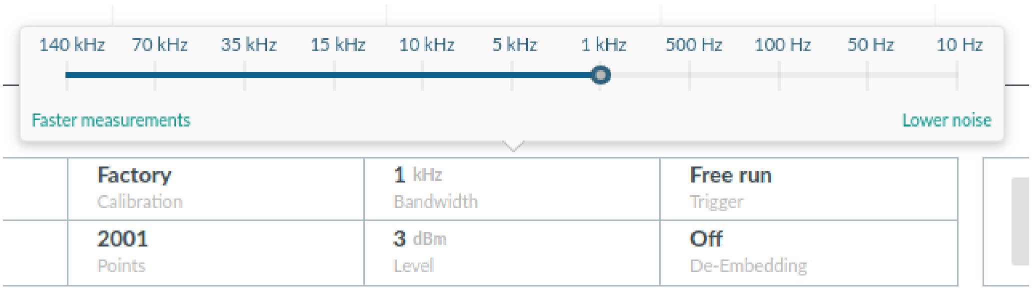


Figure 2.3: Setting the receiver bandwidth, via the popup located below the main display.

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.

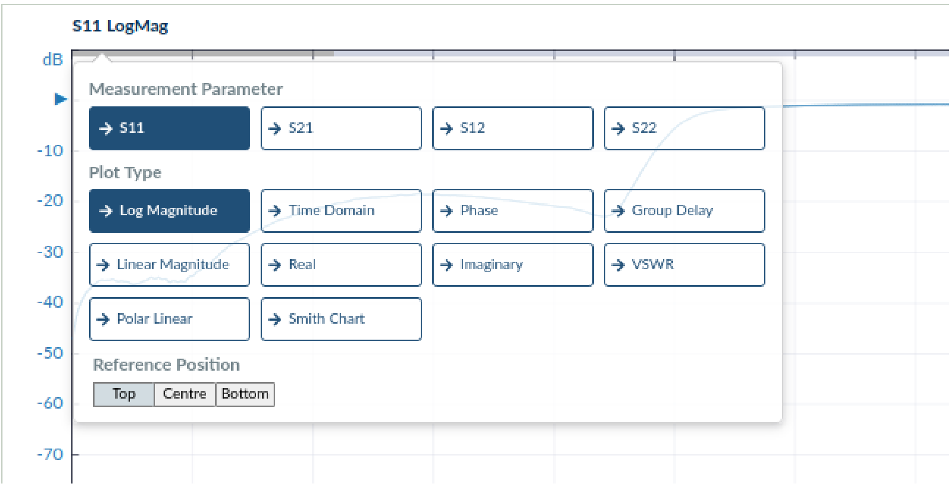


Figure 2.4: The axis options pop-up context menu, for configuring the measurement parameter and plot type of that axis.

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 VNA Control 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	$\leq$ 118 dB	$\leq$ 124 dB
Frequency resolution	$\leq$ 10 Hz	$\leq$ 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 the necessary

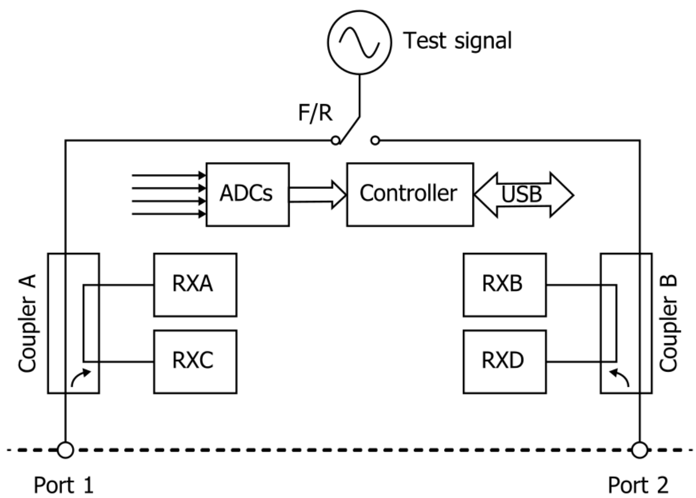


Figure 3.1: Simplified block diagram of the PicoVNA units.

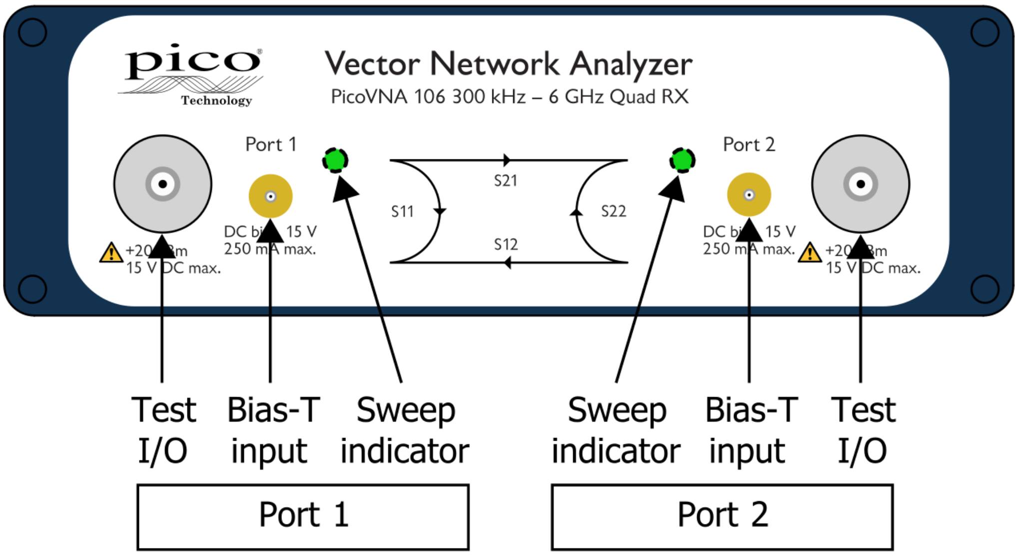


Figure 3.2: Front panel of the PicoVNA 106 (PicoVNA 108 is similar).

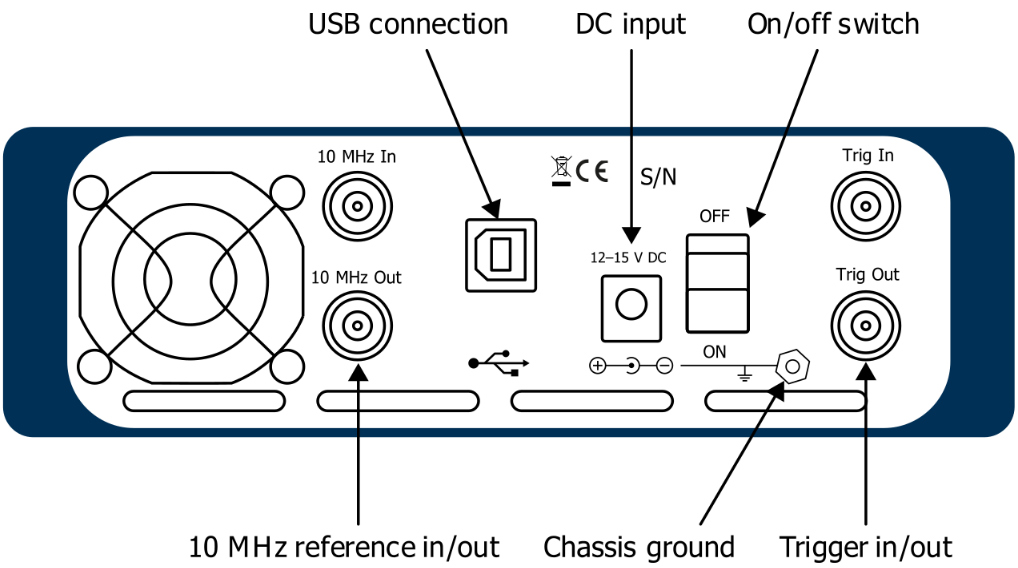


Figure 3.3: Back panel of the PicoVNA 106 (PicoVNA 108 is similar).

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

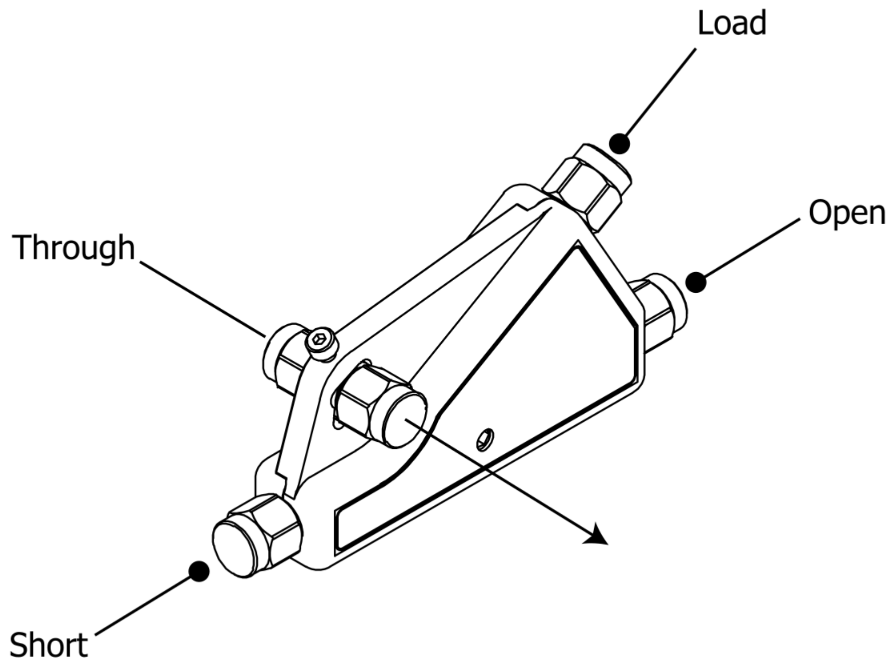


Figure 3.4: SOLT-STD-M/F and SOLT-PREM-M/F manual calibration standards.

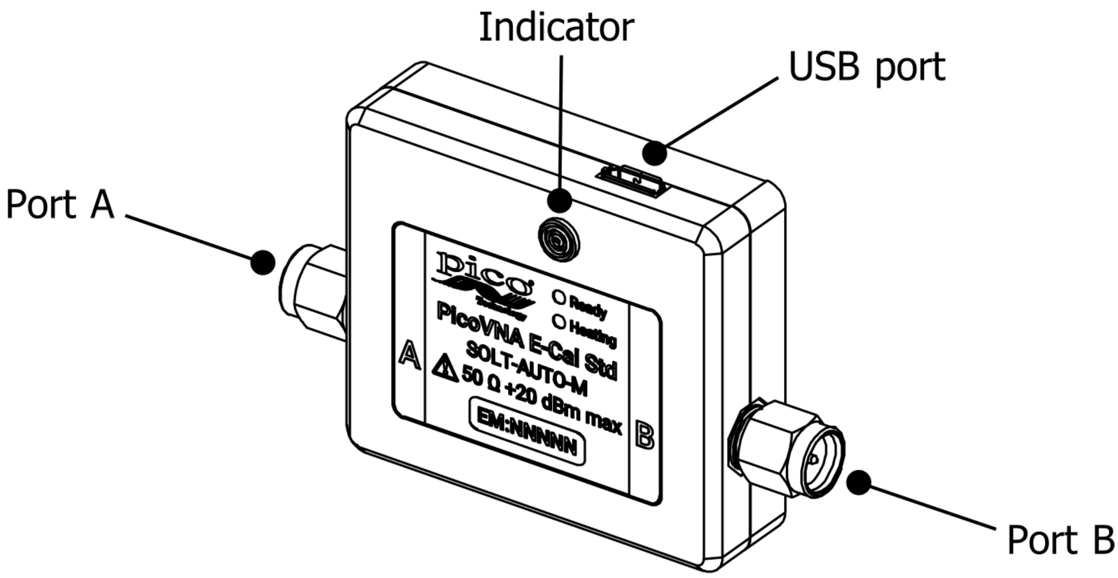


Figure 3.5: SOLT-AUTO-M/F automatic (E-Cal) calibration standards.

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

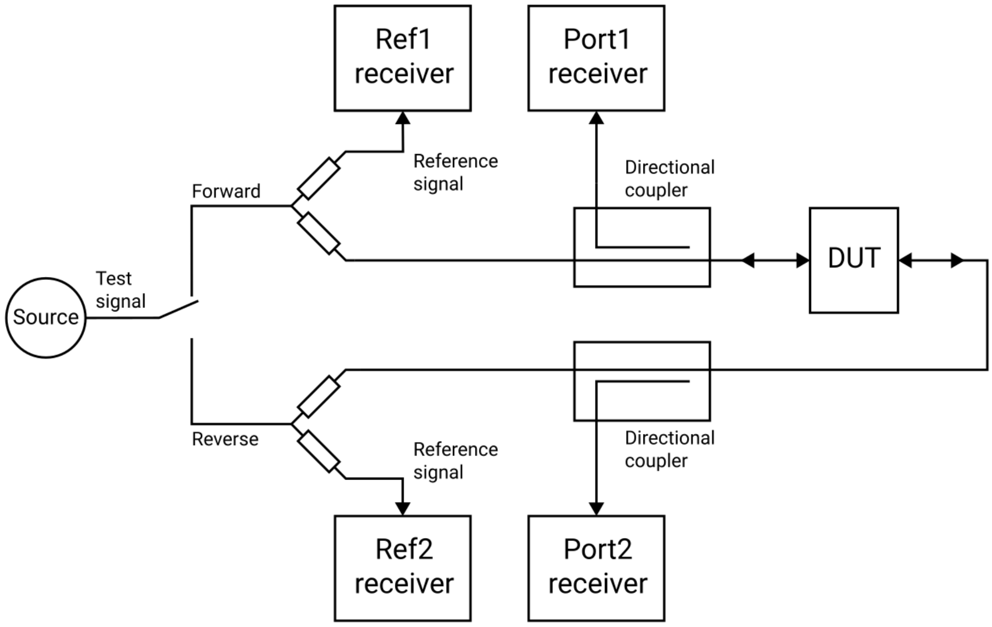


Figure 3.6: Simplified block diagram of the measurement system, showing the VNA and its connection to the DUT.

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.

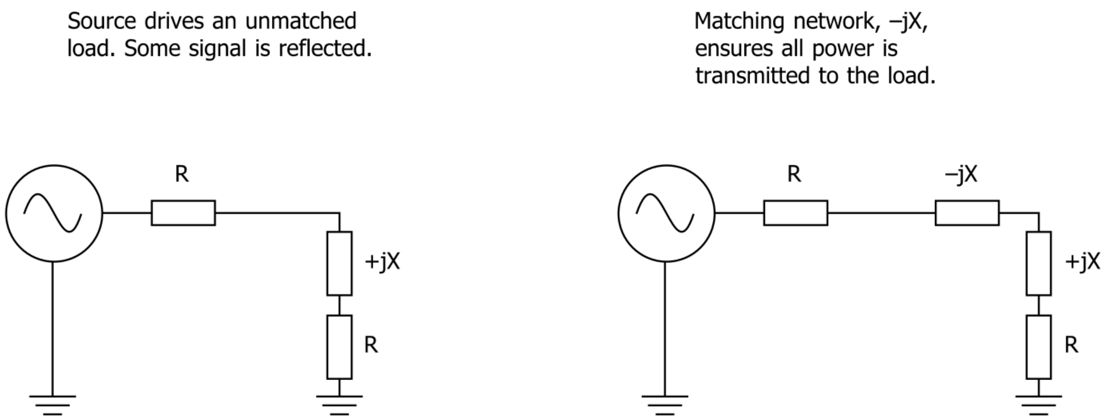


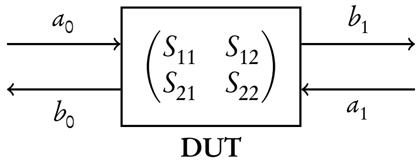
Figure 3.7: Matching a load for maximum power transfer.

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:

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

a_i, b_i and S_{ij} are functions of frequency ($\mathbb{R} \to \mathbb{C}$), 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.

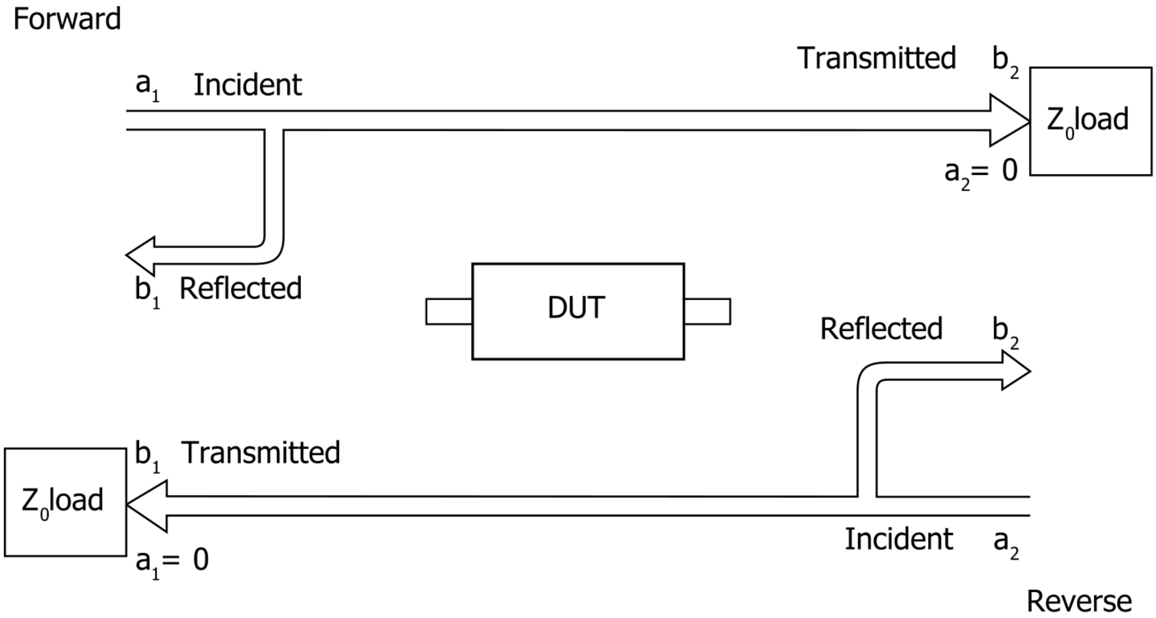


Figure 3.8: Definitions of the a and b waves considered when defining S-parameters.

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.

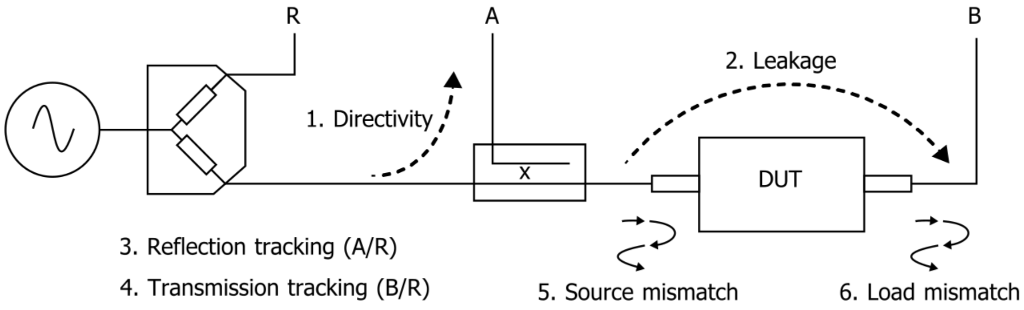


Figure 3.9: Six key sources of errors in the forward measurement. Another six sources exist in the reverse measurement (not shown).

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, $g(\omega)$, is defined as the rate of change of phase, ϕ with frequency, ω:

$$g(\omega) = \frac{\mathrm{d}\phi(\omega)}{\mathrm{d}\omega} \tag{3.2}$$

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 VNA instruments compute group delay at at frequency $\omega(N)$ (with measurement point index N) using the *backwards difference* numerical approximation to the derivative in Equation 3.2:

$$g(\omega(N)) = \frac{\phi(\omega(N)) - \phi(\omega(N-A))}{\omega(N) - \omega(N-A)}, \tag{3.3}$$

where A is the *group delay aperture*. The default value for aperture is 1 point; different values can be set via the *Enhancement* sidebar.

Setting a larger aperture will reduce the effect of noise in a group delay measurement. Likewise, it is usual to apply some degree of trace smoothing to remove very rapidly changing perturbations from group delay traces. However, care should be exercised to ensure that detail in phase linearity is not lost and genuine sharp group delay variations are not masked.

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 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.

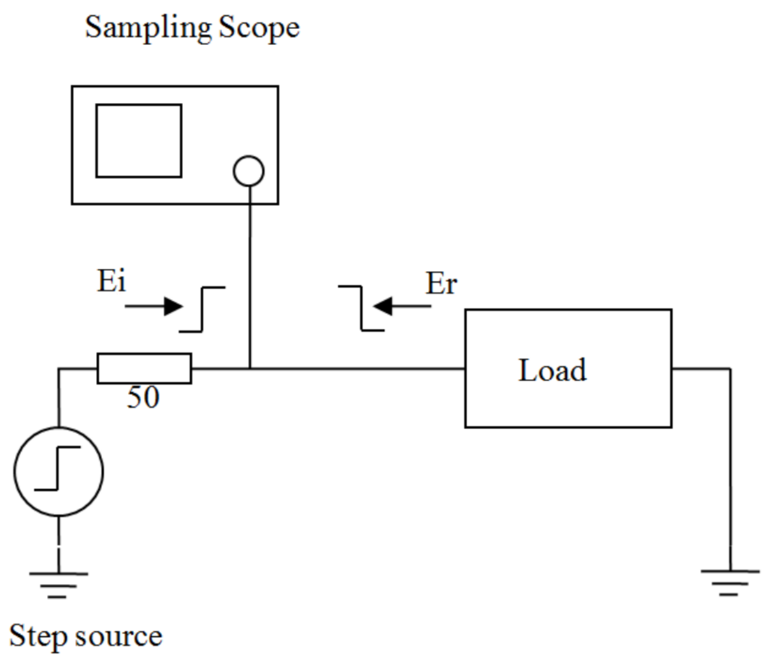


Figure 3.10: Traditional TDR setup

3.7.1.1 Example: shorted 50 ohm transmission line

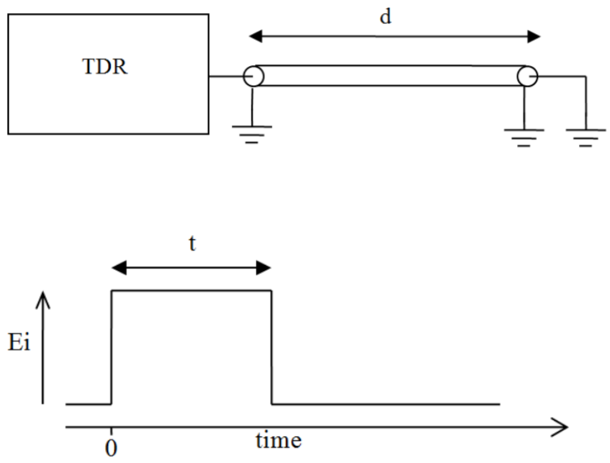


Figure 3.11: Simplified representation of the response of a shorted line

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

$$d = \frac{t}{2}v \tag{3.4}$$

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

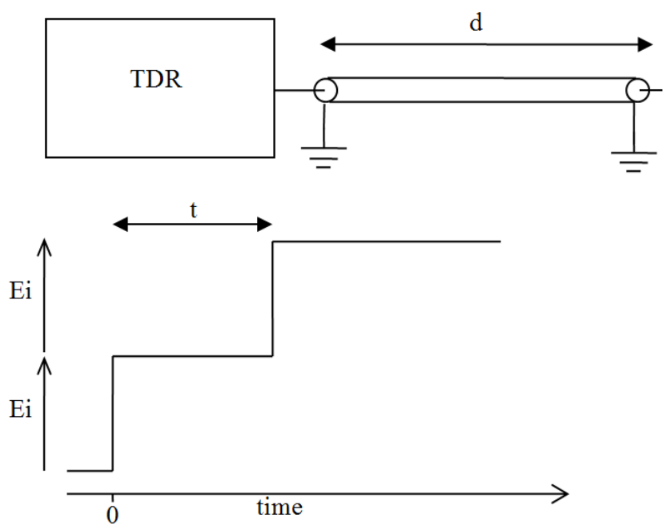


Figure 3.12: Simplified representation of the response of an open line

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

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

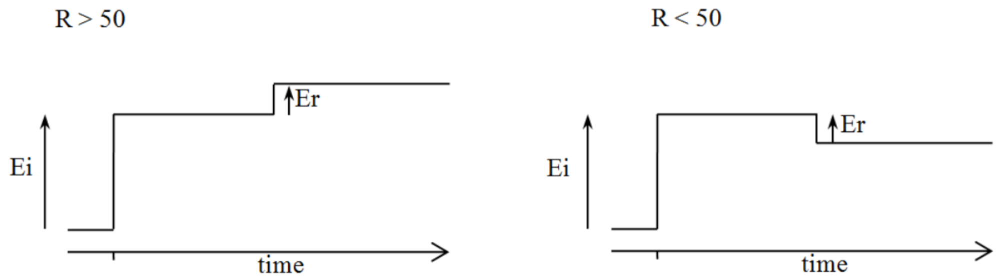


Figure 3.13: Simplified representation of the response of a resistively terminated line

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.

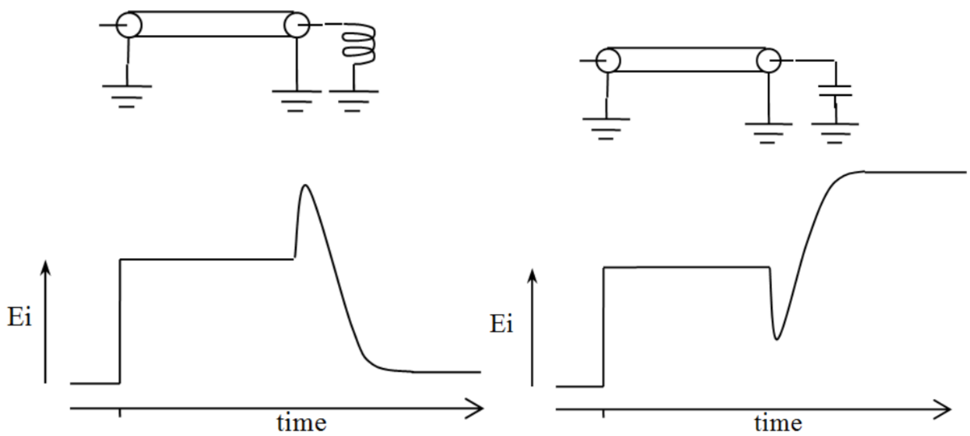


Figure 3.14: Simplified representation of the response of a reactively terminated line

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.

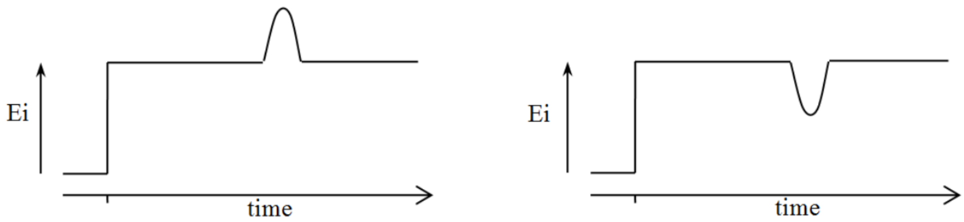


Figure 3.15: Simplified representation of the response of a line discontinuity

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 VNA Control 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 Ω, 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

$$R = \frac{N-1}{f_H - f_L} \tag{3.5}$$

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

The resolution is given by

$$\Delta t = \frac{1}{2f_H} \tag{3.6}$$

In bandpass mode, the resolution is half that given by Equation 3.6.

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 lowpass 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 VNA Control 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 VNA Control 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 VNA Control 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.

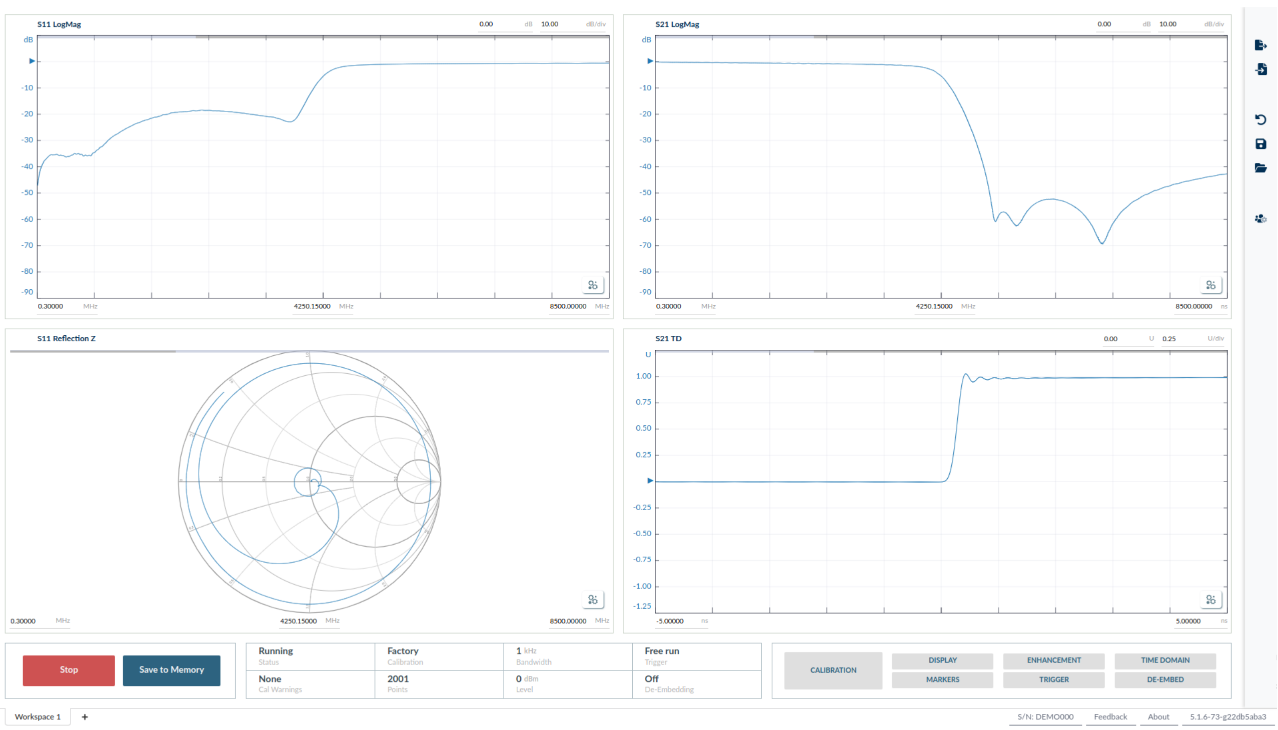


Figure 4.1: The VNA Control 5 software main window.

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.

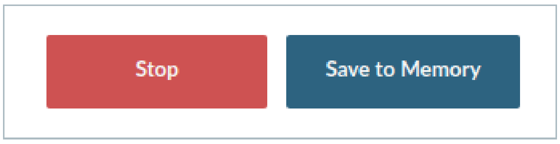


Figure 4.2: The start/stop button, and save to memory button.

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.

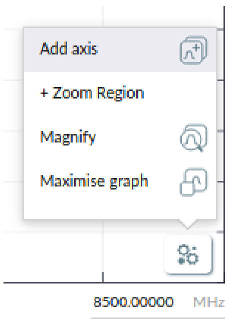


Figure 4.4: The button to add a second axis to a plot, in the lower right corner of the plot.

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.

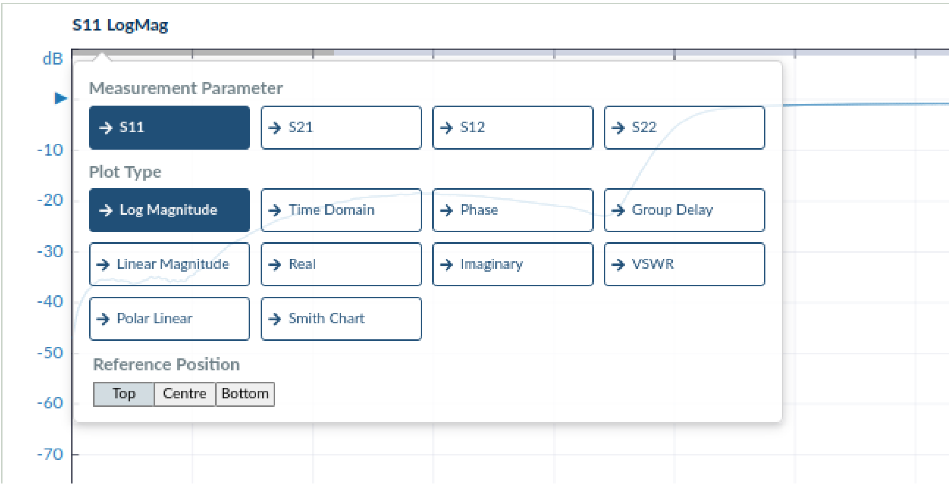


Figure 4.5: The axis options pop-up context menu, for configuring the measurement parameter and plot type of that axis.

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 VNA Control 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 VNA Control 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.

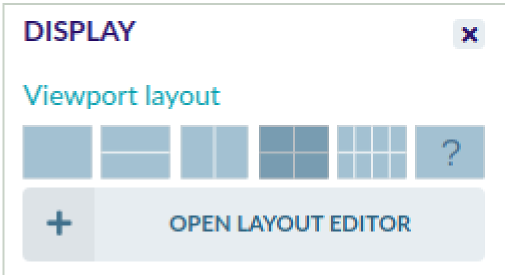


Figure 4.8: Options in the Display sidebar for configuration plot layout

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.

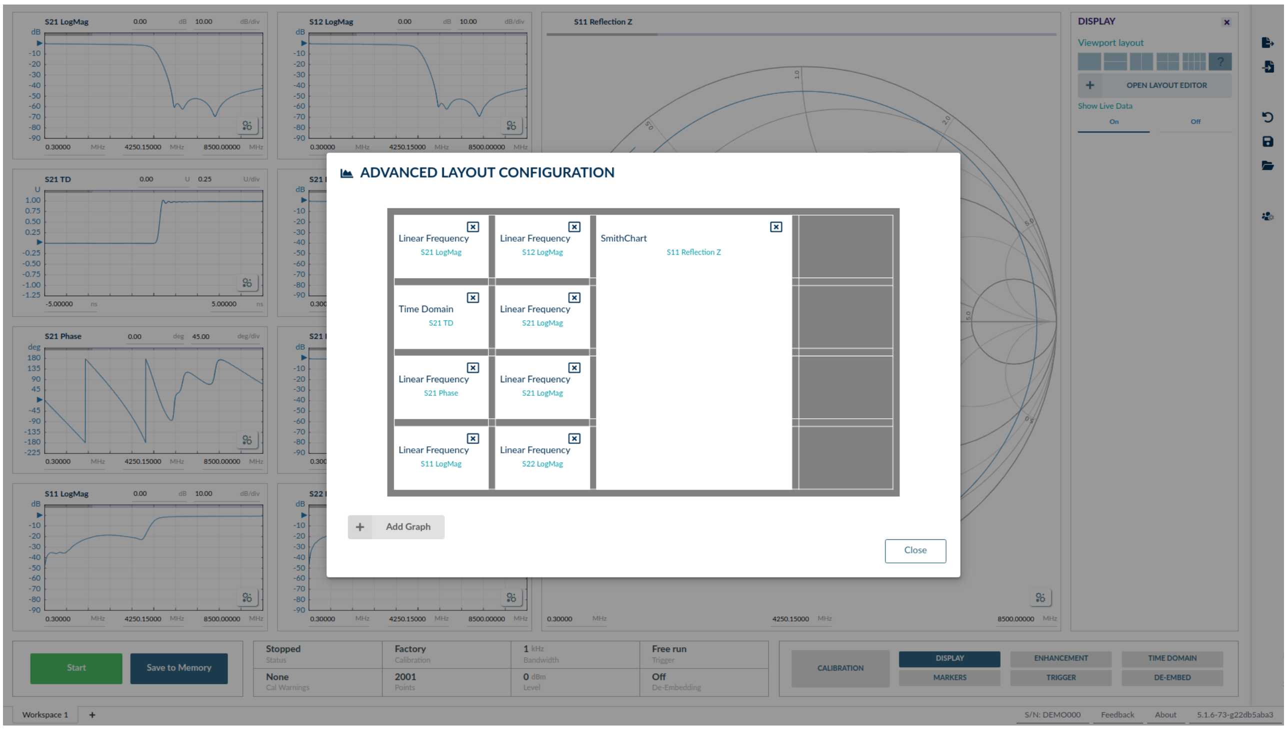


Figure 4.9: The advanced layout editor

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.

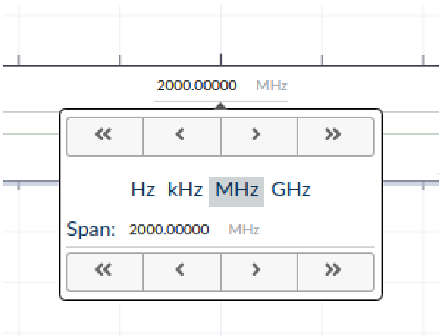


Figure 4.10: Measurement span controls.

4.4 Memory

VNA Control 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.

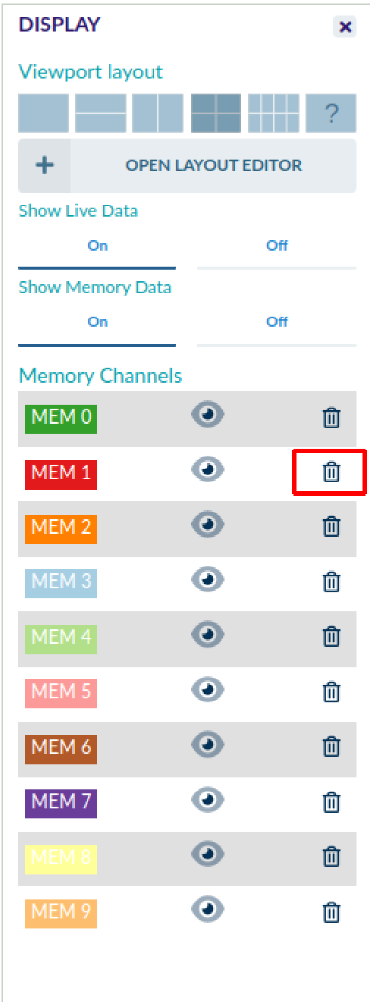


Figure 4.11: Deleting a memory trace

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.

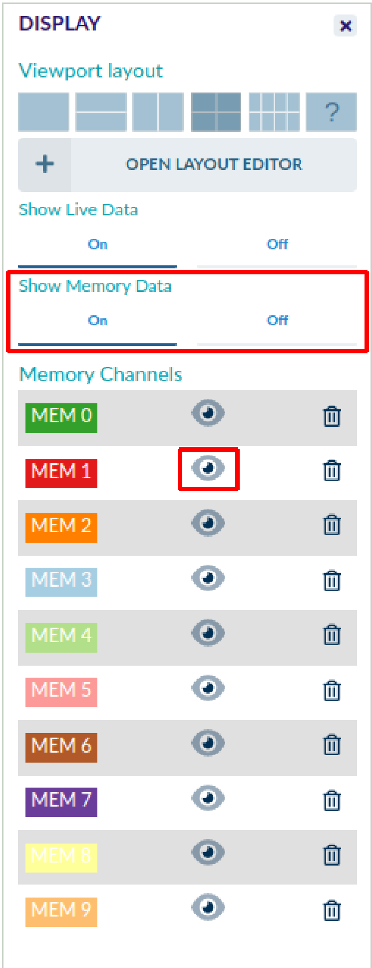


Figure 4.12: Memory trace global visibility controls

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.

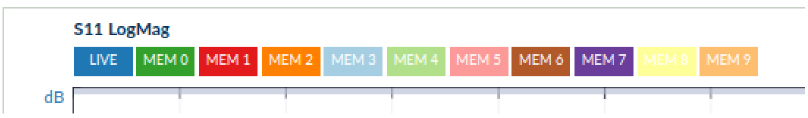


Figure 4.13: Per-plot memory trace visibility controls

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. The Import Data modal (shown in Figure 4.14), is opened via the Workspace sidebar (click on the button labelled "Workspace" towards the lower right of the screen). 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.

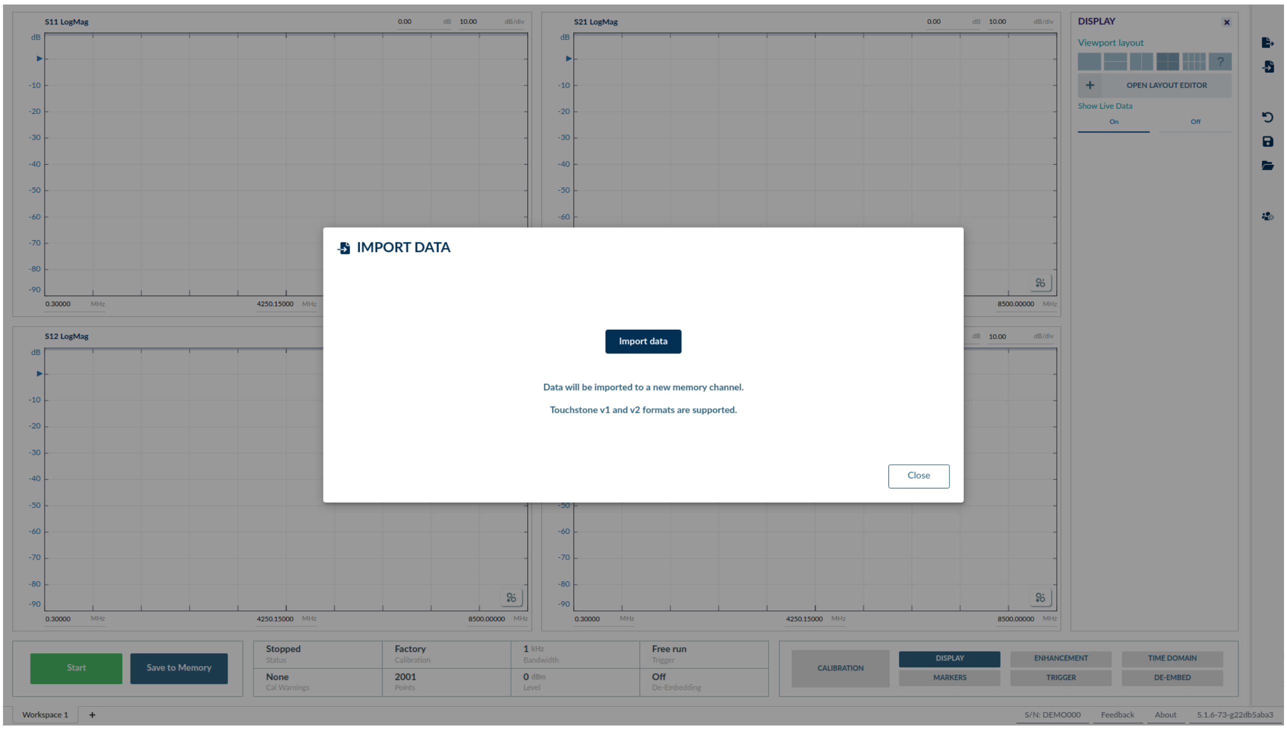


Figure 4.14: Per-plot memory trace visibility controls

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.

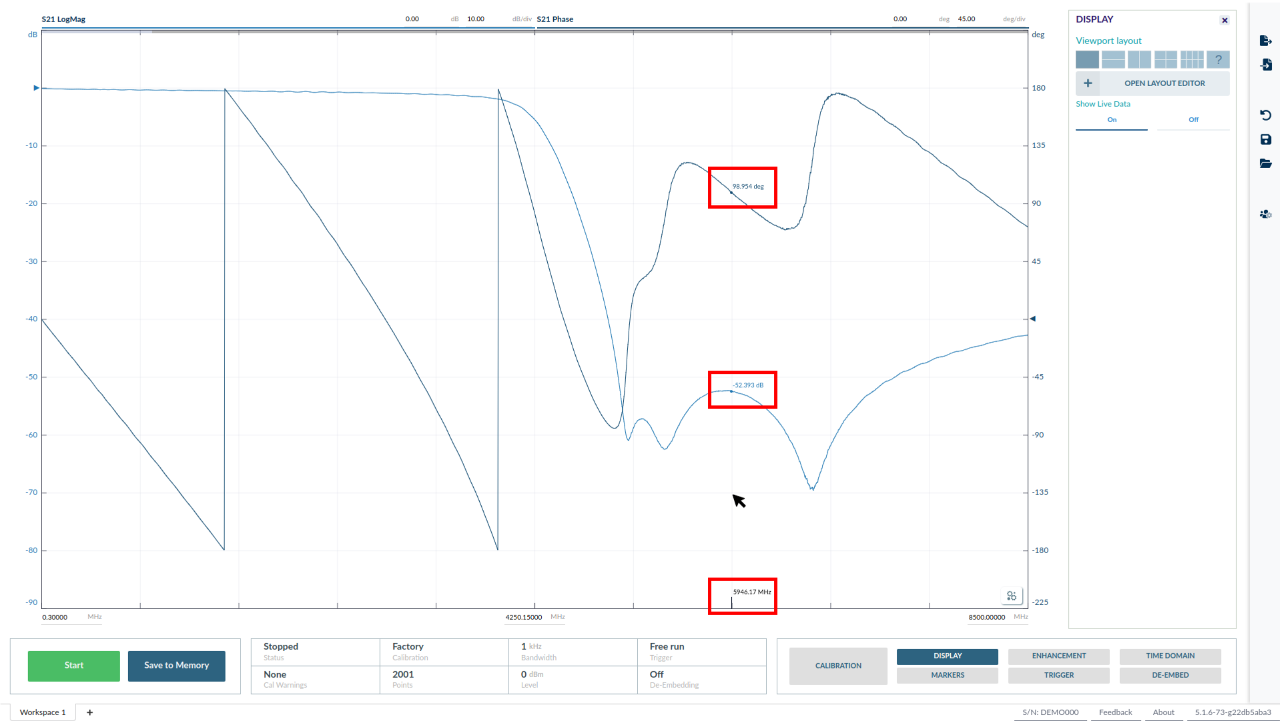


Figure 4.15: Hovering the mouse cursor over a trace yields an on-plot readout at the frequency or time associated with the current mouse cursor position.

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.

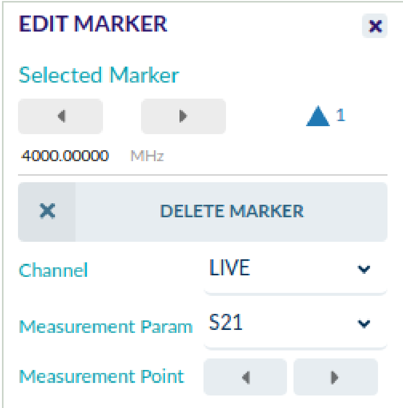


Figure 4.16: Use the markers sidebar to edit marker settings.

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.

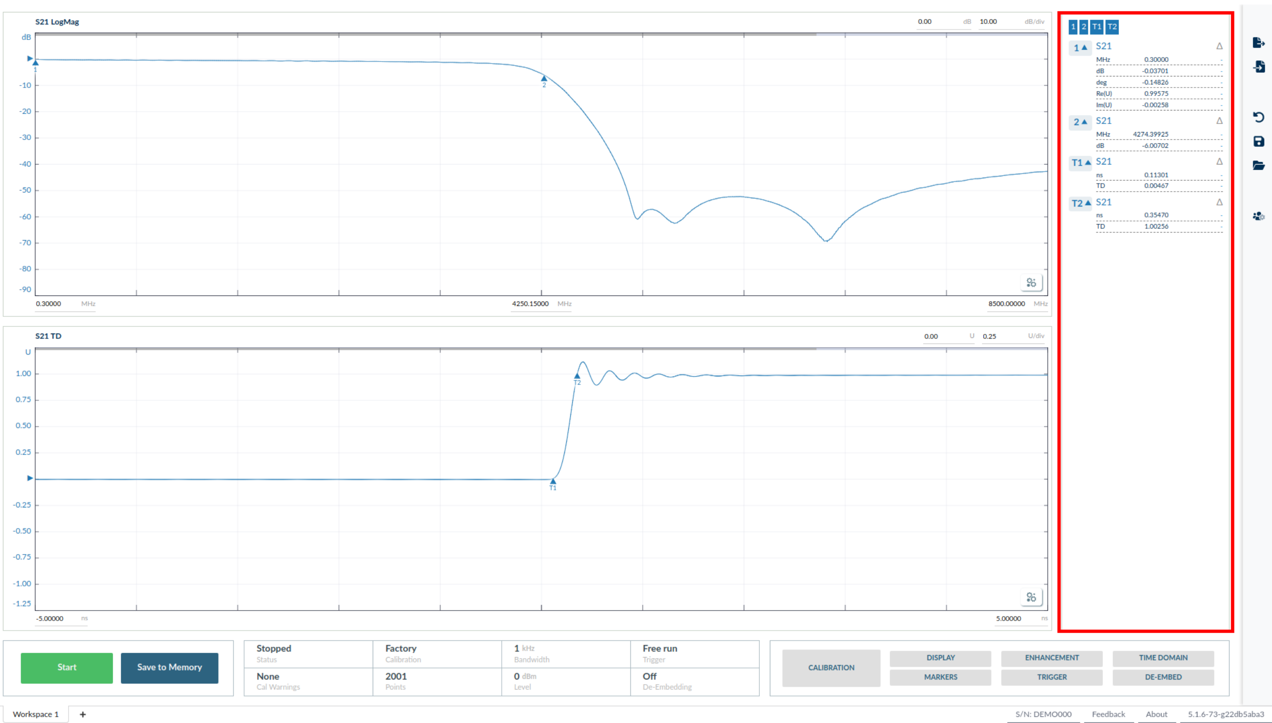


Figure 4.17: Highlights the marker readouts panel, here showing a selection of frequency domain and time domain marker readouts.

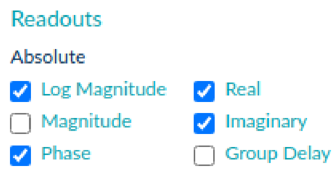


Figure 4.18: Select which readouts appear for a given marker. A marker will be visible on any trace type for which it has a readout enabled.

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.

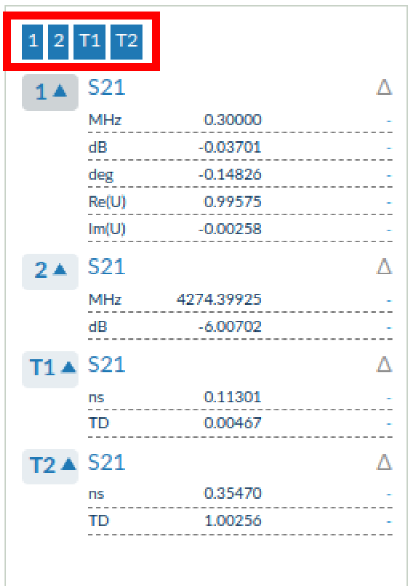


Figure 4.19: Reduce clutter by using the marker filter controls.

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.

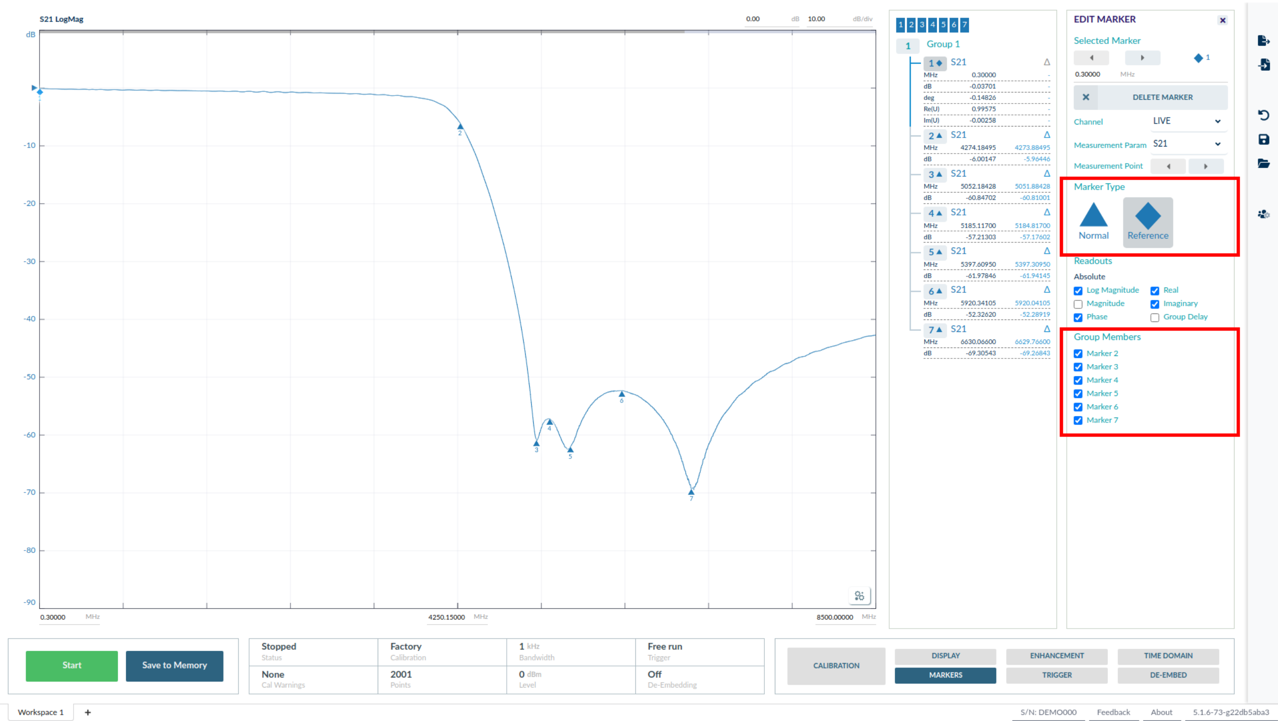


Figure 4.20: A marker group, with the controls for converting a marker to a reference marker and adding other markers to the associated group highlighted.

An unlimited number of marker groups can be created in the VNA Control 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 VNA Control 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.

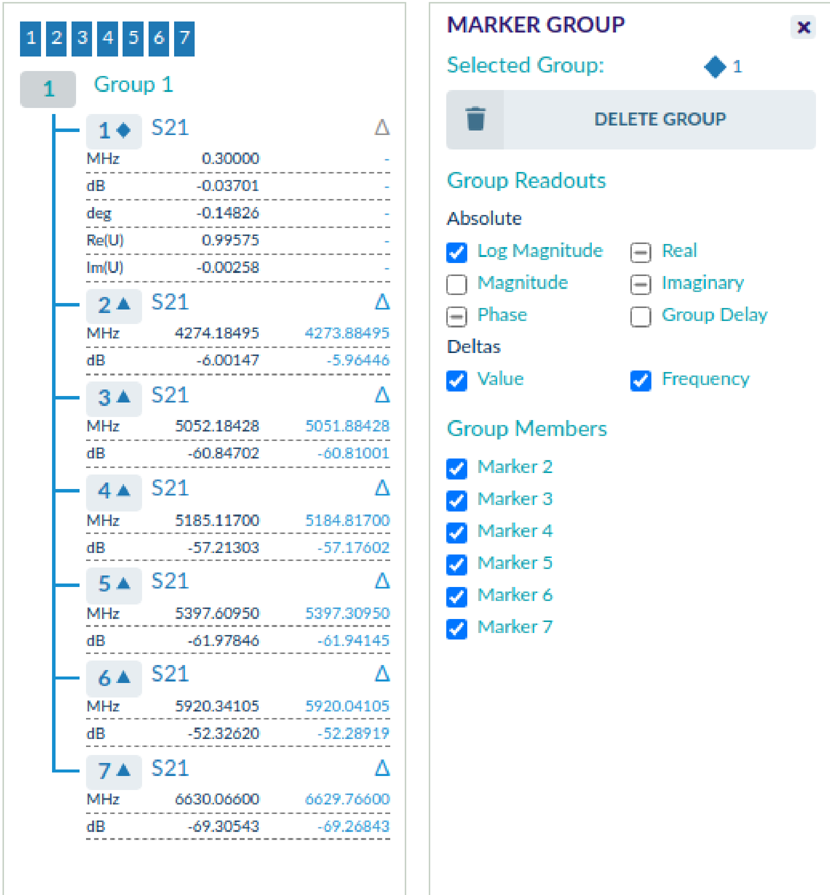


Figure 4.21: Additional controls for marker groups, accessed by selecting the marker group in the readouts panel.

4.5.6 Tracking markers

Markers can be configured to search for peaks or other features within a trace. If the positions of the features move from one measurement sweep to the next, tracking markers will automatically update their x-positions when the new data is acquired to follow the feature being tracked. Tracking can be turned on or off for individual markers at any time; when tracking is turned off, the marker will stay at a constant x-position.

Markers can track any of the following features:

1. *Global Maximum*. The largest value within the trace.
2. *Global Minimum*. The smallest value within the trace.
3. *nth Local Maximum*. Counting peaks from left-to-right, the nth peak within the trace. The size of peaks that are counted is determined by the hysteresis parameter.
4. *nth Local Minimum*. Counting from left-to-right, the nth trough within the within the trace. The size of the local minima that are counted is determined by the hysteresis parameter.
5. *nth Local Extremum*. Counting from left-to-right, the nth peak or trough within the trace. The size of the local maxima or minima that are counted is determined by the hysteresis parameter.
6. *nth* $-x$ *dB point*. Only available for LogMag traces. Counting from left-to-right, the nth point whose y-axis value is equal to the global maxinum of the trace minus x dB.

7. *nth +x dB point*. Only available for LogMag traces. Counting from left-to-right, the nth point whose y-axis value is equal to the global minimum of the trace plus x dB.

Features can be tracked on any trace type unless otherwise specified above.

Tracking must be configured for each marker individually. Select the marker and then use the control in the markers sidebar (shown in Figure 4.22) to configure tracking.

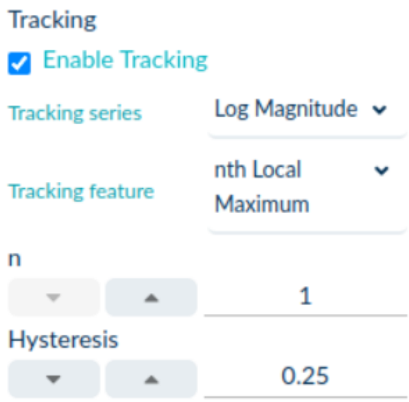


Figure 4.22: Control to turn tracking on/off and configure the feature to be tracked.

Tracking can be enabled on both *normal markers* and *reference markers*. Enabling tracking on a reference marker allows a group reference to track a feature (for example a global maximum); the reference marker position and delta readouts within the group will update automatically as new data is acquired.

Note that there is no requirement to enable a readout for the tracking series type. For example, phase could be determined at the minimum value of VSWR by tracking the VSWR series type on a marker with only a phase readout.

4.5.6.1 Example: peak search

Figure 4.23 shows an example of how several peaks and troughs can be automatically found within a trace.

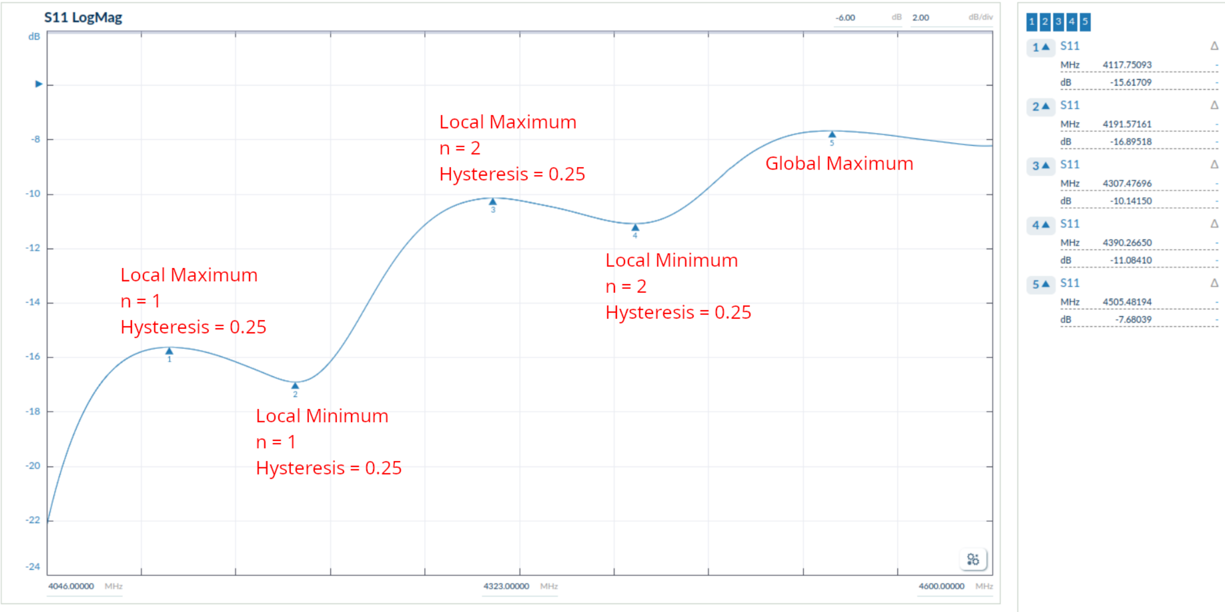


Figure 4.23: Tracking several minima and maxima within a single trace.

4.5.6.2 Example: Measuring the bandwidth of a low-pass filter

Figure 4.24 shows how the bandwidth of a low-pass filter can be measured using tracking markers. Note that the Marker 1 is tracking a y-value relative to the trace maximum and so the absolute value of the readout is not exactly −6 dB.

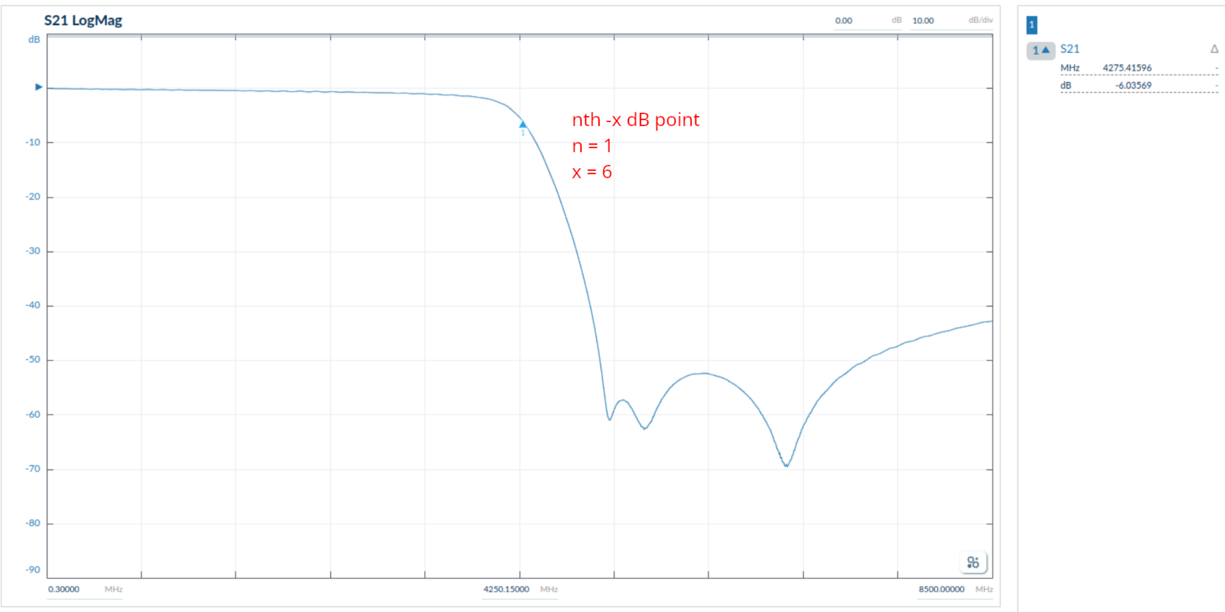


Figure 4.24: Using tracking markers to measure the bandwidth of a band-pass filter.

4.5.6.3 Example: Measuring the bandwidth and insertion loss of a band-pass filter

Figure 4.25 shows how the bandwidth of a band-pass filter can be measured using tracking markers. The bandwidth (44.5 MHz) can be determined from the delta marker readout in Group 2.

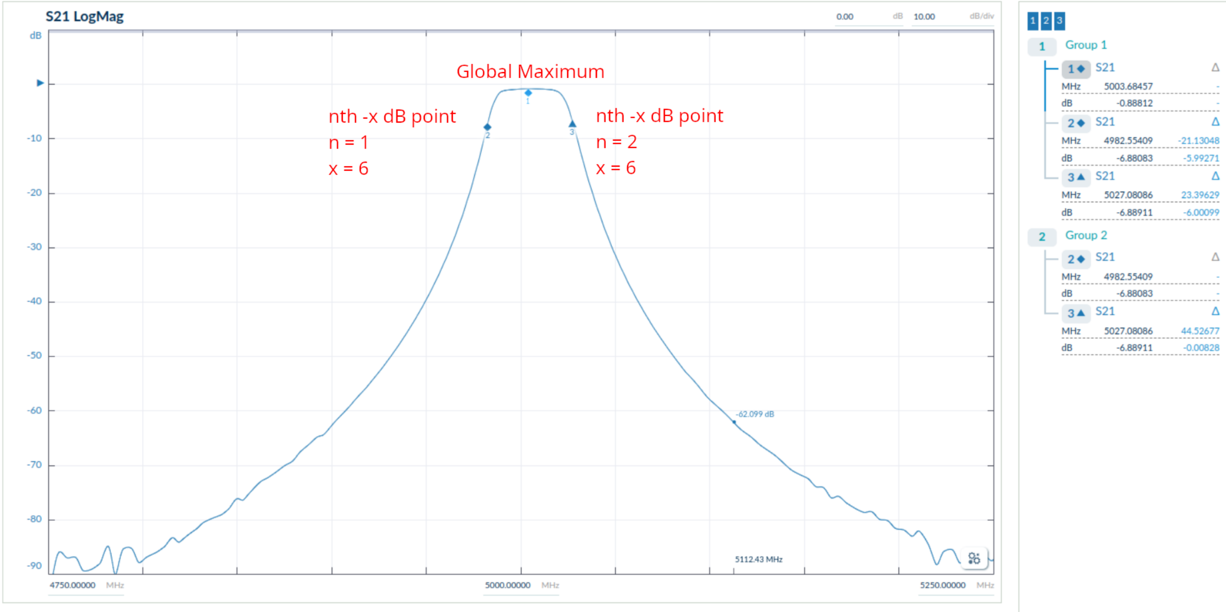


Figure 4.25: Using tracking markers to measure the bandwidth of a low-pass filter.

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
- Extra synthesiser settling time

4.6.1 Extra synthesiser settling time

In the VNA, the source and receiver are locked in both phase and frequency and sweep together through a set of frequency points. The purpose of the VNA is to measure the steady-state response of the DUT at each frequency point. For an accurate measurement of the steady-state response, the transient response must have ended at the time the measurement is made.

For most DUTs, waiting for the standard synthesiser settling time is sufficient to ensure that the steady-state response is measured. However, if the DUT is electrically long or has a high Q, it may be necessary to wait for a longer amount of time at each frequency point before performing the measurement.

The Additional Synthesiser Settling Time is the amount of extra time to wait for the DUT to settle into its steady-state response at each frequency point before performing the measurement. When measuring electrically long or high Q DUTs, the best way to set the additional synthesiser settling time is to increase it from zero until the measurement results do not change.

The minimum value of the additional synthesiser settling time parameter is 0 ms, and the maximum is 255 ms. The default value is 0 ms, which is appropriate for most DUTs.

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 4.26. +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.

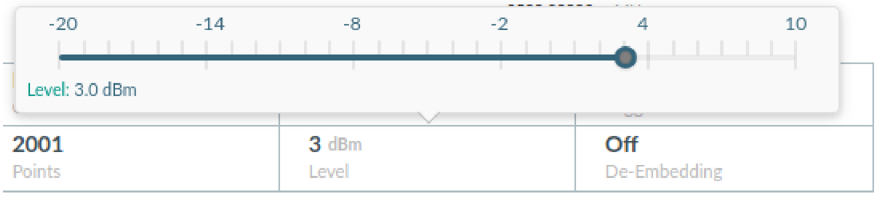


Figure 4.26: Setting the test signal level, via the popup located below the main display.

4.7.2 Receiver measurement bandwidth

The receiver bandwidth is set using the popup control shown in Figure 4.27. 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 measuremesnts over a dynamic range more than 90 dB, use a 500 Hz or less bandwidth setting during calibration.

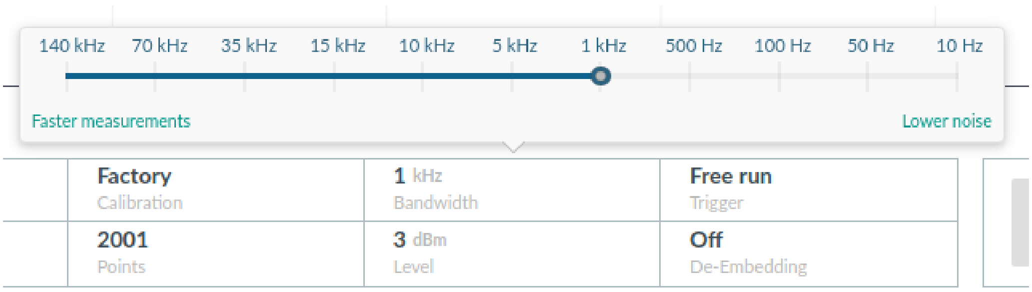


Figure 4.27: Setting the receiver bandwidth, via the popup located below the main display.

4.8 User preferences

The user preferences are accessed from the “Workspace” sidebar (click on the button labelled “Workspace” towards the lower right of the screen).

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.
- *Theme*. Select whether the application should use Light or Dark theme.

4.8.2 Data preferences and interpolation options

VNA Control 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 VNA Control 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 VNA Control 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 4.28.

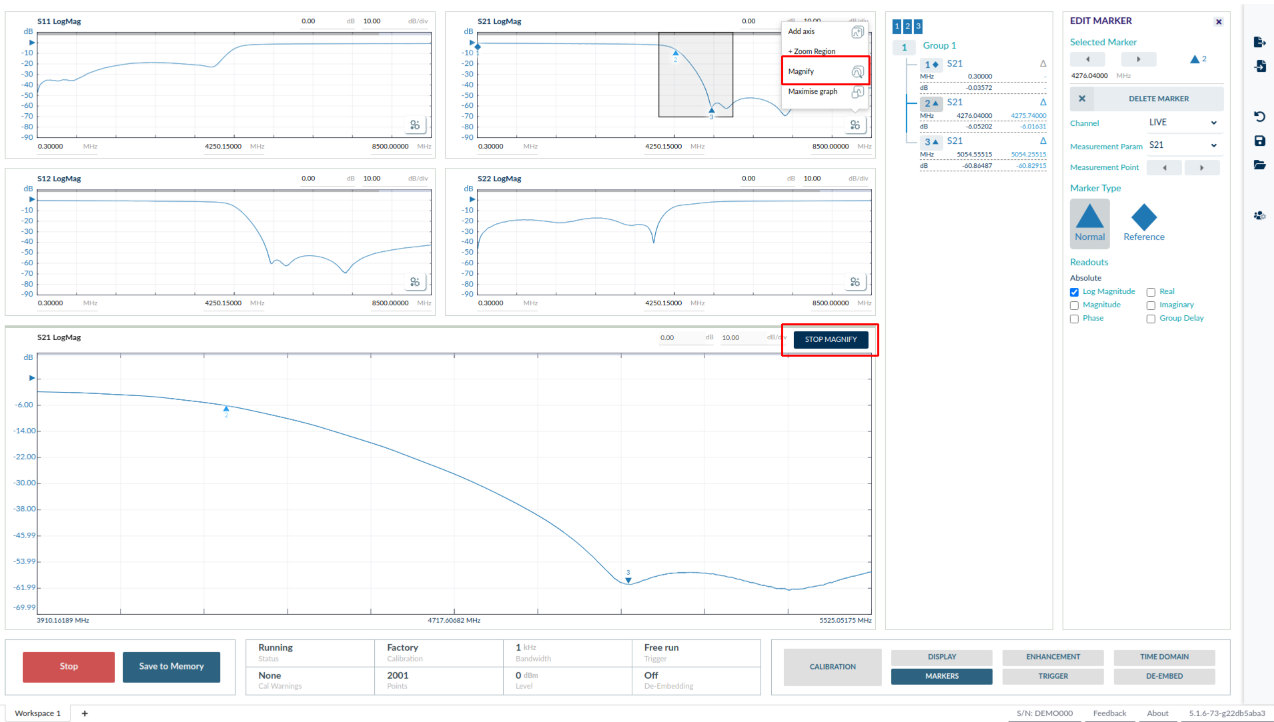


Figure 4.28: Highlights the controls for starting and stopping the magnify feature.

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 4.29.
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 4.30.
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 4.31.

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 4.32 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.

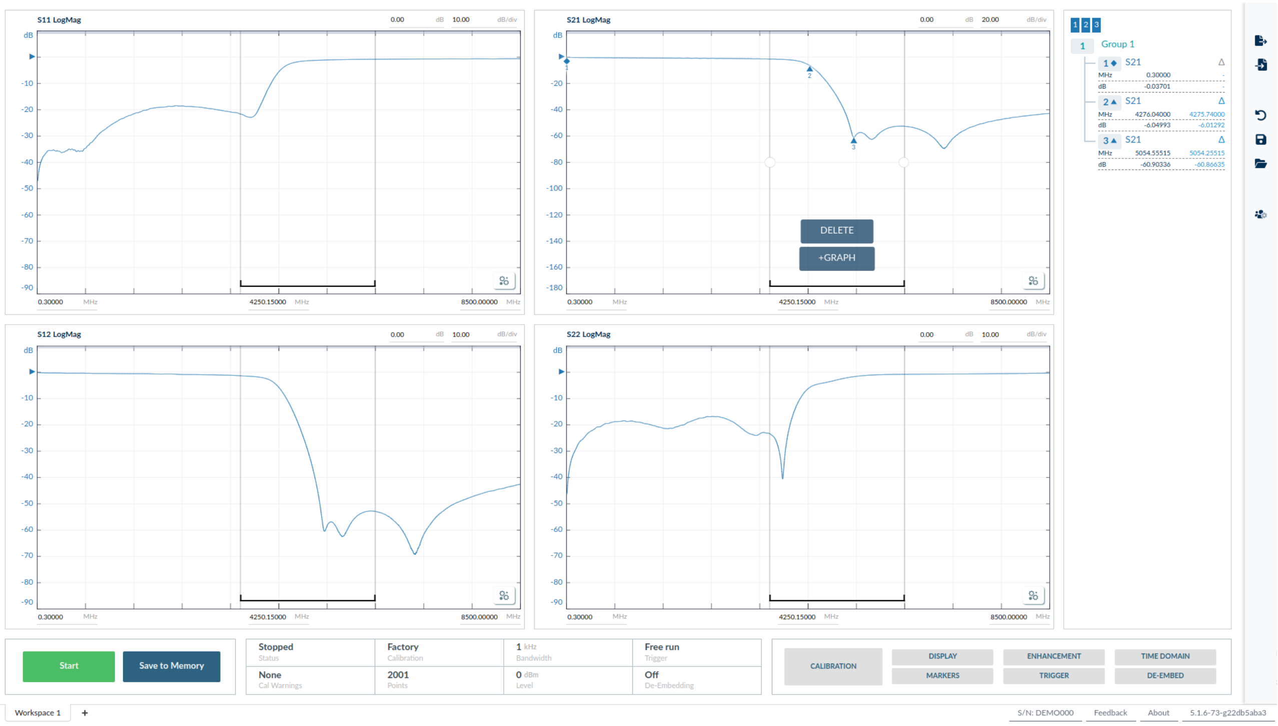


Figure 4.29: The span region is selected on the top right plot, and controls appear to either delete the selected region, or create a new plot to show the contents of that region.

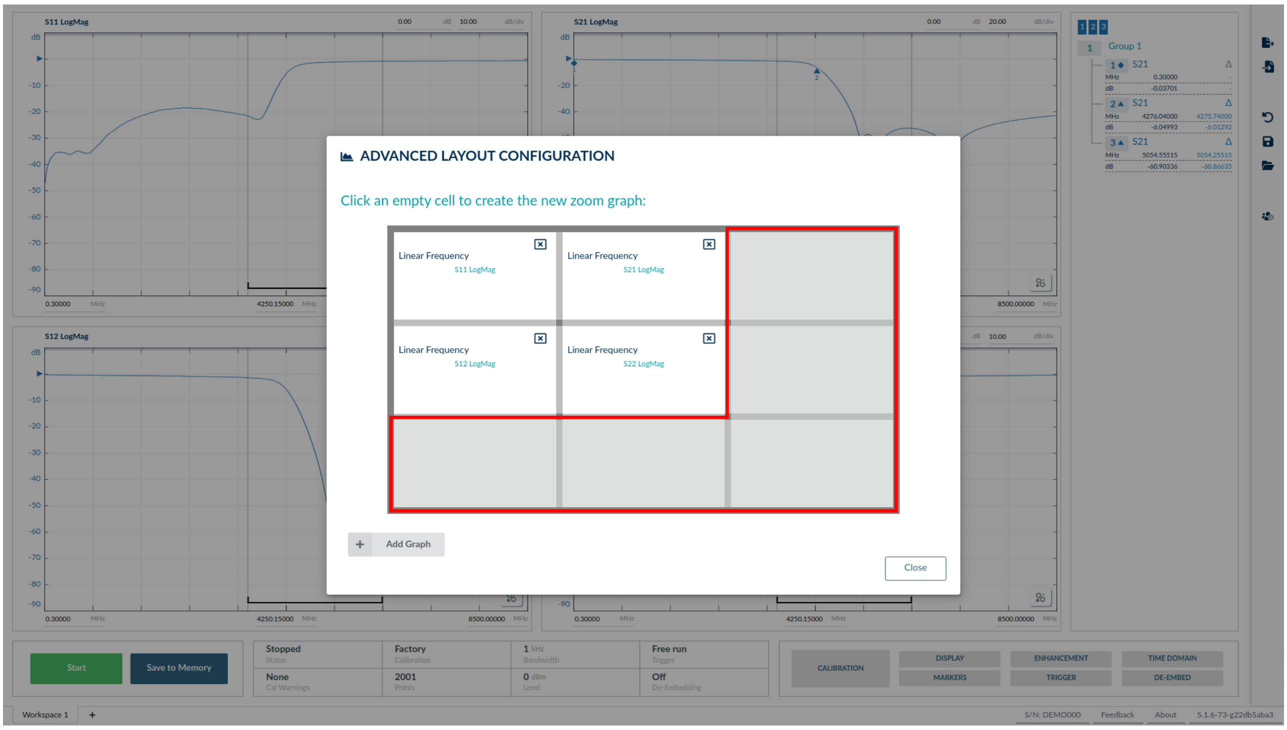


Figure 4.30: A new graph can be created in any of the available display slots (highlighted).

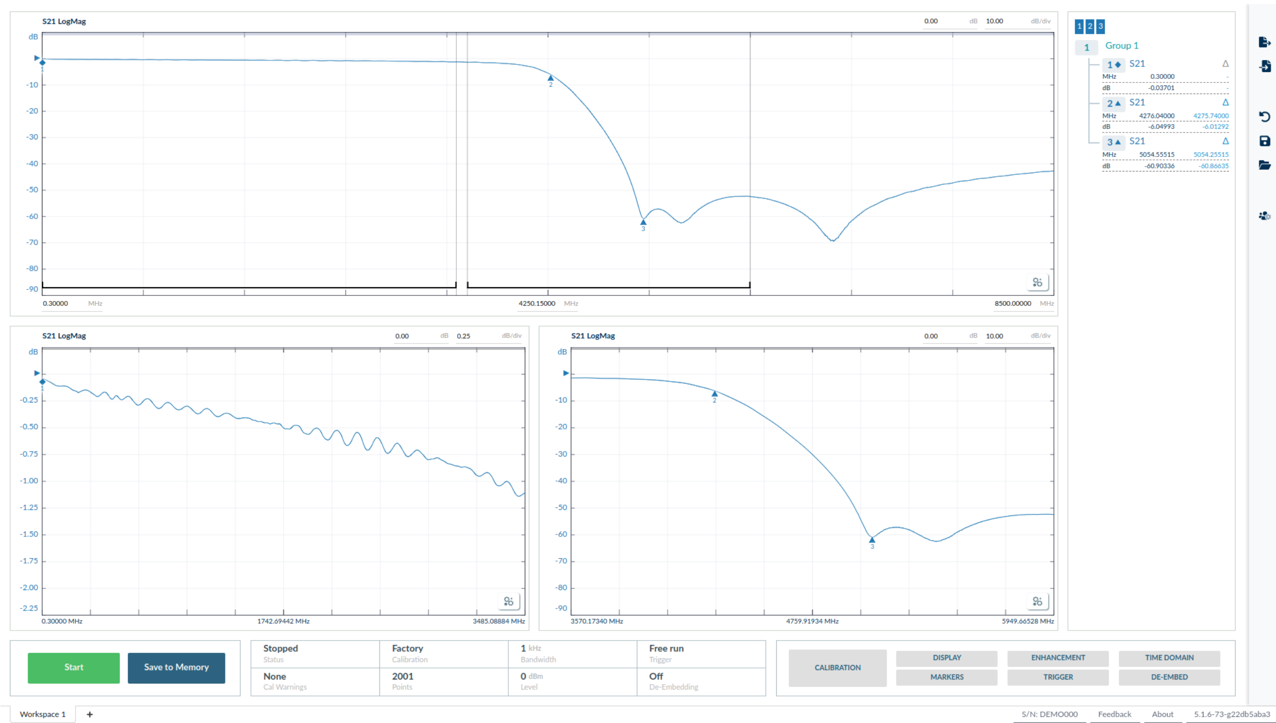


Figure 4.31: Two created span regions, showing both the pass band and transition band of a low-pass filter. The sensitivity has been adjusted in the lower left plot to inspect pass-band ripple.

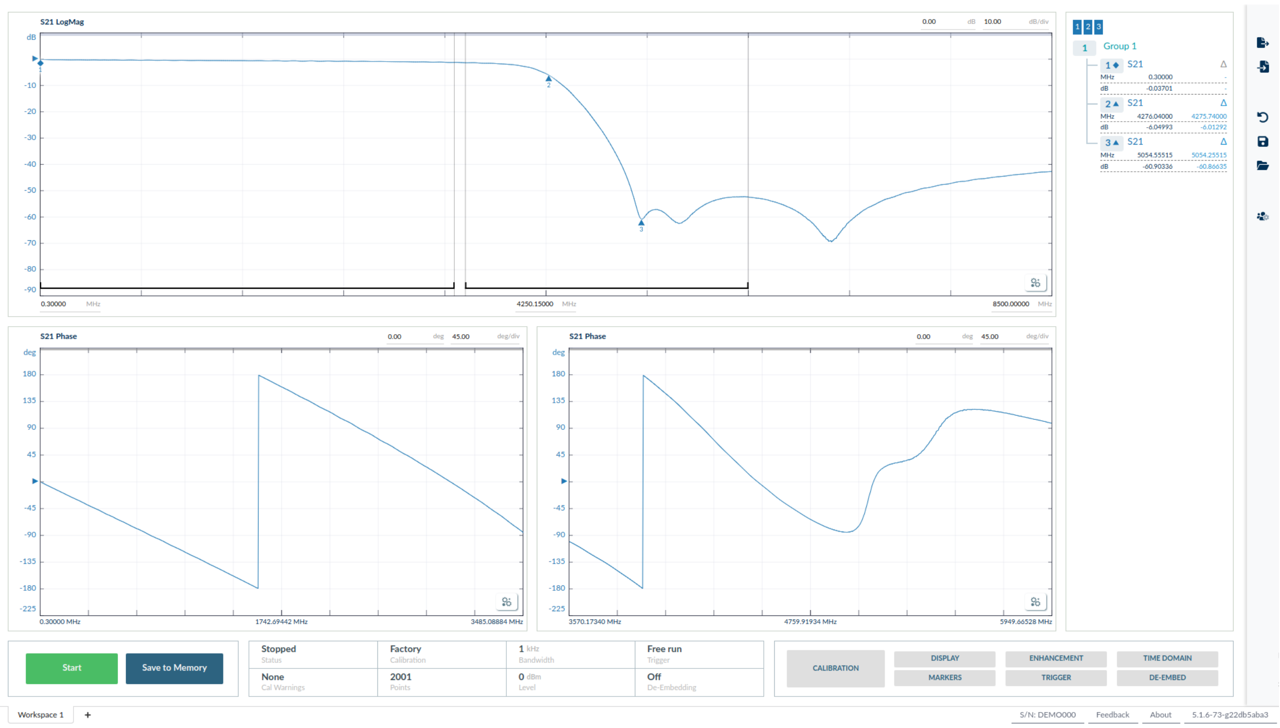


Figure 4.32: The plot type of the lower graphs can be changed to inspect the phase to be inspected in each of the span regions.

4.10 Workspaces

The VNA Control 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 4.33. 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.

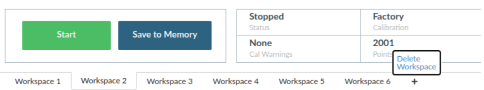


Figure 4.33: The tabbed workspace menu enables creating, switching and deleting workspaces.

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. From the *Workspace* sidebar (opened by clicking on the button labelled "Workspace" towards the lower right of the screen) 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, open the "Workspace" menu (click on the button labelled "Workspace" towards the lower right of the screen) and select "Save Session".

To load a previously saved session, open the "Workspace" menu (click on the button labelled "Workspace" towards the lower right of the screen) 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 4.34. It is also possible to choose whether to overwrite the current workspace, or recall the file to a new workspace.

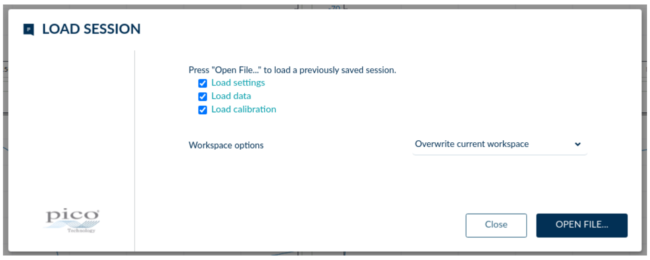


Figure 4.34: Options available when recalling a saved session.

4.11 Exporting measurement data

Measurement data can be exported to human- and machine-readable formats for processing in other software. The controls for exporting data are found in the "Workspace" sidebar (click on the button labelled "Workspace" towards the lower right of the screen).

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.

TIP!	Within a session, the settings used when exporting a file will be remembered ready for the next file export. *String interpolation* (Section 4.11.4) is a useful tool for automatically creating unique filenames when exporting data files repeatedly.

4.11.1 Touchstone

From the "Workspace" sidebar, 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.

4.11.4 String interpolation in exported filenames

String interpolation can be used to automatically insert the date/time or a sequence number into filenames. It can be useful when repeatedly exporting data from the application.

The `{` and `}` characters are used to denote the start and end of an expression that should be embedded into a filename. Exactly one expression to embed should be present between each `{` and `}` character; for example use `{Y}{m}` rather than `{Ym}` to insert the year then month.

Figure 4.35 shows an example of how the date and time can be automatically inserted into a filename.

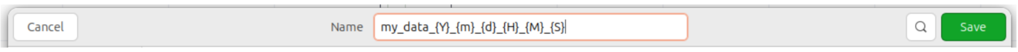


Figure 4.35: Using string interpolation to embed the date and time automatically within a filename.

String interpolation is only available via the user interface. It is not available when using remote control via SCPI.

The full list of supported embeddings are:

- `{SEQNUM}` A number that automatically increments after each file is exported. The number can be set to a specific value for a particular file export via the user interface. The number will be printed with a minimum of four digits; for example, two leading zeros would be prepended to "99".
- `{Y}` A 4-digit representation of the current year. *Example:* 2025.
- `{y}` A 2-digit representation of the current year. *Example:* 25 for 2025.
- `{m}` A 2-digit numeric representation of the current month. *Example:* 05 for May.
- `{B}` A long string representation of the current month. *Example:* October.
- `{b}` A short string representation of the current month. *Example:* Oct for October.
- `{d}` A 2-digit numeric representation of the current day in the month. *Example:* 09.
- `{H}` A 2-digit numeric representation of the current hour in the day (local time), in 24-hour format.
- `{M}` A 2-digit numeric representation of the current minute in the hour (local time).
- `{S}` A 2-digit numeric representation of the current second in the minute (local time).
- `{DEFAULT_DTM}` Prints the date and time in the default format.
  Equivalent to: `{Y}_{m}_{d}_{H}_{M}_{S}`.

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 kΩ.

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 4.36. *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.

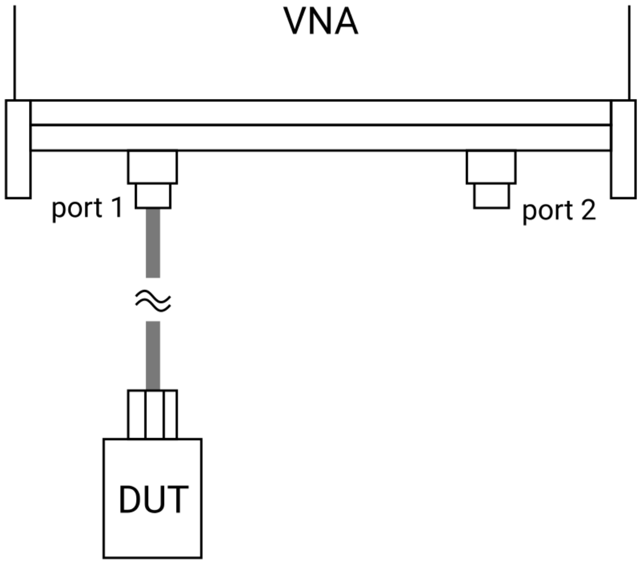


Figure 4.36: Connect the DUT to port 1 to carry out S11 measurements.

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 4.37.

For best results, the arrangement shown on the right hand side of Figure 4.37 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.

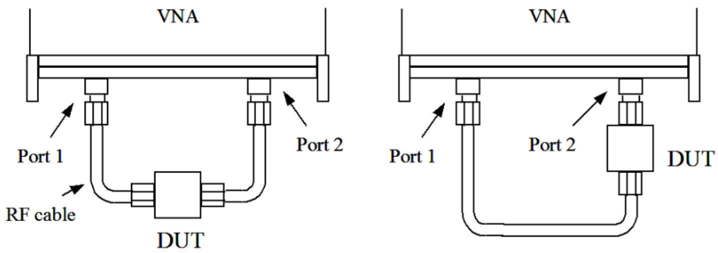


Figure 4.37: Connect the DUT between Ports 1 and 2 to carry out S21 measurements. For best results use the arrangement shown on the right.

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 4.37 is likely to yield best results in terms of repeatbility 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 4.38. 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 VNA Control 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 disussed 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.

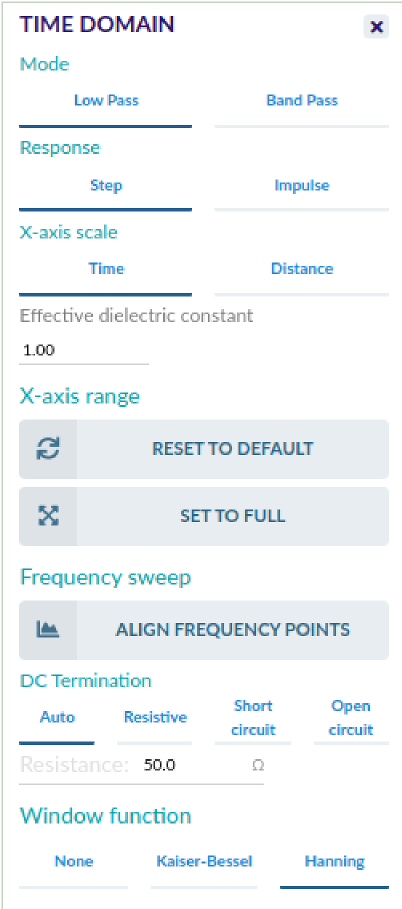


Figure 4.38: Time domain measurements can be configured using the time domain sidebar.

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 VNA Control 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 VNA Control 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.

S_{11} 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.

S_{11} and S_{21} calibration

Combines a 3-term S_{11} calibration with a normalisation measurement for S_{21}. S_{21} accuracy will be lower than when using the 12-term or 8-term calibrations, but calibration and measurements will be faster since the VNA only measures S-parameters in the forward direction.

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

E-Calibration uses a separate USB-controlled LA19-17-01 EasyCal moduleto avoid a requirement to manually connect and disconnect a number of different standards during calibration. E-Calibration options exist to support measurements of all S-parameters using 8-term error correction, or only S_{11}, or S_{11} and S_{21}.

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 from step 4 onwards.

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

5.2.1 Step 1: selection the required S-parameters

First open the Calibration sidebar and select “New Calibration”. Then select the S-parameters that you wish to measure using the new calibration. Selecting the required S-parameters at this step means that the software will only ask you to choose from suitable calibration types in stage 2.

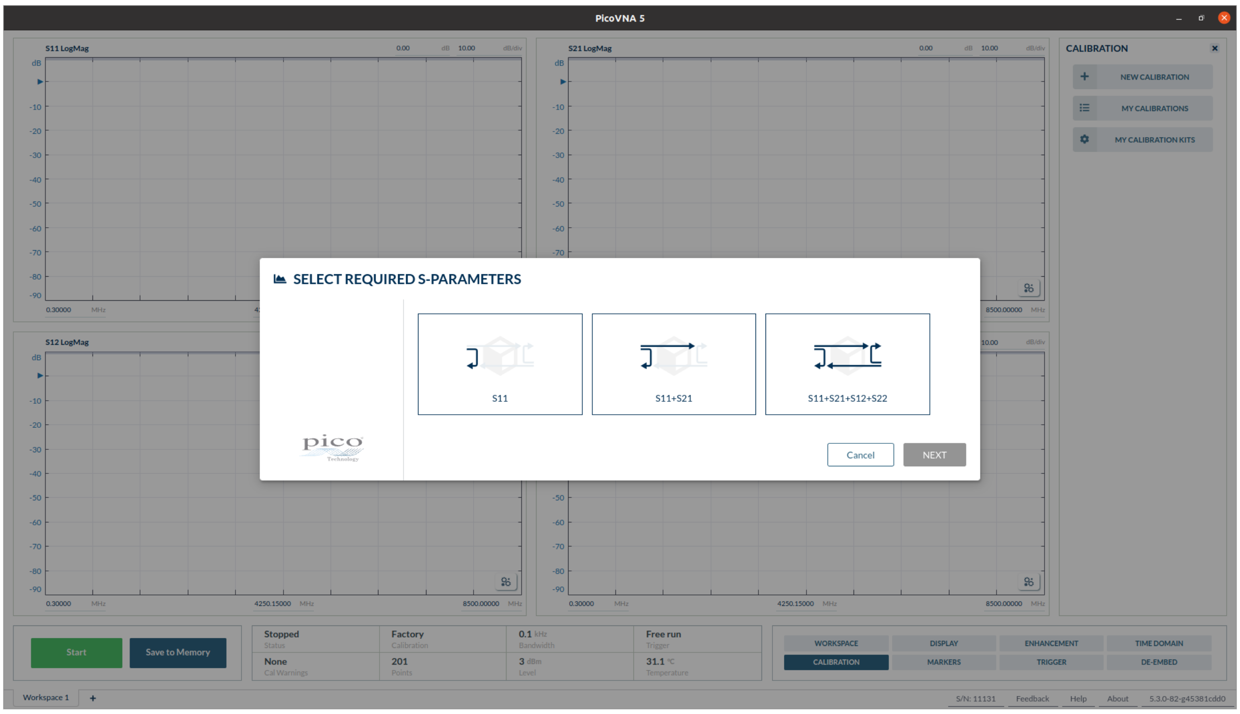


Figure 5.1: The first step when starting a new calibration: select the S-parameters that you wish to measure with the new calibration.

5.2.2 Step 2: select the calibration type

Next, select the desired calibration type from the drop-down menu (or choose an E-Calibration) and then press “Next”.

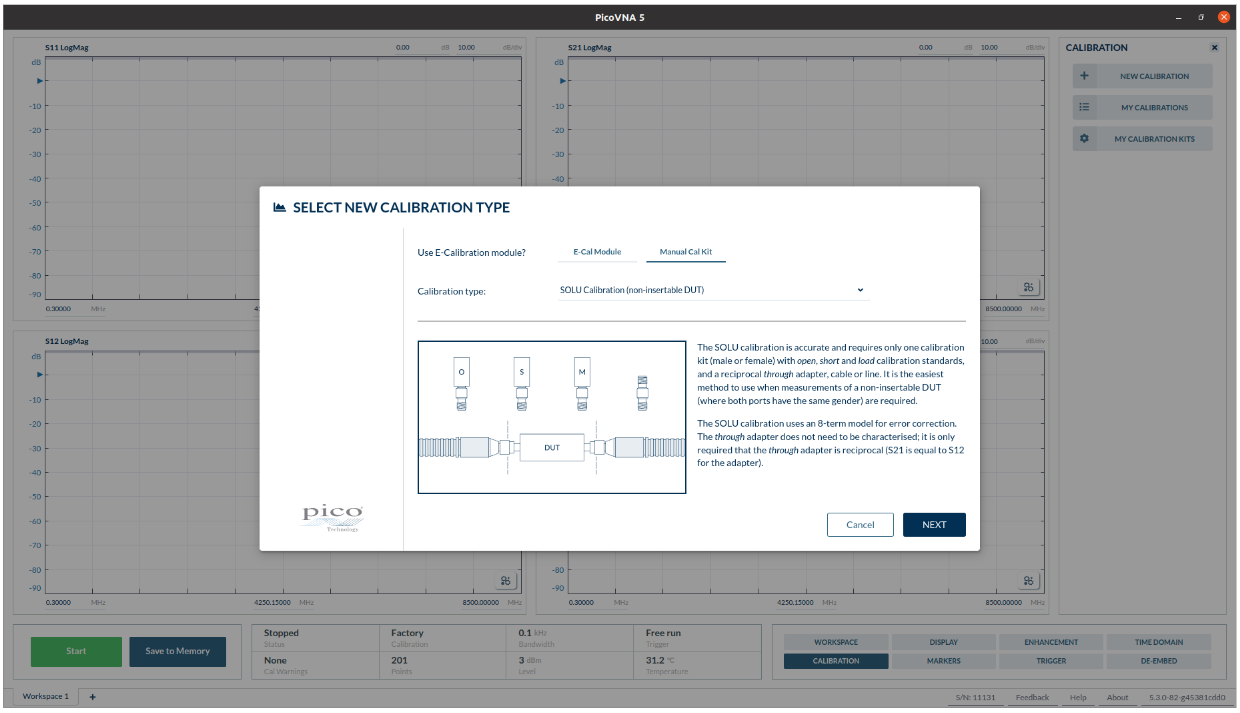


Figure 5.2: The second step when starting a new calibration: select the type of calibration to perform.

5.2.3 Step 3: 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. At this stage, enter the receiver bandwidth that you intend to use for measurements (there will be an option to reduce the receiver bandwidth for isolation measurements during calibration later in the calibration setup).

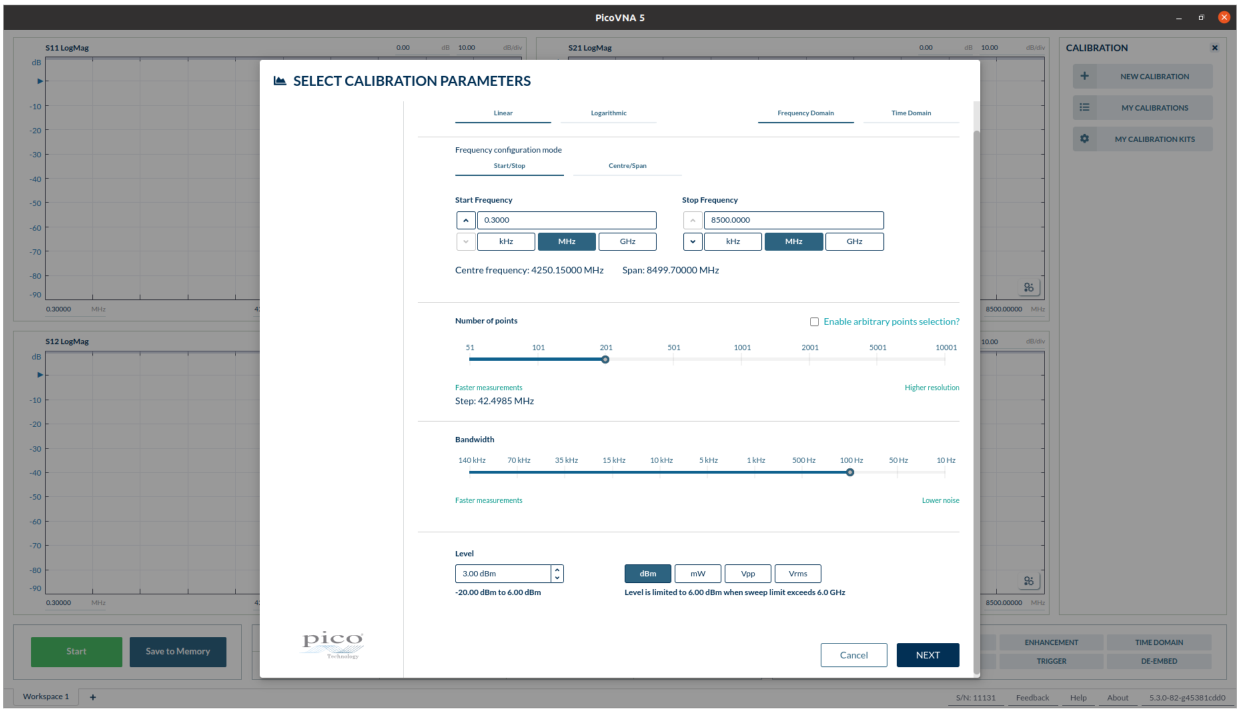


Figure 5.3: The third step when starting a new calibration: select the measurement parameters for the new calibration.

5.2.4 Step 4: 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.

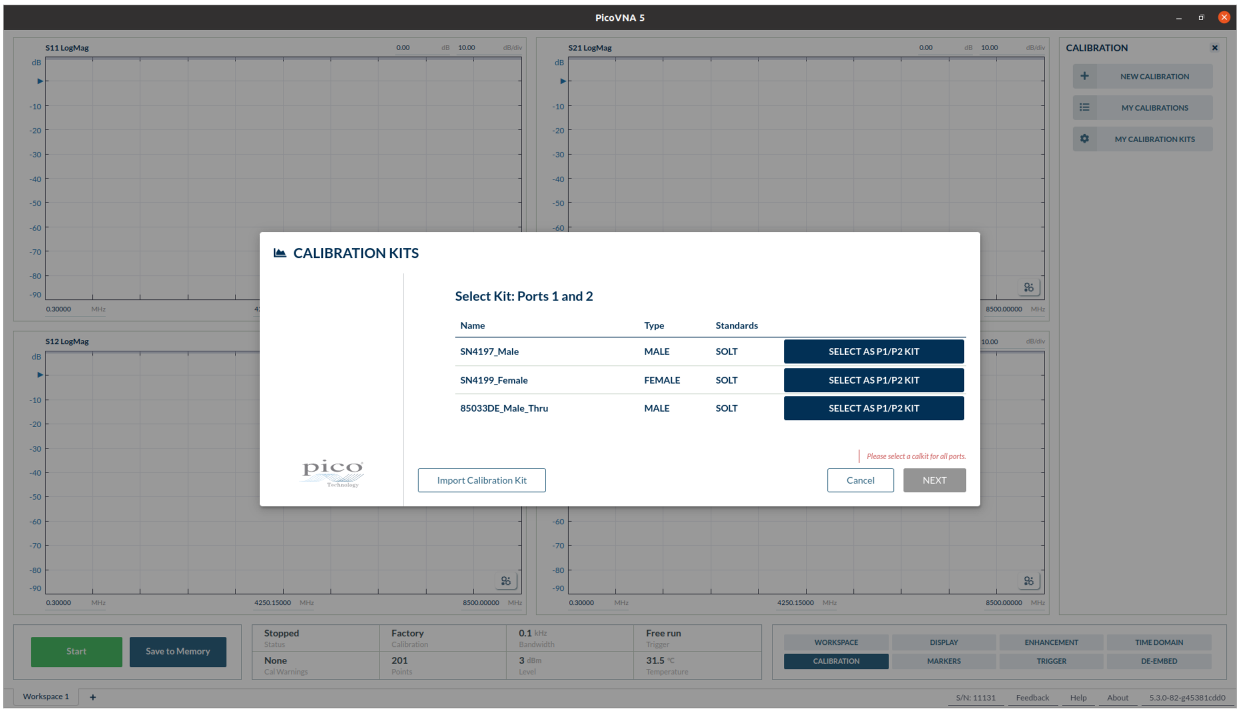


Figure 5.4: The fourth step when starting a new calibration: select or import calibration kits.

5.2.5 Step 5: specify calibration options

Leave the "use enhanced isolation" checkbox unchecked to use conventional isolation, or check the box to use enhanced isolation (these options are described in Section 5.3).

It is recommended to use a small bandwidth during isolation measurements in order to achieve the best dynamic range. In the case of conventional isolation, checking the "override bandwidth for isolation measurements" checkbox will automatically reduce the receiver bandwidth during the isolation step. In the case of enhanced isolation, checking this checkbox will automatically reduce the receiver bandwidth for all calibration measurements. However, the "override bandwidth for isolation measurements" box can be unchecked to speed up the calibration process by using the intended measurement bandwidth throughout the calibration.

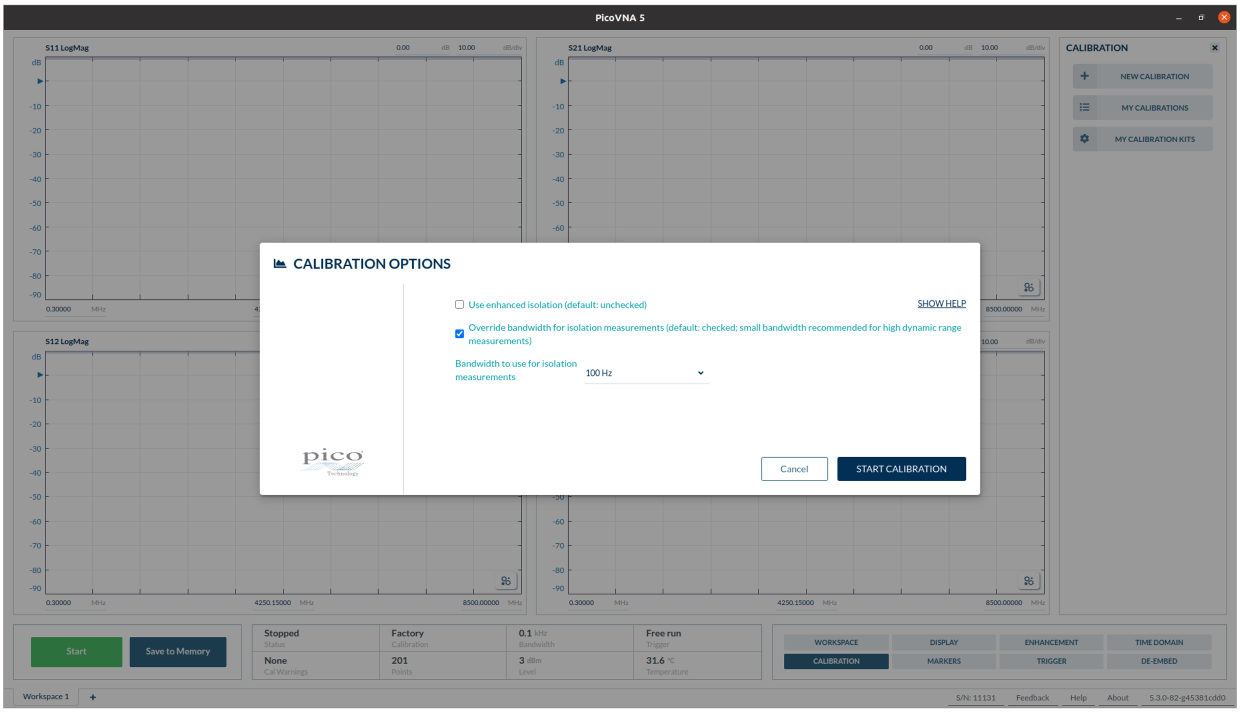


Figure 5.5: The final step before carrying out a new calibration: specify calibration options.

5.2.6 Step 6: 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.

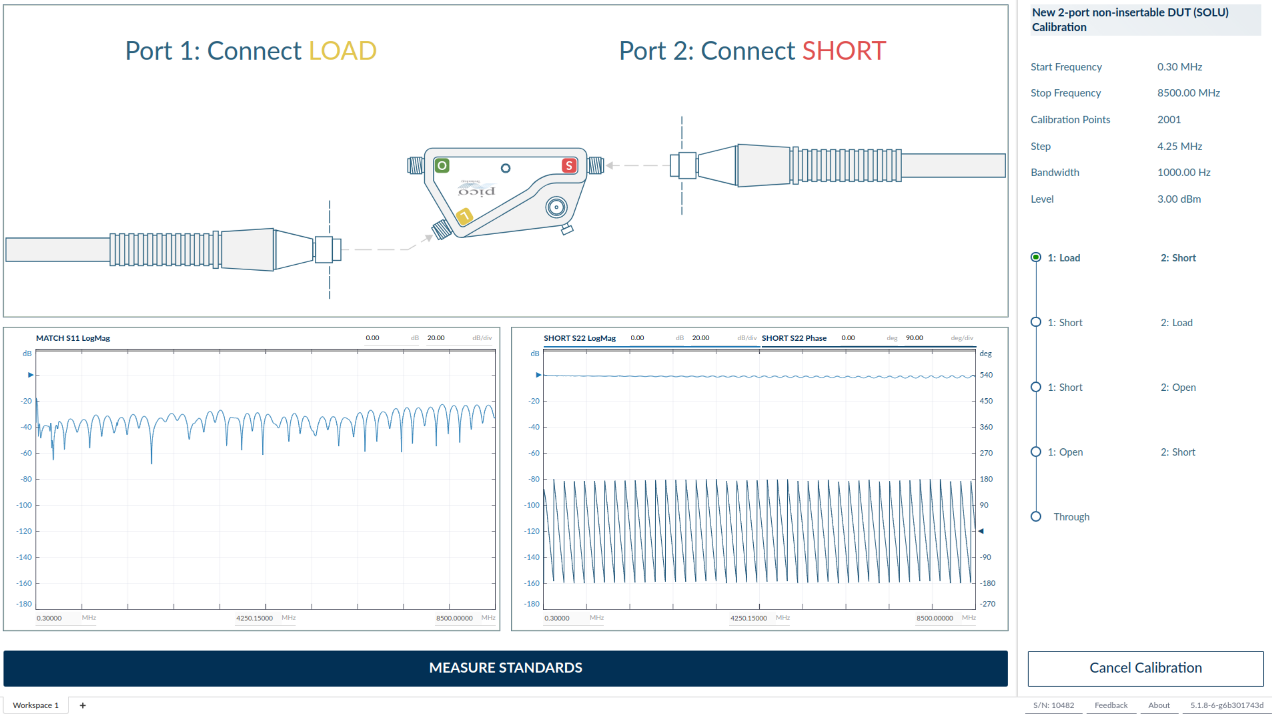


Figure 5.6: The calibration wizard: follow the instructions in the wizard in order to carry out the calibration.

5.2.7 Step 7: 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. You can also enter additional notes to help identify this calibration in the "Description" field if desired. Click "Save and Continue" to save the calibration and apply it to the current workspace.

5.3 Calibration for best dynamic range

5.3.1 Minimizing the effect of crosstalk

The error introduced due to instrument crosstalk is a limiting factor when making large dynamic range measurements. This is particularly the case at higher frequencies (for instance, above 4 GHz).

Consideration must be given to the calibration method if a calibration is to compensate for the errors due to instrument crosstalk. This is because the errors due to crosstalk are dependent on the loading at the test ports. That is, the error due to crosstalk when measuring the calibration standards may be different from the crosstalk errors when measuring the actual DUT.

The VNA Control 5 software provides two methods for minimizing the effect of crosstalk on measurements: *conventional isolation calibration* and *enhanced isolation calibration*.

5.3.2 Conventional isolation calibration

For measurements with the greatest possible dynamic range, the *conventional isolation calibration* should be used. However, care must be taken with this calibration method during the isolation calibration step. It will achieve best error correction when the terminations used for measurements are left unchanged from those used at the isolation calibration step, as shown in Figure 5.7.

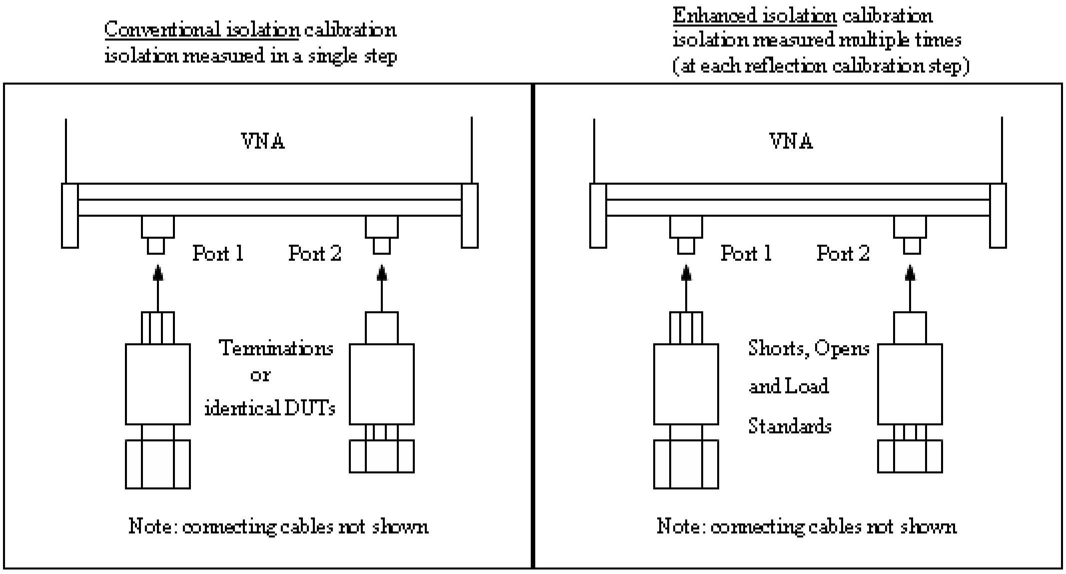


Figure 5.7: Measurements required for *conventional* and *enhanced* isolation calibrations.

To use the *conventional isolation calibration* option, leave the *Use enhanced isolation?* checkbox unchecked when starting the calibration sequence.

If it is not possible to use identical DUTs as shown in Figure 5.7 during the isolation calibration step, then the *enhanced isolation calibration* may achieve superior error correction.

5.3.3 Enhanced isolation calibration

The *enhanced isolation calibration* uses an advanced model of the effect of port termination on the internal crosstalk in the instrument and uses this model for error correction. The calibration fits this model by making crosstalk measurements at the *short*, *open* and *load* calibration steps.

No model can predict the effect of instrument crosstalk as well as actually measuring it, so this method may not perform as well as the *conventional isolation calibration* in the case that identical DUTs are available for measurement during the isolation calibration step. However, if it is not possible to use the same terminations during the isolation calibration step as those that will be used during measurements, or if measurements of a large range of different DUTs are required, then the *enhanced isolation calibration* will likely achieve superior error correction to the *conventional isolation calibration*. The *enhanced isolation calibration* is generally used with low resolution bandwidths and high test signal levels.

To use enhanced isolation, check the *Used enhanced isolation?* checkbox when starting the calibration sequence (Section 5.2.5).

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 VNA Control 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

$$f_{\text{Meas}} = k\, f_{\text{Step}} \tag{5.1}$$

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 VNA Control 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 VNA Control 5 software $L1$ and $L2$ are entered using the de-embed sidebar, in the "Port 1 offset" and "Port 2 offset" fields respectively.

VNA Control 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

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

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.

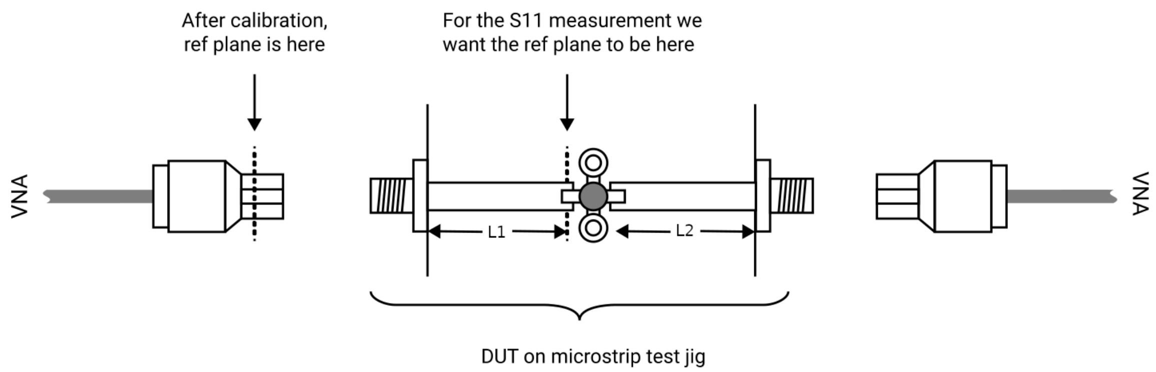


Figure 6.1: Correcting S_{11}, S_{21}, S_{12} and S_{22} phase measurement.

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 VNA Control 5 can remove the effect of these networks on the measurement using de-embedding.

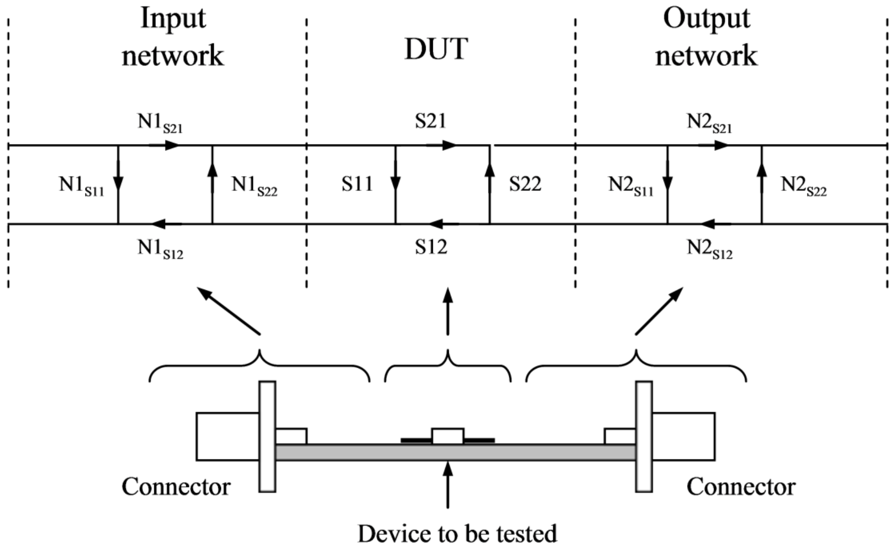


Figure 6.2: De-embedding allows the effects of the test jig's input and output networks to be removed.

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 VNA Control 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 <-> A1 <-> A2 <-> ... <-> An <-> DUT <-> Bm <-> ... <-> B2 <-> B1 <-> 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 VNA Control 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 in your programming language of choice. The Programmer's Guides can be downloaded from:

- C++: `https://www.aairobotics.com/vna5_internal_builds/temp/Pico_VNA_5_Programming_Guide_Cpp.pdf`
- Python: `https://www.aairobotics.com/vna5_internal_builds/temp/Pico_VNA_5_Programming_Guide_Python.pdf`

Example programs using the API in a number of programming languages are available at: `https://github.com/LA-Techniques/VNAControl5_SDK_Examples`.

7.2 SCPI

By default, the VNA Control 5 software listens for SCPI commands on TCP port 5025. The SCPI interface can be disabled, or the TCP port changed, via the User Preferences (Network), shown in Figure 7.1.

A VNA instrument can be controlled concurrently from both the User Interface and SCPI commands. For example, a measurement could be set up via the User Interface and then initiated via SCPI, or vice-versa.

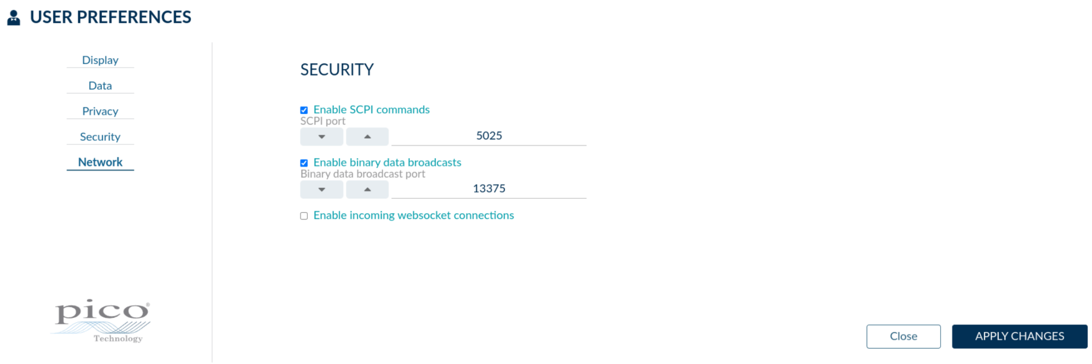


Figure 7.1: User preferences for configuring SCPI via the User Interface.

7.2.1 SCPI control in headless mode

If the User Interface is not required, the VNA Control 5 software may be started in headless mode. All SCPI functionality is available in headless mode. The serial number of the instrument to use must be provided (via command line arguments) when starting the software in headless mode.

Headless mode (Windows)

Open a Command Prompt and change the working directory to where VNA Control 5 is installed (by default `C:\Program Files\LA Techniques Ltd\VNA Control 5`). Then start the server application using:

```
bin\vnaserver -P <scpi_port> --instrument <instrument_serial_number>
```

This process is shown in Figure 7.2.

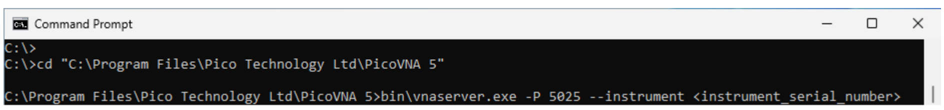


Figure 7.2: Starting the VNA Control 5 software in headless mode on Windows.

Headless mode (Linux)

Open a terminal and change the working directory to where VNA Control 5 is installed (by default `/opt/vnacontrol`). Then start the server application using:

```
bin/vnaserver -P <scpi_port> --instrument <instrument_serial_number>
```

This process is shown in Figure 7.3.

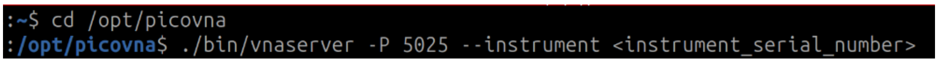


Figure 7.3: Starting the VNA Control 5 software in headless mode on Linux.

Headless mode (macOS)

Open a terminal and change the working directory to where VNA Control 5 is installed (by default `/Applications/vnacontrol5.app/Contents/MacOS`). Then start the server application using:

```
bin/vnaserver -P <scpi_port> --instrument <instrument_serial_number>
```

This process is shown in Figure 7.4.

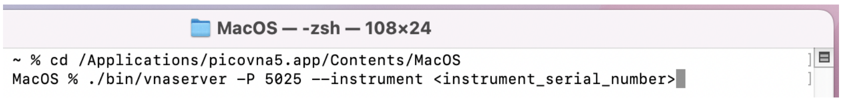


Figure 7.4: Starting the VNA Control 5 software in headless mode on macOS.

Command line arguments

In headless mode, command line arguments can be specified after the executable name. The following command line arguments are supported:

Argument	*Required?*	*Description*
`--instrument <serial>`	Yes	The serial number of the instrument to use
`-h`	No	Show help
`-P <scpi_port>`	No (Default 5025)	Listen port for SCPI
`-B <bb_port>`	No (Default 13375)	Server port for binary data broadcasts

Controlling multiple connected VNA instruments in headless mode

It is possible to control multiple VNA instruments connected to the same PC. One instance of `vnaserver` must be started for each instrument to be controlled. A different SCPI server port must be specified for each instance of `vnaserver` that is started.

7.2.2 Example programs for SCPI control

A set of short example programs that connect to PicoVNA 5 and initiate a sweep are presented below. A more comprehensive set of example programs are available at `https://github.com/LA-Techniques/VNAControl5_SDK_Examples`.

7.2.2.1 Linux: telnet

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

```
telnet localhost 5025
*IDN?
INIT
```

7.2.2.2 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

rm = pyvisa.ResourceManager()
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')
```

7.2.2.3 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')
```

7.2.3 Overview of the interface

7.2.3.1 Command syntax

SCPI commands can be written in full or abbreviated form. The documentation will specify many commands in mixed lower and upper case. The command can either be issued in full by copying the full form in the documentation, or in abbreviated form by only issuing the capitalised parts of the command. SCPI commands are not case sensitive (except for units of numeric quantities) so can be issued in upper-case, lower-case, or any combination of upper- and lower-case.

Multiple commands can be issued together by concatenating them on a single line, separated by a semicolon.

Some SCPI commands are used to set or query a parameter on the instrument, for example the number of points in the measurement. In these cases, the command to query the parameter is formed by appending a question-mark (`?`) to the end of the command used to set the parameter.

Commands with integral suffixes

Some commands require an *integral suffix* (usually an integer), where the suffix is integrated into the command itself. These commands are not valid unless the suffix is included with the command.

An example is the `MARKER<M>:X?` command. `M` denotes the integral suffix. `MARKER1:X?` would be used to query the x-coordinate of Marker 1, but `MARKER:X?` would not be a valid command as it lacks the integral suffix.

Integral suffixes should not be confused with parameters. Commands have at most one integral suffix and no space is left between the integral suffix and the command.

7.2.3.2 Parameters

Many SCPI commands require one or more parameters. The list of parameters should be separated from the command with a single space, and then parameters should be passed as a comma-separated list without spaces between parameters. For example, a command (`COMMAND`) with three parameters (`PARAM1`, `PARAM2` and `PARAM3`) would be issued as:

```
COMMAND PARAM1,PARAM2,PARAM3
```

Required and optional parameters

In the documentation:

- `<...>` indicates a required parameter.
- `[...]` indicates an optional parameter.

The square and angle brackets used for illustration in the documentation should not be issued with the command.

Required parameters should not be confused with integral suffixes, which are indicated in the documentation using the same angle bracket notation but without a space between the integral suffix and the command.

Parameter types

In the documentation, parameters are written as:

```
X: Y
```

Where `X` indicates the name of the parameter and `Y` indicates its type. Types are notated in this way for the purposes of documentation only, and should not be included when issuing a command.

Parameter types may be:

- `BOOL`. A Boolean value. True can be written as `TRUE`, `1`, `ON` or `YES`. False can be written as `FALSE`, `0`, `OFF` or `NO`.
- `DOUBLE`. An IEEE-754 double-precision floating point number.

- `INT`. An integer value.
- `STRING`. A string value, used for example to specify a file path.
- `KEYWORD`. Some parameters accept a finite set of values, specified in the documentation. In these cases, the type of the parameter is specified as `VAL1 | VAL2 | VAL3`, where `VAL1`, `VAL2` and `VAL3` indicate the values that can be passed for that parameter.

Regardless of the parameter type, parameters must be specified in ASCII text. There is no binary input mode for parameters.

Units

Where parameters require a unit (for example when specifying a frequency, bandwidth or power), enter it after the value. A space between the value and unit is optional. Units are case-sensitive.

Units that can be used are:

- `m` – metre
- `Hz` – Hertz
- `s` – seconds
- `dB` – decibels
- `W` – Watts
- `dBm` – decibels relative to 1 mW
- `vrms` – RMS voltage
- `vpp` – peak-to-peak voltage
- `deg` – degrees
- `rad` – radians
- Ω – ohms
- π `rad` – multiples of π radians
- `U` – unitless

7.2.3.3 Return values

Commands that have data to return (for example, a getter command, or a command retrieving sweep data) will return that data in a single line terminated with a newline character (unless otherwise specified).

Commands that do not produce a specific output (for example, setter commands) will return the string `OK` (followed by a newline character) if the operation succeeded. If the command failed, it will return a single-line string (terminated with a newline character) that indicates the nature of the error that occurred.

The strings returned by commands that do not produce a specific output include, but are not limited, to:

- `OK` – the operation succeeded.

- `Unknown SCPI command: [command]` – if the command issued was not a valid command.
- `Too few arguments provided to SCPI command. Need [...] got [...].` – if the number of arguments supplied was not correct.
- `No device connected` – the operation requires an instrument to be connected, but no instrument is connected.
- `This command has no effect` – if the command is included for compatibility reasons with other software and instruments, but it has no effect in PicoVNA 5.
- `Command disabled by user for security` – returned by commands that operate on the filesystem, if filesystem commands have not been explicitly enabled in User Preferences in the PicoVNA 5 software.

7.2.3.4 Data representation

Measurement data is retrieved from the instrument using the `CALCulate:DATa` series of commands. Data can be retrieved in binary or text-based (ASCII) format. The default is binary. Use the `FORMat` command to select the desired data output format.

In binary mode, data will be returned as a concatenation of IEEE-754 floating-point values. The bit-length of each number (32 or 64 bits) can be set using the `FORMat` command. The default is 64 bits (double precision). The endianness of the output data can be set using the `FORMat:BORDer` command. The default is big-endian.

In ASCII mode, data is returned as a comma-separated list of values.

If a data point is not available (for example, if the sweep was aborted early, or group delay was requested at the first measurement point), it will be replaced with a *NaN*. *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 you 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 is an IEEE754-compliant NaN, but whether or not it triggers your hardware's floating-point exception mechanism will be platform-dependent).

7.2.3.5 Specifying channels

Many commands require the user to specify what channel the command should be applied to, i.e. the live data channel, or a specific memory channel. The live data channel is specified as `0`. A memory channel is specified by the index of the memory channel, i.e. `1`, `2`, `3`, ...

7.2.3.6 Commands that use the filesystem

Some commands produce their output by writing to files (for example, when exporting data to a Touchstone or CSV file). Other commands require a file as input (for example, when loading a calibration). These commands require a path to be specified as one of their arguments.

Some commands also operate directly on the filesystem, for example to copy, create or remove files or directories.

Paths

Paths can be specified as either an absolute path or a relative path.

PicoVNA 5 maintains a virtual "working directory", where relative paths are specified from. To change the working directory, use the `MMEMory:CDirectory` command (which in turn can take an absolute path, or a relative path from the current working directory).

Safety

By default, the following filesystem commands that operate directly on the filesystem are disabled for security purposes:

- `MMEMory:COPY`
- `MMEMory:DELete`
- `MMEMory:RMDIRectory`
- `MMEMory:MOVe`
- `MMEMory:MKDIRectory`
- `MMEMory:CATalog?`

This is important, otherwise a remote attacker could open a connection to PicoVNA 5 and gain access to your filesystem.

These commands can be enabled using the User Preferences modal in PicoVNA 5.

7.2.3.7 Compatibility mode

Compatibility mode may be helpful if you wish to run a SCPI program that was written for another instrument. Some adaptation may still be required, but compatibility mode introduces many new command aliases to try to look more like some other SCPI implementations.

Compatibility mode is not helpful unless facilitating interoperability with other instruments, since the introduced aliases clutter the output of `HELP` and typically represent more convoluted ways of doing things.

Compatibility mode is disabled by default. Use the `SYStem:COMPATibility` command to enable it.

7.2.3.8 Differences from other SCPI implementations

This SCPI implementation differs from some other implementations in a few notable ways. These differences are expected to generally make the interface easier and more convenient to use, but awareness of them is useful.

- *Units are case-sensitive*. Unlike other strings, units *are* case-sensitive. Some SCPI implementations accept case-insensitive units and resolve any ambiguity (e.g. between mHz and MHz) from context. This implementation requires units to be cased appropriately, and does not perform such inference.
- *Help commands*. There is a non-standard command `HELP`. `HELP` can be used to retrieve a list of valid SCPI commands, or ask for help on a particular command (`COMMAND`) by issuing `HELP COMMAND`.
- *All commands have a reply*. All commands that do not produce a specific output will return a single-line status message. The status message will either be `OK` or a single-line human-readable error message, as described in Section 7.2.3.3. This mechanism feeds back any errors instantly, but requires the user to perform a read after every write. Use your programming environment's `readLine()` mechanism to do this.

Status replies (OK/not-OK) will always be one line long, so it is sufficient to perform a single `readLine` operation after every such command. Cases where commands produce multiline output are noted separately.

Users are discouraged from writing code that sends a command and then reads exactly 3 bytes for the response, as this will fail if any errors are encountered.

- *Command execution is synchronous or commands implicitly synchronise.* Some SCPI implementations have a distinction between synchronous and asynchronous commands, and require the user to call `*WAI` when you want to wait for asynchronous operations (such as a measurement sweep) to complete before doing something else. This becomes especially problematic when it comes to receiving errors from the device, because these end up in an asynchronously-populated buffer you must explicitly poll.

  In this implementation, commands are either synchronous, or implicitly synchronise. Commands that do things like change settings are synchronous, instantaneous, and return immediately with "OK" or an error message. Commands that take a nontrivial amount of time (such as "do a sweep") start asynchronously, and the next command you send that depends on the outcome of the asynchronous thing causes it to wait for it to finish.

  Consequently, you can send a sequence of commands such as "do some configuration", "do a sweep", "read a sweep", "change more settings", "do another sweep", all without any explicit synchronisation messages, and it will be interpreted in the obvious and reasonable way. As well as removing the possibility of mistakes from forgetting to send an explicit synchronisation command, this arrangement means that all errors appear at the time they happen.

  Since the SCPI commands are handled by software rather than the VNA itself, there are no performance implications of doing all error/success replies immediately. It's just a round trip on a TCP socket. The cost of having to do a read/write pair for every command is more than outweighed by the benefit of not having to deal with asynchronous error/state handling.

7.2.4 Overview of key SCPI commands

7.2.4.1 Getting help

Help can be obtained via SCPI. To list all available SCPI commands together with summary information, use `HELP` (with no parameters). If you pass the name of a SCPI command to `HELP`, 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.

7.2.4.2 Setting up measurements

A measurement can be set up fully configured via SCPI, including loading a calibration, setting the sweep parameters and setting up any de-embedding or enhancement required. This user manual describes relevant commands in the `SENSe`, and `CALCulate` subsystems for doing so.

However, it is often convenient to do the majority of the setup live via the PicoVNA 5 graphical user interface. Alternatively, SCPI can be used to load a session file that was previously configured using the PicoVNA 5 software. To load a session file for a previously-configured session, use the `MMEMory:LOAD:SESSion` command.

7.2.4.3 Starting a measurement sweep

A single measurement sweep can be initiated using the `INITiate` command. If a measurement sweep is already running, this command will cause it to be restarted.

7.2.4.4 Retrieving data

A note on the utility of markers

The simplest way to retrieve a measurement at one frequency is to place a marker at that point. If the requested frequency does not align with a sweep point, the measurement will be interpolated using the current interpolation preferences set via the PicoVNA 5 user interface. Markers are described in Section 7.2.4.6 and the remainder of this section will describe how to retrieve the data from an entire sweep.

Retrieving all the data from a frequency sweep

To retrieve sweep data, use:

- the `CALCulate:DATa <MParam> <Type>` command to retrieve data from the `LIVE` channel,
- the `CALCulate:DATa:MEMory<M> <MParam> <Type>` command to retrieve data from a memory channel, specifying which memory channel using the integral suffix `M`.

These commands will return the data for one *S*-parameter in the requested format. If multiple *S*-parameters are required, simply run the commands repeatedly.

Synchronisation and semantics for retrieving measurement data from the LIVE channel

If a measurement is not in progress, the `CALCulate:DATa` command will return immediately with the data from the most recent sweep. If the most recent sweep was aborted early, the 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 PicoVNA 5 User Interface, and then stopped, then the `CALCulate:DATa` command will return the data corresponding to what the UI is showing (a mixture of data from two different sweeps).

If continuous-mode sweeping is currently in progress, the `CALCulate:DATa` command will return immediately with an error. If data retrieval is required during continuous mode sweeping, either save the sweep data to a new memory channel and retrieve it from that, or alternatively use the separate binary data broadcast data retrieval interface.

If a sweep (other than continuous-mode sweeping via the PicoVNA 5 User Interface) is in progress, the `CALCulate:DATa` command will block until it has finished so the complete data from the current sweep can be returned.

7.2.4.5 Exporting data to a Touchstone or CSV file

The `MMEMory:STORe:TRACe` command is used to export data to a Touchstone or CSV file. Any type of data (including raw a/b data) can be exported to a CSV file, regardless of whether or not it is currently displayed on a graph. The type of file (Touchstone, CSV or raw a/b), channel to export (live data or a specified memory channel) and the file path of the output are specified using this command's parameters.

The touchstone data format (dB/Arg, Mag/Arg or Re/Im) is set using the `MMEMory:STORe:TRACe:OPTion:TOUCHSTONEDATAFORMAT` command. The default is real/imaginary. This option is persistent with a session when configured.

The data types to export to a CSV file (LogMag, Time Domain, Group Delay, ...) are set using the `MMEMory:STORe:TRACe:OPTion:CSVDATAFORMAT` command. The default is to export real and imaginary values. This option is also persistent with a session when configured.

7.2.4.6 Using markers

Markers in the frequency-domain

The `MARKer<M>` command can be used to create a marker, or move an existing marker between channels/plots/S-parameters. For example, if Marker 1 did not currently exist, the following would create Marker 1 and place it on the LIVE S11 LogMag trace:

```
MARKer1 0,LOGMAG,S11
```

The frequency of the marker can be set using `MARKER<M>:X`. For example, to set Marker 1 to a frequency of 2 GHz, the following command would be used:

```
MARKer1:X 2 GHz
```

The readout from a marker can be obtained using the `MARKer:Query` command. It takes one parameter: the type of data to readout (LogMag, Phase, ...). If the requested frequency (or time) does not align with a measurement point, the measurement will be interpolated using the current interpolation preferences set via the PicoVNA 5 user interface.

Markers in the time-domain

Markers in the time-domain are similar to markers in the frequency-domain, but the marker ID is prefixed with `T`. To create a time-domain marker 1 on the LIVE S11 Time Domain trace, use:

```
MARKERT1 0,S11
```

The time (or distance) of the marker can be set using `MARKERT<M>:X`. For example, to set Marker `T1` to a time of 1 ns, the following command would be used:

```
MARKERT1:X 1 ns
```

Markers are indexed separately in the time-domain from those in the frequency-domain. That is, `MARKER1` (in the frequency-domain) and `MARKERT1` (in the time-domain) have no relation.

Using tracking markers

Tracking markers can be used to find the position of a peak or other features within a trace. To configure tracking for frequency-domain markers use the `MARKer<M>:TRACKing` command, and to configure tracking for time-domain markers use the `MARKERT<M>:TRACKing` command.

For example, the position and value of the maximum within a LogMag trace can be determined as follows:

```
MARKER1:TRACK LOGMAG,GLOBALMAX
MARKER1:X?
MARKER1:Q LOGMAG
```

7.2.5 SCPI Command Reference: top-level commands

HELP

Usage:

```
HELP    [Command: STRING]
```

Description:
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`	Optional. The name of the SCPI command, or subtree, to get help for.

Example:
To get help on the `SENSE:BANDWIDTH` command, use:

```
HELP SENSE:BANDWIDTH
```

Example command returns:

```
SENSe:BANDwidth        <Bandwidth: DOUBLE>

Change the bandwidth of the sweep.

######## PARAMETERS ########

<Bandwidth: DOUBLE>        The new bandwidth.
```

*IDN?

Usage:
`*IDN?`

Description:
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.

Parameters:
This command takes no parameters.

Example:
To get information about the connected device and software version, use:

```
*IDN?
```

Example command returns:

```
Pico Technology Ltd,PicoVNA-108,A0000.00000,5.2.7-0-0
```

*OPC?

Usage:
`*OPC?`

Description:
Returns 1.

The semantics of the server already guarantee command ordering works correctly, so this command is not required. It exists for compatibility with other instruments.

Parameters:
This command takes no parameters.

*OPT?

Usage:
`*OPT?`

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

At present, no such optional features exist, so this command simply returns `1`.

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

Parameters:
This command takes no parameters.

*RST

Usage:
`*RST`

Description:
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.

Parameters:
This command takes no parameters.

*TRG

Usage:
`*TRG`

Description:
Send a manual trigger event to the device.

Parameters:
This command takes no parameters.

ABORt

Usage:
`ABORt`

Description:
Stop all ongoing measurements.

Parameters:
This command takes no parameters.

7.2.6 SCPI Command Reference: CALCulate subsystem

CALCulate:AVERaging

Usage:
`CALCulate:AVERaging <Average: BOOL>`

Description:
Change whether averaging is enabled.

Parameters:
`Average: BOOL` Required. Whether or not averaging should be enabled on the live channel.

Example 1:
To turn averaging on for the live channel, use:

```
CALCULATE:AVERAGING ON
```

Example command returns:

```
OK
```

Example 2:
To turn averaging off for the live channel, use:

```
CALCULATE:AVERAGING OFF
```

Example command returns:

```
OK
```

CALCulate:AVERaging:COUNT

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

Description:
Change the number of averages.

Parameters:
`NumAvgs: INT` Required. The new number of averages.

CALCulate:AVERaging:COUNT?

Usage:
`CALCulate:AVERaging:COUNT?`

Description:
Query the number of averages.

Parameters:
This command takes no parameters.

CALCulate:AVERaging?

Usage:
`CALCulate:AVERaging?`

Description:
Query if averaging is enabled.

Parameters:
This command takes no parameters.

CALCulate:DATa

Usage:

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

Description:
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 require multiple measurement parameters, simply run this command repeatedly.

If a measurement is not in progress, this command will return immediately with the data from 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 PicoVNA 5 User Interface, 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 continuous-mode sweeping is currently in progress, this command will return immediately with an error. If data retrieval is required during continuous mode sweeping, either save the sweep data to a new memory channel and retrieve it from that, or alternatively use the separate binary data broadcast data retrieval interface (see the PicoVNA 5 User Manual for further details).

If a sweep (other than continuous-mode sweeping via the PicoVNA 5 User Interface) is in progress, this command will block until it has finished so the complete data can be returned.

This command does not currently support averaging of data across multiple sweeps (any desired averaging must be implemented by the caller). This command will return the same data regardless of whether or not averaging is enabled.

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. For example, the following code will start a sweep and then retrieve the data from it:

```
# Start a sweep
INIT

# Retrieve the resulting measurement data. There will be a pause after running the first of thes
# 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 you 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 floating-point exception mechanism will depend on your platform (and also 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:

`MParam`	Required. Measurement parameter you want data for. Values: `S11|S21|S12|S22`.
`Type`	Required. The data you want. Values: `LOGMAG|MAG|PHASe|TD|REAL|IMAGinary|GD|VSWR|POLARlinear`.

`POLARlinear` data outputs the real and imaginary parts of each measurement point, in order.

CALCulate:DATa:LIVE

Usage:

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

Description:
An alias of `CALCulate:DATa`.

CALCulate:DATa:MEMory

Usage:

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

Description:
Identical to `CALC:DATA`, but used to retrieve data for memory channels.

Specify the desired memory channel in the integral suffix of this command name, such as:

```
CALC:DATA:MEM0
CALC:DATA:MEM4
etc.
```

It is always valid to retrieve data from a memory trace, regardless of whether or not continuous-mode sweeping is nabled via the PicoVNA 5 User Interface.

Parameters:

`MParam`	Required. Measurement parameter you want data for. Values: `S11|S21|S12|S22`.
`Type`	Required. The data you want. Values: `LOGMAG|MAG|PHASe|TD|REAL|IMAGinary|GD|VSWR|POLARlinear`.

CALCulate:DATa:STIMulus?

Usage:
`CALCulate:DATA:STIMulus?`

Description:
Output the stimulus values for the given sweep segment.

Parameters:
This command takes no parameters.

CALCulate:SMOothing

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

Description:
Change whether smoothing is enabled.

Parameters:
`Smooth: BOOL` Required. Whether or not smoothing should be enabled on this channel.

CALCulate:SMOothing?

Usage:
`CALCulate:SMOothing?`

Description:
Query if smoothing is enabled.

Parameters:
This command takes no parameters.

CALCulate:SMOothing:FACTOR

Usage:
`CALCulate:SMOothing:FACTOR <Smoothing: DOUBLE>`

Description:
Change the smoothing factor.

Parameters:
`Smoothing: DOUBLE` Required. The new smoothing factor.

CALCulate:SMOothing:FACTOR?

Usage:
`CALCulate:SMOothing:FACTOR?`

Description:
Determine the smoothing factor.

Parameters:
This command takes no parameters.

CALCulate:TIME

Usage:
`CALCulate:TIME <Mode: (BPASs | LPASs)>`

Description:
Set whether to use a low-pass or band-pass time-domain transform.

The default is low-pass.

Parameters:
`Mode` Required. The new time-domain mode. Values: `BPASs|LPASs`.

CALCulate:TIME?

Usage:
`CALCulate:TIME?`

Description:
Query whether we are currently using a low-pass or band-pass time-domain transform.

Parameters:
This command takes no parameters.

CALCulate:TIME:DCterm

Usage:
`CALCulate:TIME:DCterm <Termination: (AUTO | OPEN | SHORT | RESISTive)>`

Description:
Set the type of DC termination to use in the time domain transform.

Parameters:

`Termination`	Required. The type of DC termination to use. Values: `AUTO|OPEN|SHORT|RESISTive`.

CALCulate:TIME:DCterm?

Usage:
`CALCulate:TIME:DCterm?`

Description:
Query the type of DC termination used in the time domain transform.

Returns: AUTO, OPEN, SHORT, RESISTIVE or NONE.

Parameters:
This command takes no parameters.

CALCulate:TIME:EFFD

Usage:
`CALCulate:TIME:EFFD <D: DOUBLE>`

Description:
Set the effective dielectric constant used in conversions between time and distance for time-domain measurements.

Parameters:

`EffD: DOUBLE`	Required. The new effective dielectric constant used in for time-domain measurements.

CALCulate:TIME:EFFD?

Usage:
`CALCulate:TIME:EFFD?`

Description:
Query the effective dielectric constant used in conversions between time and distance for time-domain measurements.

Parameters:
This command takes no parameters.

CALCulate:TIME:RESPonse

Usage:
`CALCulate:TIME:RESPonse <Mode: (IMPulse | STEP)>`

Description:
Set whether to return the impulse or step response of the DUT for time-domain measurements.

Parameters:

`Mode`	Required. The new stimulus mode. Values: =IMPulse|STEP=

CALC:TIME:RESP?

Usage:
`CALCulate:TIME:RESPonse?`

Description:
Query whether to return the impulse or step response of the DUT for time-domain measurements.

Returns IMPULSE or STEP.

Parameters:
This command takes no parameters.

CALCulate:TIME:RTERM

Usage:
`CALCulate:TIME:RTERM <RT: DOUBLE>`

Description:

7.2.7 SCPI Command Reference: CHANnel subsystem

CHANnel<Ch>:COPY

Usage:
`CHANnel<Ch>:COPY [MemChanID: INT]`

Description:
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` Optional. The ID of the memory channel to write.

CHANnel:MEMory:CATalog:COUNt?

Usage:
`CHANnel:MEMory:CATalog:COUNt?`

Description:
Print the number of existing memory channels.

Parameters:
This command takes no parameters.

CHANnel:MEMory:CATalog?:

Usage:
`CHANnel:MEMory:CATalog?`

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

Parameters:
This command takes no parameters.

CHANnel:MEMory:DELete

Usage:
`CHANnel:MEMory:DELete <MemChanID: INT>`

Description:
Delete the memory channel with the given ID.

Parameters:

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

CHANnel:MEMory:DELete:ALL:

Usage:
`CHANnel:MEMory:DELete:ALL`

Description:
Delete all memory channels.

Parameters:
This command takes no parameters.

HELP

Usage:
`HELP [Command: STRING]`

Description:
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`	Optional. The name of the SCPI command, or subtree, to get help for.

INITiate:

Usage:
`INITiate`

Description:
Initiate a measurement sweep. If a measurement is already running, this command will cause it to be restarted.

For compatibility with other instruments, this command includes an optional integral suffix. However, if the integral suffix is specified, the command will return an error unless it is `0`.

Parameters:
This command takes no parameters.

INSTrument:PORT:COUNt?

Usage:
`INSTrument:PORT:COUNt?`

Determine how many ports the attached VNA has.

Parameters:
This command takes no parameters.

MARKer<M>

Usage:
`MARKer<M>    <Channel: STRING>`

```
<SeriesType>
<SParam: (S11 | S12 | S21 | S22)>
```

Description:
Create a frequency-domain marker, or move it between channels/plots/S-parameters.

Set marker `M` to be on the given channel/trace/measurement-parameter. If the marker does not exist, it is created. If a marker with that ID already exists, it is changed accordingly.

Parameters:

`Channel: STRING`	Required. The name or ID of the channel the marker should be placed on.
`SeriesType`	Required. The name or ID of the channel the marker should be placed on.
`SParam: (S11 | S12 | S21 | S22)`	Required. The measurement parameter the marker is to be associated with.

The following values can be passed to the `SeriesType` parameter:

- `LOGMAG`. Marker should appear on logmag traces.
- `LINMAG`. Marker should appear on linear magnitude traces.
- `PHASe`. Marker should appear on phase traces.
- `REal`. Marker should appear on real traces.
- `IMag`. Marker should appear on imaginary traces.
- `GD`. Marker should appear on group-delay charts.
- `VSWR`. Marker should appear on VSWR charts.
- `POLARlinear`. Marker should appear on polar-linear charts.
- `SMITH`. Marker should appear on Smith charts.

MARKer<M>:DELETE

Usage:
`MARKer<M>:DELETE`

Description:
Delete the frequency-domain marker.

MARKer<M>:Query

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

Description:
Print a measurement made at the frequency of this frequency-domain marker.

Parameters:

`Type`	Required. The measurement to print.

The following values can be passed to the `Type` parameter:

- `LOGMAG`. Print log-magnitude for the associated sparam.

- LINMAG. Print linear magnitude for the associated sparam.
- PHASe. Print phase for the associated sparam.
- REal. Print real for the associated sparam.
- IMag. Print imaginary for the associated sparam.
- GD. Print Group-delay for the associated sparam.
- VSWR. Print VSWR for the associated sparam.
- ZRE. Print the real part of the impedance in ohms (reflection measurements only).
- ZIM. Print the imaginary part of the impedance (reflection measurements only).
- INDCAP. Print the imaginary part of the impedance as an inductance or capacitance measurement (reflection measurements only).

MARKer<M>:READOUT

Usage:

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

Description:
Configure the readouts shown in the UI for this frequency-domain marker.

Parameters:

Type	Required. The value to extract.
State: BOOL	Required. Whether or not to show this readout value in the UI.

The following values can be passed to the Type parameter:

- LOGMAG. Log-magnitude.
- LINMAG. Linear magnitude.
- PHASe. Phase.
- REal. Real.
- IMag. Imaginary.
- GD. Group Delay.
- VSWR. VSWR.

MARKer<M>:READOUT:AOFF

Usage:

```
MARKer<M>:READOUT:AOFF
```

Description:
Disable all readouts from this frequency-domain marker in the PicoVNA 5 User Interface.

Parameters:
This command takes no parameters.

MARKer<M>:TRACKing

Usage:

```
MARKer<M>:TRACKing
    <TrackingFunction: (LOGMAG | LINMAG | PHASe | REal | IMag | GD | VSWR | OFF)>
    [TrackingFeature: (GLOBALMAX | GLOBALMIN | NTHMAX | NTHMIN | NTHEXTREME
                              | NTHMINUSXDBPOINT | NTHPLUSXDBPOINT)]
    [OptionalParam1: STRING]
    [OptionalParam2: STRING]
```

Description:
Turn tracking on or off for a frequency-domain marker, and specify the series type to track. To turn tracking on, specify a tracking function, tracking feature and any other parameters required for the tracking feature. To turn tracking off, specify `OFF` for the tracking function and no further arguments.

This command may require a number of additional parameters, depending on the tracking feature specified.

Supported tracking features are:

- Global maximum (`GLOBALMAX`). Required parameters: none.
- Global minimum (`GLOBALMIN`). Required parameters: none.
- nth local maximum (`NTHMAX`). Required parameters:
  - n (natural number)
  - hysteresis (real number)
- nth local minimum (`NTHMIN`). Required parameters:
  - n (natural number)
  - hysteresis (real number)
- nth local extremum (`NTHEXTREME`). Required parameters:
  - n (natural number)
  - hysteresis (real number)
- nth x dB point (NTHXDBPOINT). Only available for LogMag traces. Required parameters:
  - n (natural number) x (real number)

Optional parameters are specified by appending them to the required parameters (see examples below).

Parameters:

`TrackingFunction`	Required. The series type to track, or OFF to disable tracking.
`TrackingFeature`	Required if enabling tracking. The feature to track (see list above).
`OptionalParam1`	Required only for some tracking features (see above).
`OptionalParam2`	Required only for some tracking features (see above).

Example:
To set marker 1 to track the global minimum of SWR:

```
MARKER1:TRACK VSWR,GLOBALMIN
```

Example:
To set marker 1 to track the 3rd local extremum of phase:


```
MARKER1:TRACK PHASE,NTHEXTREME,3,0.5
```

Example:
To set marker 1 to track the 1st (trace max)-6 dB point.

```
MARKER1:TRACK LOGMAG,NTHMINUXXDBPOINT,1,-6
```

MARKer<M>:TYPe

Usage:
`MARKer<M>:TYPe <MarkerType: (REFerence | NORmal)>`

Description:
Change the type of a frequency-domain marker (reference or normal).

Does nothing if the marker is already of the specified type.

Parameters:

`MarkerType`	Required. The type of marker that this marker should become.

The following values can be passed to the `MarkerType` parameter:

- `REFerence`. The marker will become a reference marker.
- `NORmal`. The marker will become a normal (non-reference) marker.

MARKer<M>:TYPe?

Usage:
`MARKer<M>:TYPe?`

Description:
Query if a frequency-domain marker is a reference marker or not.

Parameters:
This command takes no parameters.

MARKer<M>:VISible

Usage:
`MARKer<M>:VISible <Visible: BOOL>`

Description:
Temporarily hide or show a frequency-domain marker.

Parameters:

`Visible: BOOL`	ON (show marker), OFF (hide marker)

MARKer<M>:VISible?

Usage:
`MARKer<M>:VISible?`

Description:
Determine if a frequency-domain marker has been hidden.

Parameters:
This command takes no parameters.

MARKer<M>:X

Usage:
`MARKer<M>:X <X: DOUBLE>`

Description:
Set the x-position of the frequency-domain marker. Specify the frequency at which to position the marker.

Parameters:

`X: DOUBLE`	The x-value at which to position the marker.

MARKer<M>:X?

Usage:
`MARKer<M>:X?`

Description:
Get the x-position of the frequency-domain marker.

Parameters:
This command takes no parameters.

MARKERT<M>

Usage:
```
MARKERT<M>    <Channel: STRING>
              <SParam: (S11 | S12 | S21 | S22)>
```

Description:
Create a time-domain marker, or move it between channels/S-parameters.

Set marker `M` to be on the given channel/trace/measurement-parameter. If the marker does not exist, it is created. If a marker with that ID already exists, it is changed accordingly.

Parameters:

`Channel: STRING`	Required. The name or ID of the channel the marker should be placed on.
`SParam: (S11 | S12 | S21 | S22)`	Required. The measurement parameter the marker is to be associated with.

MARKER<M>:DELETE

Usage:
`MARKERT<M>:DELETE`

Description:
Delete the time-domain marker.

MARKERT<M>:Query

Usage:
`MARKERT<M>:Query`

Description:
Extract some interesting value at the point this frequency-domain marker is associated with.

Parameters:
This command takes no parameters.

MARKer<M>:TRACKing

Usage:
```
MARKERT<M>:TRACKing
    <TrackingFunction: (TD | OFF)>
    [TrackingFeature: (GLOBALMAX | GLOBALMIN | NTHMAX | NTHMIN | NTHEXTREME)]
    [OptionalParam1: STRING]
```



```
[OptionalParam2: STRING]
```

Description:
Turn tracking on or off for a time-domain marker, and specify the series type to track. To turn tracking on, specify a tracking function, tracking feature and any other parameters required for the tracking feature. To turn tracking off, specify `OFF` for the tracking function and no further arguments.

This command may require a number of additional parameters, depending on the tracking feature specified.

Supported tracking features are:

- Global maximum (`GLOBALMAX`). Required parameters: none.
- Global minimum (`GLOBALMIN`). Required parameters: none.
- nth local maximum (`NTHMAX`). Required parameters:
  - n (natural number)
  - hysteresis (real number)
- nth local minimum (`NTHMIN`). Required parameters:
  - n (natural number)
  - hysteresis (real number)
- nth local extremum (`NTHEXTREME`). Required parameters:
  - n (natural number)
  - hysteresis (real number)

Optional parameters are specified by appending them to the required parameters (see examples below).

Parameters:

`TrackingFunction`	Required. The series type to track, or OFF to disable tracking.
`TrackingFeature`	Required if enabling tracking. The feature to track (see list above).
`OptionalParam1`	Required only for some tracking features (see above).
`OptionalParam2`	Required only for some tracking features (see above).

Example:
To set marker T1 to track the global minimum of the step/impulse response (as configured separately):

```
MARKERT1:TRACK TD,GLOBALMIN
```

Example:
To set marker T1 to track the 3rd local extremum of the step/impulse response (as configured separately):

```
MARKERT1:TRACK TD,NTHEXTREME,3,0.5
```

MARKERT<M>:TYPe

Usage:

```
MARKERT<M>:TYPe <MarkerType: (REFerence | NORmal)>
```

Description:
Change the type of a time-domain marker (reference or normal).

Does nothing if the marker is already of the specified type.

Parameters:

`MarkerType`	Required. The type of marker that this marker should become.

The following values can be passed to the `MarkerType` parameter:

- REFerence. The marker will become a reference marker.
- NORmal. The marker will become a normal (non-reference) marker.

MARKERT<M>:TYPe?

Usage:
```
MARKERT<M>:TYPe?
```

Description:
Query if a time-domain marker is a reference marker or not.

Parameters:
This command takes no parameters.

MARKERT<M>:VISible

Usage:
```
MARKERT<M>:VISible <Visible: BOOL>
```

Description:
Temporarily hide or show a time-domain marker.

Parameters:

Visible: BOOL	ON (show marker), OFF (hide marker)

MARKERT<M>:VISible?

Usage:
```
MARKERT<M>:VISible?
```

Description:
Determine if a time-domain marker has been hidden.

Parameters:
This command takes no parameters.

MARKERT<M>:X

Usage:
```
MARKERT<M>:X <X: DOUBLE>
```

Description:
Set the x-position of the time-domain marker. Specify a time (or distance) at which to position the marker.

Parameters:

X: DOUBLE	The x-value at which to position the marker.

MARKERT<M>:X?

Usage:
```
MARKERT<M>:X?
```

Description:
Get the x-position of the time-domain marker.

Parameters:
This command takes no parameters.

MMEMory:APPLY:CALibration

Usage:
`MMEMory:APPLY:CALibration`

Description:
Load a user calibration from a file and immediately apply it in the current workspace.

The user calibration to be loaded must have been performed from the PicoVNA 5 software (i.e. it must be a `.calx` file). It is not possible to load calibrations that were performed by the PicoVNA 3 software (from `.cal` files) via SCPI.

To export a calibration from the PicoVNA 5 software to a file, so this command can be used to load it, use the `Export` feature in the Calibration History modal, accessed via the `Calibrations` → `My Calibrations` menu.

This does not add the calibration to the list of calibrations known to the server (it does not appear in the PicoVNA 5's `my calibrations` list).

Parameters:

`Path:`	`STRING`	Required. Path to the calibration to load.

MMEMory:CATalog?

Usage:
`MMEMory:CATalog? [Dir: STRING]`

Description:
List the files in the specified directory, or the current directory if none is specified.

For security reasons, this command will have no effect unless filesystem commands are explicitly enabled via User Preferences in the PicoVNA 5 software.

Parameters:

`Dir:`	`STRING`	The directory to list.

MMEMory:CDirectory

Usage:
`MMEMory:CDirectory <NewPath: STRING>`

Description:
Change the current working directory (the directory that paths are interpreted in relation to).

Parameters:

`NewPath`	Required. The new path to interpret relative paths in relation to.

MMEMory:COPY

Usage:
`MMEMory:COPY <Source: STRING> <Dest: STRING>`

Description:
Copies a file.

For security reasons, this command will have no effect unless filesystem commands are explicitly enabled via User Preferences in the PicoVNA 5 software.

Parameters:

`Source:`	`STRING`	Required. Copy from.
`Dest:`	`STRING`	Required. Copy to.

MMEMory:CP

Alias of `MMEM:COPY`.

MMEMory:DELete

Usage:
`MMEMory:DELete <File: STRING>[Dir: BOOL]`

Description:
Delete the selected file.

For security reasons, this command will have no effect unless filesystem commands are explicitly enabled via User Preferences in the PicoVNA 5 software.

Parameters:

`File:`	`STRING`	The file to delete.
`Dir:`	`BOOL`	Optional. Whether or not to delete read-only files.

MMEMory:LOAD:SESSion

Usage:
`MMEMory:LOAD:SESSion [File: STRING]`

Description:
Import a previously-saved session.

The session may have been saved using `MMEMory:STORe:SESSion`, or the the save session function in the PicoVNA 5 software.

Parameters:

`File:`	`STRING`	Optional. The file to load from.

MMEMory:LOAD:STATe

Usage:
`MMEMory:LOAD:STATe <Compatibility: STRING> [File: STRING]`

Description:
Import the current configuration from a file.

Parameters:

`Compatibility:`	`STRING`	Required. May be 1 (for compatibility with SCPI standard), or may be the target file.
`File:`	`STRING`	Optional. The file to load from, if using the other argument for SCPI compatibility. Otherwise, omitted.

MMEMory:LS

Alias of `MMEMory:CATalog?`.

MMEMory:MKDIRectory

Usage:
`MMEMory:MKDIRectory <Dir: STRING>`

Description:
Creates a directory.

Parameters:

`Dir:`	`STRING`	Required. The directory to create.

For security reasons, this command will have no effect unless filesystem commands are explicitly enabled via User Preferences in the PicoVNA 5 software.

MMEMory:MOVe

Usage:
`MMEMory:MOVe <Source: STRING> <Dest: STRING>`

Usage:
Move a file to another location.

For security reasons, this command will have no effect unless filesystem commands are explicitly enabled via User Preferences in the PicoVNA 5 software.

Parameters:

`Source: STRING`	Required. Move from.
`Dest: STRING`	Required. Move to.

MMEMory:MV

Alias of `MMEMory:MOVe`.

MMEMory:RM

Alias of `MMEMory:DELete`.

MMEMory:RMDIRectory

Usage:
`MMEMory:RMDIRectory <File: STRING>`

Description:
Delete the selected directory and its contents.

For security reasons, this command will have no effect unless filesystem commands are explicitly enabled via User Preferences in the PicoVNA 5 software.

Parameters:

`File: STRING`	Required. The directory to delete.

MMEMory:STORe:SESSion

Usage:
`MMEMory:STORe:SESSion [File: STRING]`

Description:
Export the current session to a file.

Parameters:

`File: STRING`	Optional. The file to export to.

MMEMory:STORe:STATe

Usage:
`MMEMory:STORe:STATe <Compatibility: STRING> [File: STRING]`

Description:
Export the current configuration to a file.

Parameters:

`Compatibility: STRING`	Required. May be 1 (for compatibility with SCPI standard), or may be the target file.
`File: STRING`	Optional. The file to export to, if using the other argument for SCPI compatibility. Otherwise, omitted.

MMEMory:STORe:TRACe

Usage:
`MMEMory:STORe:TRACe <Channel: STRING> <Type: STRING> <OutputFilePath: STRING>`

Description:
Output data to Touchstone or CSV format. Raw A/B data can also be exported where it is available.

The data (S-parameters) to export are set by the following commands:

- `MMEMory:STORe:TRACe:OPTion:NUMPORTS`
- `MMEMory:STORe:TRACe:OPTion:ONEPORTPARAMETER`

Touchstone options are set by the following commands:

- `MMEMory:STORe:TRACe:OPTion:TABS`
- `MMEMory:STORe:TRACe:OPTion:TOUCHSTONEDATAFORMAT`

CSV options are set by the following commands:

- `MMEMory:STORe:TRACe:OPTion:SEPARATOR`
- `MMEMory:STORe:TRACe:OPTion:CSVDATAFORMAT`

This command synchronises in the same was as the CALCulate:DATa command. If the channel to export data from is a memory channel, the command will export the data and return immediately. Otherwise:

- If a measurement is not in progress, this command will export the data from the most recent sweep and return immediately.
- If the most recent sweep was aborted early, this command will export 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 PicoVNA 5 User Interface, and then stopped, then this command will export the data corresponding to what the UI is showing (a mixture of data from two different sweeps).
- If continuous-mode sweeping is currently in progress, this command will return immediately with an error and not export any data. If data export is required during continuous mode sweeping, save the sweep data to a new memory channel and export it from that.
- If a sweep (other than continuous-mode sweeping via the PicoVNA 5 User Interface) is in progress, this command will block until it has finished so the complete data from the current sweep can be exported.

This command does not currently support averaging of data across multiple sweeps (any desired averaging must be implemented by the caller). This command will export the same data regardless of whether or not averaging is enabled.

Parameters:

`Channel: STRING`	Required. Name of the channel to export. See documentation on specifying channels.
`Type: STRING`	Required. The type of file to export. Valid options are `S2P|CSV|RAWAB`.
`OutputFilePath: STRING`	Required. The relative path (including file name and extension) of the output file that will be created or overwritten. See documentation on specifying file paths.

MMEMory:STORe:TRACe:OPTion:CSVDATAFORMAT

Usage:
`MMEMory:STORe:TRACe:OPTion:CSVDATAFORMAT <DataTypes: STRING>`

Description:
Set the data types that will be exported to a CSV file by the MMEMory:STORe:TRACe command when the CSV format is specified. The data types to export are specified as a colon-separated list.

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

It is not valid to request both frequency-domain data types and time-domain data types in the same CSV file (it is necessary to perform multiple CSV exports if both frequency-domain and time-domain data are required).

For example, to cause the MMEMory:STORe:TRACe to output (only) time domain data for each measurement parameter, use: MMEMory:STORe:TRACe:OPTion:CSVDATAFORMAT TD

To cause the MMEMory:STORe:TRACe to output linear magnitude and phase data for each measurement parameter, use: MMEMory:STORe:TRACe:OPTion:CSVDATAFORMAT MAG;PHASE

Parameters:

`DataTypes:`	`STRING`	Required. A colon-separated list of data types that should be exported whenever saving a CSV file.

The data types can be any of:

- `LOGMAG` – Log-magnitude data (dB)
- `MAG` – Linear magnitude (U)
- `PHASE` – Phase (degrees)
- `TD` – Time Domain (U)
- `REAL` – Real (U)
- `IMAG` – Imaginary (U)
- `GD` – Group Delay.
- `VSWR` – VSWR (U)
- `POLAR` – Outputs the real and imaginary parts of each measurement point, in order.

MMEMory:STORe:TRACe:OPTion:NUMPORTS

Usage:
`MMEMory:STORe:TRACe:OPTion:NUMPORTS    <NumPorts: INT>`

Description:
For Touchstone and CSV exports, set whether to export:

- 1-port S-parameters – export data for S11/S22 (1-port S-parameters), *OR*
- 2-port S-parameters – export data for S11,S21,S12,S22 (2-port S-parameters)

By default, the 2-port option is selected and all S-parameters are exported when using the MMEMory:STORe:TRACe command for exporting CSV or Touchstone files.

If the 2-port option is selected, the MMEMory:STORe:TRACe:OPTion:ONEPORTPARAMETER command can be used to select which of S11 OR S22 is exported by the MMEMory:STORe:TRACe command.

Parameters:

`NumPorts:`	`INT`	Required. A single character: either 1 (for S11/S22 exports) or 2 (for S11,S21,S12,S22 exports).

MMEMory:STORe:TRACe:OPTion:ONEPORTPARAMETER

Usage:

`MMEMory:STORe:TRACe:OPTion:ONEPORTPARAMETER <OnePortParameter: STRING>`

Description:

If 1-port exports have been selected using MMEMory:STORe:TRACe:OPTion:NUMPORTS, which of S11 or S22 will be exported in text file exports?

Parameters:

`OnePortParameter:`	`STRING`	Required. Either `S11` or `S22`.

MMEMory:STORe:TRACe:OPTion:SEPARATOR

Usage:

`MMEMory:STORe:TRACe:OPTion:SEPARATOR <Separator: STRING>`

Description:

Set the separator for CSV file exports (including raw a/b data exports). The separator must be a single character.

Parameters:

`Separator:`	`STRING`	Required. The separator to use for CSV file exports. The separator must be a single character.

MMEMory:STORe:TRACe:OPTion:TABS

Usage:

`MMEMory:STORe:TRACe:OPTion:TABS <UseTabs: BOOL>`

Change whether tabs are used as column separators in Touchstone exports.

Parameters:

`UseTabs:`	`BOOL`	Required. Whether or not to use tabs instead of spaces as column separators in touchstone files.

MMEMory:STORe:TRACe:OPTion:TOUCHSTONEDATAFORMAT

Usage:

`MMEMory:STORe:TRACe:OPTion:TOUCHSTONEDATAFORMAT <Format: STRING>`

Description:

Set the data format used by the MMEMory:STORe:TRACe command during Touchstone export.

Parameters:

`Format:`	`STRING`	Required. One of: `REIM`, `MAGANG` or `DBANG`.

The following values can be passed to the `Format` parameter:

- `REIM` – Real/Imaginary.

- `MAGANG` – Magnitude/Angle.
- `DBANG` – dB Magnitude/Angle.

The default is Real/Imaginary.

SENSe:BANDwidth

Usage:
`SENSe:BANDwidth <Bandwidth: DOUBLE>`

Description:
Change the bandwidth of the sweep.

Parameters:
`Bandwidth: DOUBLE` The new bandwidth.

SENSe:BANDwidth?

Usage:
`SENSe:BANDwidth?`

Description:
Query the bandwidth of the sweep.

Parameters:
This command takes no parameters.

SENSe:FREQuency:STARt

Usage:
`SENSe:FREQuency:STARt <StartFreq: DOUBLE>`

Description:
Change the start frequency of the sweep.

Parameters:
`StartFreq: DOUBLE` The new start frequency.

SENSe:FREQuency:STARt?

Usage:
`SENSe:FREQuency:STARt?`

Description:
Query the start frequency of the sweep.

Parameters:
This command takes no parameters.

SENSe:FREQuency:STOP

Usage:
`SENSe:FREQuency:STOP <StopFreq: DOUBLE>`

Description:
Change the end frequency of the sweep.

Parameters:
`StopFreq: DOUBLE` The new end frequency.

SENSe:FREQuency:STOP?

Usage:
`SENSe:FREQuency:STOP?`

Description:
Query the end frequency of the sweep.

Parameters:
This command takes no parameters.

SENSe:LEVel

Usage:
`SENSe:LEVel <PowerLevel: DOUBLE>`

Description:
Change the power level of the sweep.

Parameters:
`PowerLevel: DOUBLE` The new power level.

SENSe:LEVel?

Usage:
`SENSe:LEVel?`

Description:
Query the power level of the sweep.

Parameters:
This command takes no parameters.

SENSe:SWEep:POINts

Usage:
`SENSe:SWEep:STEP <FreqStep: DOUBLE>`

Description:
Change the frequency step of the sweep.

This will update the number of sweep points as necessary to produce a sweep with this step over the configured frequency range.

Parameters:
`FreqStep: DOUBLE` The new frequency step.

SENSe:SWEep:POINts?

Usage:
`SENSe:SWEep:POINts?`

Description:
Query the point count of the sweep.

Parameters:
This command takes no parameters.

SENSe:SWEep:STEP

Usage:
`SENSe:SWEep:STEP <FreqStep: DOUBLE>`

Description:
Change the frequency step of the sweep.

This will update the number of sweep points as necessary to produce a sweep with this step over the configured frequency range.

Parameters:
`FreqStep:` `DOUBLE` The new frequency step.

SENSe:SWEep:STEP?

Usage:
`SENSe:SWEep:STEP?`

Description:
Query the frequency step of the sweep.

Parameters:
This command takes no parameters.

SENSe:TEMPerature?

Usage:
`SENSe:TEMPerature?`

Description:
Returns the instrument's internal temperature in degrees centigrade.

If no instrument is yet connected, or an instrument is connected that does not support temperature readings, an error message will be returned.

If the instrument is still initialising, NaN will be returned. In this case, run this command again later to obtain a temperature reading.

Parameters:
This command takes no parameters.

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.

