PicoVNA®

Vector Network Analyzers

User's Guide

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
This 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 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.t 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.

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		

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 behavior.

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 radius.

To prevent measurement errors and extend the useful life of test leads and accessory connectors, ensure that liquid and particulate 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.

# 2   Quick start guide

2.1   Installing the software
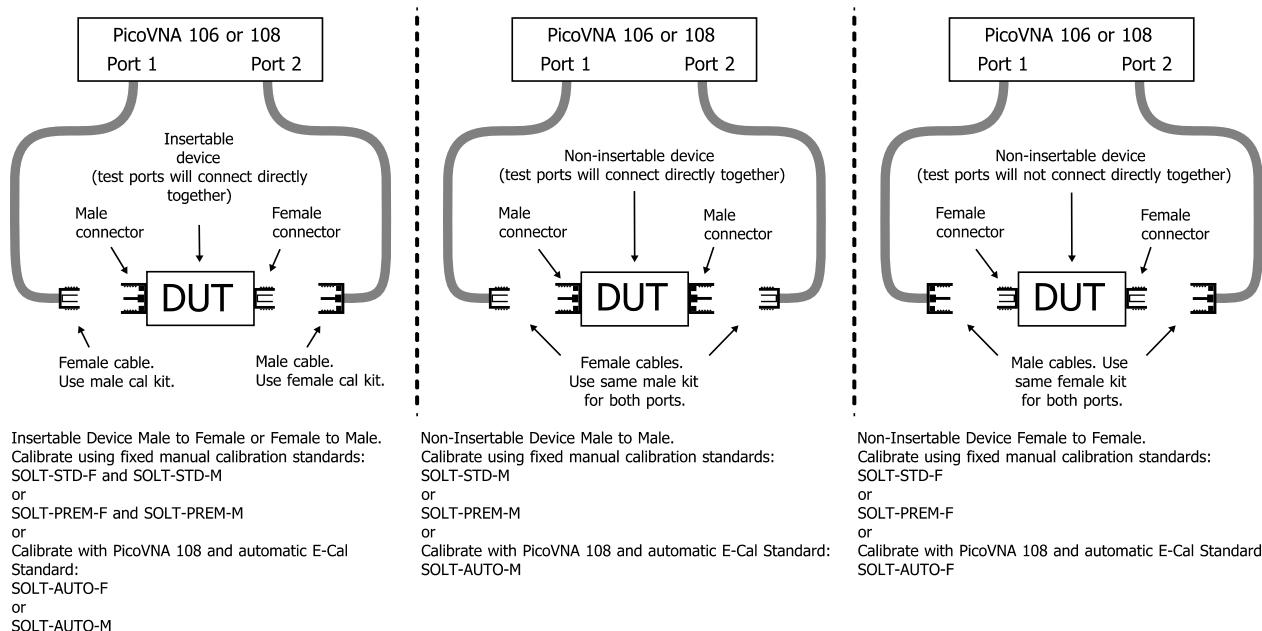
- Obtain the software from www.picotech.com/downloads:
    o **PicoVNA 2** (for the PicoVNA 106 model)
    o **PicoVNA 3** (for the PicoVNA 108 model)
- Connect the PicoVNA unit to the computer and wait while Windows automatically installs the driver.

In case of difficulties, refer to Software installation for more details.

Mixer measurements (PicoVNA 108 only)
Control of the PicoSource AS108 300 kHz to 8 GHz signal source is built into the PicoVNA software. If you wish to carry out mixer measurements using other sources or sensors it is very likely that you will need to install the Keysight® IO Libraries Suite to support communication with external instruments through either the USB or GPIB interfaces. Please see www.keysight.com for details.

2.2   Loading the calibration kit(s)

Insertable Device Male to Female or Female to Male.
Calibrate using fixed manual calibration standards:
SOLT-STD-F and SOLT-STD-M
or
SOLT-PREM-F and SOLT-PREM-M
or
Calibrate with PicoVNA 108 and automatic E-Cal
Standard:
SOLT-AUTO-F
or
SOLT-AUTO-M

Non-Insertable Device Male to Male.
Calibrate using fixed manual calibration standards:
SOLT-STD-M
or
SOLT-PREM-M
or
Calibrate with PicoVNA 108 and automatic E-Cal Standard:
SOLT-AUTO-M

Non-Insertable Device Female to Female.
Calibrate using fixed manual calibration standards:
SOLT-STD-F
or
SOLT-PREM-F
or
Calibrate with PicoVNA 108 and automatic E-Cal Standard:
SOLT-AUTO-F

For manual SOLT calibration:

- Run the PicoVNA 2 or PicoVNA 3 software
- In the main menu, select **Tools > Calibration kit**
- Click **Load P1 kit,** select the data for your Port 1 kit and then click **Apply**
- Click **Load P2 kit**, select the data for your Port 2 kit and then click **Apply**

Select the calibration kit(s) required depending on the device to be tested.

Note: If testing a non-insertable DUT with, for example, female connectors, use a single female kit for ports 1 and 2.
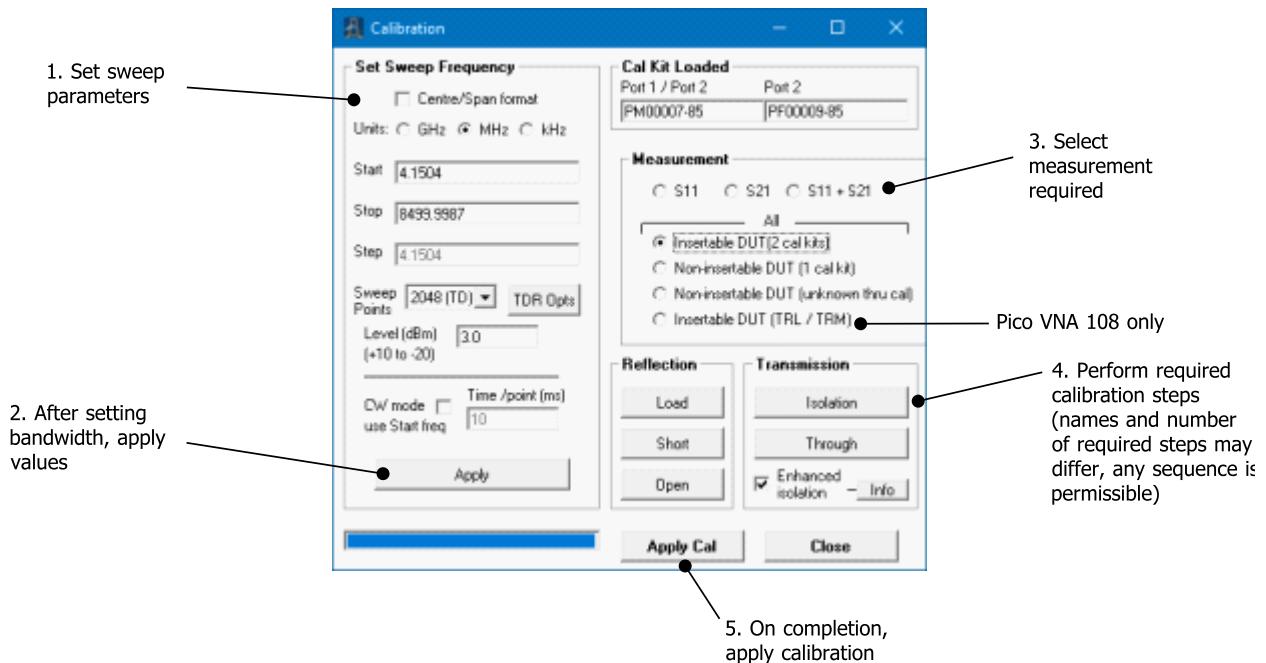
For the PicoVNA 108 and an automated calibration:

- Run the PicoVNA 3 software
- Connect the E-Cal module to a spare USB port on the controlling PC
- In the main menu, select **Tools** > **Calibration kit**

- Click **Electronic Cal kit**
- Select the E-Cal module and Port Adaptor arrangement to suit the test ports
- Connect the E-Cal module, port adaptor and test ports to exactly match the selected configuration
- Click **Find** and load EasyCal data
- Upon completion select **Exit**
- Then click **Apply** in the **Calibration Kit Parameters** menu

2.3   Setting up calibration parameters
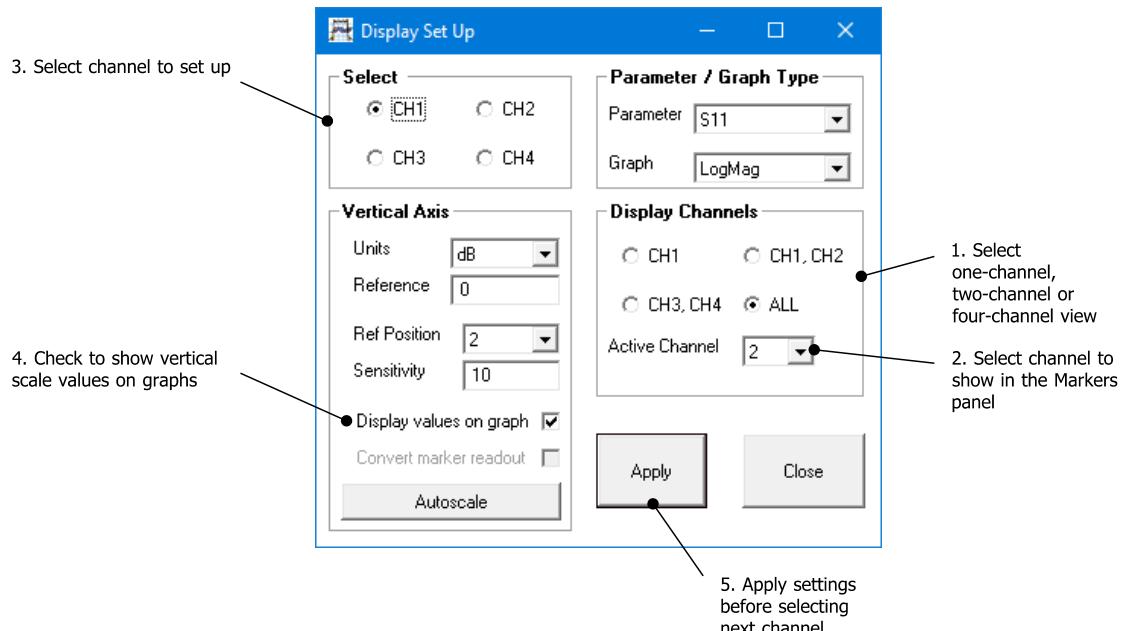
- Click **Calibration** to open the **Calibration** window:

1. Set sweep parameters

2. After setting bandwidth, apply values

3. Select measurement required

Pico VNA 108 only

4. Perform required calibration steps (names and number of required steps may differ, any sequence is permissible)

5. On completion, apply calibration

2.4   Setting up display parameters

See [Display Setup](#) for details on using the mouse to set values.

- Click **Display** in the main window to open the **Display Set Up** window:

- When finished, click **Start** in the main window to begin measurements

2.5   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 averaging	Calibration power	Comments
Fastest speed	10 kHz	None	+0 dBm	Set bandwidth to 140 kHz during measurement
Best accuracy and ~100 dB dynamic range	100 Hz	None	−3 dBm	Leave bandwidth set to 100 Hz during measurement
General use, fast speed, ~90 dB dynamic range	1 kHz	None	+0 dBm	Leave bandwidth set to 1 kHz during measurement
Best dynamic range	10 Hz	None	+6 dBm	Leave bandwidth set to 10 Hz during measurement. Refer to "Calibration for best dynamic range – minimizing the effect of crosstalk".

2.6   Running in demo mode

Demo mode allows you to explore the user interface software with no instrument connected.

- To enter demo mode, run the PicoVNA 2 or PicoVNA 3 software with no instrument connected.
- For demo mode, click **Ignore** in the dialog that appears.
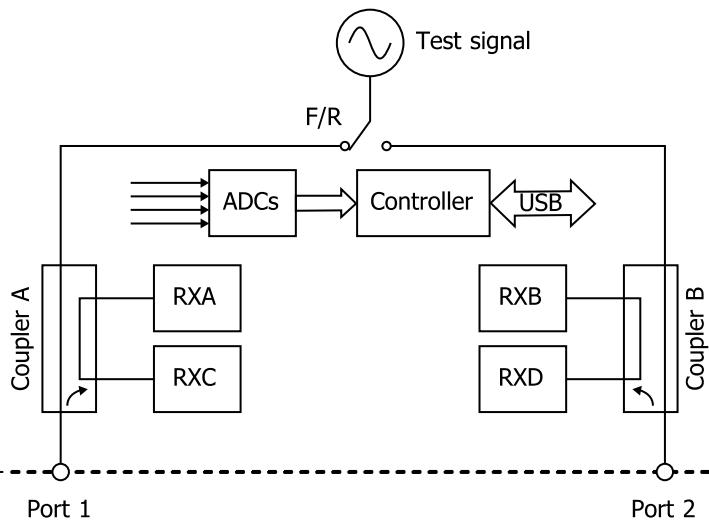
The software will then offer you a selection of demonstration measurements.

3   Description

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

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

A simplified block diagram of the instrument is shown below:
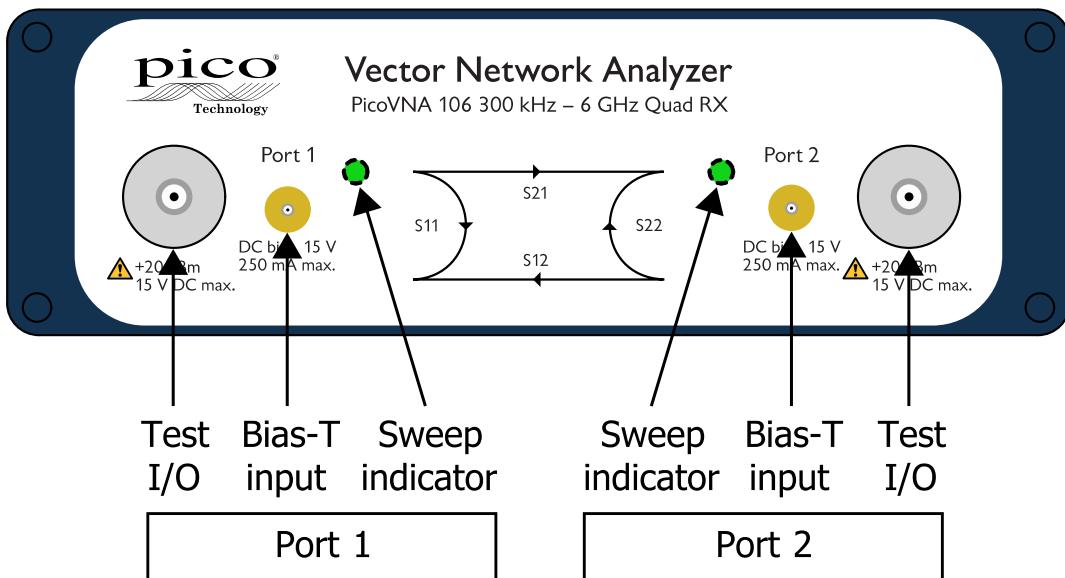
Simplified block diagram of the PicoVNA units
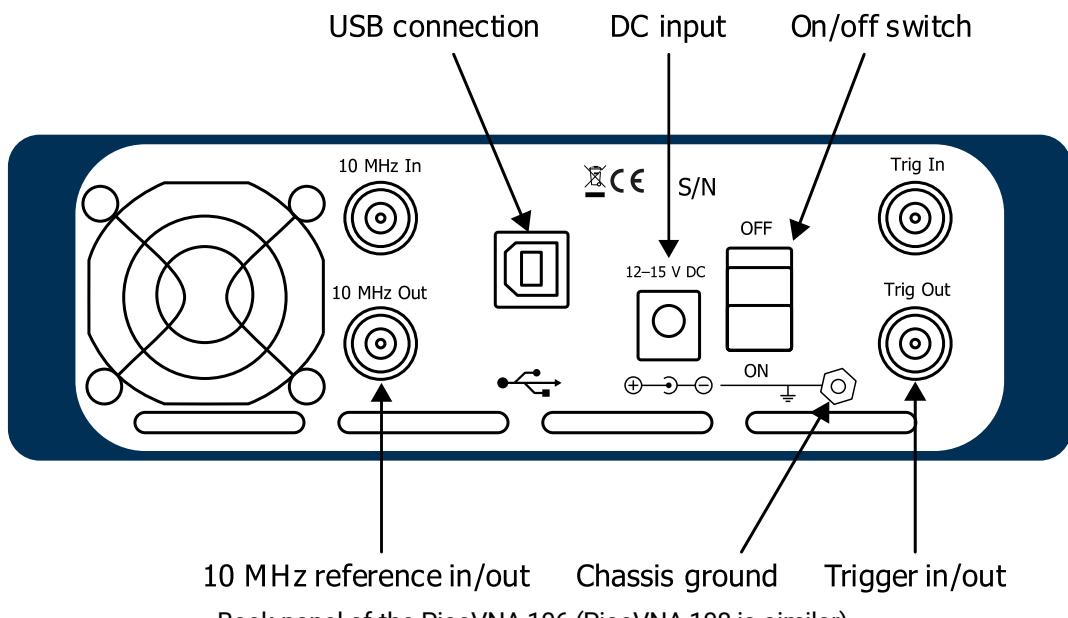
The architecture is based on a four-receiver (Quad RX) arrangement using a bandwidth of up to 140 kHz. Couplers A and B are wideband RF bridge components which provide the necessary directivity in both directions. Signal detection is by means of analog-to-digital converters used to sample the IF signal. The sample data is processed by the embedded controller to yield the I and Q components. The detection system operates with an IF of 1.3 MHz and employs a patented circuit technique to yield fast speeds with very low trace noise.

The instrument's software runs on a personal computer and communication with the instrument is through the USB interface. The software carries out the mathematical processing and allows the display of measured parameters in many forms, including:
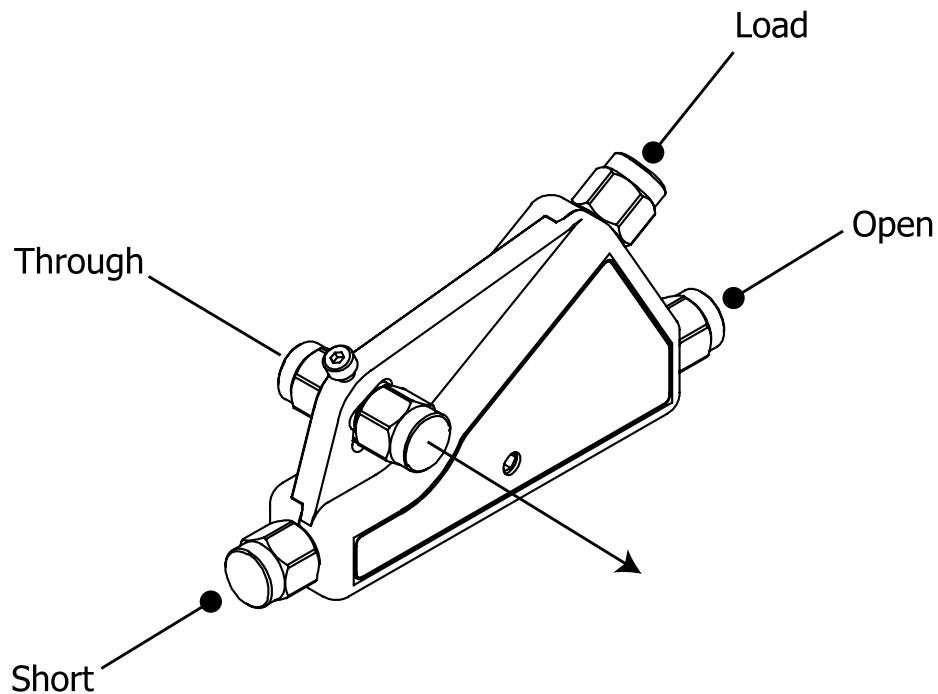
- frequency domain
- time domain
- de-embedding utility
- measuring output power at the 1 dB gain compression point
- measuring AM to PM conversion
- measuring frequency mixer characteristics (PicoVNA 108 only)
- measuring phase and amplitude alignment of two external signal sources (PicoVNA 108 only)
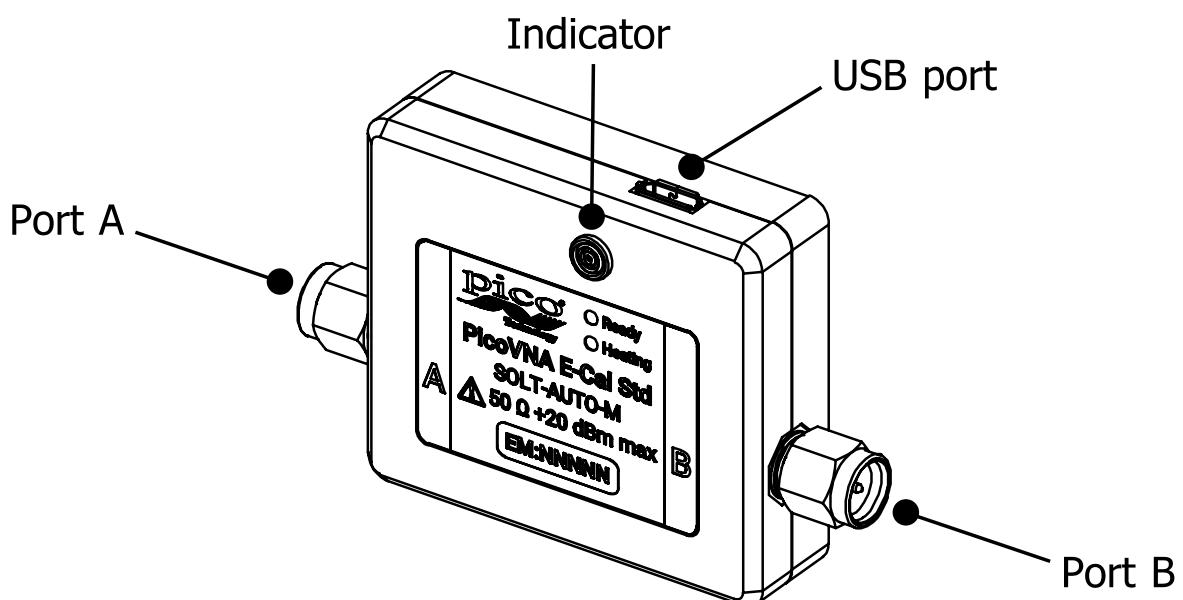
Front panel of the PicoVNA 106 (PicoVNA 108 is similar)

Back panel of the PicoVNA 106 (PicoVNA 108 is similar)

SOLT-STD-M/F and SOLT-PREM-M/F manual calibration standards

**SOLT-AUTO-M/F automatic (E-Cal) calibration standards**
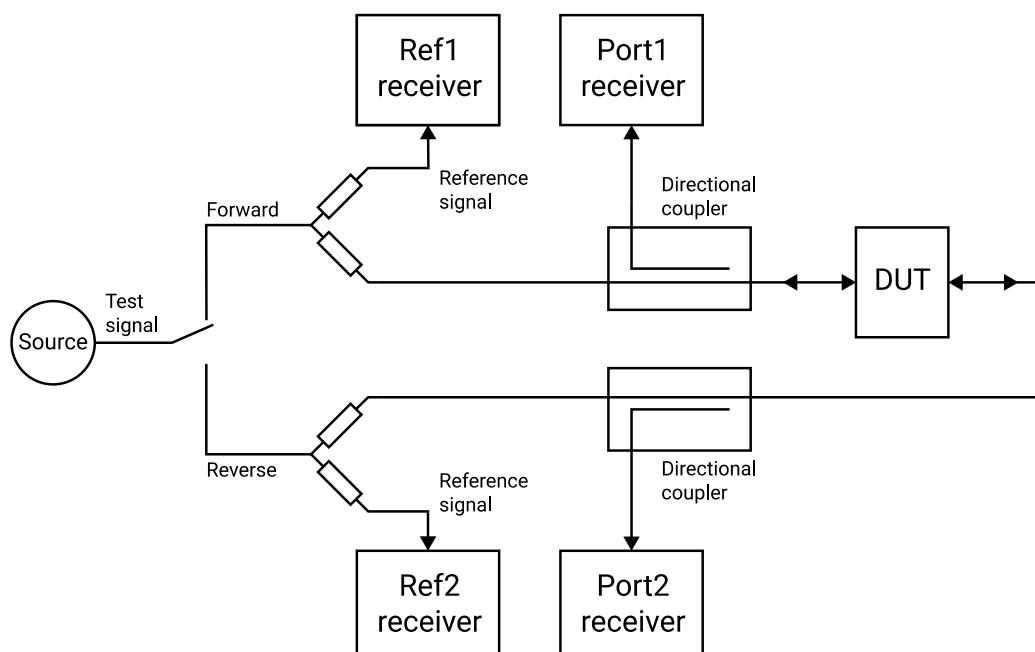
4   Vector network analyzer basics

4.1   Introduction

A vector network analyzer 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 vector network analyzer measures both the magnitude and phase of these signals.

4.2   Structure of the VNA

The VNA consists of a tunable RF source, the output of which is split into two paths. The signal feeds to the couplers are 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 Port1 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 Port2 receiver where its magnitude and phase are measured. The measurements at the Port1 and Port2 receivers are referenced to the measurements made by the Ref1 and Ref2 receivers so that any variations due to the source are removed. The Ref1 and Ref2 receivers also provide a reference for the measurement of phase.


Simplified vector network analyzer block diagram
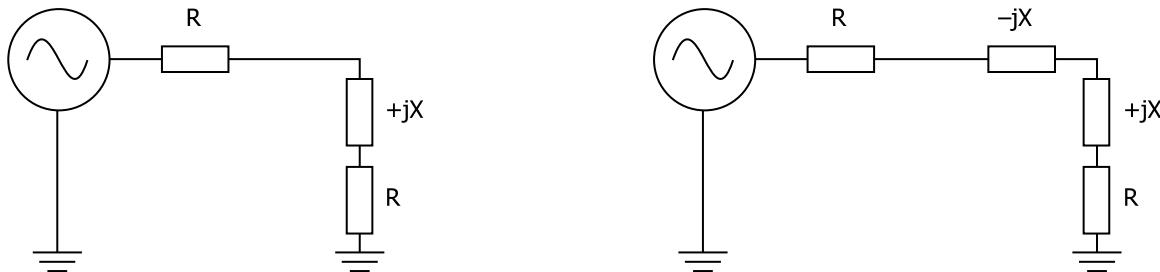
In reverse mode, the test signal is applied to the output of the DUT, and the Port2 receiver is used to measure the reflection from the output port of the DUT while the Port1 receiver measures the reverse transmission through the DUT.

4.3   Measurement

Vector network analyzers have the capability to measure phase as well as magnitude. This is important for fully characterizing 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 (see figure).

Source drives an unmatched
load. Some signal is reflected.

Matching network, −jX,
ensures all power is
transmitted to the load.

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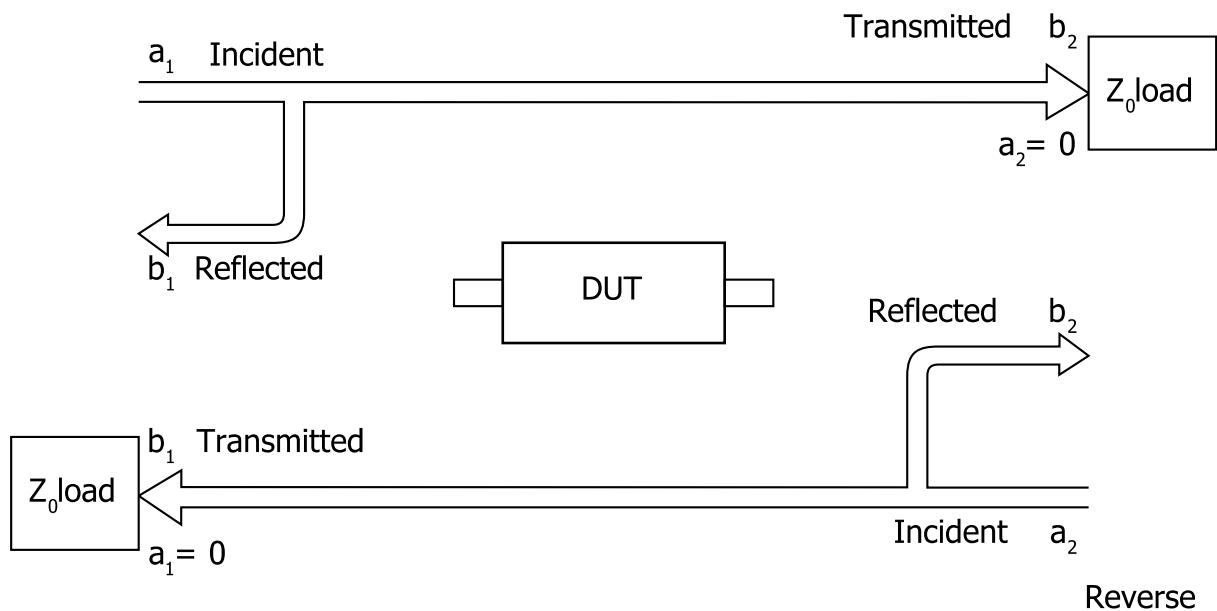
The ability to measure phase is also important for determining phase distortion in a network. Phase distortion can be important in both analog and digital systems. In digital transmission systems, where the constellation depends on both amplitude and phase, any distortion of phase can have serious effects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

4.4   S-parameters

The basic measurements made by the vector network analyzer are S (scattering) parameters. Other parameters such as H, Y, T and Z parameters may all be deduced from the S-parameters if required. The reason for measuring S-parameters is that they are made under conditions that are easy to produce at 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 device under test or may cause oscillation.

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 (see figure below).

Forward

a₁   Incident

Transmitted   b₂

Z_0load

$a_2 = 0$

b₁   Reflected

DUT

Reflected   b₂

Z_0load

b₁   Transmitted

$a_1 = 0$

Incident   a₂

Reverse

$$S_{11} = \frac{reflected}{incident} = \frac{b_1}{a_1}\bigg|a_2 = 0 \qquad\qquad S_{22} = \frac{reflected}{incident} = \frac{b_2}{a_2}\bigg|a_1 = 0$$

$$S_{21} = \frac{transmitted}{incident} = \frac{b_2}{a_1}\bigg|a_2 = 0 \qquad\qquad S_{12} = \frac{transmitted}{incident} = \frac{b_1}{a_2}\bigg|a_1 = 0$$

S-parameter definitions

The measured parameters are presented in a file similar to the one below. The format is as follows:

- Header lines: these start with a ! symbol and give general information such as time and date.
- Format line: this starts with a # symbol and gives information about the format of the data.
  - First field gives the frequency units, in this case MHz
  - Second field indicates the parameters measured, in this case S-parameters
  - Third field indicates the format of the measurement, in this case MA meaning magnitude and angle. Others formats are RI, meaning real and imaginary, and DB, meaning log magnitude and angle.
- Data lines. The number of columns of data depends on the parameters that have been measured.
  - A 1-port measurement measures the reflected signal from the device under test and usually produces three columns. If the format is MA (magnitude and angle), the first column is the measurement frequency, the second is the magnitude of S_{11} and the third is the angle of S_{11}. If the format is RI, the second column is the real part of S_{11} and the third column is the imaginary part of S_{11}.
  - When a reflection and transmission measurement is made there are five columns of data. Column 1 is the measurement frequency, columns 2 and 3 contain S_{11} magnitude and angle or real and imaginary data, and columns 4 and 5 contain S_{21} magnitude and angle or real and imaginary data.
  - If a full 2-port measurement is made, there will be nine columns of data. Column 1 contains frequency information, columns 2 and 3 S_{11} data, 4 and 5 S_{21} data, 6 and 7 S_{12} data, and 8 and 9 S_{22} data.
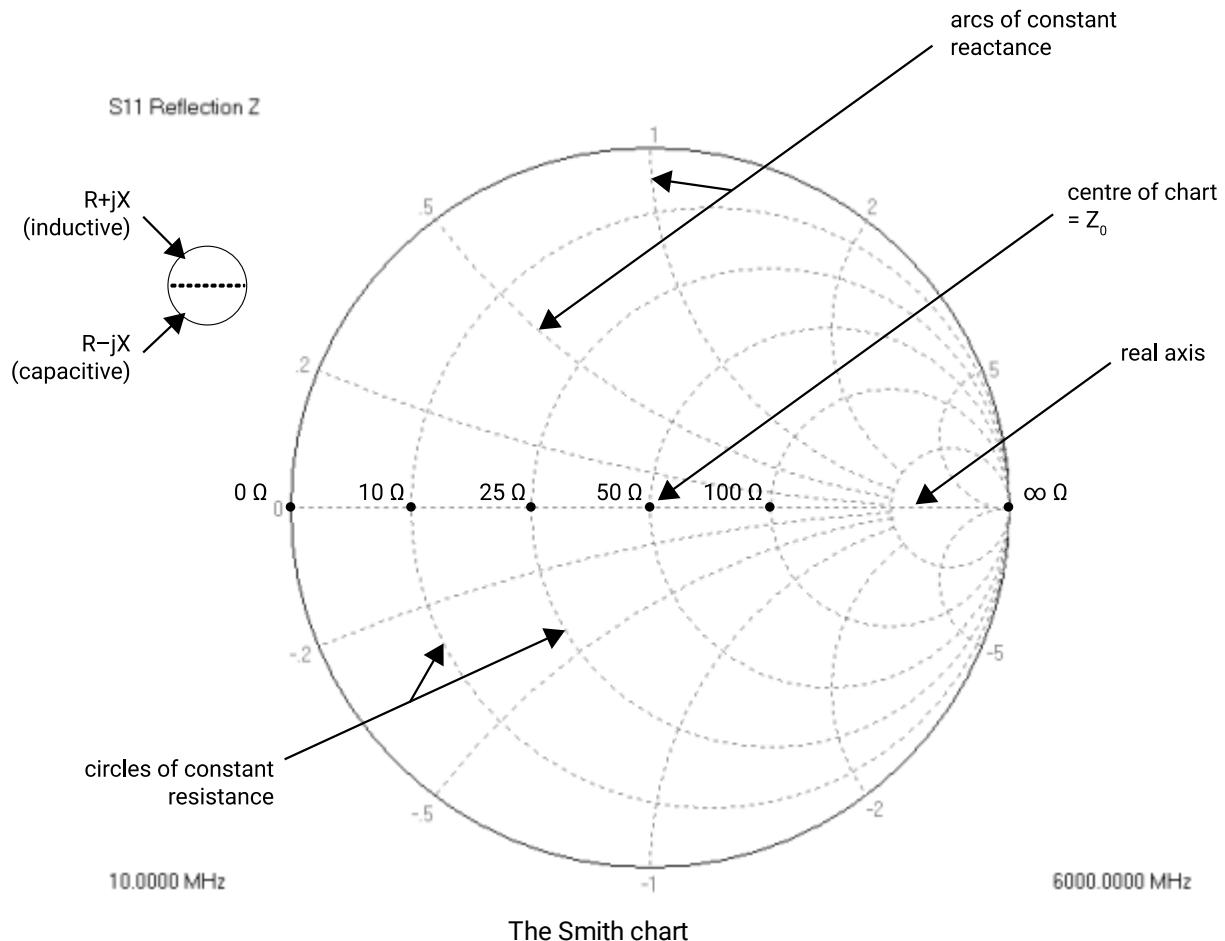
The PicoVNA 106 and 108 can generate full set of 2-port parameters but you can choose to export either 1-port .s1p or full 2-port .s2p S-parameter files to suit most RF and microwave circuit simulators.

Part of a typical 2-port S-parameter file is shown below. The header shows that the frequency units are MHz, the data format is Magnitude and Angle and the system impedance is 50 Ω. Column 1 shows frequency, 2 and 3 S_{11}, 4 and 5 S_{21}, 6 and 7 S_{12}, and 8 and 9 S_{22}.

```
! 06/09/2005  15:47:34
! Ref Plane: 0.000 mm
# MHZ S MA R 50
!
3        0.00776   16.96   0.99337    -3.56   0.99324    -3.53   0.00768   12.97
17.985   0.01447   19.99   0.9892    -20.80   0.98985   -20.72   0.01519   15.23
32.97    0.01595   20.45   0.98614   -37.96   0.98657   -37.95   0.01704    6.40
47.955   0.01955   28.95   0.98309   -55.15   0.98337   -55.10   0.018      1.75
62.94    0.02775   24.98   0.98058   -72.29   0.98096   -72.29   0.0199    -6.07
77.925   0.03666   11.76   0.97874   -89.46   0.9803    -89.45   0.02169  -23.06
92.91    0.04159   -6.32   0.97748  -106.62   0.9786   -106.62   0.01981  -48.43
107.895  0.0426   -24.79   0.97492  -123.77   0.97579  -123.89   0.01424  -87.79
122.88   0.0396   -41.35   0.97265  -141.25   0.97269  -141.30   0.00997 -166.81
137.865  0.03451  -52.96   0.96988  -158.65   0.96994  -158.76   0.01877  113.15
152.85   0.03134  -56.07   0.96825  -176.27   0.96858  -176.28   0.03353   69.81
167.835  0.03451  -57.72   0.96686   166.10   0.96612   165.99   0.04901   34.83
182.82   0.04435  -67.59   0.9639    148.18   0.96361   148.21   0.06131    1.42
197.805  0.05636  -86.28   0.96186   130.15   0.96153   130.06   0.07102  -33.33
212.79   0.06878 -110.45   0.95978   111.82   0.95996   111.90   0.07736  -69.57
227.775  0.08035 -136.14   0.9557     93.50   0.9568     93.41   0.08303 -107.21
242.76   0.09099 -161.24   0.95229    74.84   0.95274    74.89   0.08943 -144.34
257.745  0.10183  175.34   0.94707    56.03   0.94755    55.95   0.09906 -179.63
```
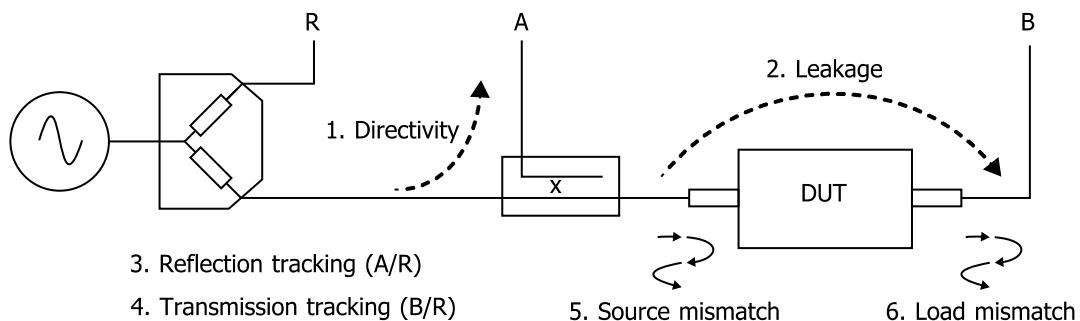
4.5   Displaying measurements

Input and output parameters, S_{11} and S_{22}, are often displayed on a polar plot or a Smith chart. The polar plot shows the result in terms of the complex reflection coefficient, but impedance cannot be directly read off the chart. The Smith chart maps the complex impedance plane onto a polar plot. All values of reactance and all positive values of resistance, from 0 to ∞, fall within the outer circle. This has the advantage that impedance values can be read directly from the chart.

The Smith chart

4.6   Calibration and error correction

Before accurate measurements can be made, the network analyzer needs to be calibrated. 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.

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

4.7   Other measurements

S-parameters are the fundamental measurement performed by the network analyzer, but many other parameters may be derived from these including H, Y and Z parameters.

4.7.1   Reflection parameters

The input reflection coefficient Γ can be obtained directly from S_{11}:

$$\Gamma = \frac{V_{reflected}}{V_{incident}} = S_{11} = \rho\angle\phi$$
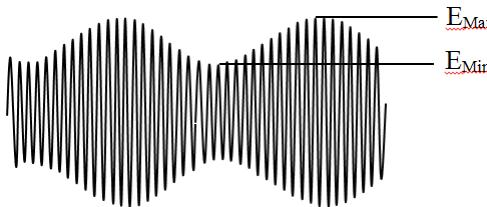
ρ is the magnitude of the reflection coefficient i.e. the magnitude of S_{11}:

$$\rho = |S_{11}|$$

Sometimes ρ is expressed in logarithmic terms as return loss:

return loss $= -20\log(\rho)$

VSWR can also be derived:

$$\text{VSWR} = \frac{E_{max}}{E_{min}} = \frac{1 + \rho}{1 - \rho}$$

VSWR definition

4.7.2   Transmission parameters

Transmission coefficient *T* is defined as the transmitted voltage divided by the incident voltage. This is the same as S_{21}.

$$\text{T} = \frac{V_{transmitted}}{V_{incident}} = S_{21} = \tau\angle\phi$$

If T is less than 1, there is loss in the DUT, which is usually referred to as *insertion loss* and expressed in decibels. A negative sign is included in the equation so that the insertion loss is quoted as a positive value:
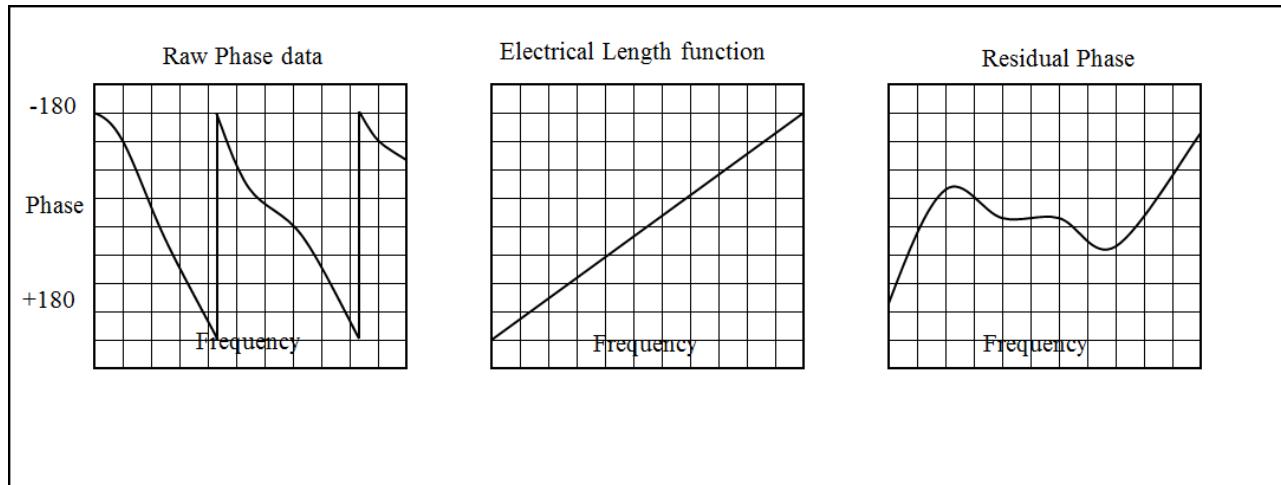
$$insertion\_loss(dB) = -20\log\left|\frac{V_{trans}}{V_{incident}}\right| = -20\log\tau$$

If T is greater than 1, the DUT has gain, which is also normally expressed in decibels:

$$insertion\_gain(dB) = 20\log\left|\frac{V_{trans}}{V_{incident}}\right| = 20\log\tau$$

4.7.3   Phase

The phase behavior of networks can be very important, especially in digital transmission systems. The raw phase measurement is not always easy to interpret as it has a linear phase increment superimposed on it due to the electrical length of the DUT. Using the reference plane function the electrical length of the DUT can be removed leaving the residual phase characteristics of the device.

Operation on phase data to yield underlying characteristics

4.7.4   Group delay

Another useful measurement of phase is group delay. Group delay is a measure of the time it takes a signal to pass through a network versus frequency. It is calculated by differentiating the phase response of the device with respect to frequency, i.e. the rate of change of phase with frequency:
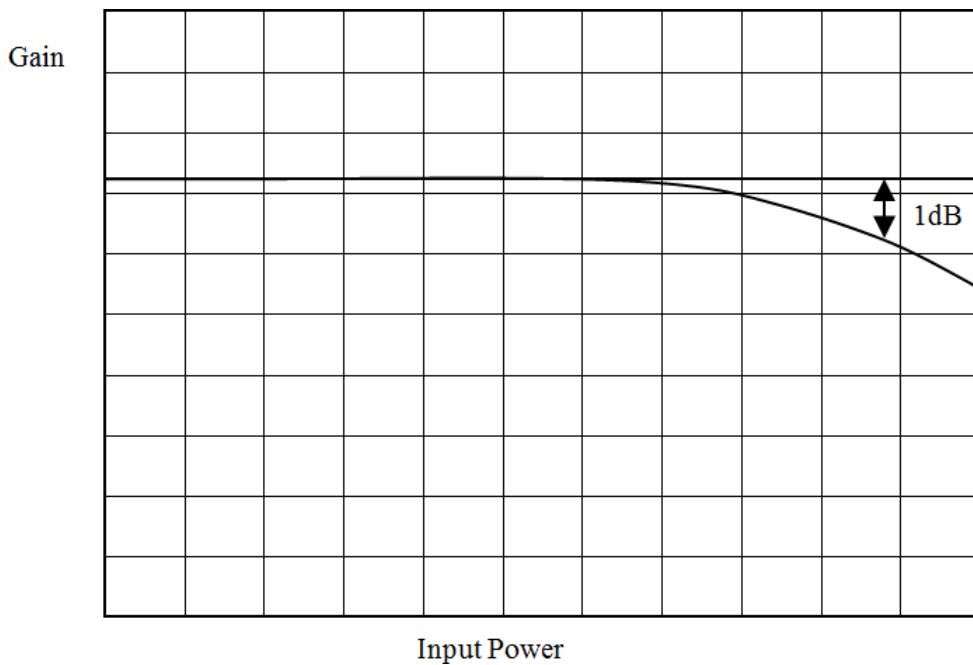
$$group\_delay = \frac{d\phi}{d\omega}$$

The linear portion of phase is converted to a constant value typically, though not always, representing the average time for a signal to transit the device. Differences from the constant value represent deviations from linear phase. Variations in group delay will cause phase distortion as a signal passes through the circuit.

When measuring group delay the aperture must be specified. Aperture is the frequency step size used in the differentiation. A small aperture will give more resolution but the displayed trace will be noisy. A larger aperture effectively averages the noise but reduces the resolution.

4.7.5   Gain compression

The 1 dB gain compression point of amplifiers and other active devices can be measured using the power sweep. The small signal gain of the amplifier is determined at low input power, then the power is increased and the point at which the gain has fallen by 1 dB is noted.

The 1 dB gain compression is often used to quote output power capability.

4.7.6   AM to PM conversion

Another parameter that can be measured with the VNA is AM to PM conversion. This is a form of signal distortion where fluctuations in the amplitude of a signal produce corresponding fluctuations in the phase of the signal. This type of distortion can have serious effects in digital modulation schemes where both amplitude and phase accuracy are important. Errors in either phase or amplitude cause errors in the constellation diagram.
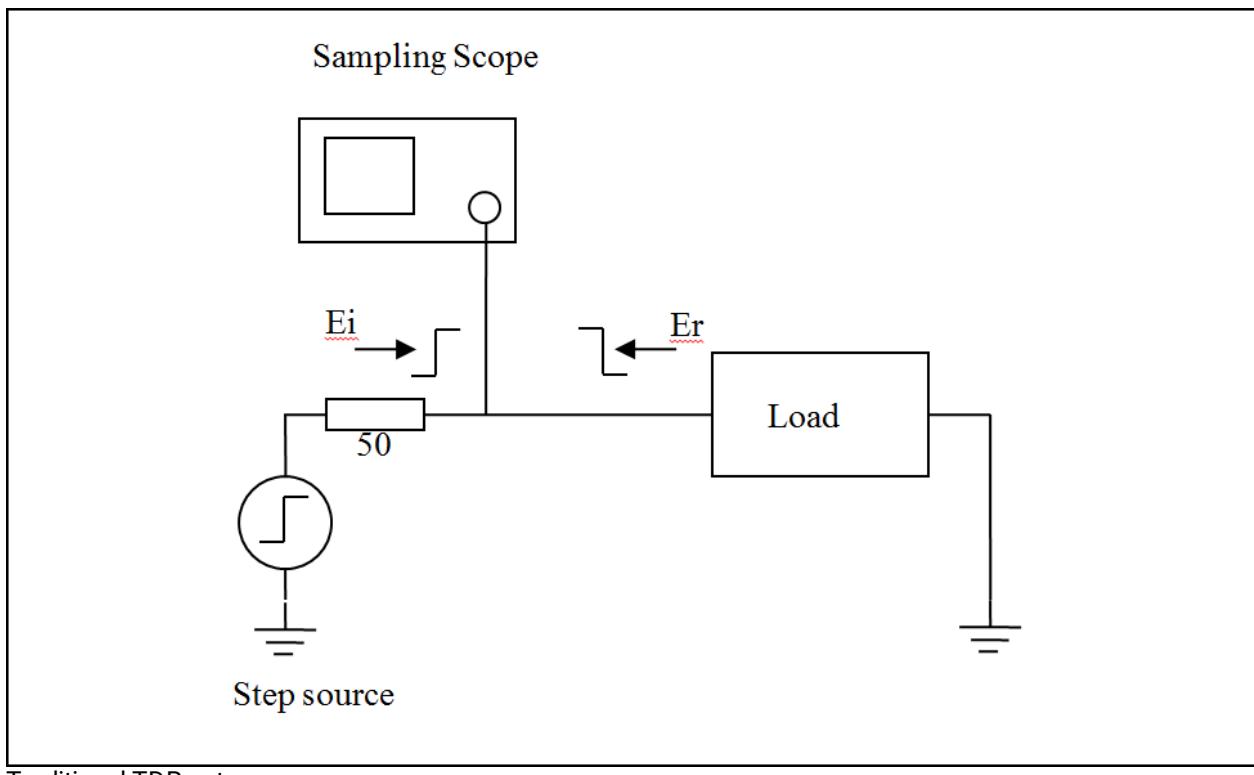
## 4.7.7   Time domain reflectometry (TDR)

Time domain reflectometry 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 network analyzer can determine the time domain response to a step input from a broad band frequency sweep at harmonically related frequencies. An inverse Fourier Transform is performed on the reflected frequency data (S_{11}) to give the impulse response in the time domain. The impulse response is then integrated to give the step response. Reflected components of the step excitation show the type of discontinuity and the distance from the calibration plane.
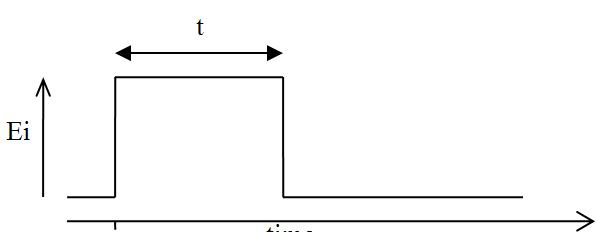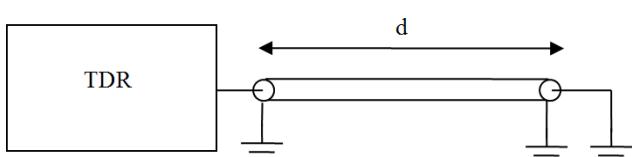
A similar technique is used to derive a TDT (Time Domain Transmission) signal from the transmitted signal data (S_{21}). This can be used to measure the rise time of amplifiers, filters and other networks. The following provides a more detailed treatment of TDR and TDT.

4.7.7.1   Traditional TDR

The traditional TDR consists of a step source and sampling oscilloscope (see figure below). A 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 scope. By measuring the ratio of the input voltage to the reflected voltage, the impedance of the load can be determined. Also, by observing the position in time when the reflections arrive, it is possible to determine the distance to impedance discontinuities.

Traditional TDR setup

### 4.7.7.1.1   Example: shorted 50 ohm transmission line
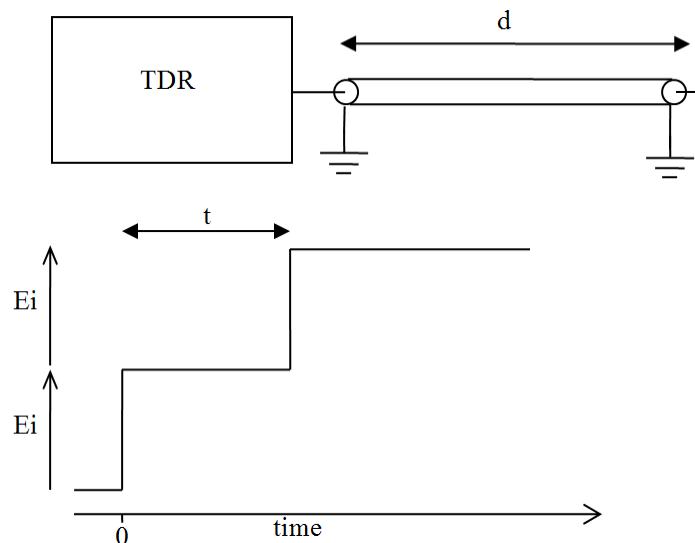
Simplified representation of the response of a shorted line.

For a transmission line with a short circuit (figure above) the incident signal sees the characteristic impedance of the line so the scope measures Ei. 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 canceling 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 canceled by the reflection. The result measured by the scope is a pulse of magnitude Ei 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:

$$d = \frac{tv}{2}$$

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.

4.7.7.1.2   Example: open-circuited 50 ohm transmission line

Simplified representation of the response of a open line
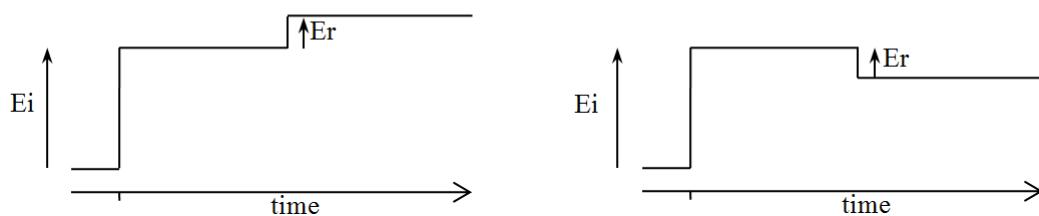
In the case of the open circuit transmission line (figure above) the reflected signal is in phase with the incident signal, so the reflected signal combines with the incident signal to produce an output at the scope that is twice the incident signal. Again, the distance *d* can be calculated if the velocity of the signal is known.

4.7.7.1.3   Example: resistively terminated 50 ohm transmission line
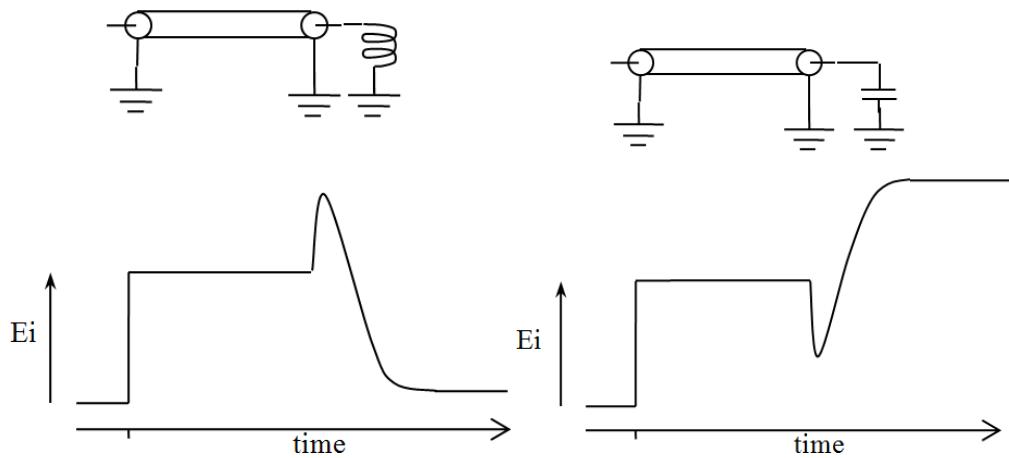
$$\rho = \frac{Er}{Ei} = \frac{R-50}{R+50}$$

Simplified representation of the response of a resistively terminated line
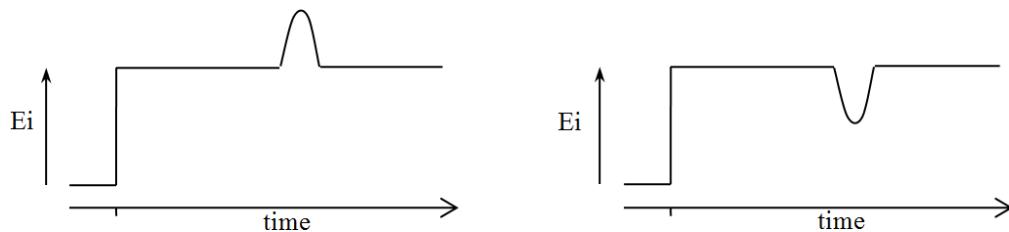
4.7.7.1.4   Reactive terminations and discontinuities

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

Simplified representation of the response of a reactively terminated line

Similarly, the position and type of 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 a 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.

Simplified representation of the response of a line discontinuity

4.7.7.2   Time domain from frequency domain

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

4.7.7.2.1   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. This is the method supported by the PicoVNA 106 and 108.

The lowpass method uses an Inverse Fourier Transform to determine the impulse response in the time domain from the reflection coefficient measured in the frequency domain. 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. Once the impulse response is computed, the step response may be determined from the time integral of the impulse response. In the step response mode the trace is similar to that of a TDR, except that 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 example TDR plots above).

To facilitate the use of the Inverse Fourier Transform to compute the time domain response, the samples in the frequency domain must be harmonically related and consist of 2^n points. For this reason, the TDR facility in the PicoVNA 106 and 108 makes available special 512, 1024, 2048 and 4096-frequency-point calibrations with a stop frequency of up to 6000 MHz (PicoVNA 106) or 8500 MHz (PicoVNA 108). The resulting alias-free range is a function of the number of frequency points (*N*) and the total frequency span. It is given by the expression:

$$R = \frac{N - 1}{FreqSpan}$$

So, the available ranges on the PicoVNA units are approximately as follows:

Model	PicoVNA 106	PicoVNA 108
Ranges	100 ns, 171 ns, 341 ns, 683 ns	60 ns, 120 ns, 240 ns, 481 ns
Time resolution	98 ps to 84 ps	58 ps

The transform returns twice the number of points of the calibration in the time domain. Therefore the above ranges provide time resolutions approximately as shown.

4.7.7.2.2   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 as good as in the lowpass mode. However, the method can be used for circuits where there is no DC path and hence is suitable for AC-coupled circuits such as bandpass filters. This method is not currently supported by the PicoVNA 106 and 108.

4.7.7.3   Windowing

The bandwidth of the network analyzer is limited by the frequency range, so the frequency domain data will be truncated at the bandwidth of the analyzer. Also the analyzer gathers data at discrete frequencies. The result of the sampled nature of the data and the truncation in the frequency domain is to produce a sin(*x*)/*x* response when transformed to the time domain. 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 implementing the Inverse Fourier Transform.

The windowing function progressively reduces the data values to zero as the edge of the frequency band is approached, thus minimizing the effect of the discontinuities. When the modified data is transformed, the ringing is reduced or removed depending on the selected windowing function. However, the windowing function reduces the bandwidth and so increases the width of the pulse in impulse response mode and slows the edge in step response mode. A balance must be made between the width of the pulse, or speed of the edge, and the amount of ringing to be able to determine closely spaced discontinuities. The PicoVNA 106 and 108 allow you to choose a rectangular window (no bandwidth reduction), a Hanning window (raised cosine), or a Kaiser−Bessel window. The order of the Kaiser−Bessel window is configurable.

4.7.7.4   Aliasing

The sampled nature of the data means it is subject to the effects of aliasing. The result is repetition of time-domain response at the effective sampling rate in the frequency domain. This limits the maximum time delay and hence maximum cable length that can be observed. In the PicoVNA 106 this is 683 ns (approximately 138 m of cable) and in the PicoVNA 108 it is 481 ns (approximately 97 m of cable).

5   Getting started

Refer to the Quick Start Guide above for initial instructions, then return here for more detail.

5.1   Minimum requirements

A PC or laptop is required to operate the VNA. The recommended minimum requirements are stated in the Specifications.

The performance of the software is influenced by the performance of the PC and video adaptor installed in it. It is important that an adaptor with good graphics performance is used. As a general guide, it is recommended that an adaptor with at least 64 MB of memory is used.

5.2   Software installation

Follow the Quick Start Guide to install the software from the disk or from www.picotech.com. The installer will copy the program and the USB driver to your computer. You need administrative privileges in order to run the installer.

The installer creates a support directory at one of these locations:
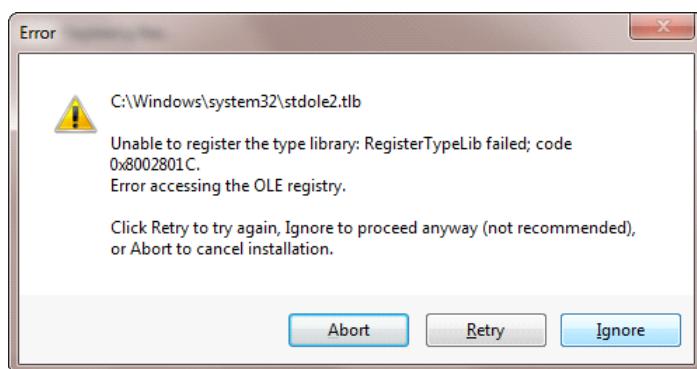
- PicoVNA 106: `C:\User\Public\Documents\PicoVNA2`
- PicoVNA 108: `C:\User\Public\Documents\PicoVNA3`

This directory contains the following files:

- `xxx-log.txt`   The status log file. '`xxx`' is the serial number
- `DefCal.cal`   Default calibration data (last used calibration)
- `UsersGuide.pdf`   This *User's Guide*
- `Support\`   Folder with data files to support the software

5.2.1   Typical error messages

On Windows 7 machines it is common to see the following error message:

It is safe to click **Ignore** to continue the installation.

5.2.2   Mixer measurements (PicoVNA 108 only)

Control of the PicoSource AS108 300 kHz to 8 GHz signal source is built into the PicoVNA software. If you wish to carry out mixer measurements using other sources or sensors it is very likely that you will need to install the Keysight® IO Libraries Suite to support communication with external instruments through either the USB or GPIB interfaces. Please see www.keysight.com for details.

5.3   Switching on the VNA

When the VNA is powered on, the front-panel channel activity indicators will flash to indicate that the controller has started correctly.
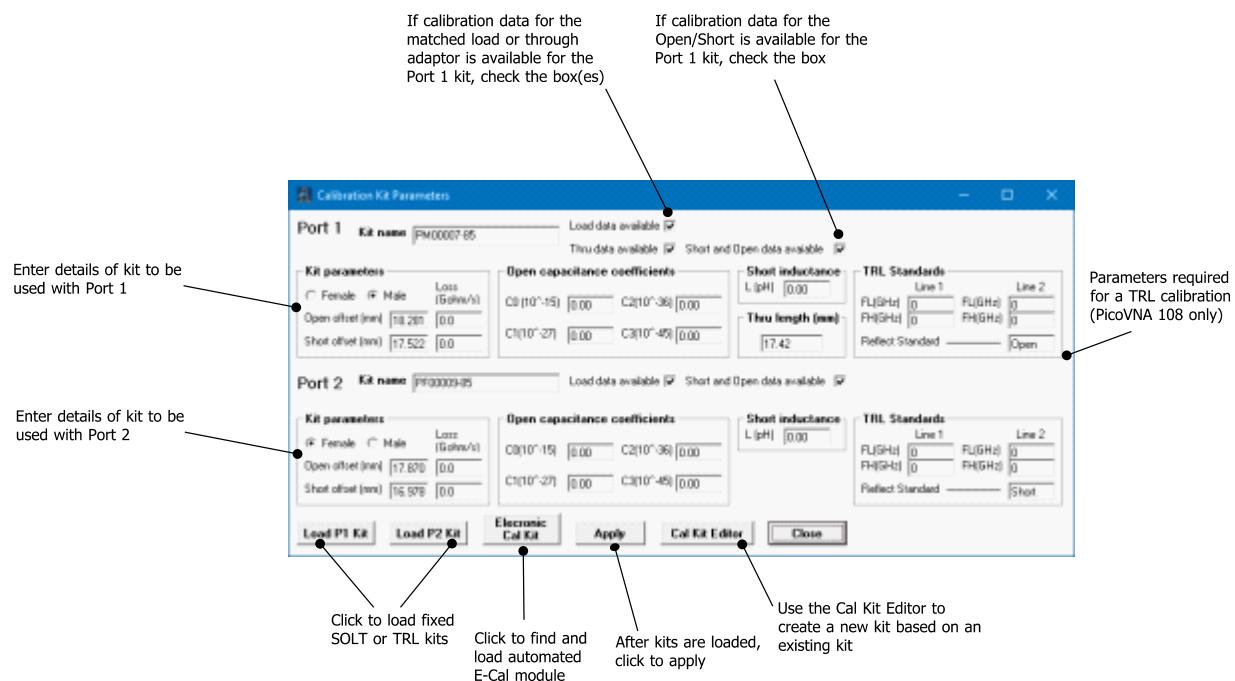
5.4   Calibration kit parameters

The minimum requirements to carry out a 12-term calibration (full error correction) depend on the device to be tested. For example, the most accurate calibration is for *insertable* devices, and this requires a total of six standards: three of the four in each of the male and female cal standards.

An 'insertable' device is one that has connectors of different sexes at its ports. On the other hand, a calibration for a non-insertable device can be carried out using only three standards by using the *unknown thru* calibration method.

The calibration kits parameters can be inspected using the **Calibration Kit Parameters** window (see below) found under the **Tools** menu. From this the kit editor can be launched to modify and create new kits as discussed later in the section.

The *unknown thru* calibration method only requires that the *thru* adaptor be reciprocal: that is, have $S_{21} = S_{12}$.

Calibration Kit window. The short/open offsets are in mm in air.

5.4.1   Manual fixed SOLT calibration - insertable DUT

Two Pico calibration kits required: Premium PC3.5 kits SOLT-PREM-M and SOLT-PREM-F or Standard SMA kits SOLT-STD-M and SOLT-STD-F or alternative calibration kits comprising:

- Open circuit (2 pieces, one male and one female)
- Short circuit (2 pieces, one male and one female)
- Matched termination (2 pieces, one male and one female)

For insertable DUTs the requirement is for two calibration kits, one of each sex. Generally, it is required that the matched termination should be of good quality and, as a guide, should have a return loss of better than 40 dB. However, the PicoVNA 106 and 108 allow terminations with relatively poor return loss values to be used and still maintain good accuracy. This is discussed in [Using a matched termination](#).

5.4.2   Manual fixed SOLT calibration - non-insertable DUT

One Pico calibration kit required: Premium PC3.5 kit SOLT-PREM-M or SOLT-PREM-F or Standard SMA kits SOLT-STD-M or SOLT-STD-for alternative calibration kit comprising:

- Open circuit (1 piece)
- Short circuit (1 piece)
- Matched termination (1 piece)
- Either a characterized through connection adaptor (1 piece) or any uncharacterized reciprocal adaptor

For non-insertable DUTs only a single calibration kit is required. In addition, a reciprocal but otherwise *unknown thru* adaptor, or a fully characterized *thru* adaptor, is required. The latter is supplied with all Pico standard kits.

5.4.3   Open circuit model

The open circuit capacitance model used is described by the equation below, where *F* is the operating frequency. Generally, with typical open circuit standards, the effect is small, amounting to no more than a few degrees of phase shift at 6 or 8.5 GHz.

$$C_{open} = C_0 + C_1F + C_2F^2 + C_3F^3$$

In addition, an offset length (sometimes referred to as offset delay) can be entered as well as the loss of the offset line.

5.4.4   Short circuit model

The short circuit inductance is modeled by an inductance component and in addition, a non-zero offset length can be entered together with the loss of the offset line.
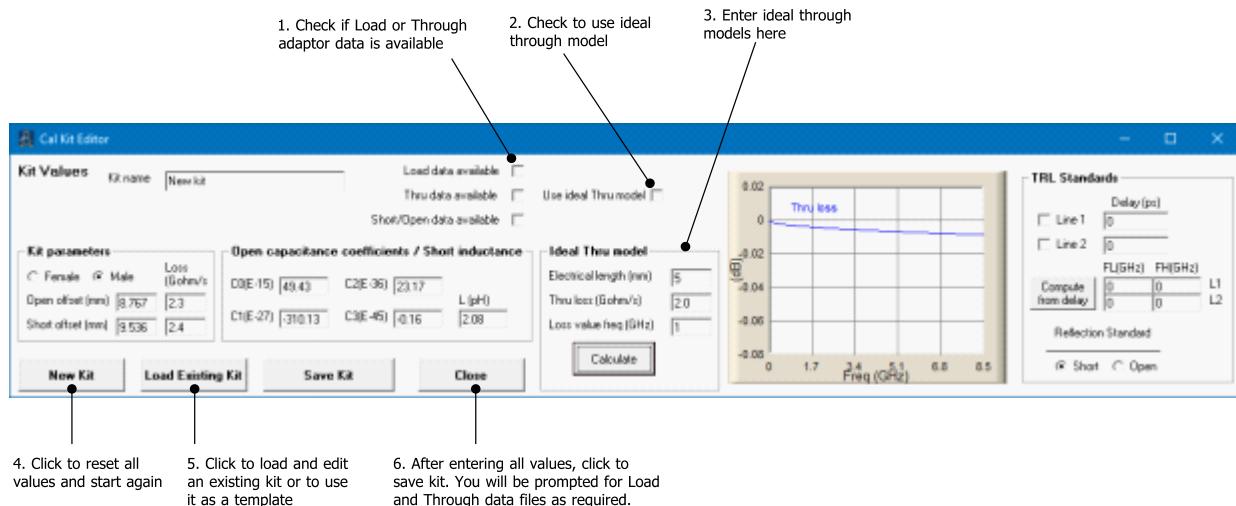
5.4.5   Short and open without models

The PicoVNA 106 and 108 support short and open standards defined by data only. In this case the data is supplied in the form of a 201-frequency-points table. Each frequency point has three comma-separated entries: frequency (in MHz), real part of the reflection coefficient and the imaginary part of the reflection coefficient.

5.4.6   Calibration kit editor

As already mentioned, the calibration kit editor can be used to create or edit an existing calibration kit. The figure below shows the editor window. A typical example is to create a new kit using an existing kit as a template to speed the process. So, the process would be to first load the existing calibration kit from the [Calibration Kit Parameters](#) window. Type the new kit name in the name box and modify the parameters as needed. Finally, click **Save Kit** to save the new kit with a new name.

In the above example, if the existing kit loaded had load data or through data and you want to replace this with new data, uncheck the appropriate box and then check it again.

1. Check if Load or Through adaptor data is available

2. Check to use ideal through model

3. Enter ideal through models here

4. Click to reset all values and start again

5. Click to load and edit an existing kit or to use it as a template

6. After entering all values, click to save kit. You will be prompted for Load and Through data files as required.

Calibration Kit Editor

The calibration kits optionally supplied with the PicoVNA 106 and 108 provide an economical solution while retaining good measurement accuracy. They are supplied with SMA or precision PC3.5 (SMA-compatible) connectors. Refer to the *PicoVNA 100 Series Data Sheet* for details.

5.4.7   Using a matched termination with poor return loss or unmodeled short and open

A successful calibration can be carried out without the need for a good-quality matched load. In order to retain accuracy, it is necessary to provide the instrument with accurate performance data of the matched load to be used. The data needs to be in a fixed format thus:

Frequency (MHz)	S11 (real)	S11 (imaginary)
↓	↓	↓
1.0	−1.7265E-03	7.7777E-05
30.995	−1.6588E-03	3.3093E-04
60.99	−1.4761E-03	5.9003E-04
90.985	−1.4653E-03	1.0253E-03
120.98	−1.3841E-03	1.2608E-03
150.975	−1.1924E-03	1.5800E-03
240.96	−1.0884E-03	1.9085E-03
300.95	−8.7216E-04	2.1355E-03
330.945	−7.0326E-04	2.4109E-03
360.94	−5.7006E-04	2.6790E-03

There must be 201 data lines. Typically these should cover the band 0.3 MHz to (6.00 GHz or 8.50 GHz). **No empty or comment lines are allowed.**

Format for characteristics of matched load

In the case when the models for the open and short are not known, it is possible to enter measured data in the same format as shown above. This approach can give good results if the open and short can be measured accurately, particularly at the higher frequencies where it is usually difficult to model components accurately.

When supplied, the data for the through connection adaptor must be in the format shown below. The data must be a full set of S-parameters with no empty or comment lines. It is important that the data spans as much of the full frequency range as possible, for example from 0.3 MHz to (6000 MHz or 8500 MHz).

Freq (MHz)	S11r	S11i	S21r	S21i	S12r	S12i	S22r	S22i
0.3	1.1450E-04	-1.0852E-04	0.9965E-01	-1.0394E-03	9.9947E-01	-7.4717E-04	1.0723E-04	4.9711E-05
40.3	2.9307E-04	1.9923E-04	9.9973E-01	-1.0241E-02	9.9934E-01	-1.0505E-02	2.0715E-04	2.0814E-04
80.3	4.1774E-04	4.3168E-04	9.9922E-01	-1.9672E-02	9.9927E-01	-1.9668E-02	2.8195E-04	2.8897E-04
120.3	5.3415E-04	5.7609E-04	9.9898E-01	-2.9165E-02	9.9855E-01	-2.8852E-02	4.0525E-04	2.8043E-04
160.3	7.1924E-04	6.4942E-04	9.9883E-01	-2.9165E-02	9.9855E-01	-2.8852E-02	4.0646E-04	2.8133E-04
200.3	7.8941E-04	7.5903E-04	9.9834E-01	-3.8214E-02	9.9846E-01	-3.8128E-02	5.4323E-04	2.2344E-04
240.3	9.9069E-04	7.8162E-04	9.9792E-01	-5.7033E-02	9.9758E-01	-4.7805E-02	5.7273E-04	2.9411E-04
280.3	1.0791E-03	8.0397E-04	9.9715E-01	-6.6419E-02	9.9699E-01	-6.5967E-02	5.7191E-04	2.6551E-04
320.3	1.2779E-03	8.5429E-04	9.9648E-01	-7.5557E-02	9.9625E-01	-7.5449E-02	6.3081E-04	2.9580E-04

...

and so on, to a total of 201 frequency points

Format for the characteristics of the through connector. These must be a full set of S-parameters (real and imaginary).

To add matched *load*, *short* and *open*, or *thru* adaptor data to a calibration kit, follow the steps below:

- Load kit using the Kit Editor (see Calibration Kit)
- Check the **Load Data Available** box and similarly the boxes for the **Thru** and **Short and Open circuits** in the **Kit Editor parameters** window.
- If the existing kit already has load, short and open, or through data, uncheck and recheck the appropriate box. **If this is not done, the existing data will be kept and copied to the new kit.**
- If needed, manually enter the rest of the kit parameters. Ensure that the correct offset is entered.
- Click **Save Kit**
- When prompted, select the data file containing the matched load or the *thru* adaptor data in the format shown above.
- Save the kit for future use by clicking the **Save Kit** button (see Calibration Kit).

Note: When a kit is loaded, any available *matched load* or *thru* adaptor data that is associated with the kit will be automatically loaded.
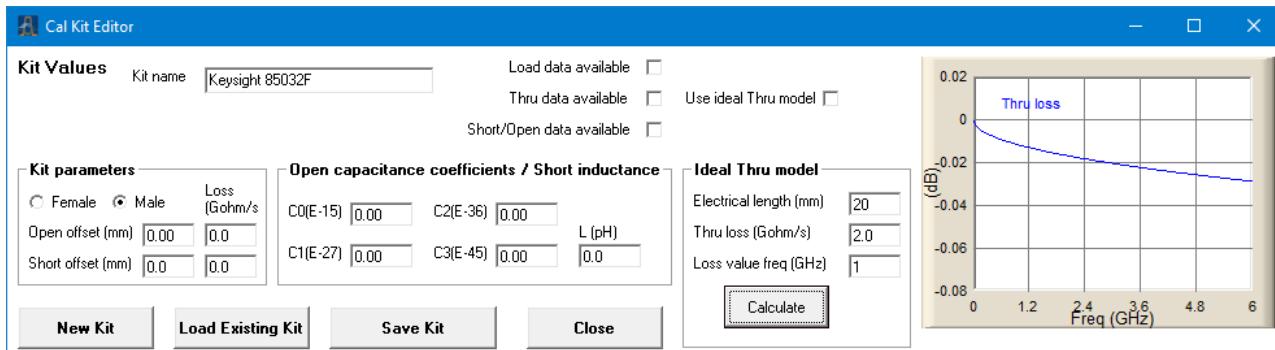

The calibration kits available for the PicoVNA 106 and 108 come complete with *matched load*, *short* and *open*, and *thru* adaptor data. Copy these files to your computer for easy access.

It is critically important that the correct kit data, with the correct serial number, is loaded.

5.4.8   Using a third-party calibration kit

The PicoVNA 106 and 108 may be used with third-party calibration kits, such as the Keysight/Agilent 85032F, that are characterized by polynomial coefficient models either in written form or as a text file.

1. Use the PicoVNA cal kit editor (**Tools** > **Calibration Kit** > **Cal Kit Editor**).

2. Uncheck all the "**data available**" boxes.

3. Enter the four poly coefficients of **Open capacitance**.

4. Enter only the L0 poly coefficient of **Short inductance** (neglecting the small and HF dominating coefficients)

5. Enter the **Short** and **Open Loss** terms.

6. Convert **Short** and **Open offset** times (ps) to distance (mm) in air and enter those.

7. The short and open Z_0 values are not used (assumed 50 Ω).

8. Nothing is entered for the Load.

9. As this Cal Kit does not have a **Thru**, we have left the length as zero. If a Thru is provided, measure the length (reference plane to reference plane in mm) and enter that to recreate these files.

10. Save the cal kit file(s) generated by the editor. We suggest including the calibration kit model number, and serial number if provided, in the file name.

5.4.9 Defining and Using TRL/TRM Calibration Standards (PicoVNA 108 Only)

Below is a summary explanation of preparation for a TRL/TRM calibration. Further detail can be gained from the white paper entitled TRL calibration for SMT devices using the PicoVNA 108.

Higher Frequencies - Reference line length
For the TRL calibration of higher frequencies it is generally recommended that the line length, ΔL, is selected to provide no less than 20º and no more than 160º of phase shift with respect to the thru length over the band of operation. In practice, best results are achieved by restricting the range to around 30º to 150º.
The required reference line length can be calculated as follows.

$$\Delta L = \frac{\varnothing}{360}\left(\frac{c}{f\sqrt{\varepsilon_{\text{eff}}}}\right)$$

Φ = phase shift in degrees
f = frequency
c = speed of light
ε_{eff} = effective dielectric constant
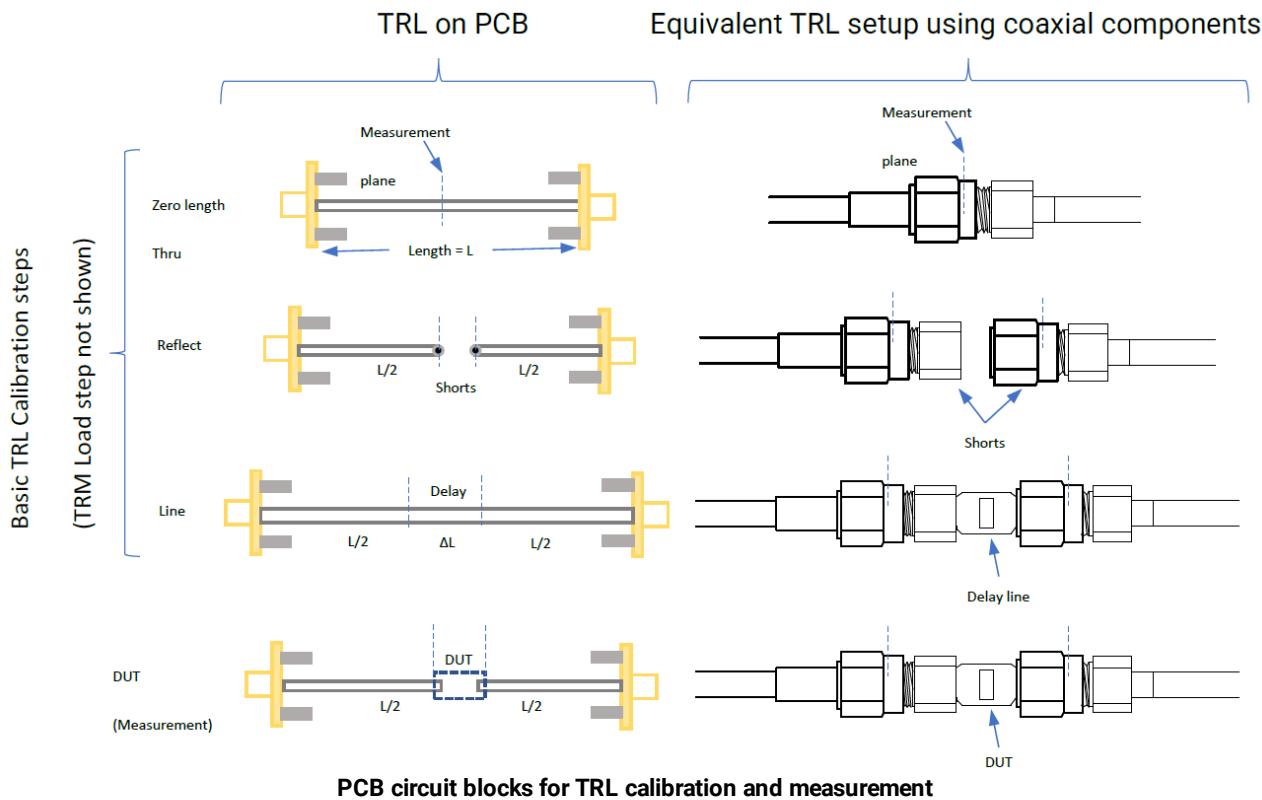
It is sensible to avoid lower microwave frequencies in order to avoid skin depth effects. So, keeping to 1.5 or 2 GHz and above may be a good idea.

Note: The absolute value of L is not important.
However, all L/2 sections shown must be identical and be exactly half the value of L.

PCB circuit blocks for TRL calibration and measurement

For example, assuming a nominal 50 Ω line with resulting effective dielectric constant of 3.35, to achieve 30º phase shift at, say, 1.5 GHz, we find that:
ΔL = 9.1 mm
This reference line length of 9.1 mm would in turn provide 150º of phase shift at 7.5 GHz. So, the useable bandwidth for this line, as a TRL line standard, is 1.5 GHz to 7.5 GHz.
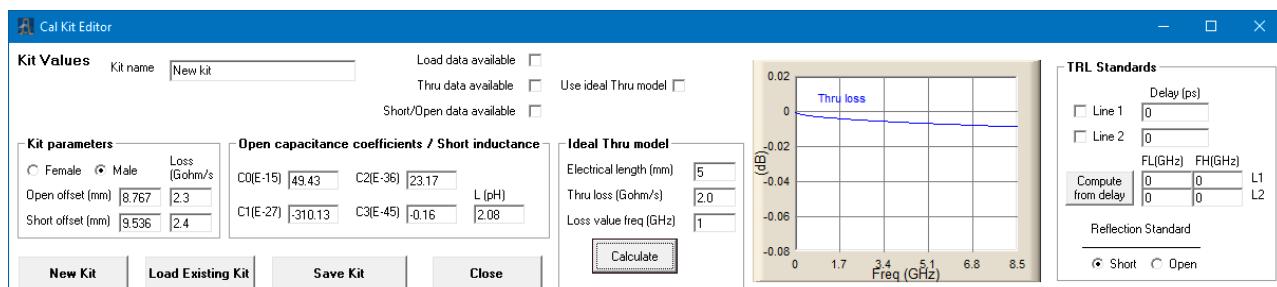
Lower frequencies - Matched Loads for TRM calibration
The PicoVNA 108 automatically switches to TRM at frequencies below those supported by the TRL reference line(s). The TRM technique relies on matched loads to set the reference impedance. This approach works well since good matched loads can easily be implemented at lower microwave frequencies (< 2 GHz). The frequency range of the TRL reference line is set in the calibration kit definition and is described in the following section.

TRL calibration kit
In order to perform a TRL calibration with the PicoVNA 108, a calibration kit file needs to be created. This can be done very easily using the calibration kit editor (**Tools** > **Calibration kit** > **Cal Kit Editor**).

Use the calibration kit editor to create the TRL cal kit file

TRL calibration kit – entering the reference line information
In this example we will use only one of the possible reference lines ('Delays') so we check just the box next to 'Line 1' to indicate that the cal kit has only one reference line. The Line 2 box is left unchecked as shown above.

We can either enter the electrical delay in ps and click the button **Compute from delay** to set the frequency range of the line, or preferably, enter directly a narrower frequency range we wish to assign to the reference line. The low frequency is entered into the box labeled **FL** and the high frequency into the box **FH**. Both values are in GHz.

TRL calibration kit – entering the Reflect Standard information

The next step is to select whether the Reflect Standard is going to be a short or an open circuit. Click the appropriate radio button as required. Note that it is only necessary to know approximately the value of the reflection coefficient of the Reflect Standard. So, for example we could use on-PCB short circuits implemented with vias to ground. For this, we can enter 100 pH as an approximate value of the inductance into the box labeled **L (pH)**. Alternatively a more accurate value might be available from design CAD or direct measurement.

Likewise if we chose to use Open reflection standards we would enter a capacitance value at C0.
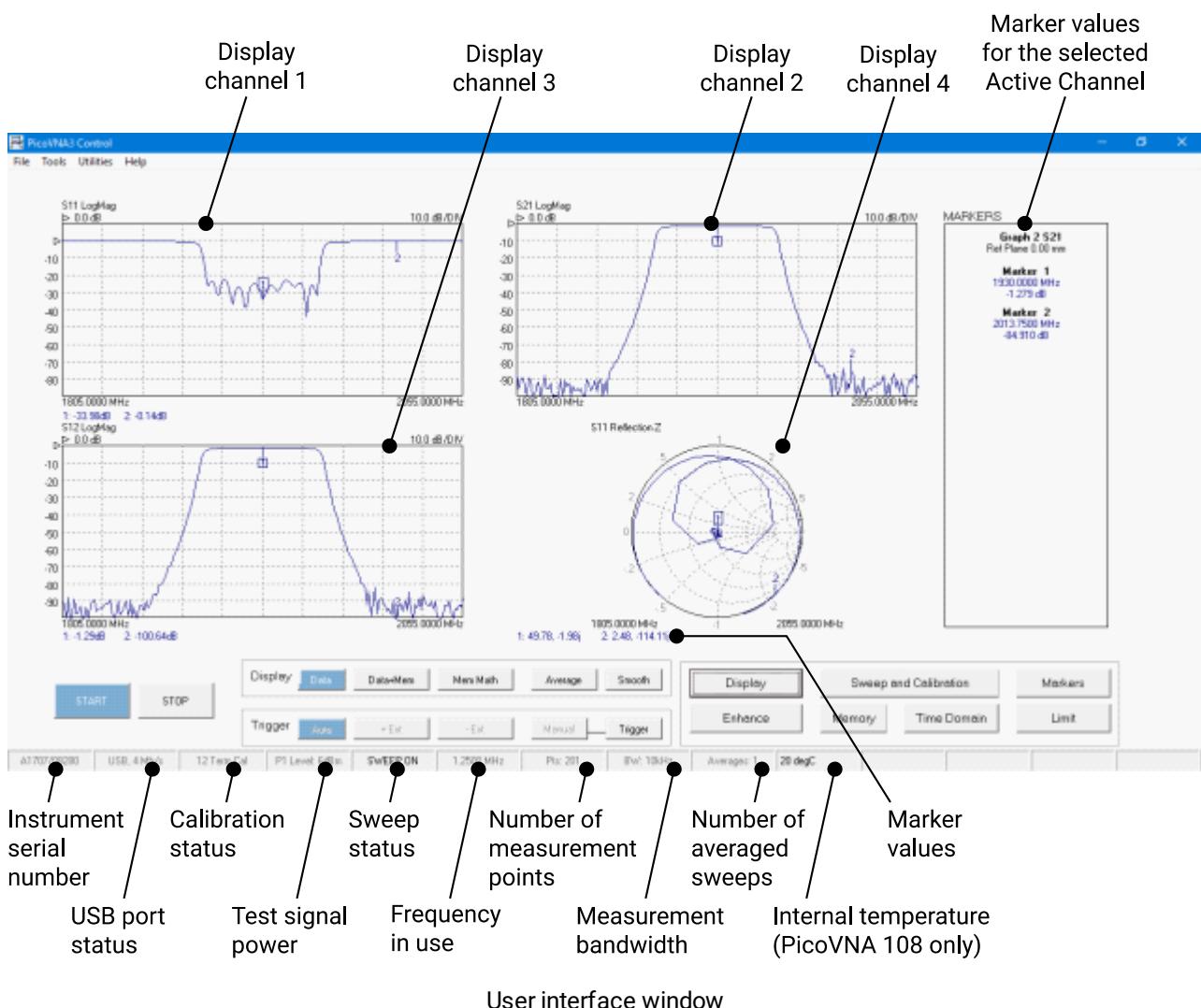
Finally, we enter the desired Kit name in the top left box and click **Save Kit** to save the file to disk. We would recommend indication of this being a TRL Kit with Open/Short reflect standards and possibly its Max frequency coverage within the file name.

6   Operation

The PicoVNA 2 and PicoVNA 3 software allows you to program the measurement parameters and plots the measurement results in real time. The main window includes a status panel that displays information including calibration status, frequency sweep step size and sweep status. The **Help** menu includes a copy of this manual.

6.1   The PicoVNA 2 or 3 main window

The PicoVNA 2 main window is shown below. PicoVNA 3 is similar. It is dominated by a large graphics area where the measurement results are plotted together with the readout of the markers. One, two or four plots can be displayed simultaneously. The plots can be configured to display the desired measurements.

User interface window
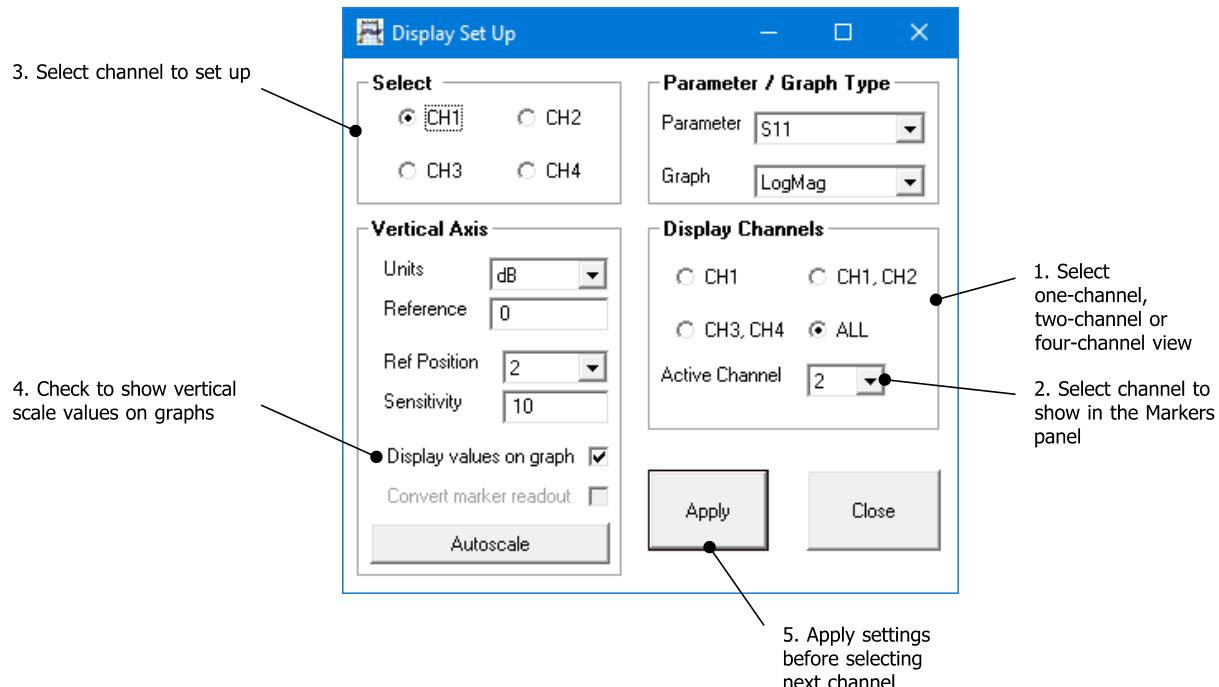
6.1.1   Display setup

Setting up the display is carried out through the **Display Set Up** window which is called up from the main window by clicking **Display**. The window is shown below. The typical sequence to set up the display is as follows:
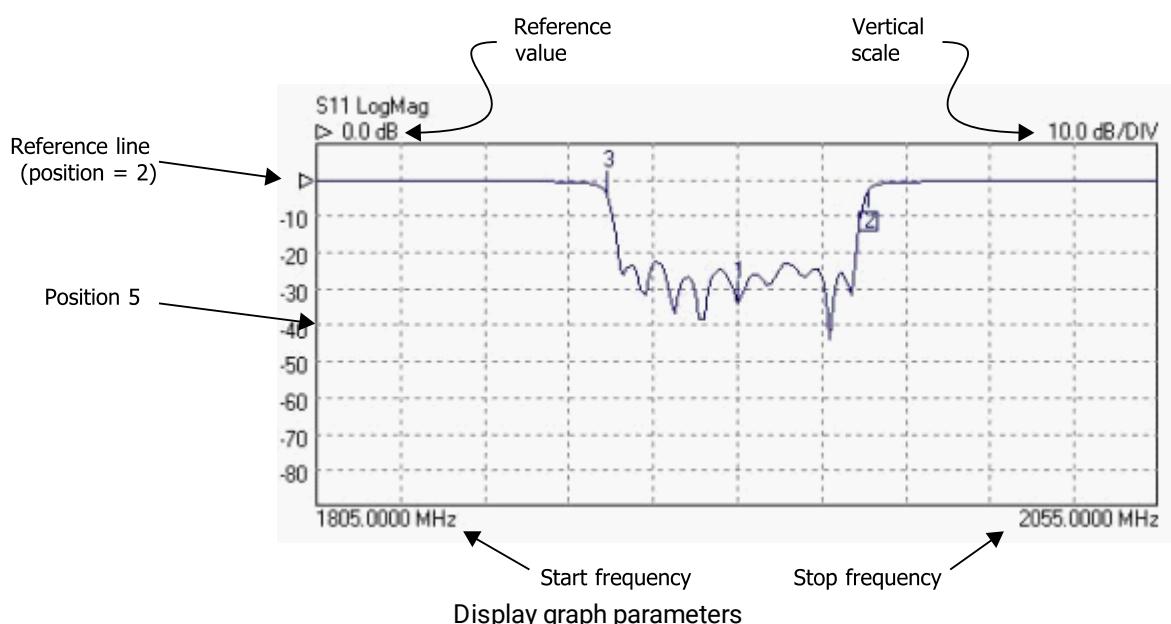
- Set the number of channels to be displayed by clicking the appropriate radio button under **Display Channels**
- Select the desired active channel from the drop-down list (can also be selected by clicking on a marker in the main window on the desired display channel)
- Select the channel to set up by clicking the appropriate radio button under **Select**

- Choose the desired parameter to display on this channel from the drop-down list under **Parameter / Graph Type**
- Choose the desired graph type from the drop-down list under **Parameter / Graph Type**
- Select the vertical axis values from the **Vertical Axis** section. Optionally, click **Autoscale** to automatically set the sensitivity and reference values. Note that reference position 1 is at the top (see second figure below).
- Click **Apply** to apply the selected values
- Repeat the above steps for each display needed

Note: The Active Channel must be one of the displayed channels.

3. Select channel to set up

4. Check to show vertical scale values on graphs

1. Select one-channel, two-channel or four-channel view

2. Select channel to show in the Markers panel

5. Apply settings before selecting next channel
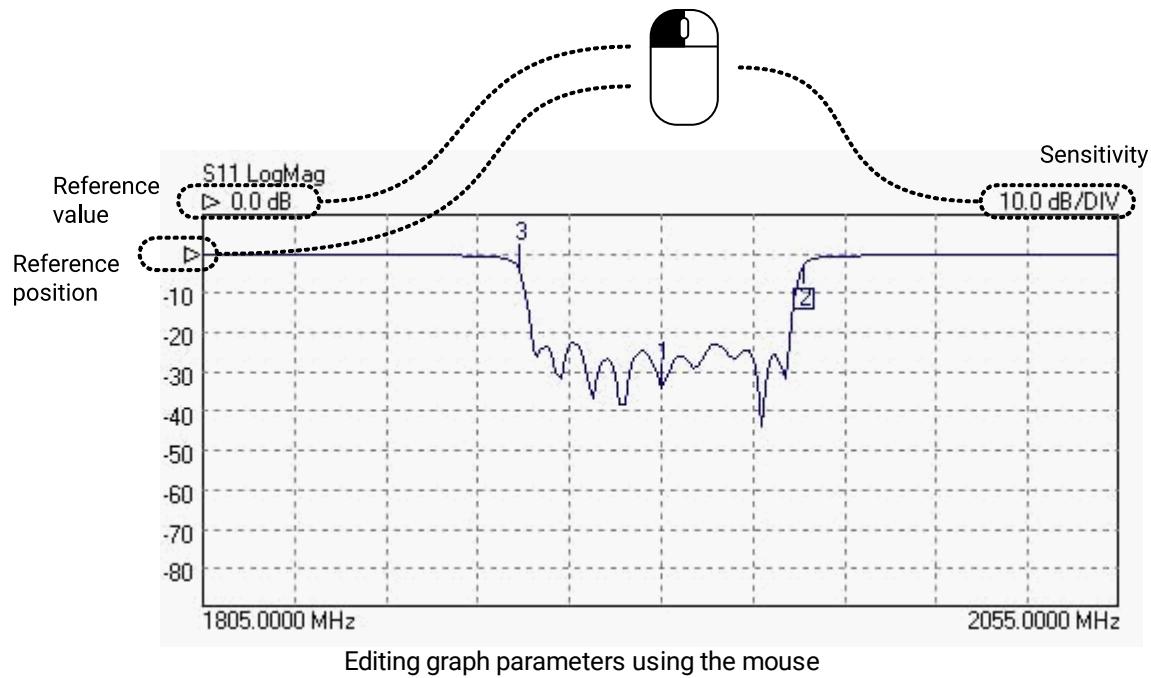
The Display Set Up window is used to set up the measurements display

Reference value

Vertical scale

Reference line (position = 2)

Position 5

Start frequency

Stop frequency

Display graph parameters

The **colors** of the main graphics display can be changed to suit individual preferences. This can be done by selecting the **Color Scheme** item from the **Tools** menu. To set a color, click the color preview box next to the item name.

Once you have set up a color scheme, you can save and recall it as a **Cal and Status** or just a **Status** setting using the **File** menu.

Editing graph parameters using the mouse

The figure above shows how the mouse can be used to quickly adjust reference position, reference value and vertical scale sensitivity.for the graph. Drag the indicated values up and down to adjust, or type a new value where the cursor indicates.

6.1.2   Data markers

It is possible to display up to eight markers on each display. They are set up by clicking on the **Markers** button (see figure below). There are four possible marker modes as follows:

Active marker: The active marker is the marker used for comparison when the delta marker mode (switched on by selecting a reference marker) is on. One of the displayed markers must be chosen as the active marker.
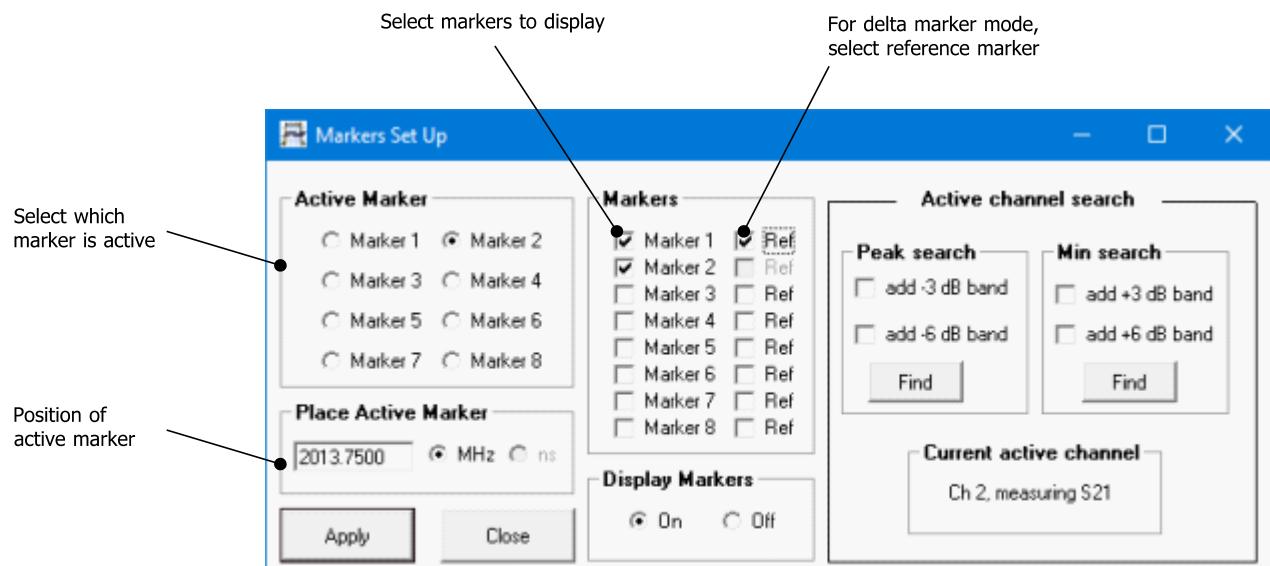
Reference marker: The reference marker causes the delta marker mode to be switched on. The value difference between the active marker and the reference markers is shown on the right hand marker display panel.

Fixed marker: A fixed marker cannot be moved and its position is not updated with subsequent measurement values. It provide a fixed reference point. Only a reference marker can be made a fixed marker. Once a marker is fixed, it cannot be moved until it is unfixed.
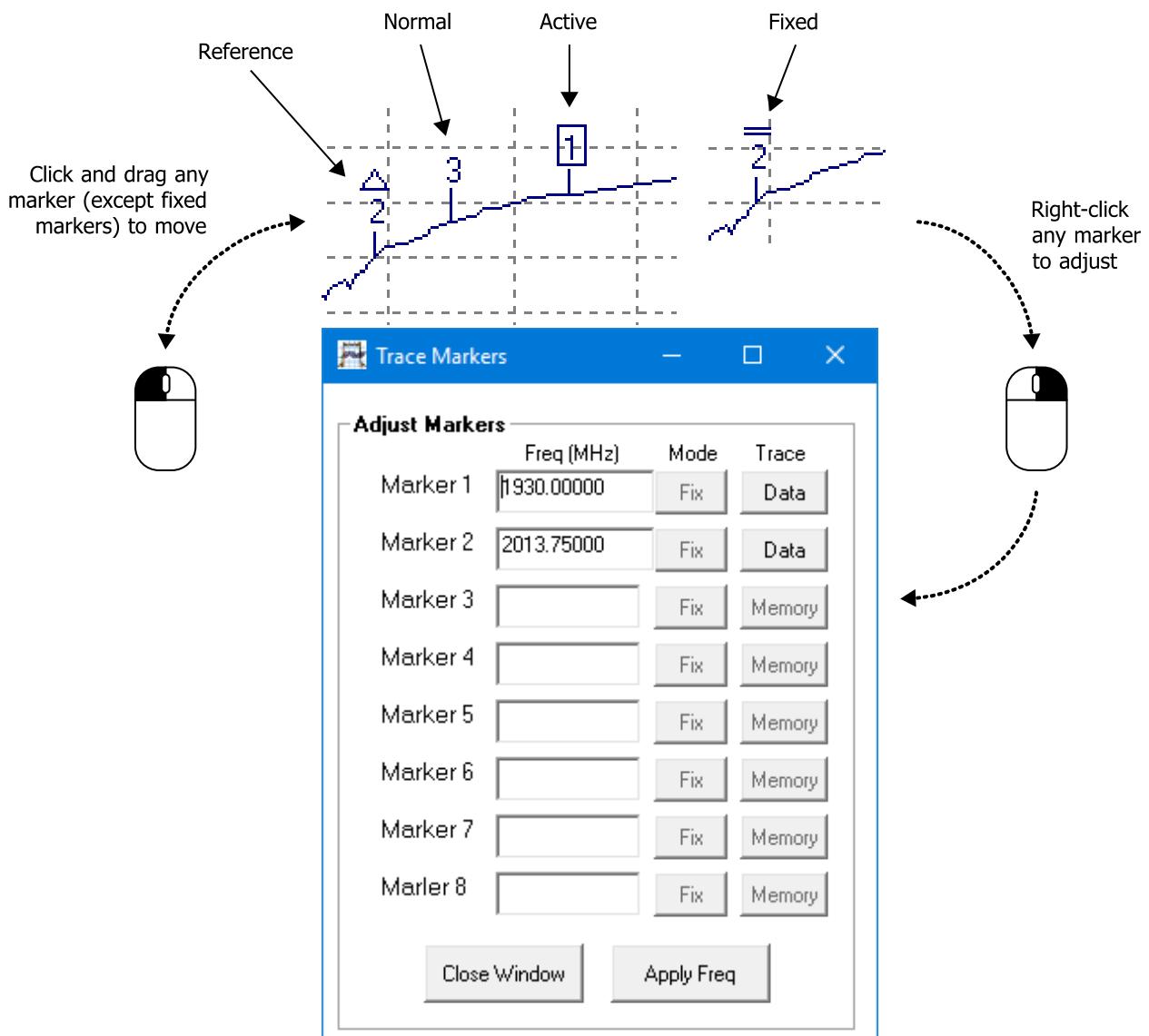
Normal marker: The value of a normal marker is displayed on the right-hand marker readout panel and in lower resolution readouts below each measurement plot.

Any marker (except a fixed marker) can be moved to a new position by left clicking on it (on any displayed channel) and dragging it to a new position.

The markers set up form provides a **Peak / Minimum Search** facility. This places marker 1 at either the peak or minimum value on the displayed trace on the active channel when the corresponding **Find** button is pressed.

Select markers to display

For delta marker mode,
select reference marker

Select which
marker is active

Position of
active marker

Markers Set Up

Active Marker

○ Marker 1   ● Marker 2
○ Marker 3   ○ Marker 4
○ Marker 5   ○ Marker 6
○ Marker 7   ○ Marker 8

Place Active Marker

2013.7500   ● MHz ○ ns

Apply   Close

Markers

☑ Marker 1   ☑ Ref
☑ Marker 2   ☐ Ref
☐ Marker 3   ☐ Ref
☐ Marker 4   ☐ Ref
☐ Marker 5   ☐ Ref
☐ Marker 6   ☐ Ref
☐ Marker 7   ☐ Ref
☐ Marker 8   ☐ Ref

Display Markers

● On   ○ Off

Active channel search

Peak search

☐ add -3 dB band

☐ add -6 dB band

Find

Min search

☐ add +3 dB band

☐ add +6 dB band

Find

Current active channel

Ch 2, measuring S21

The Markers Set Up dialog is used to display measurement markers

Change the marker type by right-clicking on any marker on the active channel. Note that only the reference marker can be fixed.
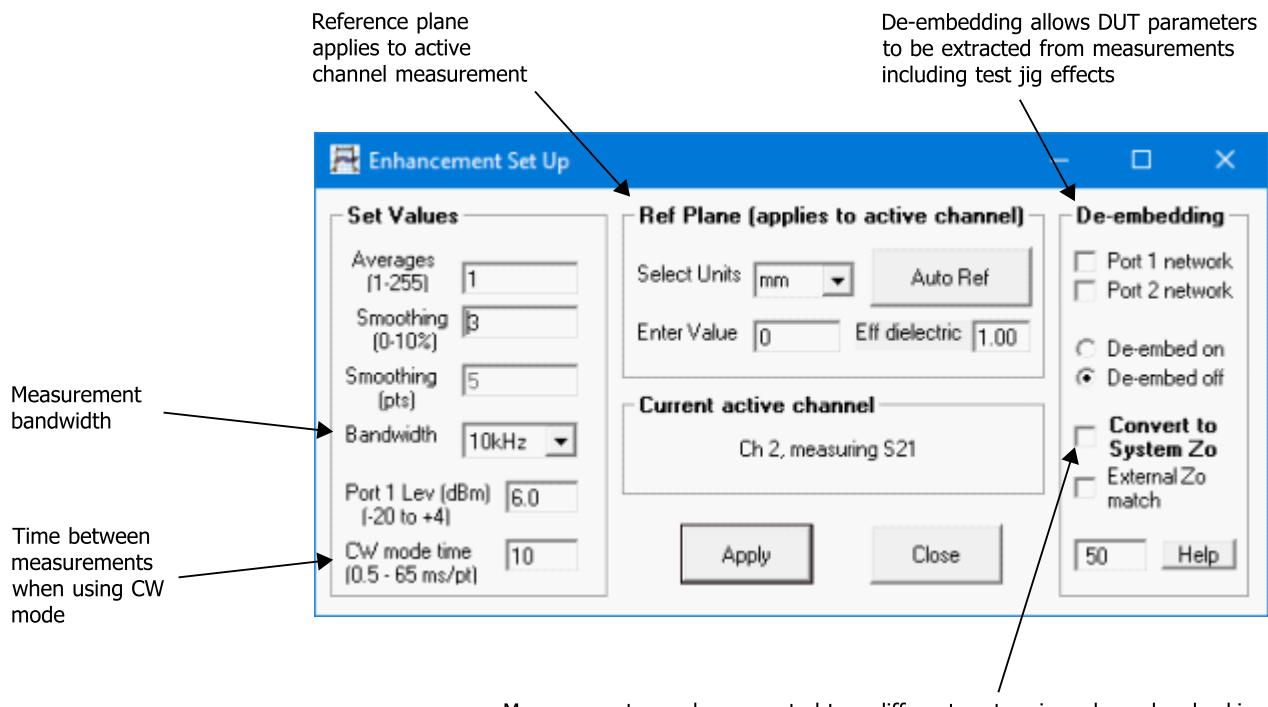
The peak / minimum search facility provides a means of placing additional markers to indicate the **3 or 6 dB bandwidth**. If either the 3 dB or 6 dB band box are selected, then clicking **Find** will place markers 2 and 3 on the frequency points either side of marker 1 which are 3 dB or 6 dB relative to it. Note that for best accuracy a sufficient number of sweep points should be used. This will ensure a fine enough resolution to allow accurate determination of the band points.

6.1.3   Measurement enhancement

The measurement enhancement options are displayed (see figure below) by clicking **Enhancement** in the main UI window. The options available are as follows.

- Averages (1 to 255, on a point by point basis)
- Trace Smoothing (0 to 10%)
- Bandwidth (140 kHz to 10 Hz)
- Port 1 Level (+6 dBm to −20 dBm for PicoVNA 106, +10 dBm to −20 dBm for PicoVNA 108; 0.1 dB resolution)
- CW sweep time per point (0.5 to 65 ms/point for PicoVNA 106, 0.5 to 220 ms/point for PicoVNA 108)
- Reference Plane Extension (manual entry or automatic)
- Effective dielectric constant of device under test (manual entry to correct plane extension values)
- De-embedding (specify embedding networks at ports 1 and or 2)

- Impedance conversion for devices that are not 50 Ω

Reference plane
applies to active
channel measurement

De-embedding allows DUT parameters
to be extracted from measurements
including test jig effects

Measurement
bandwidth

Time between
measurements
when using CW
mode

Measurements can be converted to a different system impedance by checking
this box and entering the desired impedance (value must be real between 10
and 200 Ω). The use of external matching pad is also supported.

The measurement enhancement window

The **Bandwidth** setting refers to the receiver bandwidth. Maximum sweep speed is achieved with the highest (140 kHz) setting. On the other hand, the widest dynamic range (lowest noise floor) is achieved with the lowest value, 10 Hz. Note that the bandwidth setting used during calibration determines the maximum dynamic range achievable during measurements. So, consider this when carrying out a calibration. For example, if you need to carry out measurement over more than, say 90 dB dynamic range, then use a 500 Hz or less bandwidth setting when calibrating.

The **Port 1 Level** sets the test signal level. The default value is +3 dBm as this gives best overall measurement accuracy. However, it may be necessary, particularly when measuring active devices (e.g. amplifiers) to reduce the test level. For maximum dynamic range, then use the highest power setting. For best measurement accuracy it is recommended that the calibration is carried out at the same test level as it is intended to use for the measurement. Whenever the test level is different to that used for the calibration, a '?' will be added to the calibration status indicator on the Status Panel (Fig. 6.1)

The **Reference Plane** facility allows the reference plane of each parameter measurement to be arbitrarily moved away from the calibration plane. The value entered applies to the measurement parameter (S_{11}, S_{21}, S_{12} or S_{22}) displayed on the active channel. Note that the same plane value will be used for all other measurements on that same parameter regardless if they are on the active channel or not.

The **Auto Reference** automatically moves the reference plane. It uses the measurement on the active channel. This feature is particularly useful, for example, when measuring microstrip devices and it is necessary to remove the effect of the connecting input and output lines. It takes the effective dielectic constant value entered to correct the displayed value. Refer to Reference plane extension and de-embedding for more details.

Note: The reference plane must be at 0 mm for the Auto Ref function to work correctly. Also, Enhancement window changes only take place when the instrument is sweeping.
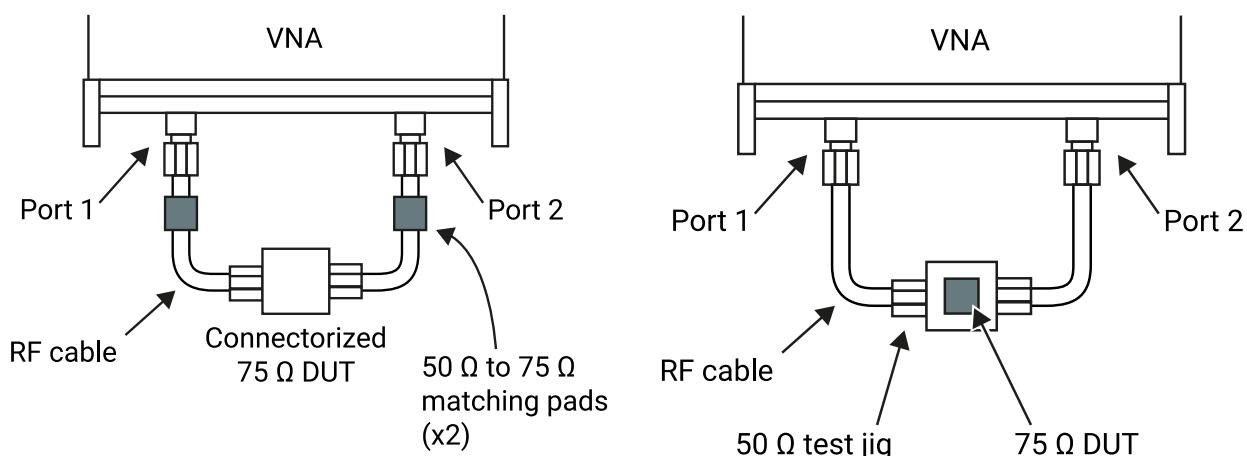
The **Effective Dielectric** of the device under test can be entered so that the displayed Reference Plane extension values (shown on the Enhancement Window) are corrected accordingly when the Auto Ref button is clicked. The default value is 1.0 and the maximum value allowed is 50.0.

> **Note:** The reference plane extension value shown in the [main window](#) on the markers display panel on the right is the reference plane extension as shown in the Enhancement window.

The **de-embedding** facility is explained in detail in [Reference plane extension and de-embedding](#).

The **System Z$_0$ Conversion** facility allows measurements, which are always taken in 50 Ω, to be converted to another impedance that you select. This feature can be useful, for example, for measuring 75 Ω devices. The value of Z$_0$ entered must be real (purely resistive) and must be within the range of 10 Ω to 200 Ω. Whenever this facility is selected, an indicator is displayed on the top right corner of the graphics display as shown in the second figure below. **Note** that when requested, impedance conversion will performed on the **live measurement** and any stored **memory trace**.

There are two possible ways of using the **System Z$_0$ Conversion** facility. For example, 75 Ω devices can be measured using the techniques illustrated below.

Impedance matching pads can be used to measure a connectorized device. Use external matching pads and calibrate with a 75 Ω calibration kit.

A discrete device mounted on a 50 Ω test jig is simpler to measure. Calibrate with a 50 Ω calibration kit, use de-embedding to remove the test jig and allow mathematical conversion to 75 Ω impedance.

Possible techniques for measuring 75 Ω devices
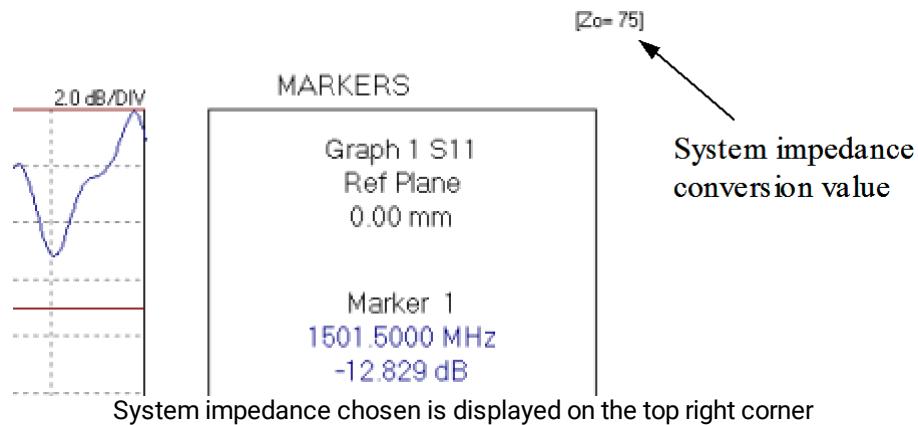
The steps necessary for each of the two techniques illustrated in the figure above are as follows:

75 Ω device with connectors
i.   Connect **50 Ω to 75 Ω impedance matching networks** (e.g. matching pads) at the ends of the cables connected to ports 1 and 2.
ii.   In the **Enhancement** window, check the **Convert System Zo** box
iii. Check **External Zo match** to indicate external matching networks in use
iv.   Enter **75** in the **Convert System Zo** value box and click **Apply**
v.   Proceed to calibrate using a **75 Ω calibration kit**
vi.   Connect the DUT and **start the measurement**

75 Ω device mounted on 50 Ω test jig
i.   In the **Enhancement** window, uncheck the **Convert System Zo** box
ii.   Calibrate at the ends of the test cables using a 50 Ω calibration kit
iii. Apply de-embedding to remove test jig effects. See [Calibration kit](#) for some suggestions.
iv.   In the **Enhancement** window, check the **Convert System Zo** box
v.   Uncheck the **External Zo match** box (in this case mathematical impedance conversion is done by the software)
vi.   Enter 75 in the **Convert System Zo value** box and click **Apply**
vii. Connect the DUT and start the measurement

System impedance chosen is displayed on the top right corner
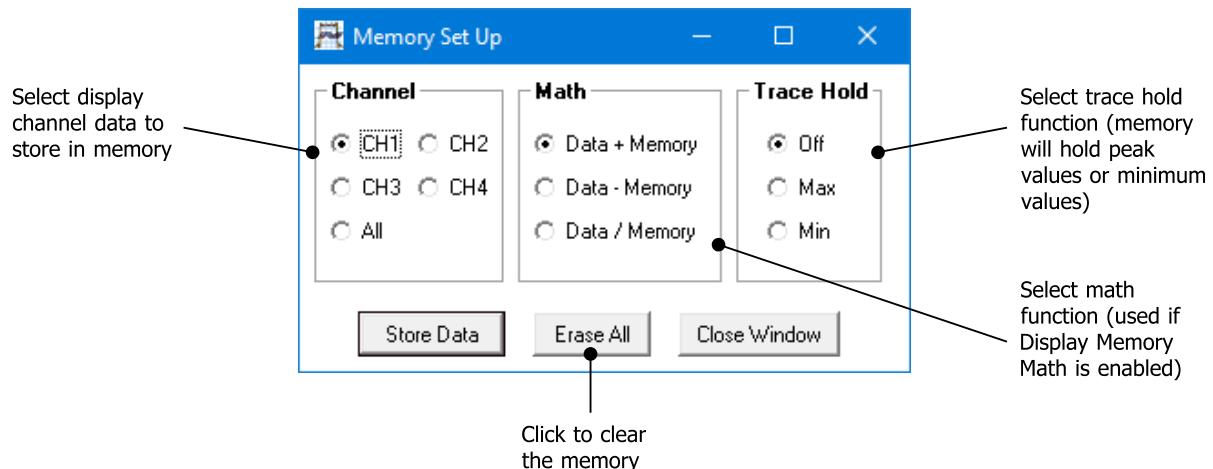
> **Note:** S-parameters are interrelated, so, when using the Z_0 conversion facility (and no external impedance matching networks) without a full set of S-parameters available (e.g. only an S_{11} calibration) the program will assume values for the unavailable parameters as shown in the following table. A warning will be displayed in such cases.

S_{11}	S_{12}	S_{21}	S_{22}
10^{-6}, j0.0	10^{-6}, j0.0	10^{-6}, j0.0	10^{-6}, j0.0

Values assumed for parameters not available during Z_0 conversion

6.1.4   Memory facility

The current displayed data on each channel can be stored in memory. Also, each channel can be stored independently of all others. The **Memory Set Up** window is used to store the data and this window can be displayed by clicking **Memory** in the main window.

The Memory Set Up window is used to store data into memory

Once the data is stored, it can be displayed by clicking **Display Data and Memory** in the main window.

There are three vector math functions available: sum, subtraction and division. The selected function is used when you select the **Display Memory Math** function on the main window.

The trace hold is used to store the maximum or minimum values on the memory trace. Trace hold is **not** available when group delay is displayed.

6.1.5   Limit lines facility
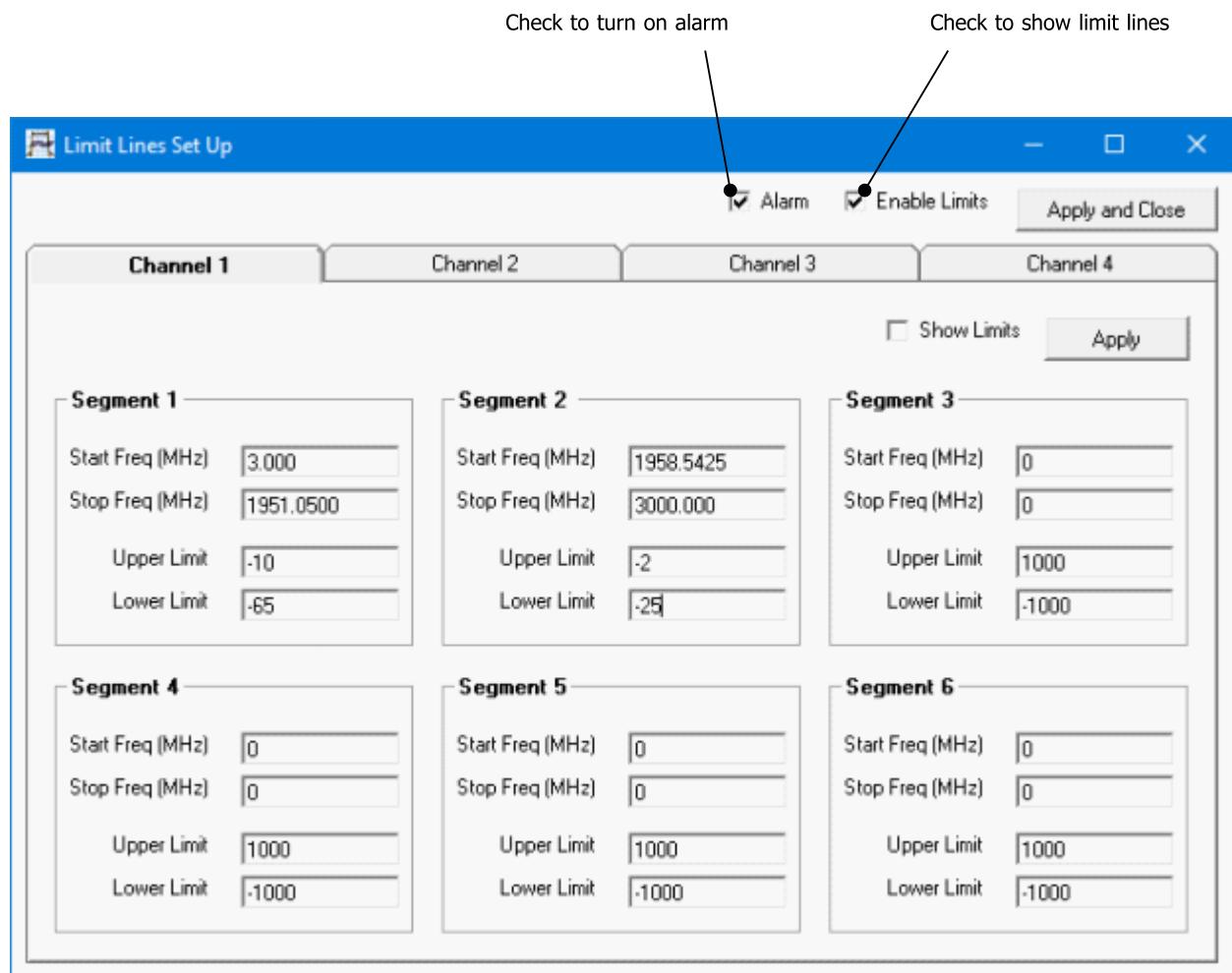
The limit lines facility allows six segments to be defined for each displayed graph. By taking advantage of the overlapping capability (see below) a maximum of 11 segments can be created The set up window, shown below, is displayed by clicking **Limit Lines** in the main window.
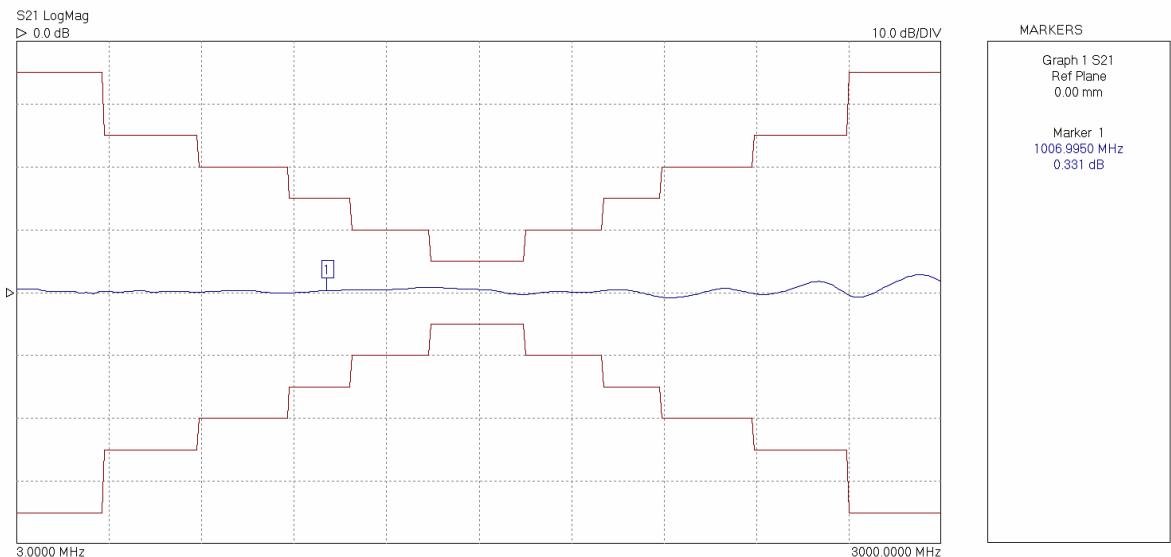
Overlapping segments
All valid segments entered are loaded in sequence (i.e. segment 1 first) with the each segment loaded having priority over the previous segment. This feature allows overlapping segments to be loaded. For example, if segment 1 is specified to cover, say, 400 to 800 MHz, then a second segment can be specified to a section of this band, for example, 500 to 600 MHz. This would result in a total of three segments—that is, 400 to 500, 500 to 600 and 600 to 800 MHz—even though only two were specified. An example of a complex 11-segment template is shown in the first plot below.
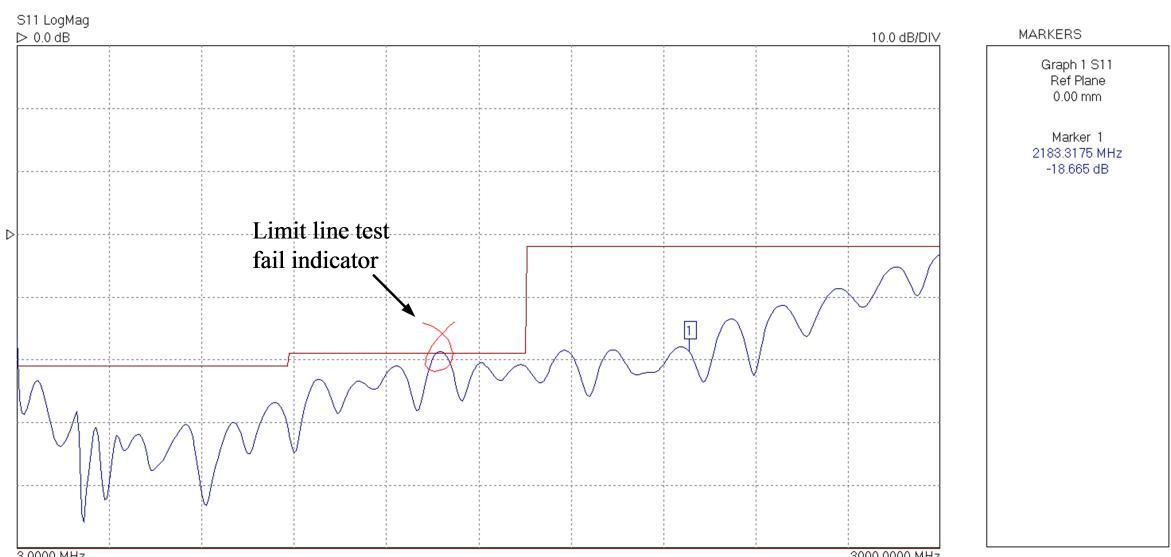
Alarm
An alarm facility is provided with the limit lines. This provides audible warning during a sweep if any measurement exceeds the limits set. A visible indication of the last measurement and measurement channel in error is provided on the status panel where normally the calibration type is displayed. In addition a symbol is drawn on the trace indicating the last error point detected as shown in the second plot below. The alarm is available for all graph types except Smith plots.

The Limit Lines Set Up allows at least six segments per graph

---

Complex Limit Lines templates are possible by overlapping segments

Limit Lines failure graphical visual indicator

6.1.6   Status panel

The status panel in the main window provides useful information as follows:

- **Instrument serial number**
- **Calibration status** (S_{11}, S_{21}, S_{11} + S_{21}, 12 terms or U/T). A question mark indicates that the test power has been changed from that used for calibration
- **Test signal power.** This is the Port 1 signal level
- **Sweep status.** Indicates whether instrument is sweeping
- **Frequency step.** Step size of sweep
- **Sweep points.** Number of points in programmed sweep
- **Limit Lines alarm** if any measurement exceed the set limits (temporarily replaces **Calibration status**)
- **Internal instrument temperature** (PicoVNA 108 only)

6.1.7   Triggered sweep

It is possible to synchronize each measurement sweep to an external trigger. Simply click the appropriate radio button in the main window 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.

Trigger selection radio button on main panel (PicoVNA 106)

Trigger selection radio button on main panel (PicoVNA 108)
Note that Save on Trigger works in +Ext, -Ext and Manual modes only.

When the **Manual** trigger option is selected, the instrument will wait until the **Manual** button is pressed before starting a sweep.

6.1.8   Sweep trigger output

The rear panel **Trigger Output** terminal provides a 3 V logic output with the rising edge synchronized 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.

6.1.9   Measurement start / stop

The measurement **Start / Stop** buttons (see figure) are used to start or stop the instrument's sweep mode (measurement mode). This is necessary as functions which require reprogramming the instrument can only take place when the instrument is idle. The instrument status is shown in the Status Panel as described in the previous section.

The Start / Stop Measurement buttons control the sweep status

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. This can be changed from the **Tools > Diagnostics** menu.

6.1.10   PC data link interruption

The data flow between the VNA and its controlling PC can be interrupted by external factors. If the software cannot restore the link, a message similar to this will appear:

Warning message when the link with the PC is interrupted
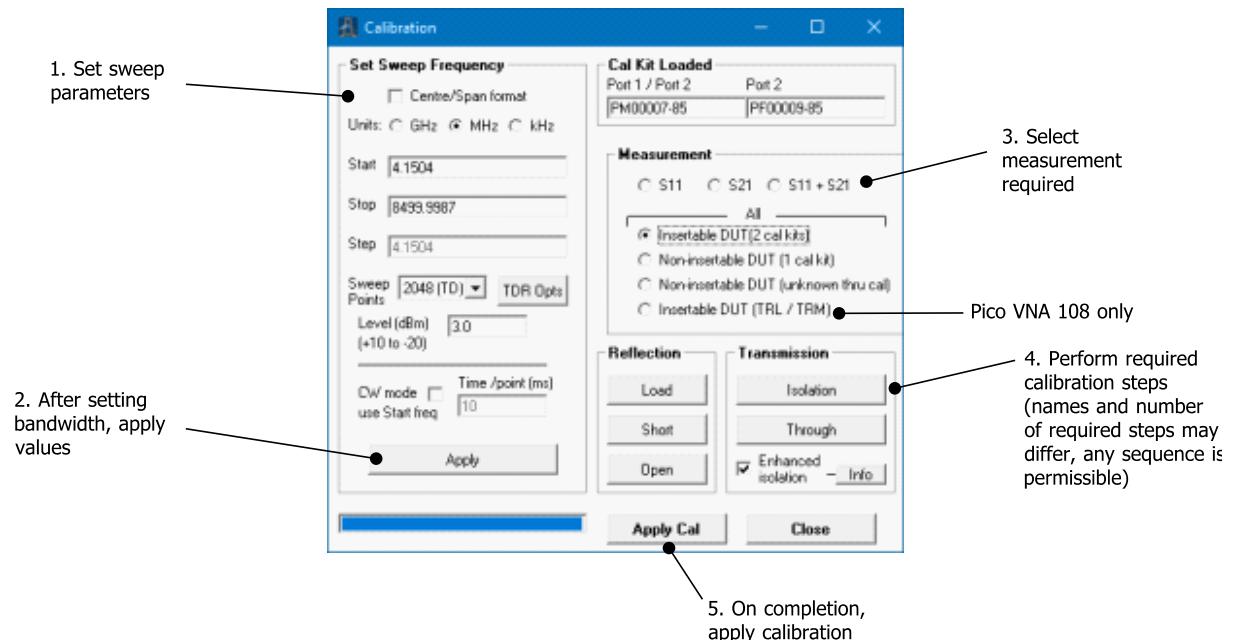
In such a case:

- Restart the software using the selection in the drop-down menu under **Tools**
- Switch the VNA off and on again (using the switch on the back) when prompted to do so
- Wait until the front panel lights have stopped flashing
- Click **OK** to complete the software restart
- Recalibrate the instrument

You should rarely see a 'No Response' message. If it happens often, check that the PC is not running other applications and that the VNA software is not running as a background task when the sweep is on.

6.2   Calibration

The instrument must be calibrated before any measurements can be carried out. This is done by loading a previous calibration (see **File** menu) or carrying a fresh calibration by clicking **Calibration** in the main window, which brings up the **Calibration** window as shown here:

1. Set sweep parameters

2. After setting bandwidth, apply values

3. Select measurement required

Pico VNA 108 only

4. Perform required calibration steps (names and number of required steps may differ, any sequence is permissible)

5. On completion, apply calibration

Note: The frequency sweep is set by entering the start, stop and selecting the number of sweep points. Alternatively, by entering the centre frequency and span after clicking on the **Centre/Span format** option box.
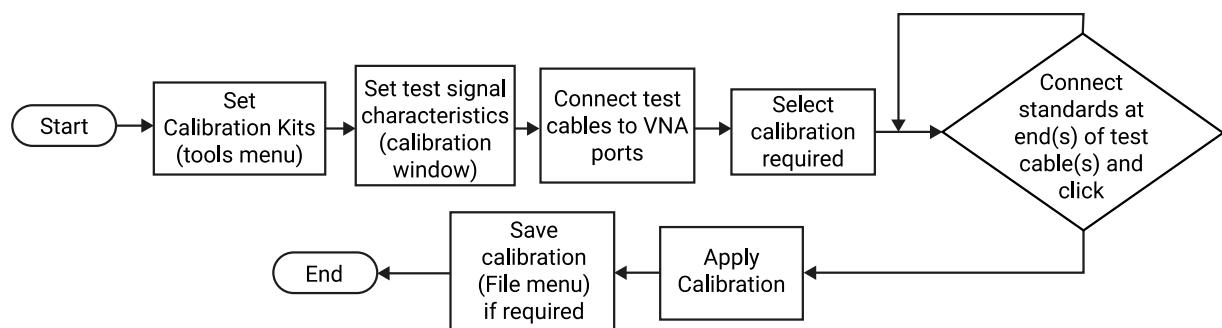
The table below summarizes the calibration types available together with the standards required to complete the calibration. For best overall accuracy, particularly when measuring low isolation devices with poor return loss values, a 12-term calibration should be performed.

Required calibration standards	S_{11}	S_{21}	$S_{11} + S_{21}$	12 terms (insertable DUT)	12 terms or 8 terms* (non-insertable DUT)
Fixed SOLT standards	Matched load Open Short	Through connection Termination (see text)	Matched load Open Short Through connection	Matched load (x 2) Open (x 2) Short (x 2) Through cable	Matched load (x 1) Open (x 1) Short (x 1) *Thru* adaptor (x 1) Through cable
E-Cal automated SOLT standards (PicoVNA 108 only)	E-Cal SOLT kit only	Not supported	Not supported	E-Cal SOLT kit (use supplied port adaptor)	E-Cal SOLT kit only
TRL/TRM standards (PicoVNA 108 only)	N/A	N/A	N/A	2x Feed+Short or 2x Feed+Open, 2x Feed+Match, Thru = 2xFeed and Thru = 2xFeed+Delay.	N/A
Measurement capability	S_{11} using 3-term error correction	Frequency response with isolation correction	S_{11} using 3-term error correction Frequency response with isolation and source match correction	S_{11}, S_{21}, S_{12}, S_{22} using 12-term error correction	S_{11}, S_{21}, S_{12}, S_{22} using 12-term error correction or 8-term correction

Calibration types supported.
* The *unknown thru* calibration (8 error terms) requires only a reciprocal *thru* adaptor.

Here is the basic calibration sequence:
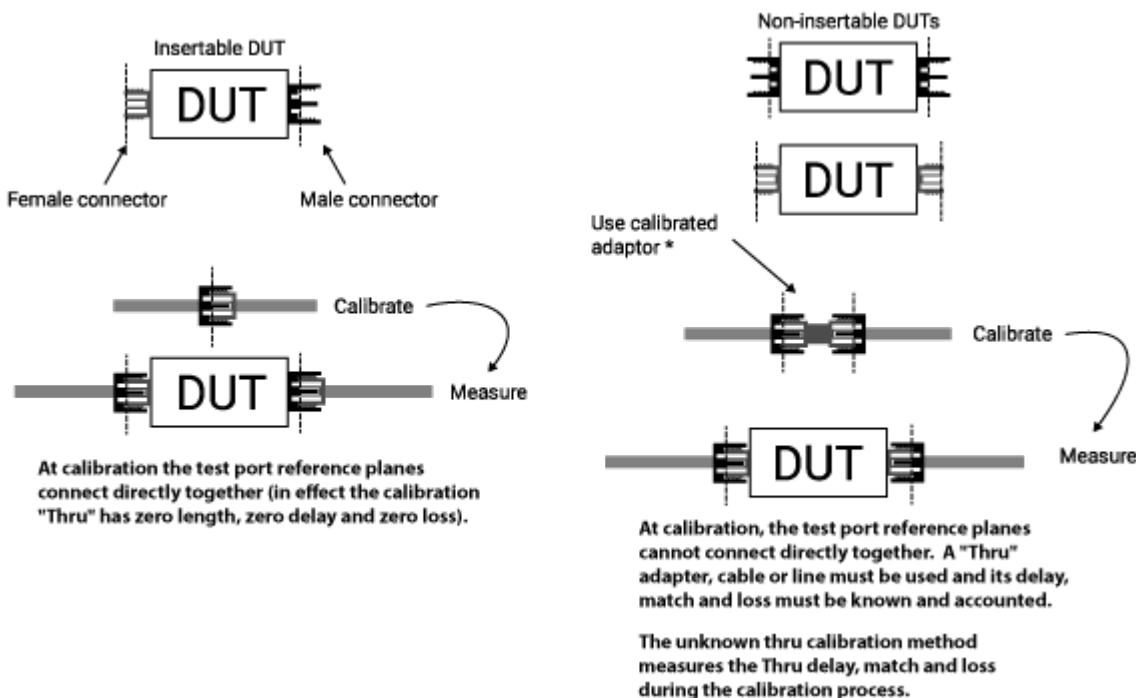
Instrument calibration sequence. This loop is fully automated when using an E-Cal module.

The calibration process involves connecting each standard in turn and clicking. An asterisk will appear once it has been measured so that the next standard can be done.

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

Calibration for measuring non-insertable devices

Insertable and non-insertable DUTs

It is important to be aware of the difference between 'insertable' and 'non-insertable' devices and the impact on measurement and calibration technique. The figure above illustrates the difference between an insertable device and non-insertable devices. The key issue is that with non-insertable devices an adaptor will be required during the calibration measurement as shown. In order to obtain accurate DUT measurement data, the effect of the adaptor needs to be removed from the measurements. Some of the possible ways of doing this with the PicoVNA 106 and 108 are as follows:

At calibration		
Calibration used	**Adaptor removal method**	**Comments**
(A) 12-term (insertable DUT)	N/A	There is no adaptor delay, match or loss to correct. Two fixed Short Open Load kits (male and female) or one automated E-Cal kit are required
(B) 12-term (non-insertable DUT)	Calibration removes known (previously measured) adaptor characteristics	Accurate but requires kit with an s-parameter characterized "known" thru adaptor standard. Only one calibration kit is required
(C) 8-Term (*unknown thru* method)	Calibration automatically removes adaptor effect. Calibration includes measurement of and removal of the unknown thru characteristics.	Accurate and easiest method as it does not require a characterized *thru* standard. One fixed Short Open Load kit required plus any unknown adaptor, cable or line. One automated E-Cal kit can be used, its Thru will be measured in this case.
At measurement: Alternatively any calibration can be performed and then one or two adaptors added to the test port(s) to achieve connection to the DUT. The characteristics of the adaptor(s) can then be corrected thus:		
Calibration used	**Adaptor removal method**	**Comments**
(D) Any except 12-term or 8-term	De-embedding	Accurate but requires prior knowledge of adaptor characteristics or prior measurement of the adaptor s-parameter characteristics
(E) Any except 12-term or 8-term	Reference plane extension	Quick and easy but errors due to loss of adaptor remain, this method removes the delay (phase) errors from each test port but errors due to loss of the adaptor(s) remain. A further normalization of adaptor loss can be achieved using an estimate of loss at 1 GHz, the Auto Ref feature or trace Math. However, mismatch errors will remain.

Techniques for dealing with non-insertable DUTs

Note that for the 8-term method, *isolation calibration* is done automatically by the software using measurements taken during the *short*, *open* and *load* steps.

Note that only the 12-term non-insertable DUT calibration and 8-term *unknown thru* methods support a non-zero length thru connection. Other calibrations (S_{21} or S_{11}+S_{21} or full 12-term insertable DUT) require a thru connection of zero length. In effect, this means that the calibration port terminals should be of opposite sexes. In other words, it should be possible to connect the terminals together without the use of an adaptor. Consequently, the DUT must be an *insertable* device. If this is not the case, an adaptor will be needed during the measurement and its effect will need to be removed by either moving the reference plane or by using the de-embedding facility as indicated in the table above.

When performing just an S_{21} calibration it is possible to complete the calibration without doing the isolation calibration. Simply click **Apply Cal** after performing the *through* calibration. The isolation calibration corrects errors due to crosstalk (see Calibration and error correction) and should be used when measuring insertion losses larger than about 40 dB. The terminations to use during the isolation calibration can, as a guide, be 50 Ω loads. In some circumstances, such as when testing a highly reactive device (e.g. filter beyond cut-off), a short or an open circuit may be more appropriate or for best results two actual DUTs with 50 Ω loads at their unused ports.

6.2.1 Changing the frequency sweep settings without recalibrating

If the start or stop frequency or number of sweep points is changed when the instrument has a valid calibration, you are given the choice to either keep or delete the existing calibration. If you choose to keep the calibration, a new set of calibration error terms will be automatically generated by *interpolation* to fit in with the new sweep parameters. In this case, a "?" is added to the calibration status bar to indicate that operating parameters have changed from those used in calibration.

If it is required to change the frequency sweep parameters without recalibrating, then simply enter the new values (see **Set Sweep Frequency** values under Calibration) and click **Apply**. Once the new values are sent to the instrument, just close the window (click **Close Window**) to exit. Note that this process will **delete all memory traces** and the display data may be invalid until a fresh measurement sweep is performed. Note that new sweep span must lie entirely within the old sweep span. Extrapolation of calibration is not supported.

Take care when using interpolation, particularly at low frequencies, say below 20 MHz. For example, if starting with a wide band sweep with large frequency steps, say 500 kHz or larger, then interpolating down to a narrow band of, for example, 1 MHz to 10 MHz may lead to larger than expected errors.

6.2.2   Calibration steps for S11 measurements

The calibration for S_{11} measurements performs a three term error correction calibration. Note that if the device to be tested has a female connector, then a female calibration kit should be used for best results. The typical steps are as follows:

1. Select the calibration kit (**Tools > Calibration kit > Load P1 kit or Electronic Cal Kit (PicoVNA 108 only) > Apply**)
2. For an E-Cal Kit select the appropriate connection diagram and then **Find** and **Load EasyCal data**>**Exit**>**Apply**
3. Set the bandwidth and test power (**Enhancement** button)
4. Set the frequency range and measurement steps (**Calibration** button)
5. Select S_{11} calibration (in **Calibration** window)
6. Connect adaptor and test cable to port 1 of the instrument
7. An E-Cal calibration will complete application of required standards automatically.
8. Connect each standard in turn and click appropriate **Standard** button (in **Calibration** window)
9. When all 3 Standards are done click **Apply** (in **Calibration** window)
10. If desired, for later use, save calibration (**File > Save cal**)
11. Connect device to be tested and click **Start**

Tips:
- For best linearity and dynamic range combination use a test power level of 0 dBm
- For best accuracy calibrate using the same or lower bandwidth than you intend to use for your measurements
- You can remeasure any standard at any stage before completing the calibration. Just reconnect the standard and click again on the appropriate **Standard** button before completing the calibration

---

6.2.3   Calibration steps for S21 measurements

The simple S_{21} calibration is a frequency response calibration. Sometimes it is referred to as normalization and only corrects for response characteristics of instrument and external connections. The typical steps are as follows:

1. Set the bandwidth and test power (**Enhancement** button)
2. Set the frequency range and measurement steps (**Calibration** button)
3. Select S_{21} calibration (in **Calibration** window)
4. Connect adaptors and test cable 2 to port 1 of the instrument
5. Connect ends of test cable together (the 'through' connection) and select **Through** (in **Calibration** window)
6. Connect 50 Ω load to the ends of test cables (to perform the isolation step) and select **Isolation** (in **Calibration** window)
7. Click **Apply** (in **Calibration** window)
8. If desired, for later use, save calibration (**File > save cal**)
9. Connect device to be tested and click **Start**

Tips:
- For best dynamic range, use a test power level of +6 dBm and calibrate using the same or lower bandwidth than you intend to use for your measurements
- For best accuracy (linearity) use a test power level of −3 dBm and calibrate using the same or lower bandwidth than you intend to use for your measurements

---

> Pico E-Cal kits do not support this calibration mode. Use instead an 8 or 12 term calibration as below

6.2.4   Calibration steps for S11 and S21 measurements

The S_{11} + S_{21} calibration provides three term error correction for S_{11} measurements and Source match correction for S_{21} measurements. The typical steps are as follows:

1. Select the calibration kit (**Tools > Calibration kit > Load P1 kit > Apply**)
2. Set the bandwidth and test power (**Enhancement** button)
3. Set the frequency range and measurement steps (**Calibration** button)
4. Select **S_{11} + S_{21}** calibration (in **Calibration** window)
5. Connect each standard (short, open and load) in turn and click appropriate **Standard** button (in **Calibration** window)
6. Connect ends of test cables together and click **Through**
7. Connect 50 Ω load to the ends of test cables (to perform the isolation step) and select **Isolation** (in **Calibration** window)
8. Click **Apply** (in **Calibration** window)
9. If desired, for later use, save calibration (**File > Save Cal**)
10. Connect device to be tested and click **Start**

Tips:
- For best linearity and dynamic range combination, use a test power level of 0 dBm
- For best dynamic range use a test power level of +6 dBm and calibrate using the same of lower bandwidth than you intend to use for your measurements − particularly at the *isolation* calibration step

Pico E-Cal kits do not support this calibration mode. Use instead an 8 or 12 term calibration as below

---

6.2.5   Calibration steps for all S-parameters measurements (insertable DUT)

This calibration provides full error correction for all S-parameters. Typical steps are as follows:

1. Select the calibration kits (**Tools > Calibration kits > Load P1 Kit > Load P2 Kit** or **Electronic Cal Kit** (PicoVNA 108 only) **>Apply**)
2. For an E-Cal Kit select the appropriate connection diagram and then **Find and Load EasyCal data**>**Exit**>**Apply**
3. Set the bandwidth and test power (**Enhancement** button)
4. Set the frequency range and measurement steps (**Calibration** button)
5. Select 'All − Insertable DUT' calibration (in **Calibration** window)
6. Connect each standard (short, open and load) in turn and click appropriate **Standard** button (in **Calibration** window)
7. Click **Isolation** select the first method on the left (isolation is measured with 50 Ω loads on each calibration port which is the same as the load step in 5 above)
8. Connect ends of test cables together and click **Through**
9. An E-Cal calibration will complete application of required standards at 6. 7. and 8. automatically.
10. Click **Apply** (in **Calibration** window)
11. If desired, for later use, save calibration (**File > Save Cal and Status**)
12. Connect device to be tested and click **Start**

Tips:
- For best linearity and dynamic range combination use a test power level of 0 dBm. Use the same or lower bandwidth than you will use during measurements.
- For best dynamic range use a test power level of +6 dBm and calibrate using the same or lower bandwidth than you intend to use for your measurements.

6.2.6   Calibration steps for all S-parameters measurements (non-insertable DUT)

This calibration provides full error correction for all S-parameters. It requires a calibration kit with a characterized through connection. Typical steps are as follows:

1. Select the calibration kit (**Tools > Calibration kits > Load P1 Kit or Electronic Cal Kit** (PicoVNA 108 only) **> Apply**)
2. For an E-Cal Kit select the appropriate connection diagram and then **Find and Load EasyCal data** > **Exit** > **Apply**
3. Set the bandwidth and test power (**Enhancement** button)
4. Set the frequency range and measurement steps (**Calibration** button)
5. Select **All – Non-insertable DUT** calibration (in **Calibration** window)
6. Connect each reflection standard (short/open) in turn and click appropriate **Standard** button (in **Calibration** window)
7. Click **Load** to measure the Load Standard (in **Calibration** window)
8. Connect ends of test cables together using the characterized through included in the calibration kit and click **Through**
9. An E-Cal calibration will complete application of required standards at 6. 7. and 8. automatically.
10. Click **Apply** (in **Calibration** window)
11. If desired, for later use, save calibration (**File > Save Cal and Status**)
12. Connect device to be tested and click **Start**

6.2.7   Calibration steps for all S-parameters measurements (TRL/TRM-insertable DUT)

This calibration (supported by PicoVNA 108 only) provides full error correction for all S-parameters. It requires a TRL/TRM calibration kit realised as 2x Short or 2x Open, 2x Matched Load, a Zero length Line and a known Delay length line all placed at the end of identical feed structures. Typically these are all realised upon a test substrate (e.g. PCB) and the Feed structure might be a substrate edge connector or launcher with common length feed line. Further design details are given in the figure below. Typical steps are as follows:
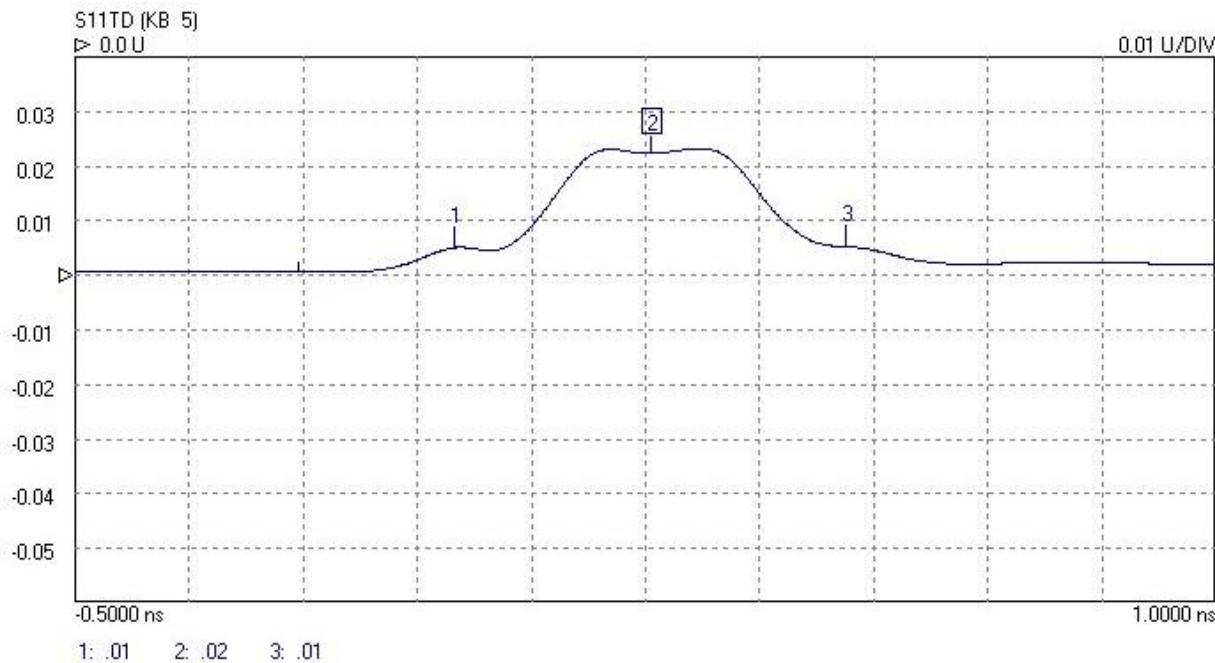
1. Select the calibration kit (**Tools > Calibration kits > Load P1 Kit > Apply**). Where the selected kit is a TRL/TRM kit.
2. Set the bandwidth and test power (**Enhancement** button)
3. Set the frequency range and measurement steps (**Calibration** button) noting that the maximum frequency may be limited by the defined cal kit.
4. Select **All – Insertable DUT (TRL/TRM)** calibration (in **Calibration** window)
5. Connect each reflection standard (Line/Reflect/Through) in turn and click appropriate **Standard** button (in **Calibration** window)
6. Click **Load** to measure the Load Standard (in **Calibration** window)
7. Click **Apply** (in **Calibration** window)
8. If desired, for later use, save calibration (**File > Save Cal and Status**)
9. Connect device to be tested and click **Start**

Note that Pico E-Cal and fixed SOLT Calibration kits are not applied during a TRM/TRL calibration.

Reference line impedance correction
It is likely, for example when using low-cost FR4 boards to carry the TRL/TRM standards that there will be an error in the characteristic impedance of the TRL reference line. This can be measured using the TDR facility in the
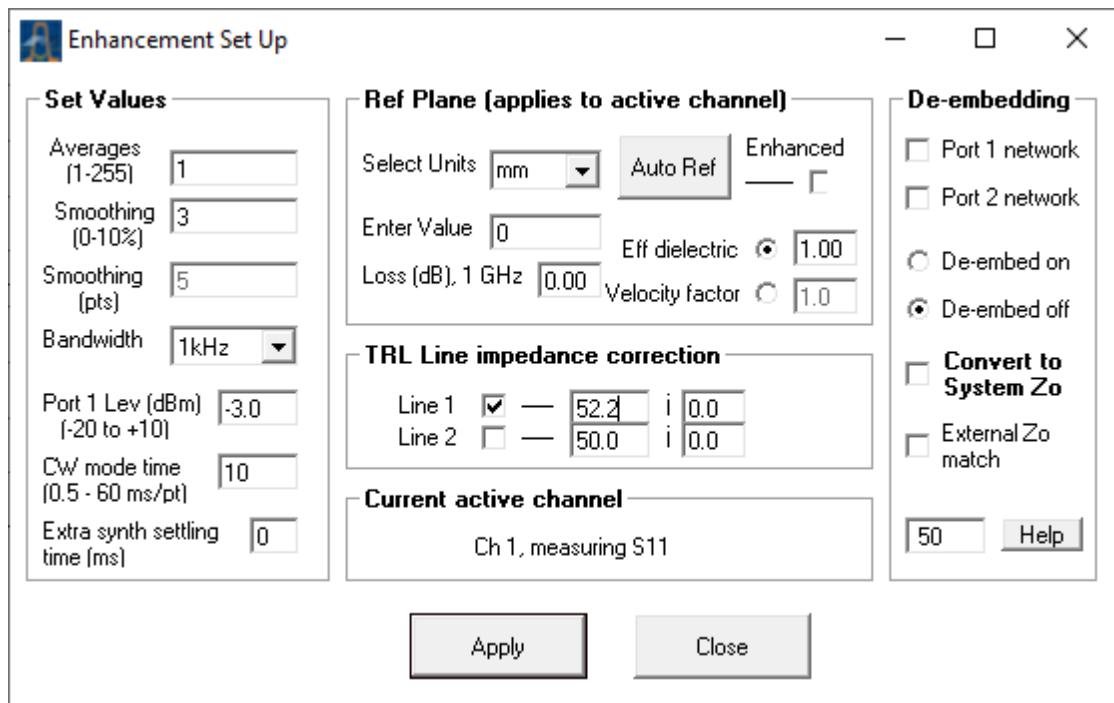
PicoVNA 108. An example result, in terms of the line's linear reflection coefficient, is shown in the figure below.

Reference line Z0 can be determined from the reflection coefficient, measured using TDR

In order to be able to carry out a TDR measurement of the reference line, it is important to bear in mind the available time resolution (or effective rise time) of the VNA TDR measurement. This is equivalent to the inverse of the frequency span (stop frequency minus the start frequency) used. By selecting the widest available span, we end up with a time resolution value of around 118 ps. Therefore, it is sensible to ensure that the overall length of the reference line, plus the interconnecting lines to the edge connectors, amounts to at least 2.5 x 118 ps. This will allow an unambiguous TDR impedance measurement to be made in the figure below.

Once the impedance of the reference line has been determined as described, the value can be entered in the Enhancement Set Up form as shown in the figure below. Once the value is entered and the box next to the corresponding line is checked, all TRL measurements will be corrected using impedance conversion back to the system impedance, typically 50 Ω. Note that the correction will only be applied over the frequency range applicable to the line selected.

TRL Measurement can be corrected using known Reference line Z0
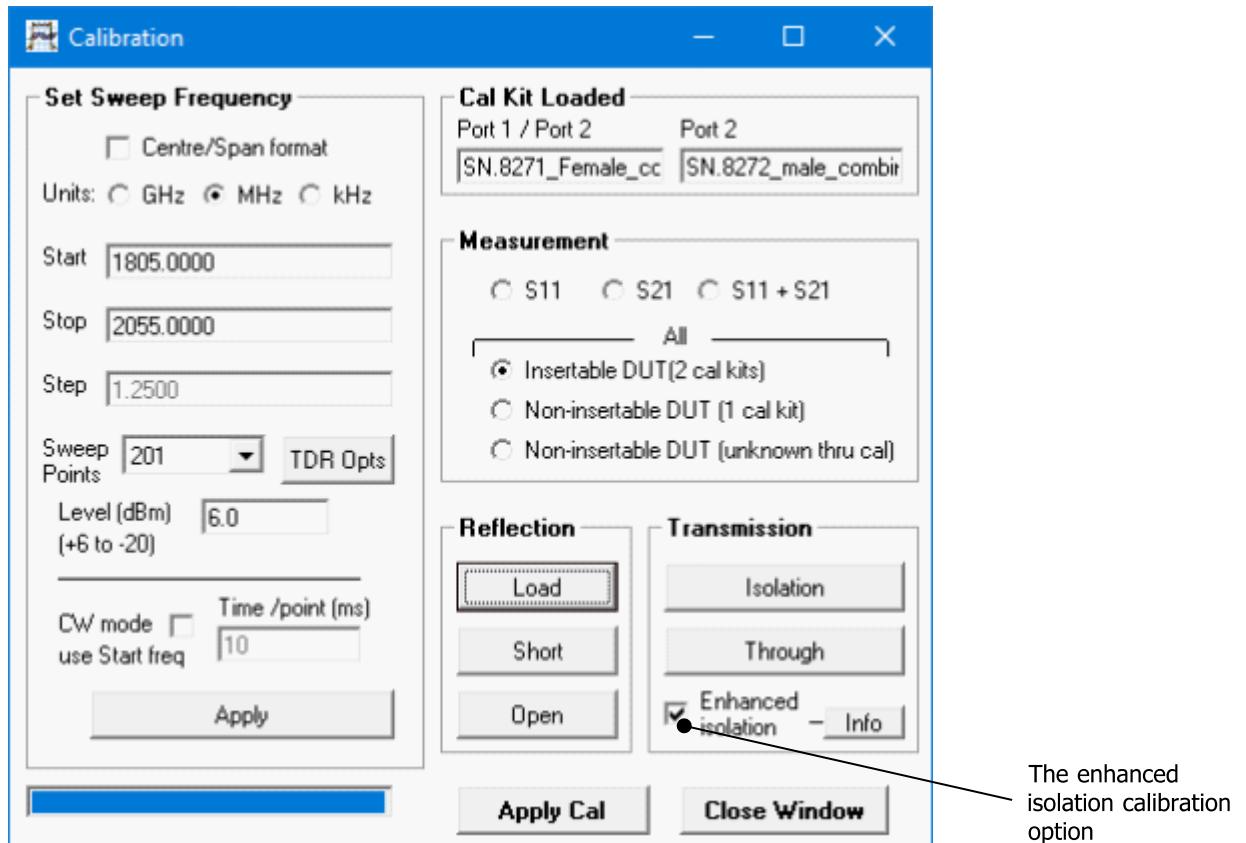
This correction of line impedance will reduce any measurement discontinuities between the TRM low frequency span and the higher frequency TRL line spans. A further reduction of discontinuity may be available from a complex impedance value for the line, perhaps derived from CAD or Math tools. You might also choose to iterate to a reactive value through trial of small values.

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

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

Enhanced isolation calibration

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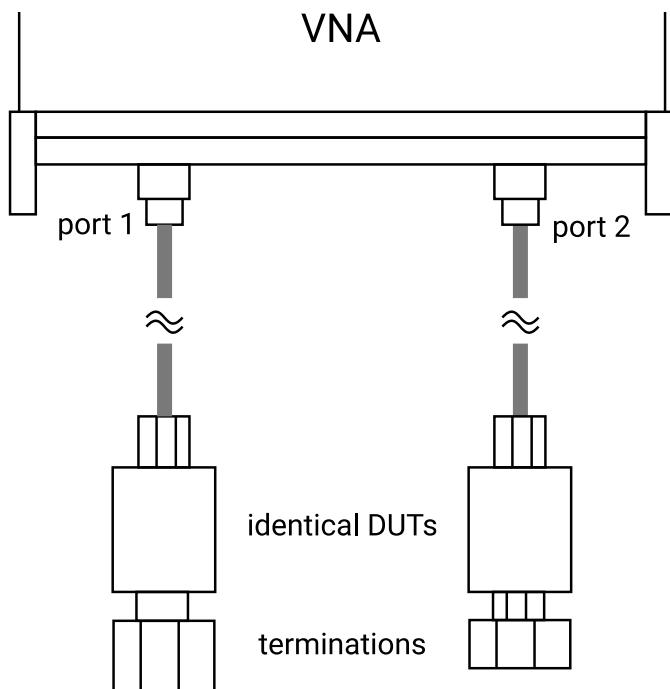
The enhanced isolation calibration helps to model the crosstalk more accurately

It is important to note that for best dynamic range, when using the enhanced isolation calibration method, each of the *short, open* and *load* steps need to be made at the same or lower resolution bandwidth than will be used for the measurement. So, for the ultimate range, each calibration step will need to be done using 10 Hz bandwidth. This is the downside of the enhanced isolation calibration (slower overall calibration process) compared to traditional isolation calibration, where only the isolation step need be taken at the lowest bandwidth setting.

Achieving the ultimate dynamic range using conventional isolation calibration

In cases when two identical DUTs are available, the ultimate dynamic range can be achieved using a conventional crosstalk (isolation) calibration step as shown in the figure below. In this approach the correct termination is presented at each port during the crosstalk calibration step. In this way its effect can be removed accurately over the entire measurement band. Note that when using this technique, only the isolation step need be performed at the lowest resolution bandwidth. The other calibration steps can be performed at higher bandwidth settings to speed up the process.

If two identical DUTs are available, a conventional isolation calibration step can be carried out as shown

6.2.9 Loading and saving calibrations and status

Load and save calibrations using the **File > Load Cal and Status** and **File > Save Cal and Status** commands.
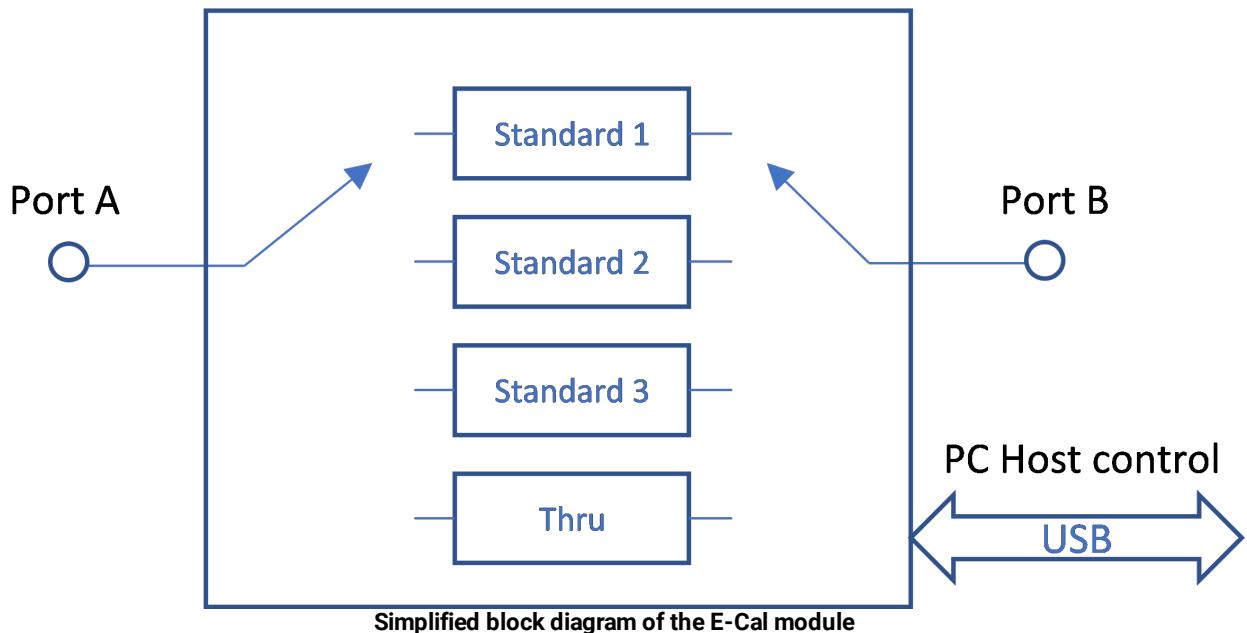
Select the file type according to the type of data you wish to load or save:
- `.cal` – includes calibration and status data
- `.sta` – includes status data only
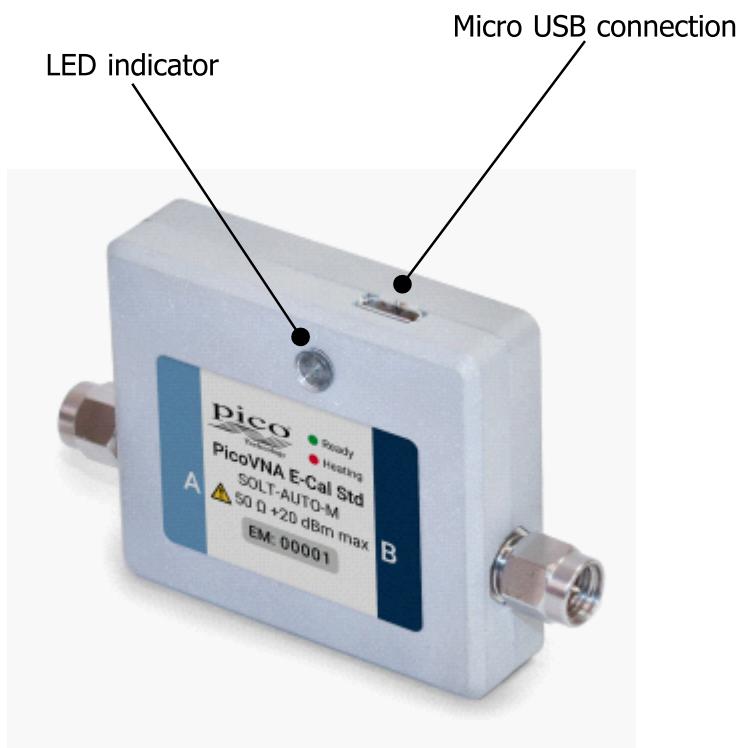
6.2.10 E-Cal 8.5 GHz Electronic Calibration Module - Principle of operation

The E-Cal module is intended to be used for the calibration of the PicoVNA vector network analyzers. The module consists of a set of calibration Standards switched in by means of high frequency electronic switches. The figure below shows the arrangement.

The PC host running the VNA UI software controls the E-Cal module through the USB connection provided. With the modules connected to the VNA, the host selects each calibration Standard in turn and records the response from the VNA. This allows calibration of the VNA to be carried out very fast and with little intervention from the user. The calibration Standards are accurately characterized in the factory and the results kept in memory within the E-Cal module which the host reads to compute the VNA error terms and thereby complete the calibration.

Simplified block diagram of the E-Cal module

A refinement of the E-Cal module is the inclusion of temperature control. Power from the USB connection is used to raise and hold constant its internal temperature. This improves the overall stability and accuracy of the module. Indication of the internal temperature of the module is provided by an LED that switches from red to green to indicate that the target working temperature of the module has been reached. The figure below shows a photograph of the module. A second option fitted with female connectors is available.
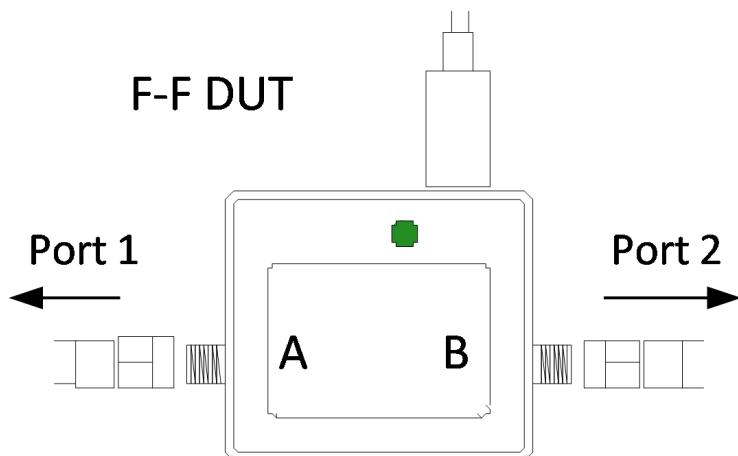
E-Cal module connections (male connector option)
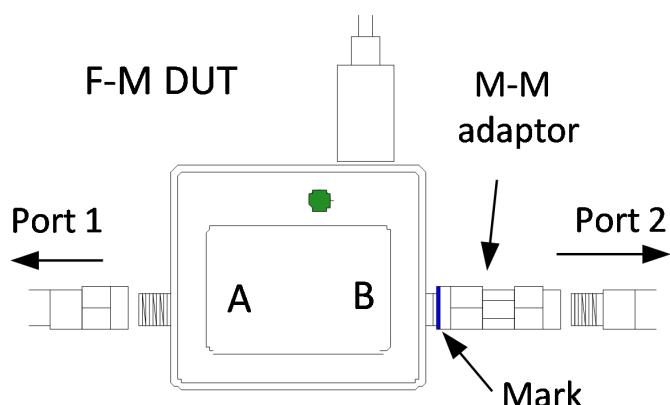
6.2.11 E-Cal 8.5 GHz Electronic Calibration Module - Setting up and operation

The E-Cal module can be used in three possible arrangements to support calibrations for both non-insertable and insertable DUTs. A non-insertable DUT is a device with the same sex RF connectors; typically female SMA connectors, for example. On the other hand, an insertable DUT is one with one female and one male connector.
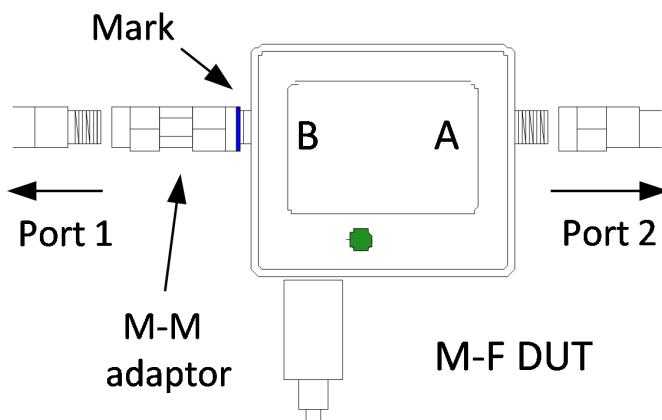
The available calibration arrangements (for the female connector version) are as follows:

Use of the E-Cal module to support insertable DUTs with female connectors
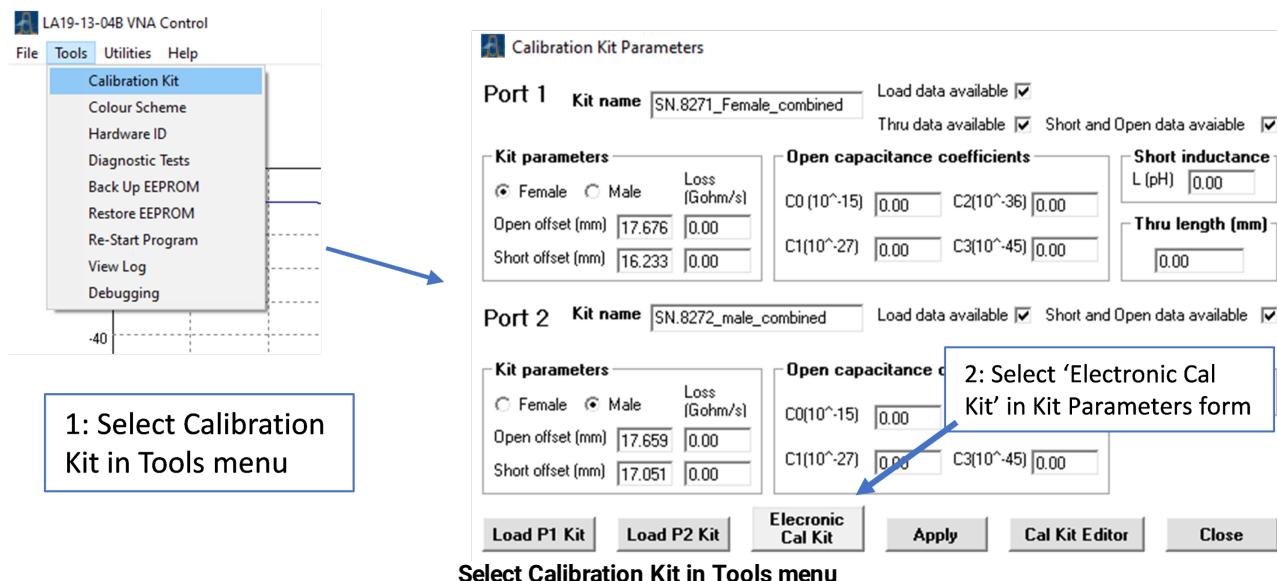
Use of the E-Cal module to support insertable DUTs with a female connector on port 1 and male on port 2
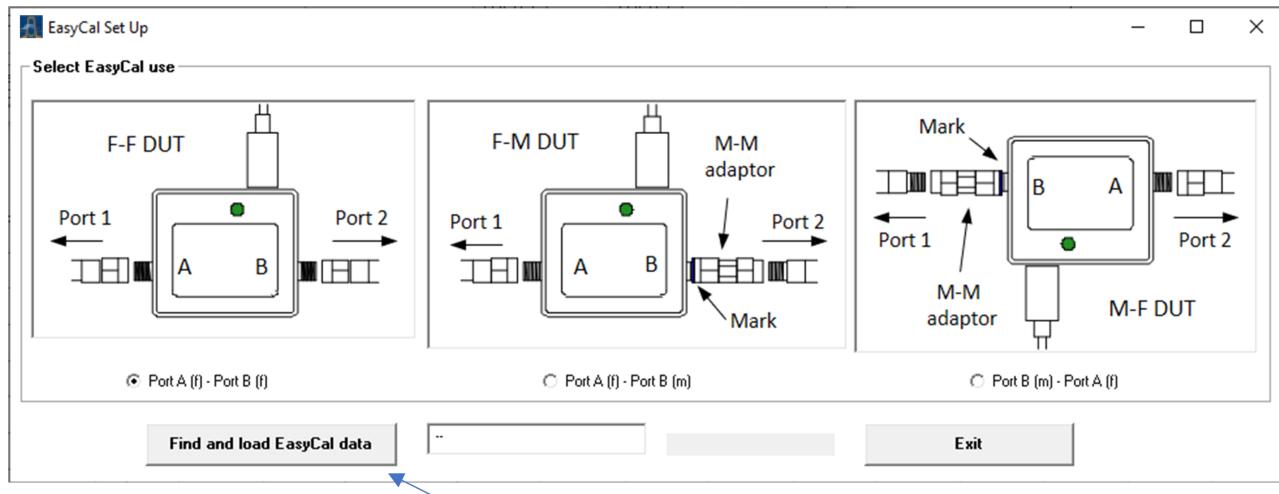
Use of the E-Cal module to support insertable DUTs with a male connector on port 1 and a female connector on port 2

For the male connector version of the unit, similar connection arrangements are possible but a F-F (female-female) adaptor is used instead, see figures above. Also, the test cable connectors' sexes shown in the figures above are reversed.

Selection of the calibration arrangement to be used is carried out as part of the 'calibration kit selection' procedure on the LA Techniques' VNA UI software. Firstly, connect the E-Cal module to the host PC and, ideally, allow a few minutes for the indicator to turn green. Once the module is connected, the steps to load the data from the module are shown below.

Select Calibration Kit in Tools menu

Select the arrangement required and click on Find and load EasyCal data
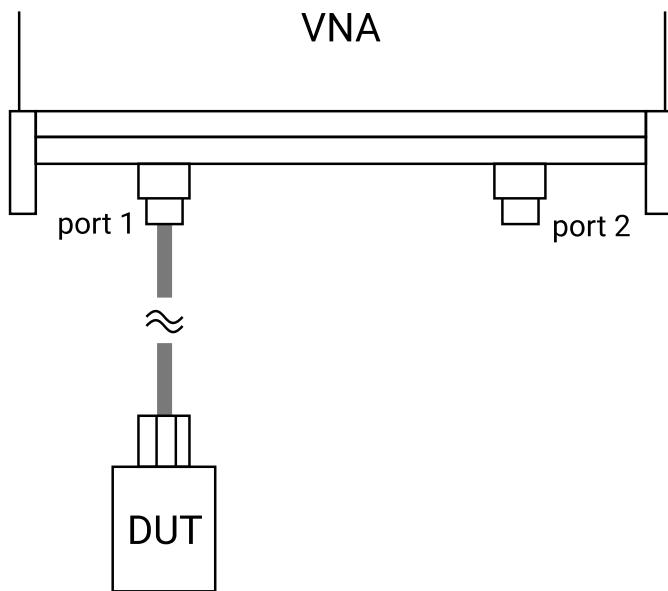
Note. The module is supplied with an adaptor which is required to deal with insertable DUTs. It is important that this adaptor is kept safe and connected correctly, with its marked end nearest the module as shown.

Once the E-Cal module's data has been loaded and connections made, select the Measurement required in the Calibration form and then click on any calibration Standard button. All Standards will be automatically measured. On completion click **Apply Cal** to exit the Calibration form. The VNA is now calibrated and ready for use.

6.3   Measurements

6.3.1   Return loss

In order to carry out return loss measurements (S_{11}) the VNA must be calibrated as described before, either S_{11} calibration only, both S_{11} and S_{21} or 12-term. The device to be tested (DUT) is then connected to Port 1 of the VNA as indicated in the figure below. *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.*

Connect device under test to Port 1 to carry out S11 measurements.
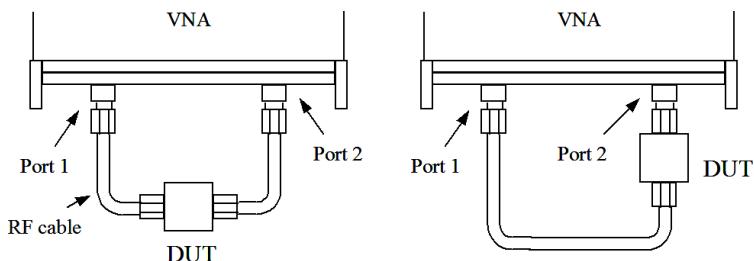
Displaying the results
The measurement result can be displayed by selecting the S_{11} parameter and an appropriate display graph as described in [Display setup](#). Note that the measured phase is relative to the calibration reference plane as discussed in [Reference plane extension and de-embedding](#). The reference plane can be shifted at any time from the **Enhancement** window. Note that changes to the reference plane only take place when the instrument is sweeping.

6.3.2   Insertion loss / gain

To carry out insertion loss measurements (S_{21}) the VNA must be calibrated with the test cables in place, either S_{21} calibration only, both S_{11} and S_{21} or full 12-term. The device to be tested (DUT) is then connected between Ports 1 and 2 of the VNA as indicated in the figure below.

For best results, the arrangement shown on the right hand side of the figure should be used whenever possible. When using an $S_{11}+S_{21}$ calibration this will minimize errors introduced by the load return loss. On the other hand, when using a 12-term calibration, this will minimize repeatability / cable flexing errors associated with the connecting cables.

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

Displaying the results
The measurement result can be displayed by selecting the S_{21} parameter and an appropriate display graph and described in Reference plane extension and de-embedding. Note that the measured phase is relative to the calibration reference plane as discussed in that section. The reference plane can be shifted at any time from the **Enhancement** window. Note that changes to the reference plane only take place when the instrument is sweeping.

6.3.3   Complete 2-port measurement

In order to measure all four s-parameters a 12-term calibration needs to be completed. The arrangement shown on the right hand side of the figure above is likely to yield best results in terms of repeatability by virtue of using only one test cable, reduces the effects of cable flexing.

Displaying the results
The measurement result can be displayed by selecting a different parameter for each of the possible four display graphs, as described in the previous section. Note that the measured phase is relative to the calibration reference plane as discussed in Reference plane extension and de-embedding. The reference plane can be shifted (independently for each parameter) at any time from the **Enhancement** window. Note that changes to the reference plane only take place when the instrument is sweeping.

Maximizing dynamic range
Refer to Calibration for best dynamic range – minimizing the effect of crosstalk for guidance on achieving the largest dynamic range.

6.3.4   Group delay

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

$$group\_delay = \frac{d\phi}{d\omega}$$

In relatively non-dispersive components such as transmission lines, group delay is the transit time through the line. However, some components such as filters can exhibit negative group delays so care is needed when attaching an interpretation to group delay.
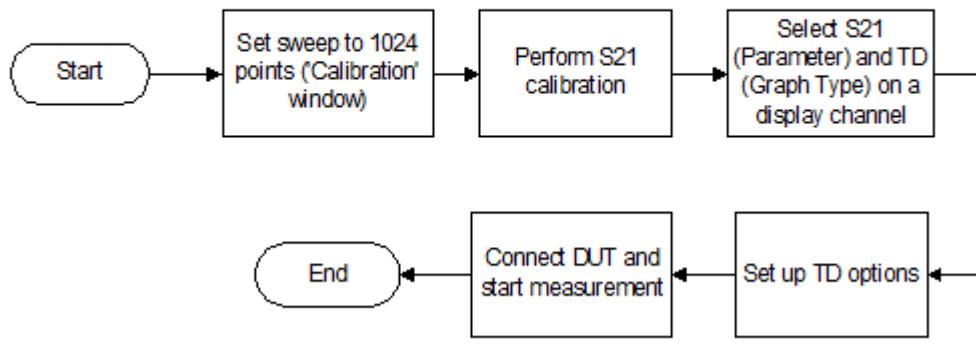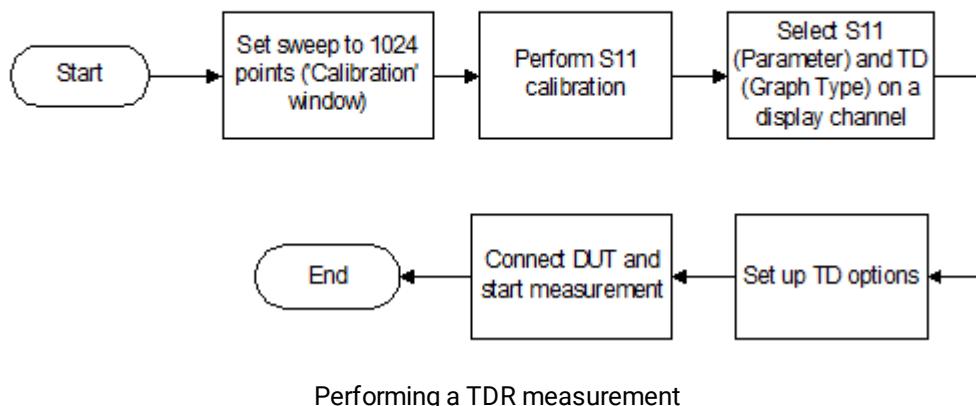
The PicoVNA 106 and 108 calculate the group delay by dividing the phase change between adjacent sweep points and dividing by the size of the sweep step. It is usual to apply some degree of trace smoothing to remove very rapidly changing perturbations from the trace. Care should be exercised to ensure that genuine sharp group delay variations are not masked by the smoothing.

Displaying the results
Group delay of any S-parameter can be measured. The result can be displayed by selecting the required parameter and group delay graph from the **Display** window as described in Display setup.

6.3.5 Time domain measurements

The time domain facility allows the display of the time domain response of a network under test. For example, time domain reflectometry (TDR) measurements can be made by first carrying out an S_{11} calibration using 1024 sweep points. Similarly, time domain transmission (TDT) measurements can be made by first completing an S_{21} calibration using 1024 sweep points. The steps necessary are shown in the flowcharts below.


Performing a TDR measurement

Performing a TDT measurement
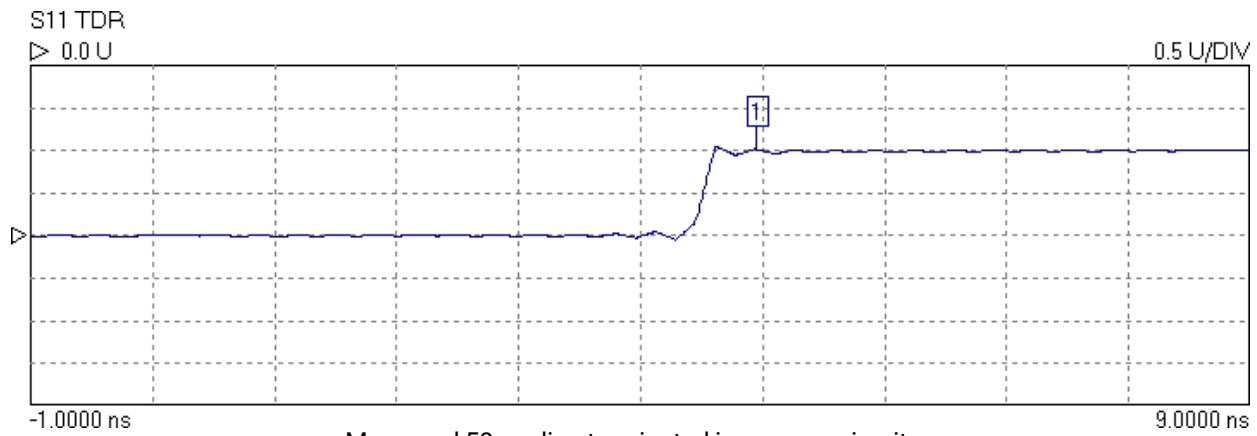
Note that carrying out time domain measurements requires a lot of mathematical processing and therefore each sweep will be noticeably slower when displaying time domain.
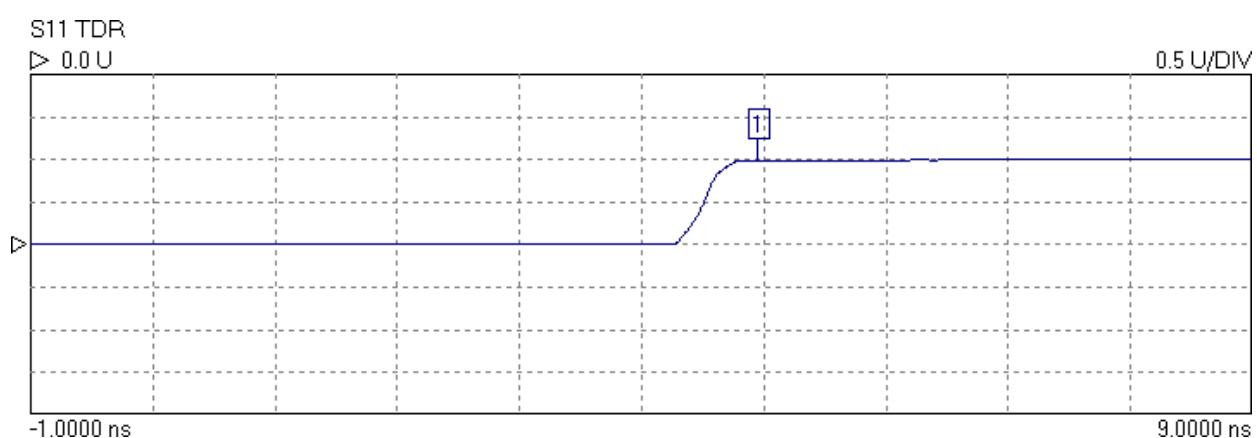
In TD mode, the plot markers display resistance and distance values for S_{11} and S_{22}, and distance values for S_{21} and S_{12}, as well as levels.

Examples of TDR measurements using the PicoVNA
The trace below shows the time domain response of a 50 cm, 50 Ω coaxial cable with an open circuit termination. The trace goes to +1 relative to the reference indicating a reflection coefficient of +1 for an open circuit. The window used is rectangular.

Measured 50 cm line terminated in an open circuit.
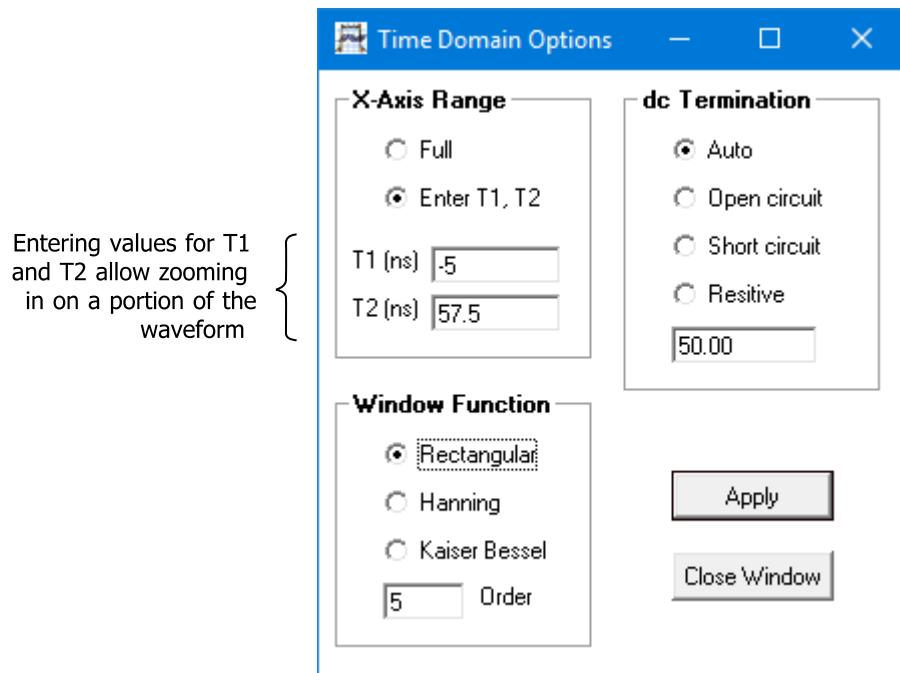
The trace below is the same as above except that the ringing either side of the transition has been reduced by the use of a fifth-order Kaiser−Bessel window. This reduces the ringing but also slows the rise time.

Same as previous figure but using the Kaiser−Bessel window.
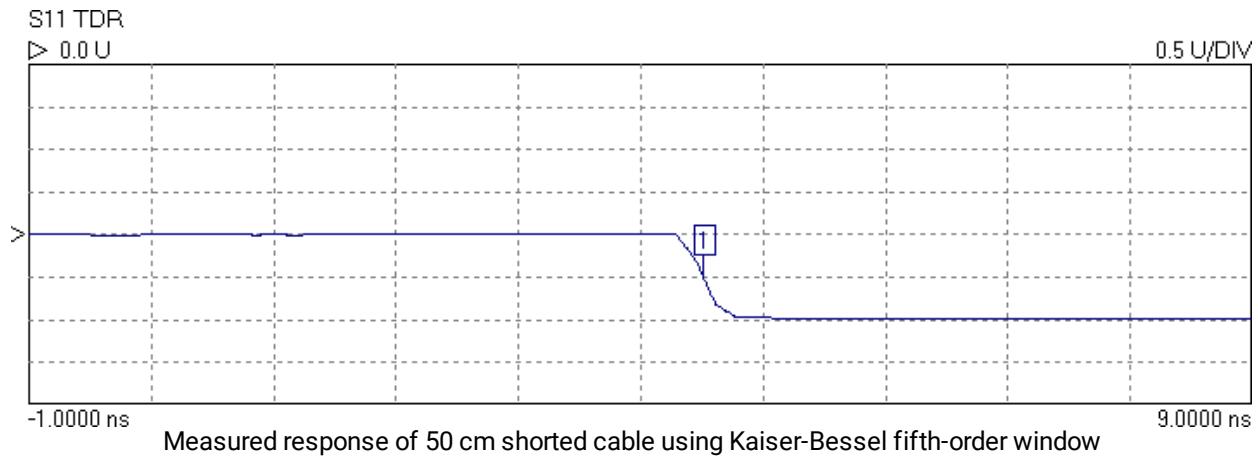
The type of window, the order of the Kaiser−Bessel window, and the time span over which the signal is displayed can be selected in the TDR options window, shown below.
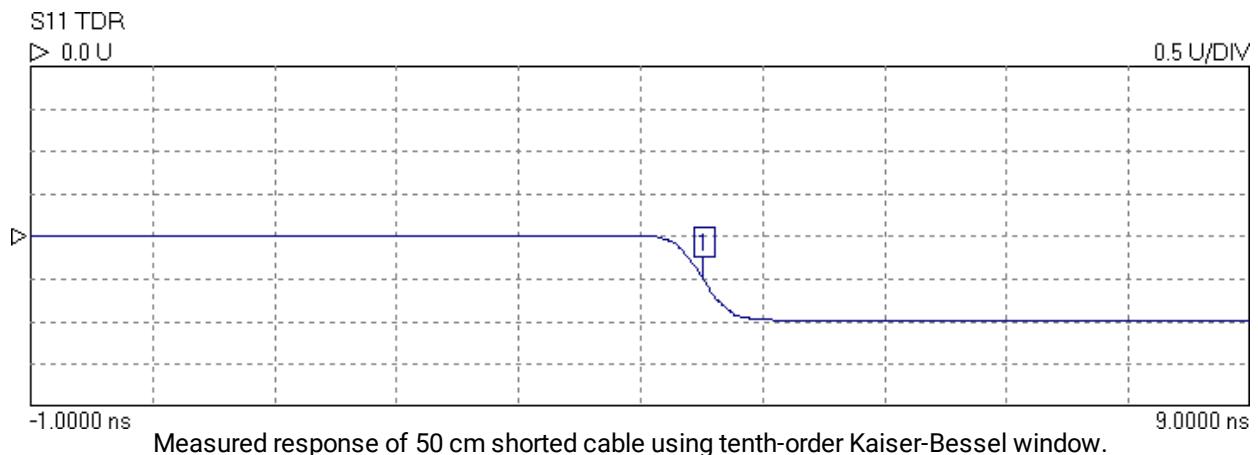
Time Domain Options window allows measurement setup

> **Note:** To set a time range either starting or ending beyond 161.66 ns, use the **Enter T1, T2** facility. However, the displayed total time span must be less than 166.66 ns.

The plot below shows the same cable terminated with a short circuit. The window is fifth-order Kaiser–Bessel. This time the trace goes to −1 relative to the reference, indicating a reflection coefficient of −1 for the short circuit.

Measured response of 50 cm shorted cable using Kaiser-Bessel fifth-order window
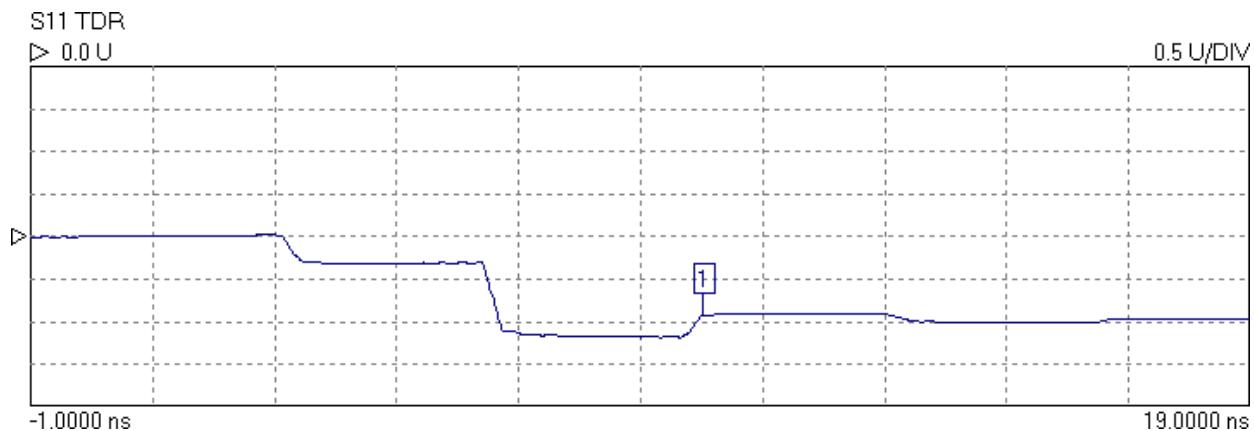
The trace below shows the effect of increasing the order of the Kaiser–Bessel window to 10. The ripple has been completely removed but the slope of the edge has been further reduced.

Measured response of 50 cm shorted cable using tenth-order Kaiser-Bessel window.
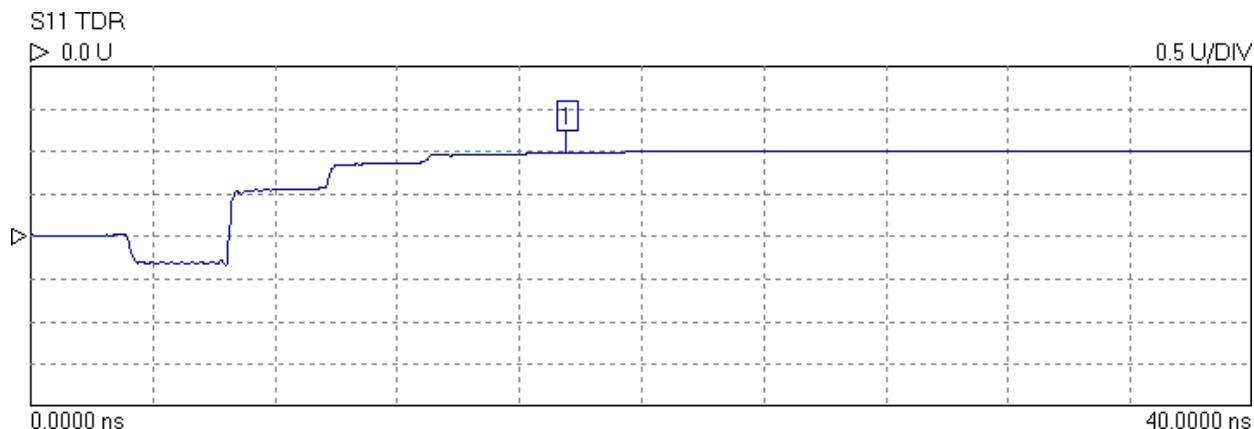
A more complicated example

The trace below shows the response of a 30 cm, 50 Ω line followed by 30 cm of 25 Ω line terminated in a short circuit. The window is third-order Kaiser–Bessel. The trace shows the multiple reflections from the discontinuity of impedance at the connection between the lines and the short circuit termination.

Measured response of multiple reflections. See text for details.

The last example is the same 50 Ω / 25 Ω cable combination but this time the termination is an open circuit. The response is also displayed over a longer period.
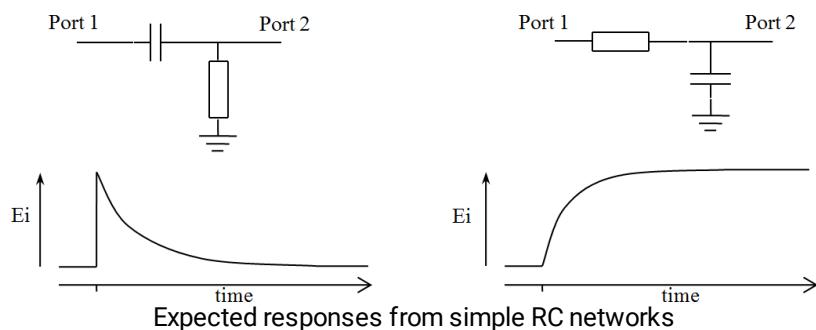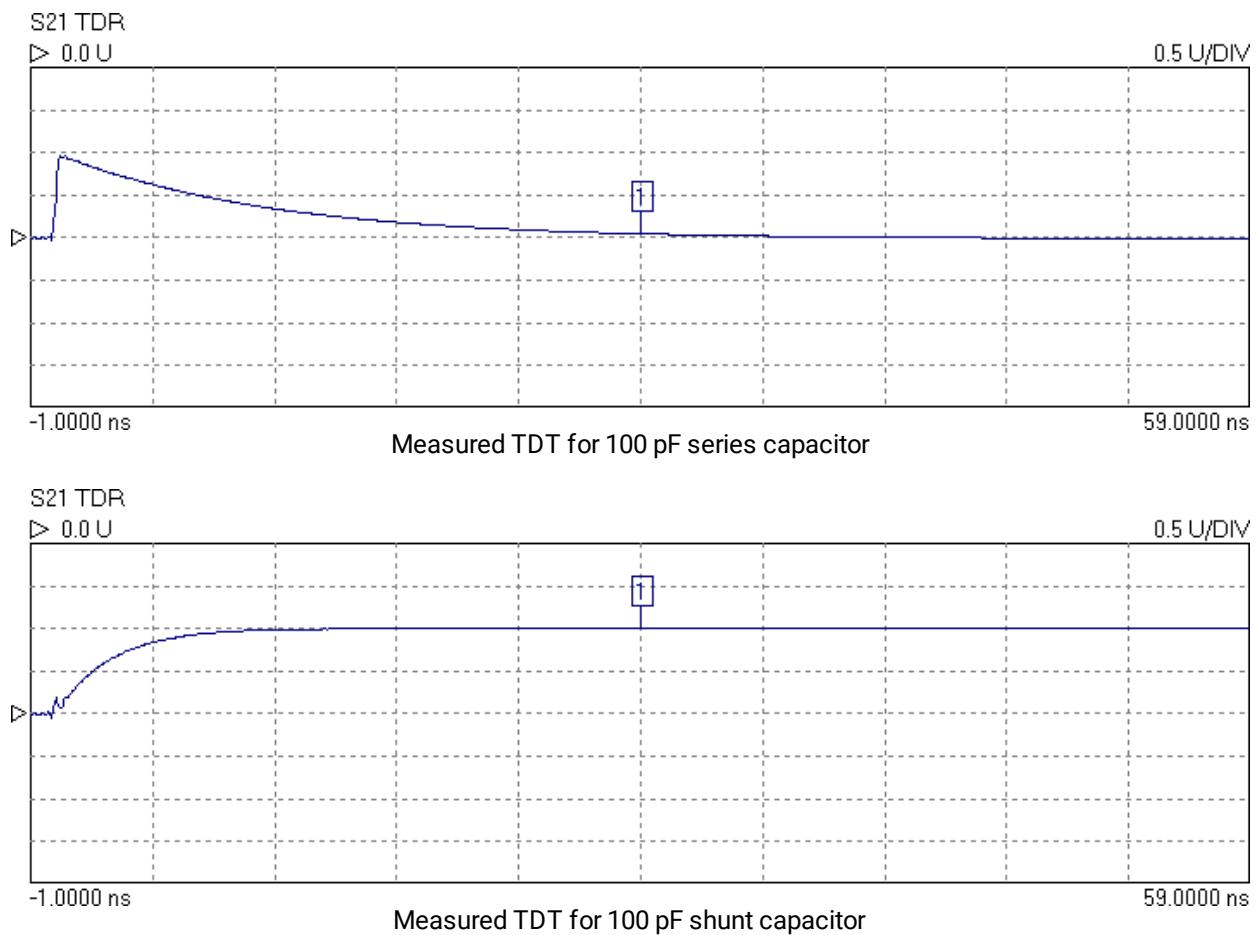

Measured response of multiple reflections. See text for details.

Time domain transmission

Time domain transmission (TDT) is similar to the TDR technique except that the transmitted signal is observed. Traditionally, this is accomplished using a step source and a sampling scope, as with the TDR, but the transmitted signal at the output of the network is observed rather than the reflected signal at the input to the network. This technique is useful for measuring the step response or rise time of amplifiers, filters and other networks.

Examples:

Expected responses from simple RC networks

Measured TDT for 100 pF series capacitor

Measured TDT for 100 pF shunt capacitor

6.3.6 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 calibration first (select 'insertable' or 'non-insertable' DUT on calibration window as shown in Display setup). The other calibration options measure only forward parameters. After the 12-term calibration is completed, simply select the reverse parameter(s) to be required on any displayed channel and start the measurement.

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

The PicoVNA 106 and 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. This facility can be used, for example, to provide DC bias to an active device being measured.
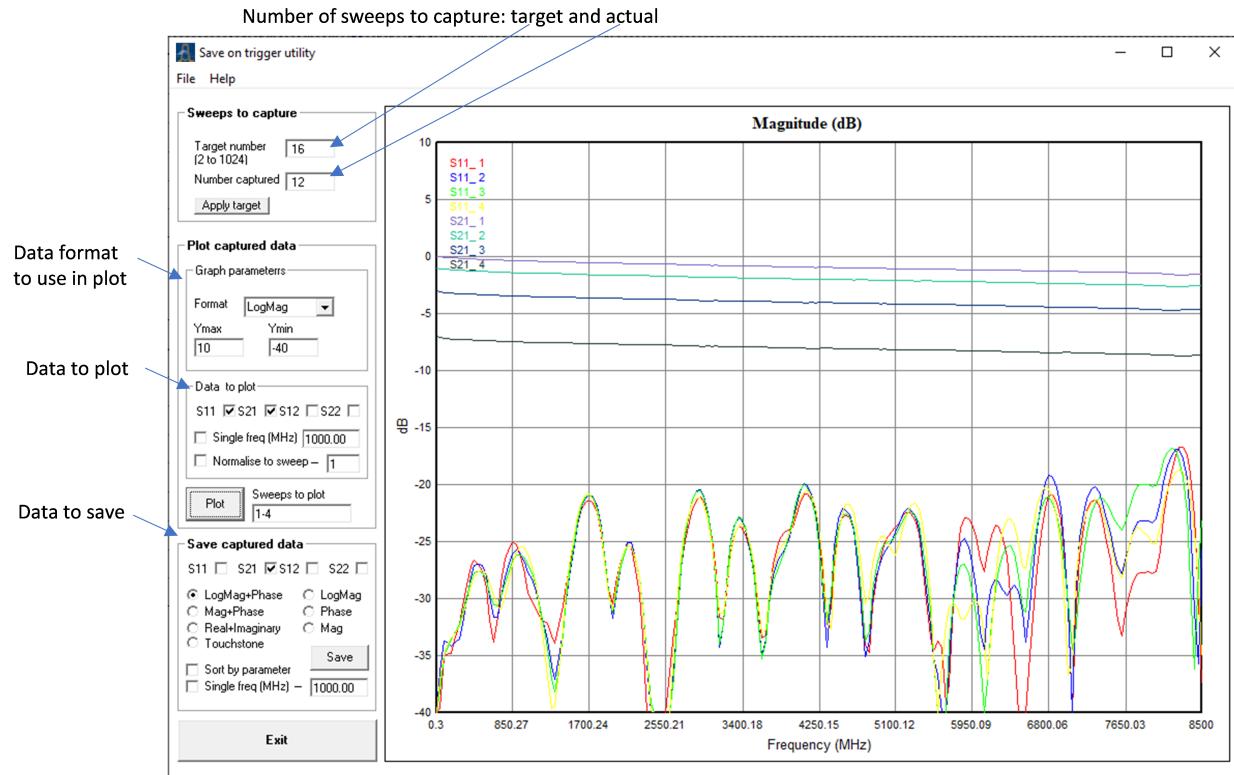
⚠️ **CAUTION**
To avoid causing permanent damage to the internal biasing circuit, do not exceed the voltage and current ratings.

6.3.8   Save-on-trigger measurements (PicoVNA 108 only)

The **Save on Trigger** facility (**Utilities** menu) provides a convenient way of measuring multi-state devices such as adjustable gain amplifiers and attenuators or phase shifters.

The Save on Trigger mode works by saving each triggered measurement sweep. Once the desired numbered of sweeps have been captured (or you stop the measurement), you can selectively plot the available data in various formats. The data can also be saved in a number of formats and sorted by parameter if so desired. A further option is to save the *entire data set* (menu option in the **File** drop-down menu) for later use. A copy of the Save on Trigger form (in **Utilities** menu) is shown below.

Save on Trigger settings form and display graph

Setting the target and enabling Save on Trigger mode
Save on Trigger operation is enabled using the check box on the trigger selection area on the main application dialog as shown on the right. When the box is first checked, you will be asked to enter the target number of sweeps to be captured. If the trigger mode is set to free run (auto trigger), you will be warned that the Save on Trigger will only operate on a trigger event, i.e. any trigger mode except free run.
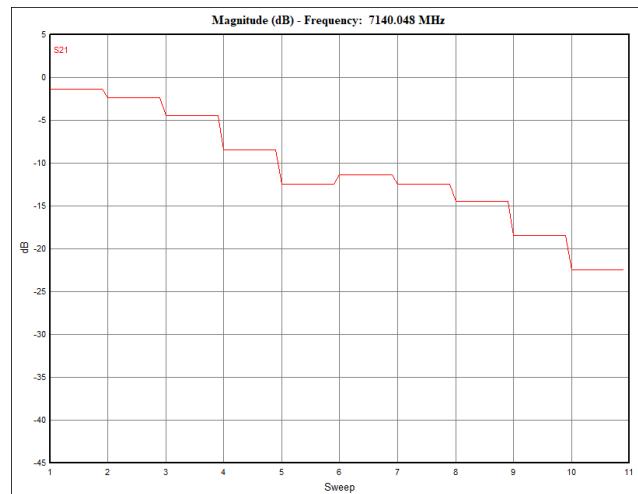
Plotting captured data
The captured data for each s-parameter measured can be plotted either in the form of a family of traces (one for each measurement sweep) over the sweep frequency (as in the graph above) or as a single trace displaying the value for a chosen frequency over the sweep number. The latter is useful, for example, to examine the attenuation or phase value of a digital attenuator at each setting at a given frequency.
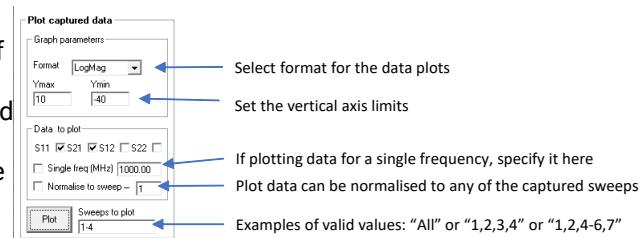
An example of a plot showing the measured data at a single frequency over the sweep number is shown on the right. This is a measurement of 10 states of a programmable attenuator. The horizontal axis represents each of the states measured (each sweep measured a different state) and the vertical axis is set to display the magnitude of S_{21} in decibels. The user-requested frequency for the plot is shown at the top.

The settings for the measurement sweeps to be plotted can be specified as shown below.

Maximum number of graph traces

When plotting s-parameter data over the measurement sweep (as on the graph above) the maximum number of traces (one for each measurement sweep) is 16 for each S-parameter. If all 4 S-parameters are being plotted this will result in a total of 64 traces. In any case, the maximum number of trace legends (which identifies the parameter and sweep number of each trace) is limited to 38.

Select format for the data plots

Set the vertical axis limits

If plotting data for a single frequency, specify it here

Plot data can be normalised to any of the captured sweeps

Examples of valid values: "All" or "1,2,3,4" or "1,2,4-6,7"

Saving the captured data

The default save mode ('sort by parameter' and 'single frequency' not ticked) creates a data file for each captured sweep. The example below shows the result of saving after capturing 12 measurement sweeps. In this, the user requested the magnitude S_{11} and S_{21}.

As can be seen, 12 data files have been created (each has the name provided by you, with the sweep number appended, e.g. "Step_Attn_5.dat" is the data file for sweep 5) and each data file has 3 columns. The first is the frequency in MHz, the second contains the requested S_{11} magnitude value and the third the requested S_{21} magnitude.

Default save mode saves a file for each captured sweep. In this example, the user requested the magnitude of S11 and S21
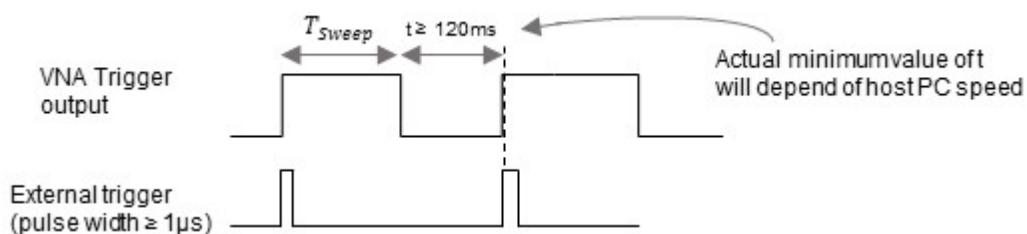
The default save data mode creates a data file for each sweep.

External trigger considerations

The save on trigger mode programs the instrument to perform a specified number of sweeps, each synchronized to an external trigger. You must 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.

The timing diagram that applies to the Save on Trigger mode is shown below. In this it is assumed that the external trigger is set to rising edge.

The measurement sweep time T_{Sweep} is a function of the number of sweep points and measurement bandwidth in use. For example, a plan with 201 points using a bandwidth setting of 140 kHz will have T_{Sweep} of 38.3 ms when measuring all 4 S-parameters. Ideally, the external system that generates the trigger signal will synchronize the trigger signal to the falling edge of the trigger output from the VNA and make allowance for the speed of the host PC and its operating system allocating USB communication resources and processing all data and graphics in time.


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

Note: In the case when the external trigger occurs sooner than the host PC can support after the end of the sweep time, it is possible that some trigger events will be missed. Controlling the VNA through the API (using the DLL file supplied) places a lighter load on the host PC (no graphics) so will support significantly faster rates.

Single frequency option

If required, it is possible to request that only data for a single frequency is saved. Ticking the 'single frequency' box and entering the desired frequency results in each saved data file containing a single line of data as shown here on the right. In this example the frequency requested was 1 GHz. The nearest calibrated data point (1020.264 MHz) is chosen as shown.

The single frequency option causes a single line of data to be saved.

Sort by parameter option

It is possible to save the data to a disk file on a parameter by parameter basis by selecting the **Sort by parameter** tick box in the **Save captured data** section of the form. So, for example, it is possible to save all the values of S_{21} in a single file with the values for each sweep in separate columns.

For example, choosing to save all 4 s-parameters sorted by parameter will result in 4 separate disk files being created as shown below:

Name	Date modified	Type	Size
Step_Attn_S11.dat	01/01/2020 14:55	DAT File	37 KB
Step_Attn_S12.dat	01/01/2020 14:55	DAT File	37 KB
Step_Attn_S21.dat	01/01/2020 14:55	DAT File	37 KB
Step_Attn_S22.dat	01/01/2020 14:55	DAT File	37 KB

The 'Sort by parameter' option creates a file for each s-parameter.
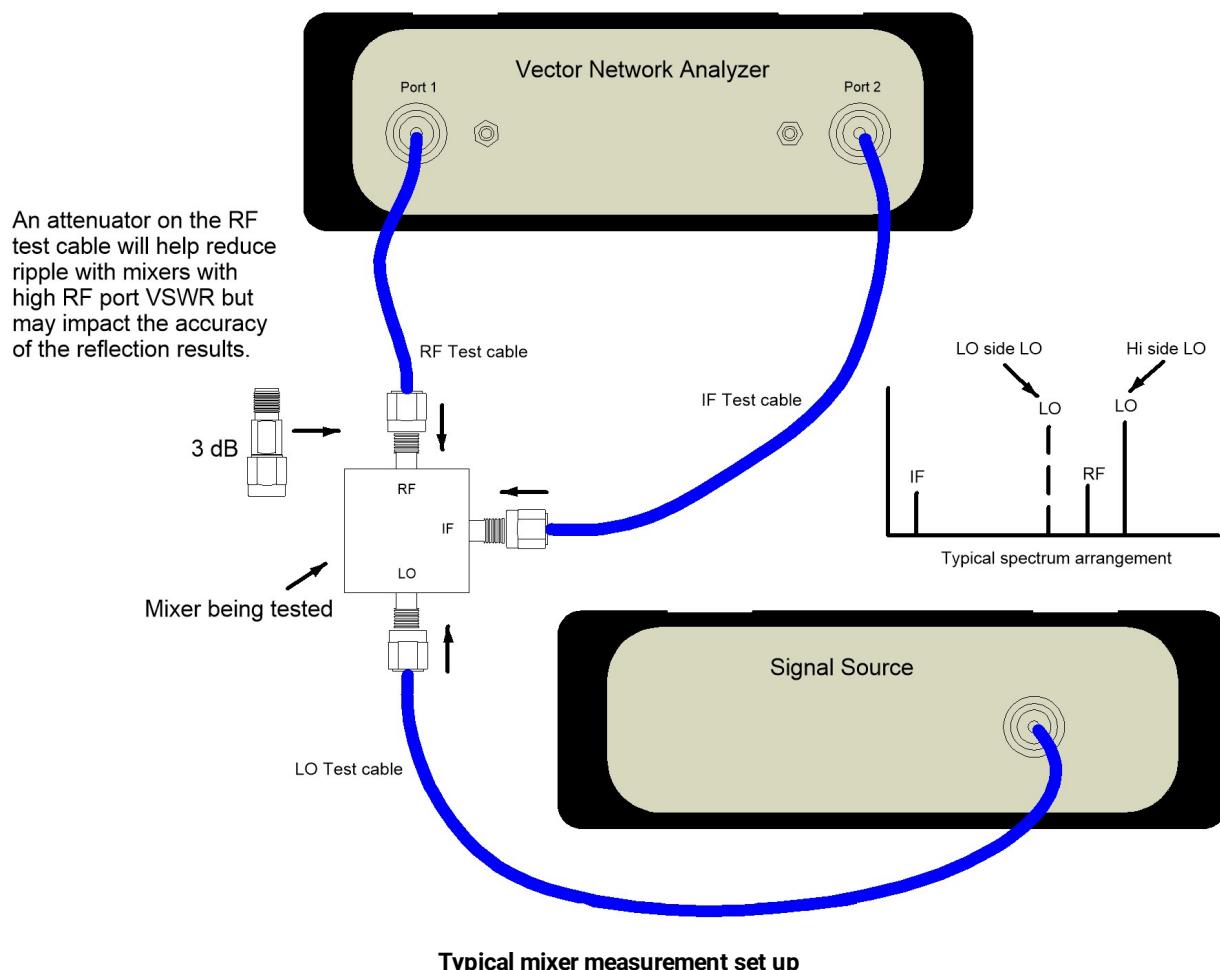
The figure below shows part of the contents of a sorted by parameter file created for the S_{11} values. In this example, the user chose to save magnitude only. As can be seen, the first column has the frequency value in MHz and subsequent columns contains the S_{11} value of the measurement sweeps captured.

S11 (mag) sweep 1, S11 (mag) sweep 2, S11 (mag) sweep 3, ...

Step_Attn_S11.dat - Notepad						
File Edit Format View Help						
0.3	0.00475	0.00328	0.00232	0.0068	0.0077	0.00731	0.008
42.7985	0.01052	0.01528	0.01251	0.01393	0.01396	0.00914	0.00958
85.297	0.01759	0.0206	0.01793	0.01808	0.01785	0.01036	0.01048
127.7955	0.01816	0.02027	0.0197	0.02021	0.02021	0.01075	0.01051
170.294	0.01831	0.0196	0.02078	0.02135	0.02156	0.01048	0.01011
212.7925	0.02165	0.02048	0.0228	0.02257	0.02254	0.01021	0.00976

Each column contains the data for each sweep

Sorted by parameter files have a column for each sweep captured.
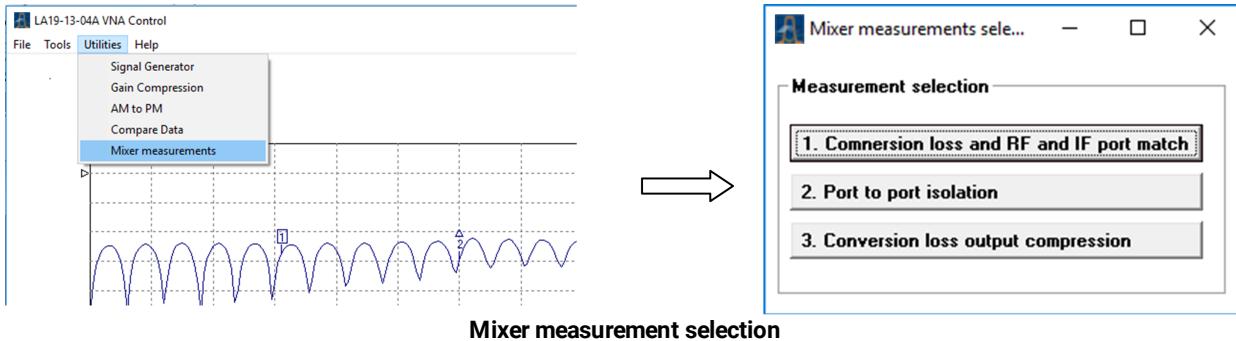
6.3.9   Mixer measurements (PicoVNA 108 only)

The PicoVNA 106 and 108 can perform measurements on mixers (frequency conversion devices) with the use of an external LO source. The user interface software provides support for some commercially available instruments as well as power sensors (power meters) needed to carry out signal level calibration for improved measurement accuracy.

Typical mixer measurement set up
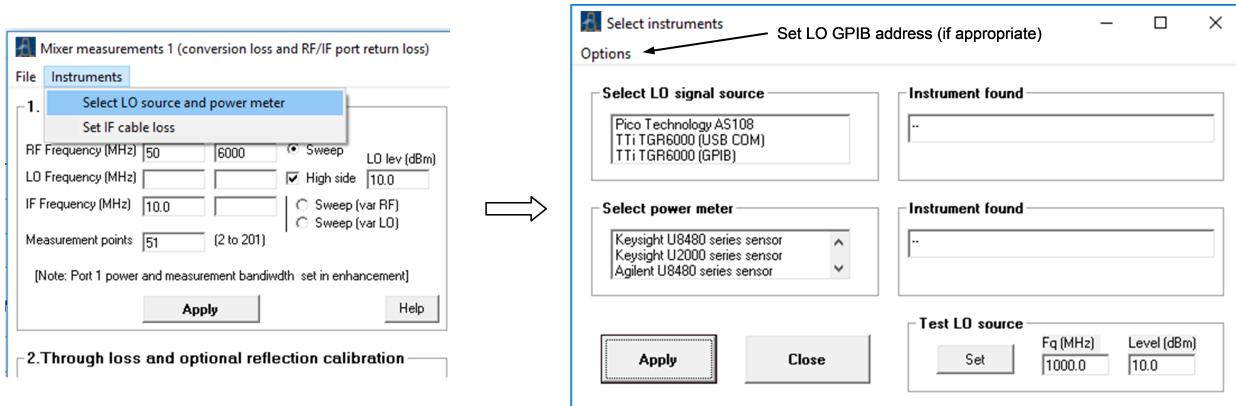
Measurement selection

The appropriate mixer measurement form is launched from the **Utilities** drop down menu as shown below:

Mixer measurement selection

External instrument selection

Before setting the measurement parameters, select the source of the LO signal and the means for calibrating the power level. This is done from the **Instruments** drop-down menu as shown below. The host PC requires the Keysight® IO Libraries Suite to support communication with external instruments such as power sensors through either the USB or GPIB interfaces. See www.keysight.com. Contact the factory if your preferred instrument(s) is not on the list in case support may be added at a later date.

External instrument (LO source and power meter) selection
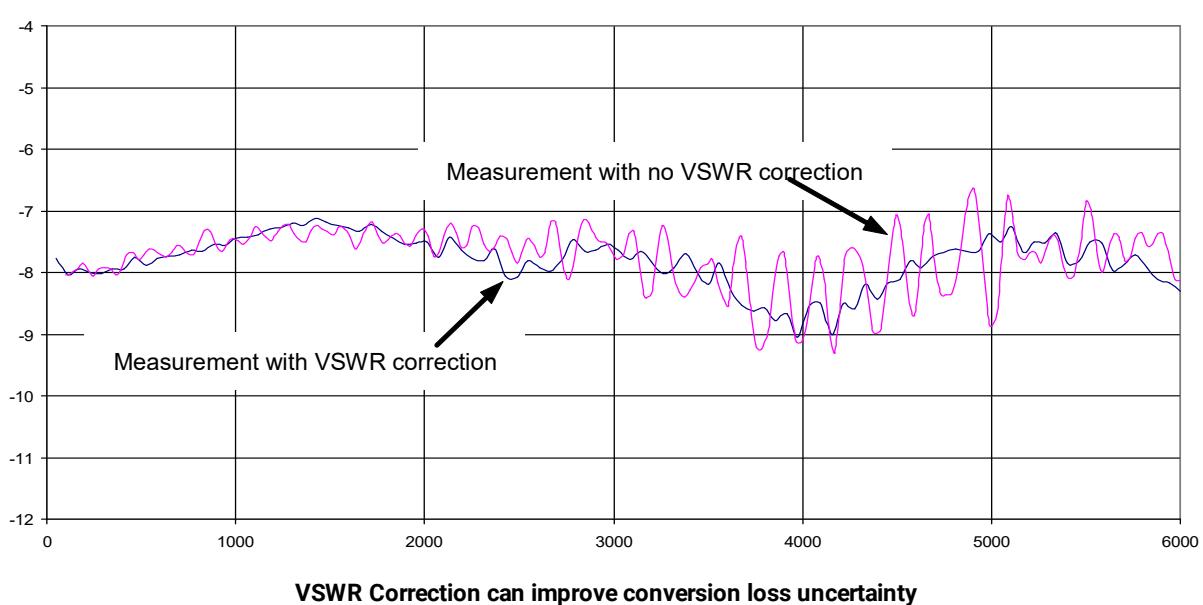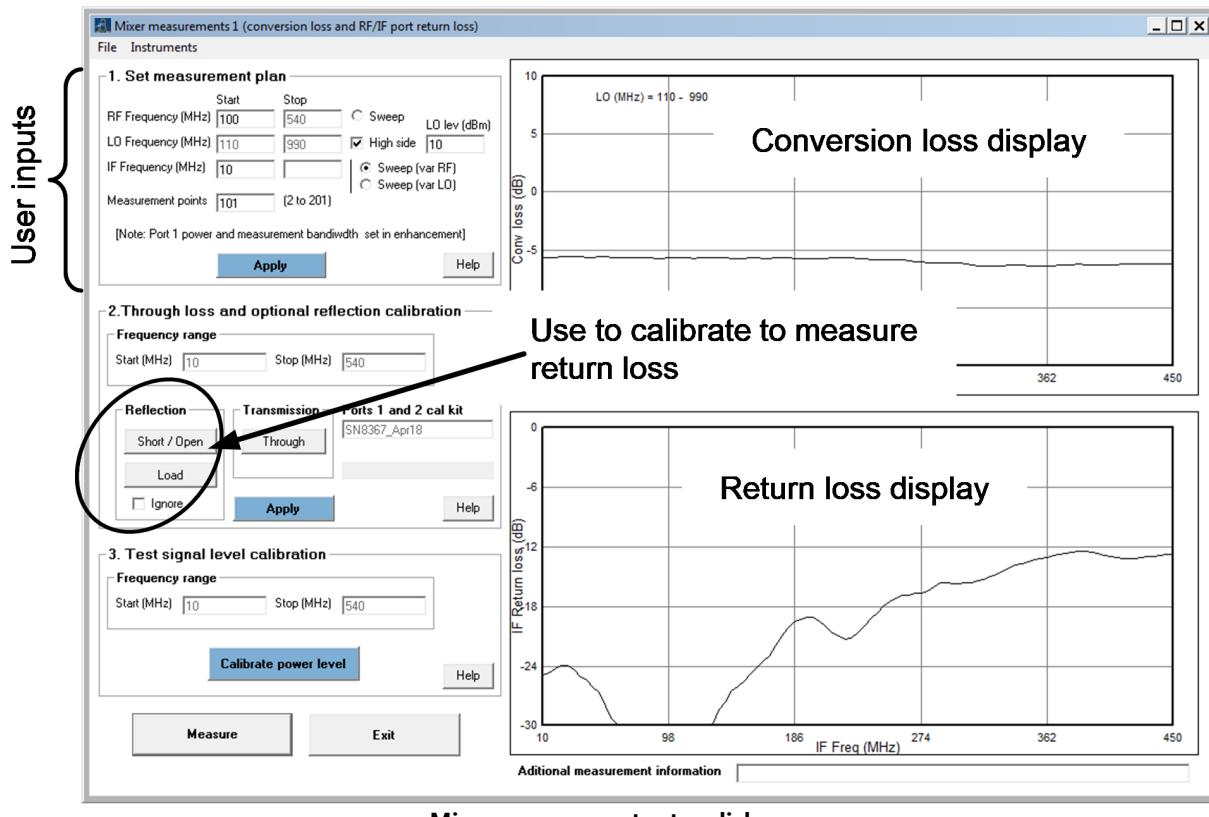
Conversion loss and return loss

This measurement is set up using the dialog shown above. It allows the frequency ranges to be set up as well as the LO power level.

You can chose whether or not to measure return loss by means of the **Ignore** check box under the **Reflection calibration** buttons. If the button is left unchecked, the instrument will perform a standard SOLT calibration to allow corrected return loss values to be displayed.

Note: The return loss of either the RF port or the IF port will be measured and displayed. If the IF frequency is swept, then the IF port return loss is measured otherwise the RF port return loss is measured and displayed.

One important advantage of return loss calibration is that the measured conversion loss will corrected for the effects, for example, of poor mixer return loss. This is sometimes referred to as VSWR correction and is illustrated in the second figure below.

Mixer measurement setup dialog
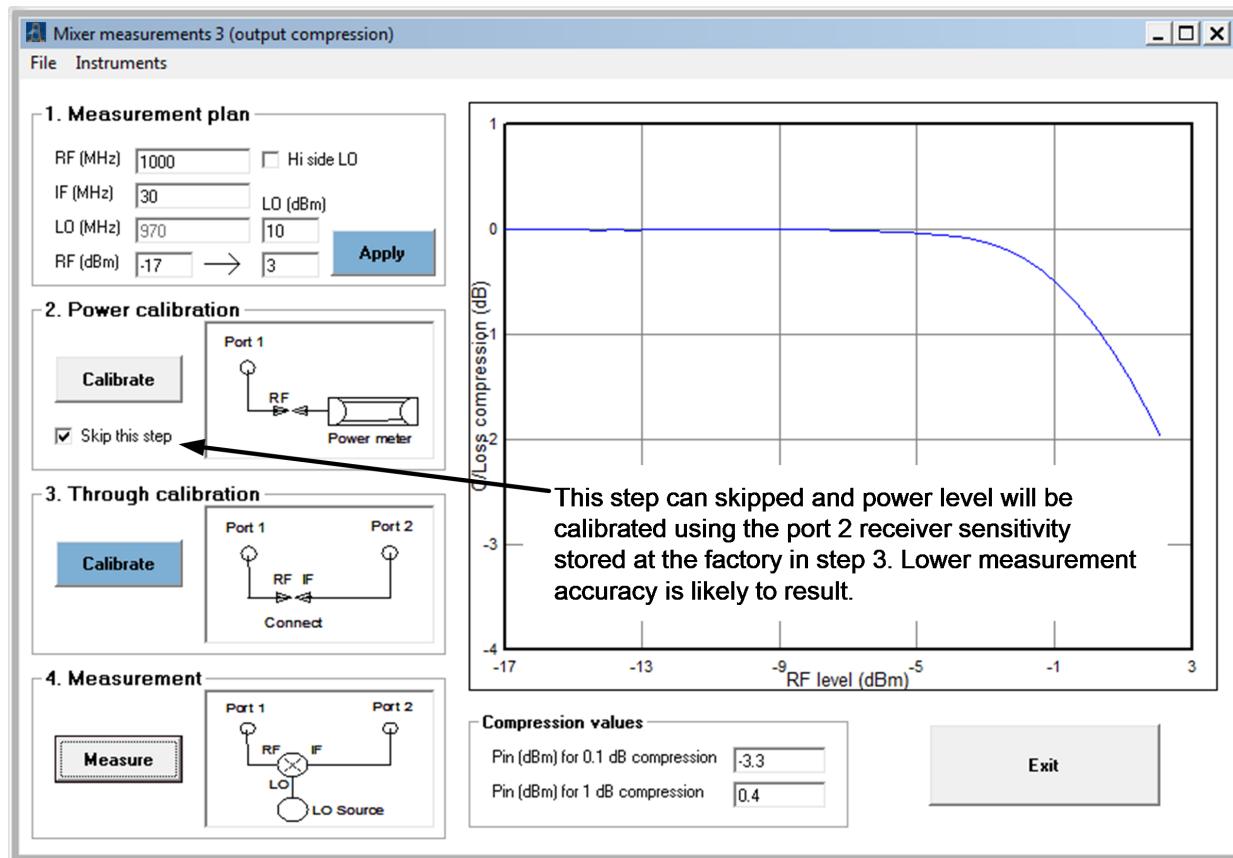
VSWR Correction can improve conversion loss uncertainty

Isolation and conversion loss compression

The other main measurement options are port to port isolation and conversion loss compression as shown under **Measurement Selection** above. Setting each of these up will require selection of the external instruments as described above under **External instrument selection**. The corresponding form for each of these set of measurements provides graphical indication of the calibration steps.

The figure below shows the conversion loss compression setup dialog. As indicated, the need for an external power meter can be bypassed albeit at the risk of reduced measurement accuracy. On completion of the measurement the variation of conversion loss with RF port power level and the 0.1 dB and 1 dB compression points are displayed.

Conversion loss compression measurement dialog

6.4   Reference plane extension and de-embedding

The *reference plane extension* facility on the PicoVNA 106 and 108 allows you to shift the measurement reference plane away from the value 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 each of the measurement parameters (S_{11}, S_{22}, S_{12} or S_{21}).

The loss associated with any plane extension can be entered directly (see figure above) in terms of the loss (in dB) at 1 GHz. The software assumes that the loss is 0 dB at dc and at other frequencies the magnitude of the loss is given by the following expression.

Loss = Loss (1 GHz) x $\sqrt{(Freq / 1 \times 10^9)}$

The **enhance option** in the **Auto Ref** facility allows the software to compute the loss as well as the optimum phase offset at each frequency in the sweep plan. This can be very useful to cancel out the effect of loss but note that some residual errors after using this feature will remain, for example mismatch errors.
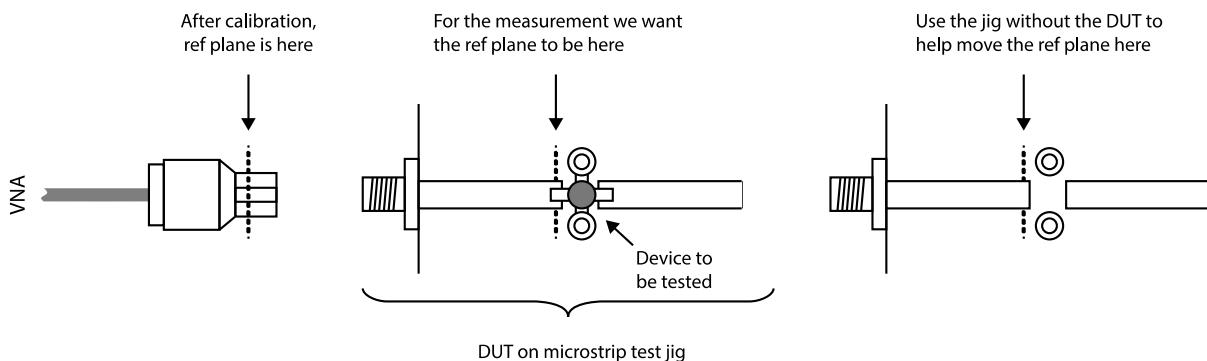
The **Auto Ref** feature assumes a perfect open for reflection measurements. That is, it tries to provide an offset to leave 0° reflection phase. Similarly, when dealing with transmission measurements, it assumes a perfect zero length through connection.

An example of an application requiring the use of reference plane extension is shown below. In this, it is desired to measure the S_{11} of a device mounted on a microstrip test jig with SMA connectors. In order to remove the effect of the interconnecting line to the input of the device, the following procedure may be followed:

- Perform an S_{11} calibration at the end of the N to SMA adaptor on Port 1
- Connect the test jig **without** the DUT mounted on it
- Display the phase of the S_{11} on active display channel
- Click **Auto Ref** in the **Enhancement** window
- Click **Apply** in the **Enhancement** window

The above steps will move the reference plane to the end of the microstrip line. This can be verified by noting that the displayed phase is close to 0° over the entire measurement band. Imperfections associated with the microstrip line and coaxial connector, such as loss and dispersion, will mean that some residual phase will remain. However, with careful design and employing good RF practice for the construction of the jig, this error should remain small.

After the above steps are completed, the DUT can be mounted on the jig and its S_{11} parameter measured.

Example of S_{11} measurement requiring reference plane extension

Note: The reference plane extension moves the reference plane for each parameter measurement independently. So, if required for example, different values can be used for S_{11} and S_{21}. A reference plane extension value entered, applies to the active channel measurement parameter (either reflection or transmission).
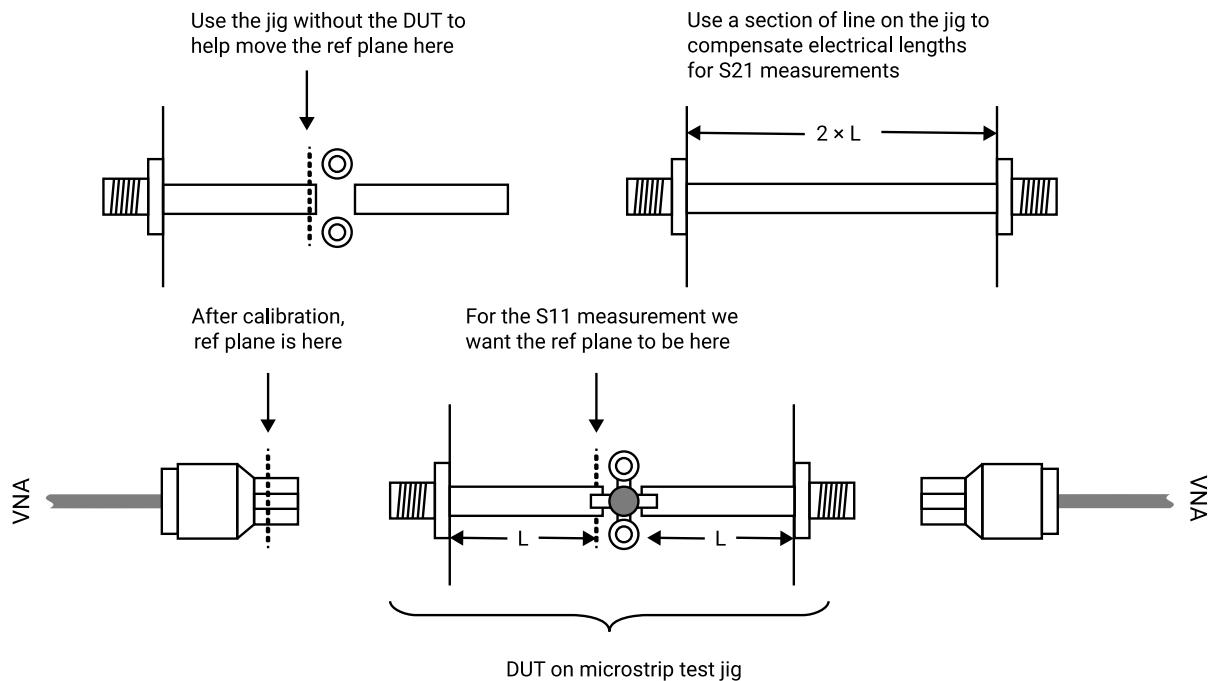
In the example above, correction was applied to the S_{11} phase but not S_{21}. An often-used way to correct the S_{21} phase is by using a calibration jig with length of microstrip line equal to the sum of the two sections of line used either side of the DUT jig (see figure below). Proceed as follows to make S_{11} and S_{21} measurements of the DUT.

Reference plane extension for S_{11} correction
- Perform a 12 term calibration (exclude test jig). Ensure that the test cable has connectors of different sex at each end. Adaptors may be needed to connect the DUT.
- Connect the input port of the test jig **without** the DUT mounted on it to Port 1
- Display the phase of the S_{11} on the **active** display channel
- Click **Auto Ref** in the **Enhancement** window
- Click **Apply** in the **Enhancement** window

Normalization for S_{21} correction
- Connect the through microstrip test line between Ports 1 and 2 of the VNA
- Display the phase of S_{21} on a non-active channel (keep active channel for S_{11})
- Start the measurement and store data on the S_{21} channel only to memory (use the memory window)
- Select **Data / Memory** for the math function in the **Memory** window
- Select the **Memory Math** display in the main window

Use the jig without the DUT to
help move the ref plane here

Use a section of line on the jig to
compensate electrical lengths
for S21 measurements

2 × L

After calibration,
ref plane is here

For the S11 measurement we
want the ref plane to be here

L   L

VNA

VNA

DUT on microstrip test jig
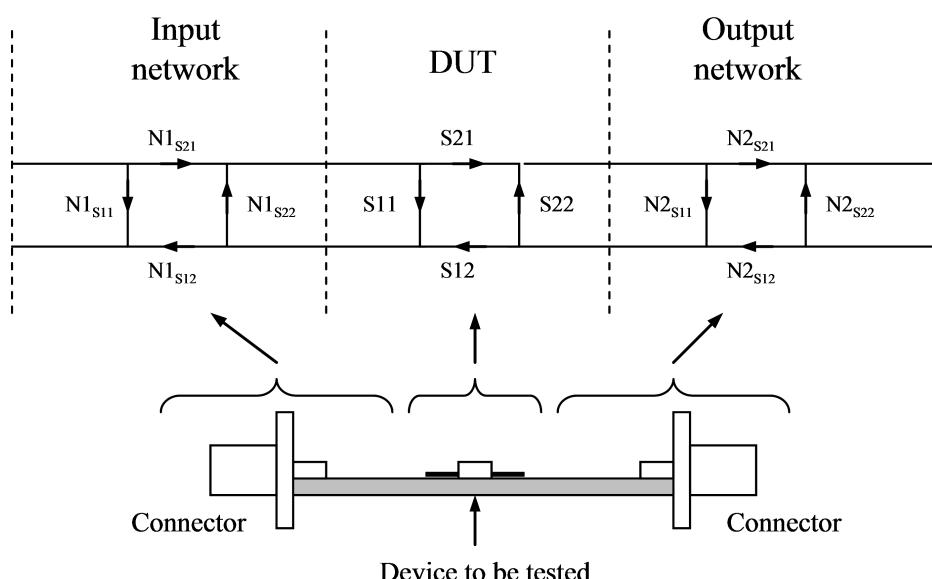
Correcting S_{21} and S_{11} phase measurements. Reference plane extension corrects S_{11} measurements and normalization to a test line corrects S_{21}.

The above steps will allow the DUT's S_{11} and S_{21} (or S_{22} and S_{12}) parameters to be measured with the right phase correction. In addition, the loss of the microstrip line will be accounted for. The same approach can be used to measure S_{12} and S_{22}. Note, however, that there will be an error on both measurements due to the imperfections of the microstrip line and connector interface. With careful design of the jig these can be kept acceptably small but further accuracy can be achieved by making use of the de-embedding facility described below.

De-embedding facility
A typical measurement jig, as shown below, includes input and output networks which introduce errors to the measured values of the device under test (DUT). For best measurement accuracy, these networks can be specified (in the form of 2 port s-parameter files) and then used to extrapolate the DUT's characteristics.

Input
network

DUT

Output
network

$N1_{S21}$

S21

$N2_{S21}$

$N1_{S11}$

$N1_{S22}$

S11

S22

$N2_{S11}$

$N2_{S22}$

$N1_{S12}$

S12

$N2_{S12}$

Connector

Connector

Device to be tested

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 S-parameter files (must be full 2-port data) for the input and output networks as shown in the figure above so that the de-embedding takes place automatically as the instrument measures the test jig. After first calibrating as usual, follow the steps below to enable de-embedding.
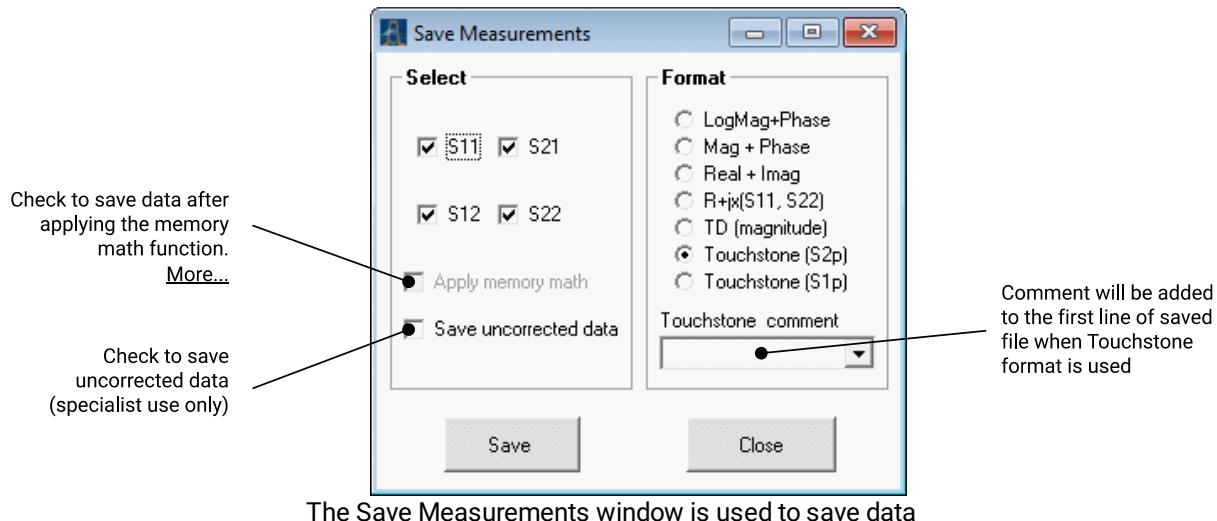
1. Select the S-parameter file(s) that represent the embedding network(s) by clicking on the embedding network check box(es) as shown in Measurement enhancement. Check box **Port 1 Network** represents the input network as shown in the figures in Reference plane extension and de-embedding, and **Port 2 Network** represents the output network. The files selected must be full 2-port S-parameter files in Touchstone format.
2. Click on the radio button in the Measurement enhancement window to enable de-embedding.

Once the above steps are completed, starting the measurement will display de-embedded results.

The de-embedding facility relies on S-parameter data for the input or output network (or both) being available. This data must be in the form of 2-port S-parameter files in Touchstone format.

6.5   Saving data

Measured data can be saved to a file by selecting **File > Save Measurements** in the main menu. Various formats are available as shown. In all cases, frequency is saved in megahertz. **Note that only the Touchstone format can later be read back into the instrument's memory trace.**

Check to save data after applying the memory math function. More...

Check to save uncorrected data (specialist use only)

Comment will be added to the first line of saved file when Touchstone format is used

The Save Measurements window is used to save data

Note: For true compatibility with the Touchstone format, only 1-port or full 2-port S-parameters should be saved. For example, selecting S_{11} and S_{21} (but not S_{12} and S_{22}) is not Touchstone compliant.

If required, the data can be saved with the memory math function applied as described earlier under Memory facility. In order to do this, check the **Apply Memory Math** box. Note that the memory math display function on the main window must be set otherwise the **Apply Memory Math** check box will be disabled.

When saving data in Touchstone format, ensure that you provide the file name extension when entering the file name. Typically, for 1-port networks, the extension ".s1p" is used and ".s2p" for 2-port networks. This will help when reading back the data files since, by default, only files with these extensions will be displayed.
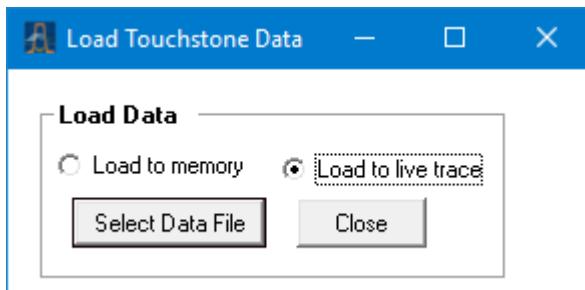

Note: Data will be saved with any system Z_0 conversion applied.

6.6   Loading data

Measured data (or data from a circuit simulator) can be read into the instrument's memory trace(s) or live trace. This can be done by selecting **File > Load Measurement** in the main menu. The file containing the data (in Touchstone) format is selected by clicking **Select Data File**.

The data will be read from the file and copied to the appropriate display channel(s). So, for example, assume you read a data file holding full 2-port data. Further, you have only two channels on display showing, say, S_{11} and S_{21}, so only the S_{11} and S_{21} data from the data file read will be copied to the memory traces of the displayed channels. **Note:** system impedance conversion will apply if turned on in the Measurement enhancement window.
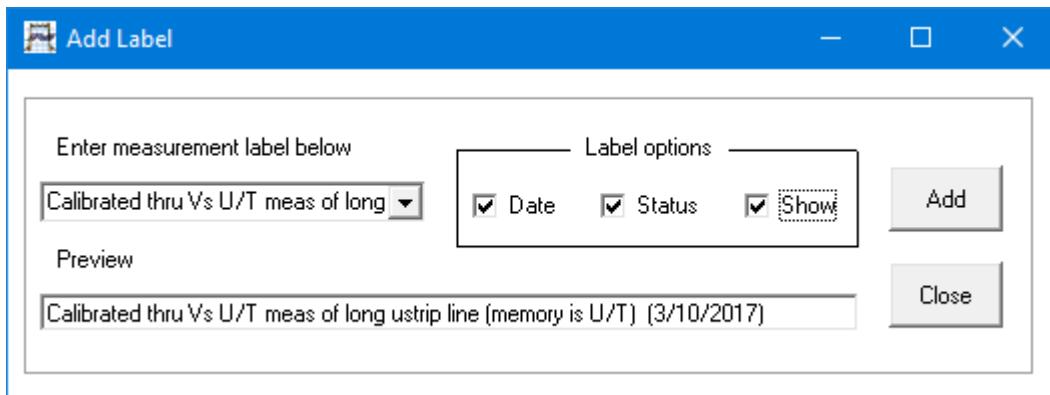
Loading data is done with the File > Load
Measurement menu command

6.7   Plotting graphics

You can plot the graphics displayed on the main window using the **File** menu. A printer setup window will appear from you can choose the desired printer and set its properties. If required, you can add a label to the plotted graphics by clicking **File > Print / Save Graphics Label**.

A label can be added when plotting or saving graphics

A similar plotting facility exists on the P1dB and AM to PM utilities' control windows.
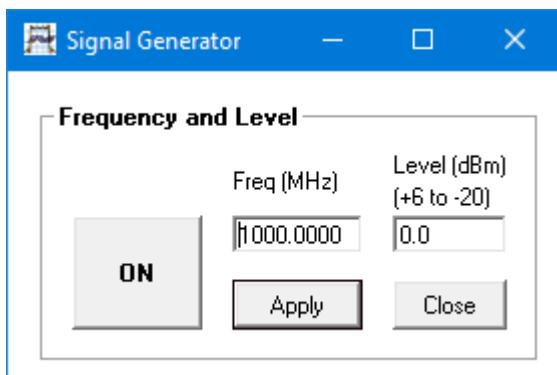
6.8   Saving graphics

The graphics shown on the main window can be saved in BMP, PNG, GIF, TIF or JPEG formats. This allows measurement results to be directly pasted into most electronic documents. The facility to save the graphics can be found under the main **File** menu. After clicking, a dialog box will appear allowing you to select the name of the file, its location and format from a drop-down box. As described in the previous section, a label can be added by clicking **File > Print / Save Graphics Label**.
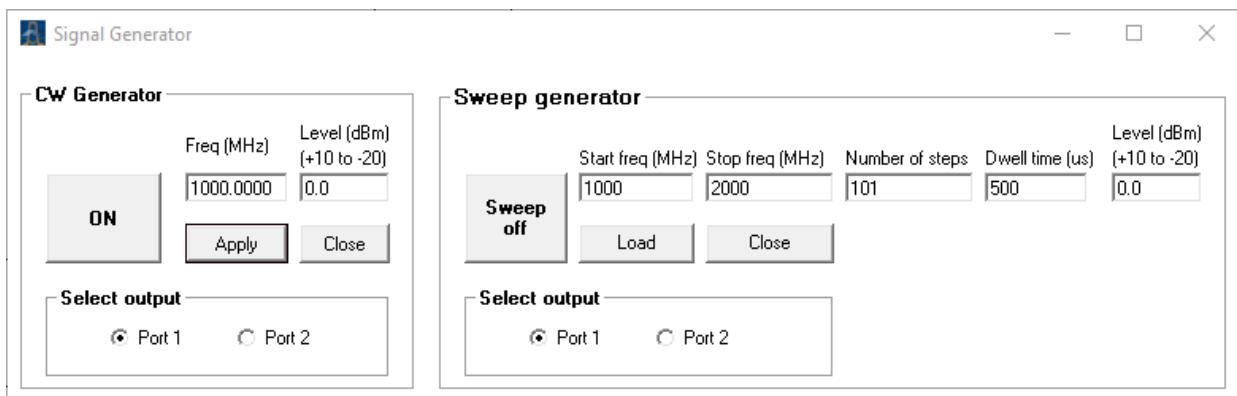
The save graphics facility is not available on the P1dB and AM to PM utilities. Instead, the graphics on these can be captured by pressing the **Alt+PrtScr** key combination. The image can then be pasted to the chosen document from the **Edit** menu.

6.9   Signal generator utility

This utility allows the instrument to act as a simple CW or sweep signal generator with variable output power. power. The output can be either port 1 or port 2. The VNA measurement sweep must be stopped first and the control window, shown below, called from the **Utilities** menu:

PicoVNA 2 (PicoVNA 106) signal generator utility control window

PicoVNA 3 (PicoVNA 108) signal generator utility control window

Maximum output level when using the generator utility: see Performance specifications.

In sweep mode, the maximum number of points in the plan is 1001 with a dwell time range of between 250 and 60 000 µs. Note that this dwell time excludes the time to program the synthesizers.

Trigger (PicoVNA 108 only)
The sweep generator mode supports the following trigger modes:

- Free running
- External rising edge
- External falling edge

These three modes can be selected from the main VNA dialog, in the **Trigger** selection box. Note that the **Manual** trigger mode is not supported by the sweep generator.

6.10   Output power at the 1 dB gain compression point utility

This utility allows the measurement of the power output at the 1 dB gain compression point (P_{1dB}) of active devices such as amplifiers. The measurement can be done at a single frequency or over the entire frequency plan specified at the last S-parameter measurement calibration. Start the utility from the **Utilities** menu in the main window.

P_{1dB} calibration
Calibration minimizes errors by removing small variations associated with the instrument's hardware. The procedure is simple, as shown below.

- Ensure that an S_{21} (or S_{11} + S_{21}, or 12-term) calibration has been carried out
- Connect Port 1 to Port 2 as shown on the left-hand side of the figure below
- Enter **Input Attenuation** and **Output Attenuation** values (or select **Read from file**)
- Enter the test frequency (or select **Use sweep plan**) and click **Calibrate**

P_{1dB} test
The basic connection arrangement is shown on the right hand side of the figure below. Note that the input and output attenuators should be carefully selected to ensure that the DUT compresses whilst preventing the power at Port 2 of the instrument exceeding the nominal limit of +10 dBm. It is recommended that the following guidelines are used to estimate the value of the input and output attenuators needed.

$$P_{1dB(DUT)} - G_{(DUT)} - 1 + A_{tt1} = -5 \pm 2 \text{ dBm}$$

$$P_{1dB(DUT)} - A_{tt2} + 5 < 10 \text{ dBm}$$
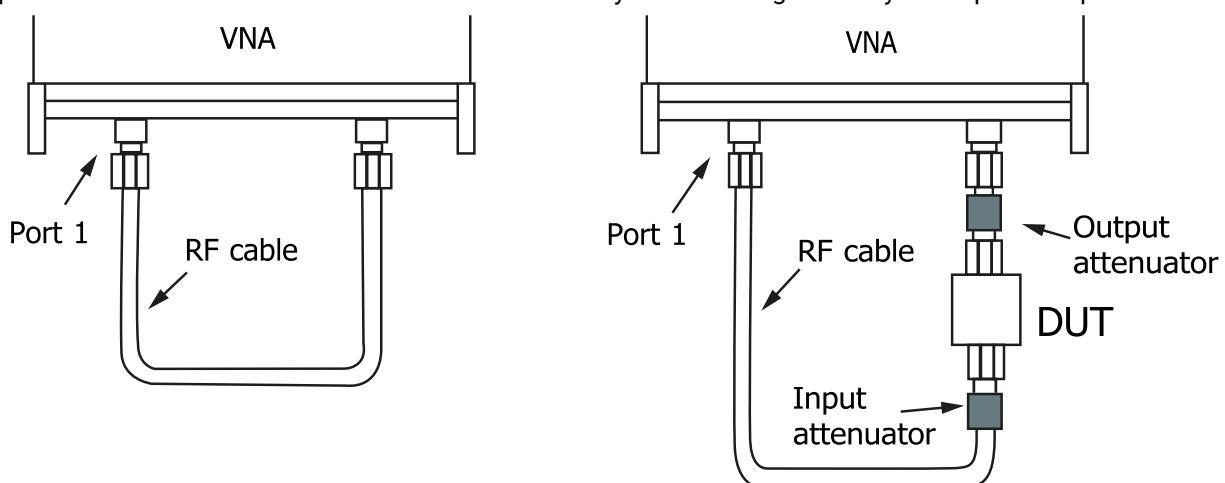
where: $P_{1dB(DUT)}$ = output power of DUT at the 1 dB gain compression point
                $G_{(DUT)}$ = linear gain of DUT
                A_{tt1}, A_{tt2} = input and output attenuators

The P_{1dB} test relies on the internally stored factory calibration of the instrument's port 2 receiver sensitivity. This is used as a power sensor to calibrate the power available from port 1 as well as measuring the output power from the device under test. The test **does not** rely on the setting accuracy of the port 1 output level.
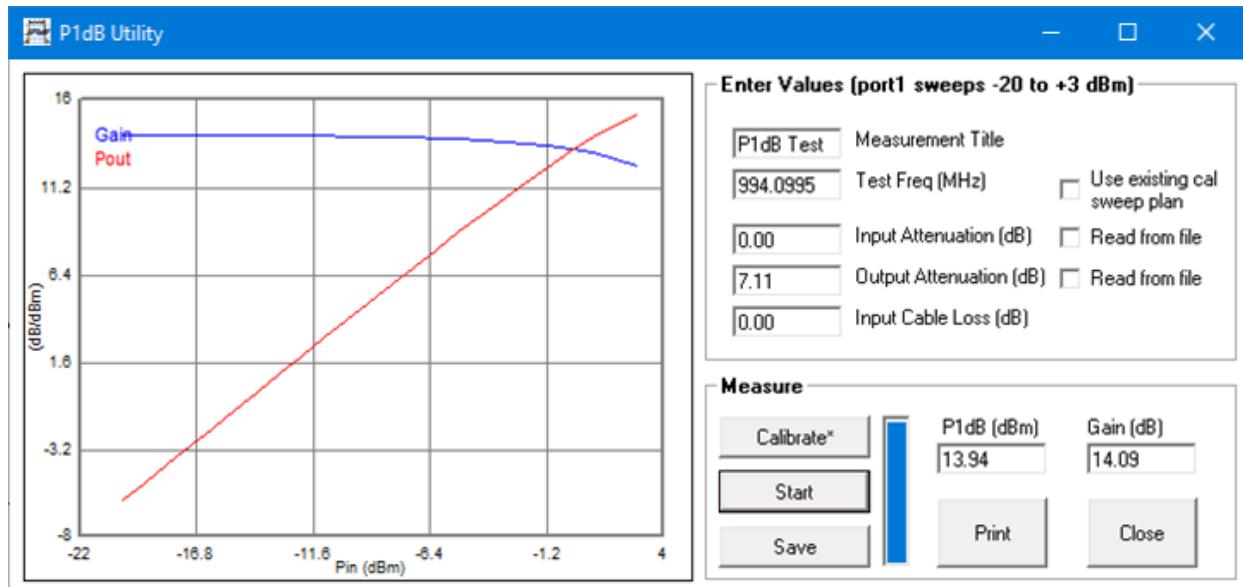
Basic connection guide for P1dB measurements. Calibration connection is shown on the left.

The instrument makes the measurement by setting the signal source (Port 1) frequency to the chosen value and then stepping its power from −20 to +3 dBm (PicoVNA 106) or to +6 dBm (PicoVNA 108) in 1 dB steps. The gain at each power setting is recorded. On completion of the power sweep, a second order curve is fitted over a narrow section centered on the point closest to the 1 dB gain compression point. The coefficients of this curve allow the actual P_{1dB} point to be calculated.

> **Note:** Choose the input attenuator with care. Ensure that there is no gain compression at the start of the power sweep (−20 dBm at Port 1) and that at least 0.7 dB of gain compression is reached at the end of the sweep (+3 or +6 dBm at Port 1). A '?' will be displayed if insufficient compression has been achieved.

After the attenuator values have been established and the DUT is in place (and powered up as appropriate), enter the values into the P_{1dB} control window (figure below). Note that the output attenuation value directly affects the P_{1dB} value, so it is important to enter an accurate value that takes into account all losses in the output path, including any connecting cable that may have been used.

Clicking **Start** will perform the test, plot the gain and output power curves, and compute the P_{1dB}. This, together with the linear gain, will be displayed in the text boxes to the right of the **Start** button. The results can then be printed (the window as displayed will be printed) or saved as a text file by clicking **Print** or **Save**.

The P1dB measurement utility control window

Attenuation values from file
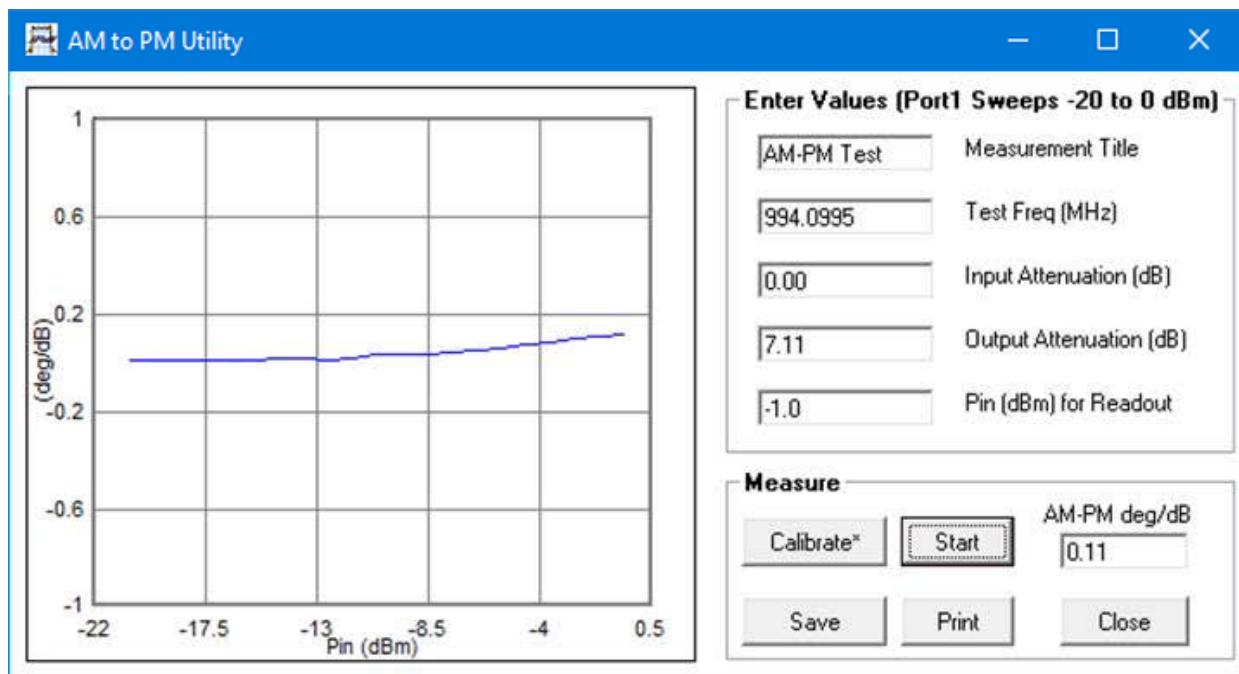
When measuring P_{1dB} using the frequency sweep plan, it is possible to read the input and output attenuation values from a file. The data is held in a simple text file with one line for each frequency point. The format must be as follows:

Frequency (MHz), magnitude (dB), phase (degrees)

Note: The number of lines in the file must match the number of sweep points in the sweep plan.

6.11   AM to PM conversion utility

This utility allows the measurement of the AM to PM conversion factor of a DUT. Generally, it is used for evaluating the linearity of active devices such as amplifiers. The utility is started from the main **Utilities** menu, shown below:

The AM to PM measurement utility control window

In order to use this facility an S_{21} calibration (or S_{11}+S_{21}, or 12-term) must have been carried out. For best results, some averaging (e.g. 16) should be used. Further, a second through calibration is suggested to remove residual phase variations. The steps are summarized as follows.

AM to PM utility (calibration)
- Perform a normal S_{21} calibration (or S_{11}+S_{21}, or 12-term); see left-hand connection diagram in <u>Quick start guide</u>
- Call up **AM to PM Utility** (window shown above)
- Enter frequency required (**Test Freq**) in megahertz
- Click **Calibrate** (connection as on left-hand side of figure below)

AM to PM utility (test)
- Connect DUT with attenuators as shown on right hand side of the figure below
- Enter attenuator values, input power at which result is required and measurement title
- Power up DUT if necessary
- Click **Start**

On completion of the AM to PM test, a graph of AM to PM as a function of input power at the DUT input will be plotted. In addition, the AM to PM factor at the specified input power entered will be displayed in the text box in the **Measure** section of the window.
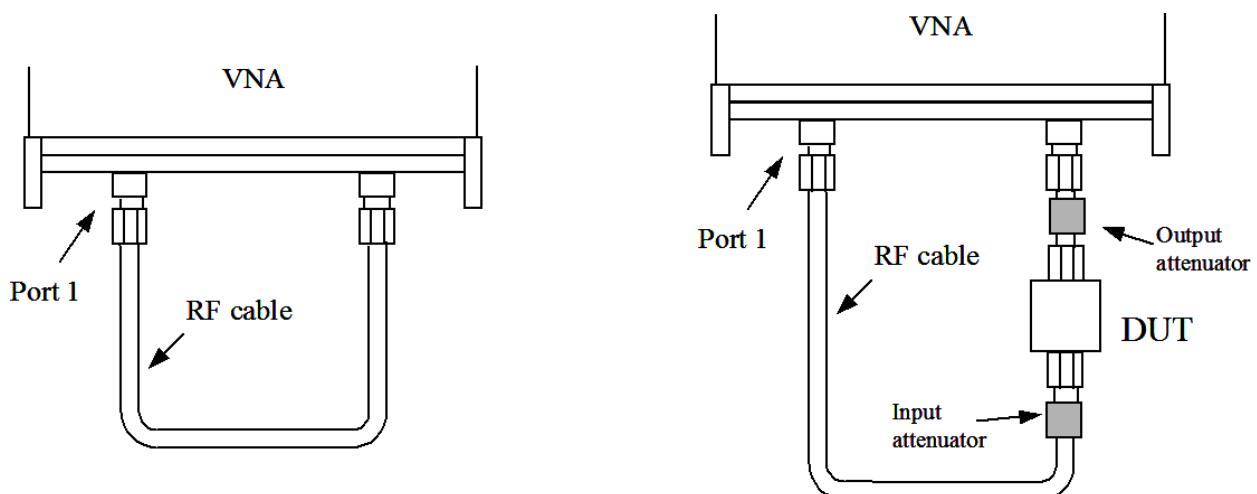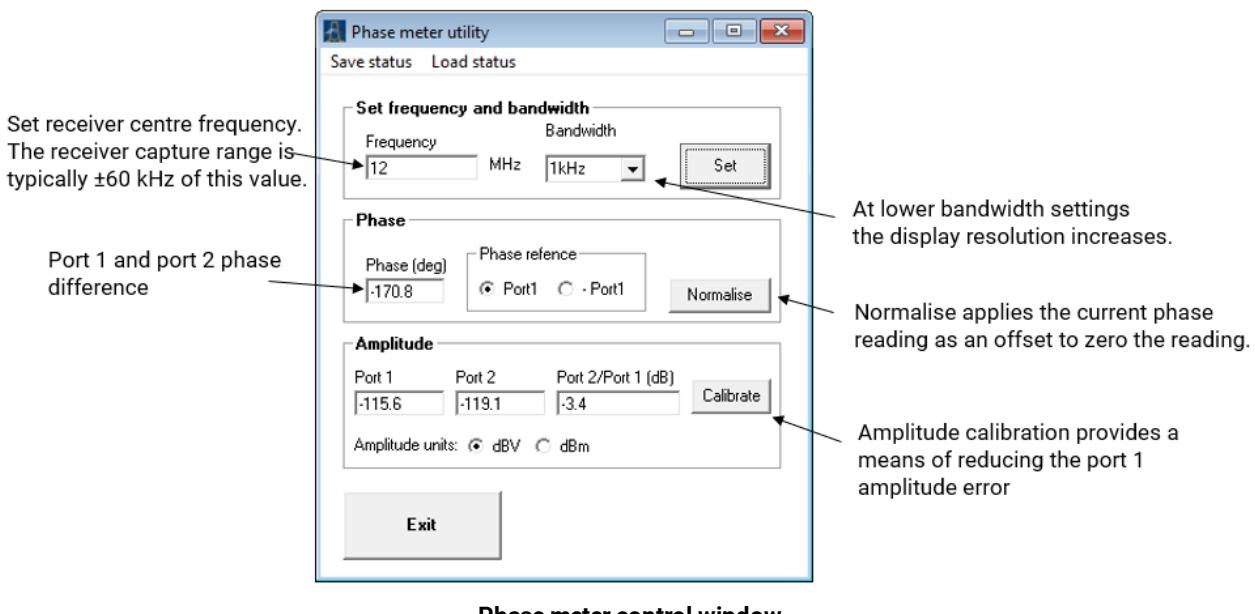
Figure: Calibration (left) and test (right) connections for AM to PM test

Note: For best AM-PM results apply some averaging (e.g. 16) and carry out an AM-PM calibration (left hand side of figure). A '?' will displayed if the requested P_{in} for readout is outside the available range.

6.12   Phase meter utility (PicoVNA 108 only)

This utility allows port 1 and port 2 of the instrument to be used purely as receivers to measure amplitude and relative phase. The control window for this utility is shown below. The key function on this is the control to set the frequency. The frequency range is 0.3 to 8500 MHz. Once it is set, the receivers will be capable of capturing input signals within ±60 kHz (typically) of this value. The input level range of signals that the utility can work over is +10 to -46 dBm, typically.

Phase meter control window

Phase meter utility display resolution
The amplitude and phase displayed resolution is dependent on the receiver bandwidth selected as shown below.

Bandwidth setting	Display resolution
> 1 kHz	0.0
> 10 Hz	0.00
10 Hz	0.000

Amplitude calibration
The phase meter utility uses the internally stored port 2 sensitivity. Unless otherwise corrected, the utility assumes that port 1 has the same sensitivity as port 2 which is likely to lead to a larger error than would otherwise be the case. To reduce this error in the port 1 level reading, click **Calibrate** and follow the instructions.

The amplitude calibration feature is a simple two-step process where the connections to ports 1 and 2 are swapped, allowing the software to make the necessary correction at the selected frequency. Note that some residual errors are likely to remain. These are associated with the impedance mismatch of the ports and accuracy of the stored port 2 sensitivity. If amplitude accuracy is critical to the measurement, you are advised to check the amplitude measurement error using an external dedicated power meter.
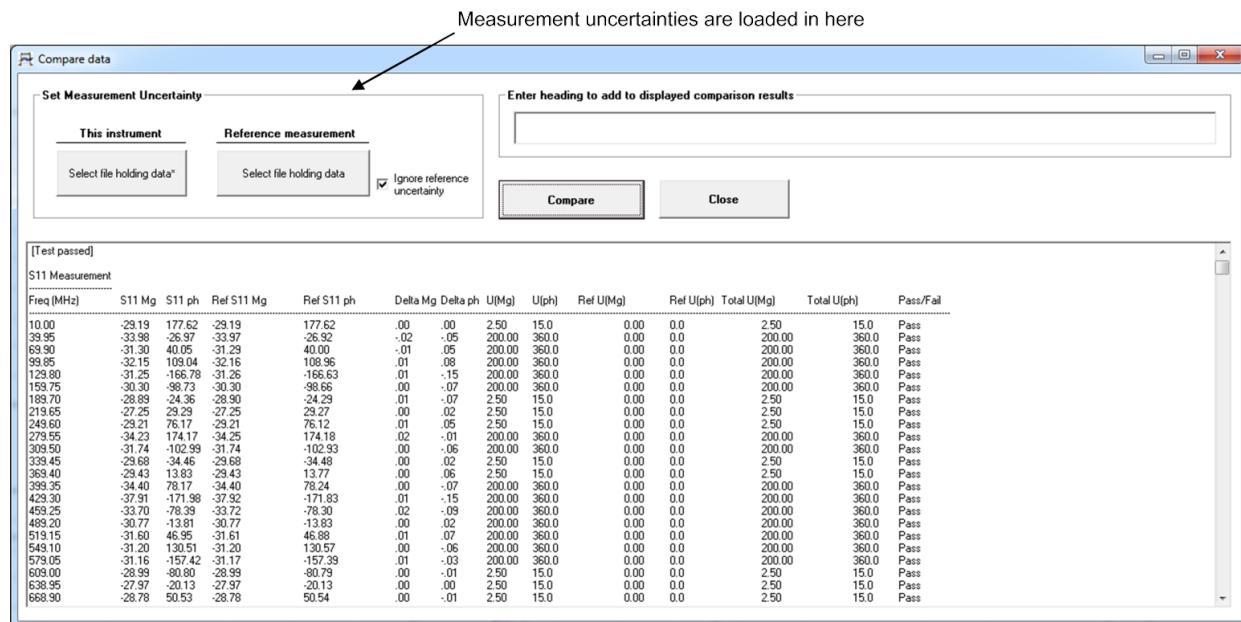
6.13   Compare data utility

The compare data utility provides a quick and simple way to compare two sets of full S-parameter measurements taking into account the instrument's measurement uncertainty and optionally, the uncertainty associated with the reference measurement. Typically this facility can be used to measure a Check Standard and compare the measurement values produced by the PicoVNA 106 or 108 with those supplied with the Check Standard. This is a simple and quick way of determining the adequacy of the calibration to be used.

The compare data utility can be found in the **Utility** drop-down menu. This brings up the dialog shown below.

To use the compare utility, follow these steps:

1. Perform a full S-parameter calibration for either an insertable or female non-insertable DUT.
2. Set display graph 1 to S11, 2 to S21, 3 to S12 and 4 to S22.
3. Measure the associated Check Standard.
4. Using **File > Load Measurements** command, load the reference measurement of the Check Standard (supplied with the standard) to the memory traces. This must be a full Touchstone S-parameter measurement - example file name:
   `SN10000X.s2p`
5. Launch the compare data utility (**Utility > Compare Data**).
6. Load the PicoVNA 106 or 108 VNA uncertainty file. If all connections are made using PC3.5 test leads and cal kits, use:
   `Instrument Uncertainty with Premium PC3.5 leads.dat`
   Otherwise use:
   `Instrument Uncertainty with Pico Standard SMA leads.dat`
   These SMA uncertainties are supported by Pico "Standard" test leads, fixed SOLT and E-Cal kits.

7. Load the reference measurement uncertainty file:
   `Check Standard Reference Measurement Uncertainty.dat`
8. Check the **Ignore reference uncertainty** check box only if comparing two measurements of the same Check Standard on the same VNA made at different times or in different environments.
9. Click the **Compare** button to perform the comparison and display the results.

Measurement uncertainties are loaded in here

Data comparison dialog

Defining uncertainties

Measurement uncertainty is defined by means of text file as illustrated below. The definition is made up of several segments. Each segment refers to reflection [REFLECTION] or transmission [TRANSMISSION] with an entry for the applicable range in dB followed by the frequency range (in MHz). After the frequency range entry, the magnitude uncertainty in dB is specified followed by the corresponding phase uncertainty in degrees.

One segment of
the uncertainty definition

```
[Default uncertainty for LA19-13-04 6GHz VNA. Apr 2017]
[REFLECTION]
[RANGEDB]
-15, 0
[FREQ]
0, 1.99999
[MAGDB]
0.7
[PHASE]
8
[REFLECTION]
[RANGEDB]
-15, 0
[FREQ]
2, 6100
[MAGDB]
0.5
[PHASE]
4
[REFLECTION]
[RANGEDB]
```

The uncertainty definition is made up of several reflection and transmission segments. A reflection segment is highlighted above.

It is possible to define the uncertainty by a polynomial. To do this, follow the [MAGDB] keyword with the keyword [POLY]. Then, the uncertainty can be define by means of 3 coefficients, say, K_0, K_1, and K_2. The uncertainty for given measured absolute magnitude value in dB, M, is given by:

$$U_p = K_0 + K_1 M + K_2 M^2$$

The same approach can be used to defining the phase uncertainty. That is, add the keyword [POLY] after the [PHASE] keyword.
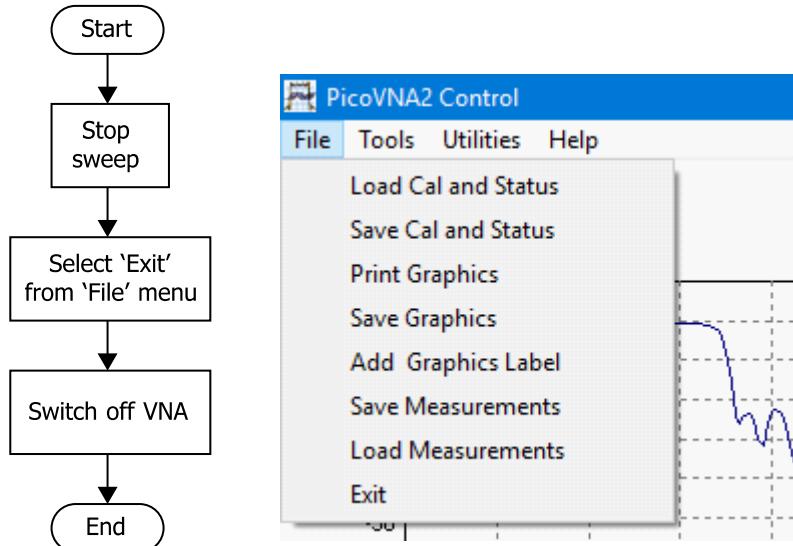
The data compare utility resolves the total combined uncertainty as follows:

$$U_C = \sqrt{U_I^2 + U_R^2}$$

In the above, U_I is the uncertainty associated with the PicoVNA unit and U_R is that provided with the reference Check Standard.

6.14   Closing down the software

You should formally shut down the user interface window before switching off the VNA. This allows the software to save the calibration and status and update the instrument's log file. The sequence is shown below:

Formally closing down the software saves the current calibration

Closing the program by clicking the top right-hand X button will end the program without saving anything. A warning will be issued.
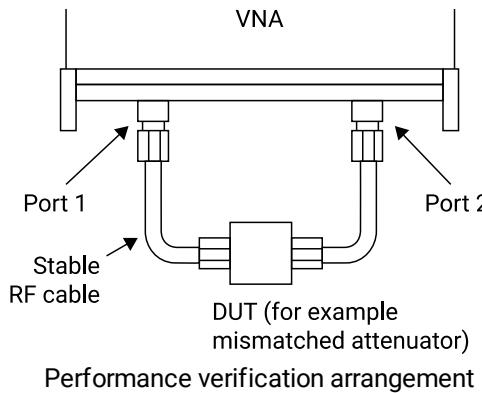
7   Performance verification and maintenance

We recommend that the instrument is checked periodically for safety (chassis grounding, fan operation, clear ventilation grilles and operator markings) and compliance with the stated electrical specification. The table below shows suggested parameters that should be checked as part of the calibration process. Note that the ventilation inlets should be checked as described later.

Measurement	DUT	Conditions	Calibration type
S_{21} and S_{12}, magnitude and phase	20 dB attenuator	51 points sweep 0.3–6000 or 8500 MHz 1 kHz BW +3 dBm test level	12-term
S_{11} and S_{22}, magnitude and phase	A known mismatch at ports 1 and 2 (−16 dB or worse return loss)	51 points sweep 0.3–6000 or 8500 MHz 1 kHz BW +3 dBm test level	12-term
or			
S_{11}, S_{21}, S_{22} and S_{12}, magnitude and phase	Mismatched attenuator (> 10 dB attenuation and −16 dB or worse return loss)	51 points sweep 0.3–6000 or 8500MHz 1 kHz BW +3 dBm test level	12-term

Suggested annual instrument verification / calibration schedule

We recommended that you compare the measured results with the values provided with the standards and verify that they are within the combined uncertainty of the instrument and the provided reference measurements. The frequency should be set to agree with those available(s) for the standard used. The recommended test arrangement is shown below. The results should be within the instrument's quoted uncertainty as detailed in the following section. Allowance should also be made for the uncertainty of the standard reference values.

Performance verification arrangement

> **Tip:** A data compare utility is provided in the PicoVNA 2 and 3 software that can be used to compare the measurements, taking into account the uncertainty of the instrument.

Note: The Pico TA430 and TA431 check standards can be used in this verification but they have too much uncertainty to make a confident verification to the full performance specification of the PicoVNAs. Nonetheless, the uncertainty of the verification, given in the result from the compare utility, may be low enough for the application. If sufficient, the use of either TA430 or TA431 of course significantly reduces ownership costs and increases the regularity at which a verification can be made.

7.1   Measurement uncertainty

The measurement uncertainty figures below are based on calibration (12-term, insertable device, with −3 dBm test power and using 10 Hz bandwidth) using the premium PC3.5 mm calibration kits optionally supplied with the instrument. The figures for S_{21} and S_{12} assume that the DUT has a value of S_{11} or S_{22} of less than 0.2. Similarly, the figures for S_{11} and S_{22} assume the DUT has a value of S_{21} or S_{12} of less than 0.2. Other external factors such as connector and cables effects are excluded.

Power	Frequency	Magnitude	Phase
−15 dB to 0 dB	Freq < 2 MHz	0.7	8°
	Freq > 2 MHz	0.5	4°
−25 dB to −15 dB	Freq < 2 MHz	0.8	10°
	Freq > 2MHz	1.0	6°
−30 dB to −25 dB	Freq < 2MHz	3.0	20°
	Freq > 2MHz	2.5	15°

Reflection (S_{11}, S_{22}) measurement uncertainty

Power	Frequency	Magnitude	Phase
+0 dBm to +6 dBm	Freq < 2 MHz	0.4	6°
	Freq > 2 MHz	0.2	2°
−40 dBm to 0 dBm	Freq < 2 MHz	0.3	2°
	Freq > 2 MHz	0.1	1°
−60 dBm to −40 dBm	Freq < 2 MHz	0.5	8°
	Freq > 2 MHz	0.3	4°
−80 dBm to −60 dBm	Freq < 2 MHz	2.0	15°
	Freq > 2 MHz	1.5	12°

Transmission (S_{21}, S_{12}) measurement uncertainty

7.2   Routine maintenance

Ventilation grilles
Check that all ventilation grilles are clear of any debris, dust or any other material that may impede the flow of air. Particularly, check the vents in the bottom panel of the instrument. It is advisable to brush these to remove any gradual build up of dust.

Failure to clean the ventilation grilles may lead to overheating and eventual failure of the instrument.

Front panel connectors
Routinely inspect the Port 1 and Port 2 N-type connectors for signs of damage or dirt. Use connector-saver adaptors (male to female through) where frequent connection and disconnection are likely.

8   Performance specification

The instrument's performance specification is given below. Unless otherwise stated, the figures apply with 10 Hz resolution bandwidth, at −3 dBm test power, 12-term calibration (for insertable DUT) using the enhanced isolation option, at an ambient temperature of 23 ± 1 °C and 60 minutes after power up.

Measuring functions	
Measuring parameters	S_{11}, S_{21}, S_{22}, S_{12} P_{1dB} (power at 1 dB gain compression) AM to PM conversion factor (PM due to AM) PicoVNA 108 only: Mixer conversion loss, return loss, compression and port isolation.
Error correction	12 error term full S-parameter correction (insertable DUT) 12 error term full S-parameter correction (noninsertable DUT) 8 error term full S-parameter unknown through correction (noninsertable DUT) S11 (1-port correction) De-embed (2 embedding networks may be specified) Impedance conversion S21 (normalize, normalize + isolation) S21 (source match correction + normalize + isolation) Averaging, smoothing Hanning and Kaiser−Bessel filtering on time-domain measurements Electrical length compensation (manual or auto) Effective dielectric constant correction
Display channels	4 channels (CH1, CH2, CH3, CH4)
Traces	2 traces per display channel
Display formats	Amplitude (logarithmic and linear), phase, group delay, VSWR, real, imaginary, Smith chart, polar, time domain
Memory trace	One per display channel
Limit lines	6 segments per channel (overlap allowed)
Markers	8 markers
Marker functions	Normal, Δ marker, fixed marker, peak / min. hold, 3 dB and 6 dB bandwidth

Signal source characteristics	
Frequency range	PicoVNA 106: 300 kHz to 6.02 GHz PicoVNA 108: 300 kHz to 8.50 GHz
Frequency setting resolution	10 Hz
Frequency accuracy	±10 ppm (23 ± 3°C)
Frequency temperature stability	±0.5 ppm/°C (15 to 35°C)
Harmonics (−3 dBm output level)	−20 dBc max
Non-harmonic spurious (typical)	−40 dBc typical
Phase noise (10 kHz)	−90 dBc/Hz (0.3 MHz to 1000 MHz) −80 dBc/Hz (1000 MHz to 4000 MHz) −76 dBc/Hz (> 4000 MHz)
Output power	**PicoVNA 106** Up to 4 GHz: +6 to −20 dBm > 4 GHz: +3 to −20 dBm **PicoVNA 108** Up to 6 GHz: +10 to −20 dBm > 6 GHz: +6 to −20 dBm

Signal source characteristics	
Power setting resolution	0.1 dB (nominal)
Output power accuracy	±1.5 dB
Reference input frequency	10 MHz ±6 ppm
Reference input level	0 ±3 dBm
Reference output level	0 ±3 dBm

Sweep functions			
Sweep type	Linear frequency sweep, CW time-based sweep, power sweep (P_{1dB} utility)		
Trigger modes Option to capture up to 1024 sweeps of data in all modes except free run.	Free run Positive trigger Negative trigger Manual trigger		
Sweep time 10 MHz to 6 or 8.5 GHz, 201-point trace length. For other lengths and bandwidths the sweep time is approximately: $T_{SWP}(s) = N \times (T_{MIN} + F_{BW} / R_{BW})$ where: N = number of frequency points $T_{MIN}(s)$ = minimum time / point (s2p: 167 µs; s1p: 85 µs) F_{BW} = bandwidth settle factor (s2p: 1.91; s1p: 0.956) R_{BW} = resolution bandwidth (Hz) For sweep repetition period, add software rearm time: T_{ARM} = average 6.5 ms or worst case 50 ms For markers on, increase T_{ARM} by 39 ms	Bandwidth	S_{11}, S_{21}, S_{11}+S_{21} calibration	Full 12- or 8-term calibration
	140 kHz	19 ms (PicoVNA 106) 20 ms (PicoVNA 108)	37 ms (20 ms and 38 ms for PicoVNA 108)
	10 kHz	37 ms	72 ms
	1 kHz	0.21 s	0.42 s
	100 Hz	1.94 s	3.87 s
	10 Hz	19.2 s	38.4 s
	LF Adder (for each low-frequency point < 2.5 MHz)	1.25 ms/pt	2.5 ms/pt
Number of sweep points, VNA mode	51, 101, 201, 401, 801, 1001, 2001, 4001, 5001, 6001, 7001, 8001, 9001, 10 001		
Number of sweep points, TD mode	512, 1024, 2048, 4096		

Receiver characteristics			
Resolution bandwidth	140 kHz, 70 kHz, 35 kHz, 15 kHz, 10 kHz, 5 kHz, 1 kHz, 500 Hz, 100 Hz, 50 Hz, 10 Hz		
Averaged displayed noise floor (dB): S_{21} calibration 10 Hz bandwidth 16 averages Test ports terminated as during isolation calibration step	Band	Typ.	Max.
	PicoVNA 106		
	0.3 to 10 MHz	−110	−100
	10 MHz to 4 GHz	−118	−108
	4 to 6 GHz	−110	−100
	PicoVNA 108		
	0.3 to 1 MHz	−100	−90
	1 MHz to 6 GHz	−124	−110
	6 to 8.5 GHz	−120	−100
Dynamic range (dB) Bandwidth 10 Hz Maximum test power +6 dBm (6 GHz), 0 dBm (8.5 GHz) 16 averages Test ports terminated as during the isolation calibration step. Isolation calibration refreshed as described in Calibration for best dynamic range.	See figure below		
Temperature stability, measured after an S_{21} calibration, (typical)	0.02 dB/°C (f < 4 GHz) 0.04 dB/°C (f ≥ 4 GHz)		
Trace noise (dB RMS)	Bandwidth	Typical	Maximum

Receiver characteristics			
Full band Test level 0 dB 201-point sweep covering 1 MHz to 6 GHz or 8.5 GHz	10 kHz	PicoVNA 106: 0.000 8 PicoVNA 108: 0.000 6	0.002
	70 kHz	0.003	0.005
	140 kHz	PicoVNA 106: 0.005 PicoVNA 108: 0.006	0.01

Test port characteristics			
Load match	Corrected: 40 dB min., 46 dB typ. Uncorrected: 16 dB (PicoVNA 106), 15 dB (PicoVNA 108) typ. uncorrected		
Source match	Corrected: 40 dB min., 46 dB typ. Uncorrected: 16 dB (PicoVNA 106), 15 dB (PicoVNA 108) typ. uncorrected		
Directivity (using PC3.5 cal kit)	Corrected: 40 dB min. corrected, 47 dB typ. corrected		
Crosstalk (dB, corrected) Test ports terminated with short circuits. Value is average displayed noise level.	Band	Typical	Maximum
	PicoVNA 106		
	0.3 kHz to 2 MHz	−100	−90
	2 MHz to 4 GHz	−110	−90
	4 GHz to 6 GHz	−100	−90
	PicoVNA 108		
	0.3 kHz to 2 MHz	−100	−90
	2 MHz to 6 GHz	−110	−90
	6 GHz to 8.5 GHz	−100	−90
Main test ports maximum input level (1 dB compression)	+10 dBm, typ (0.1 dB compression)		
Main test ports maximum input level (no damage)	+20 dBm (PicoVNA 106) +23 dBm (PicoVNA 108)		
Main test ports connectors	Type N (female)		
Bias-T maximum current	250 mA		
Bias-T maximum DC voltage	+15 V		
Bias-T current protection	Built-in resettable fuse		
Bias-T DC port connectors	SMB (female on front panel)		
Sweep trigger input voltage	Low: −0.1 to +1.0 V High: +2.0 to +4 V		

Mixer measurements (PicoVNA 108 only)	
Frequency range	0.3 to 8500 MHz
Input power sweep range	−17 to +10 dBm (6 dBm for F > 6 GHz)
Input power sweep step	0.5 dB (nominal)
LO source	External, required
Power level calibration	External power sensor supported with option to use internal receivers with reduced accuracy
Measurements	Conversion loss, return loss, isolation and compression
Accuracy (conversion loss with return loss correction applied)	0.2 dB (typical)
Display format	Graphical, conversion loss, return loss, isolation and compression

P1dB utility	
Frequency range	0.3 to 6020 MHz or 8500 MHz
Input power sweep range	PicoVNA 106: −20 to +3 dBm PicoVNA 108: −20 to +6 dBm

P1dB utility	
Input power sweep step	1 dB (nominal)
P1dB calculation method	2nd order curve fit
Display format	Graphical, gain and output power
Accuracy	0.5 dB (typical)
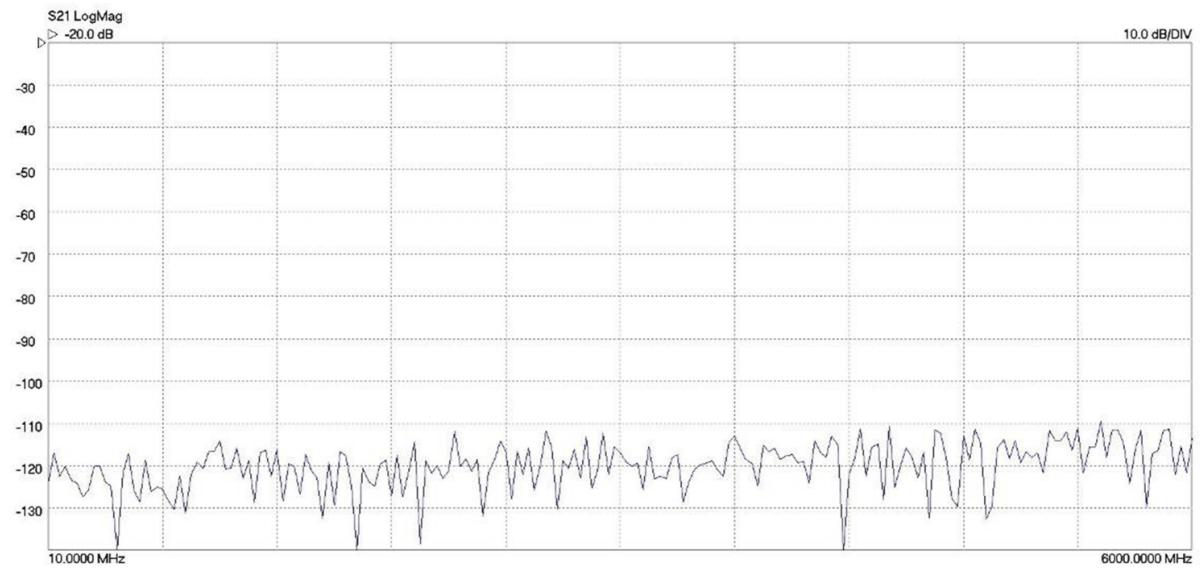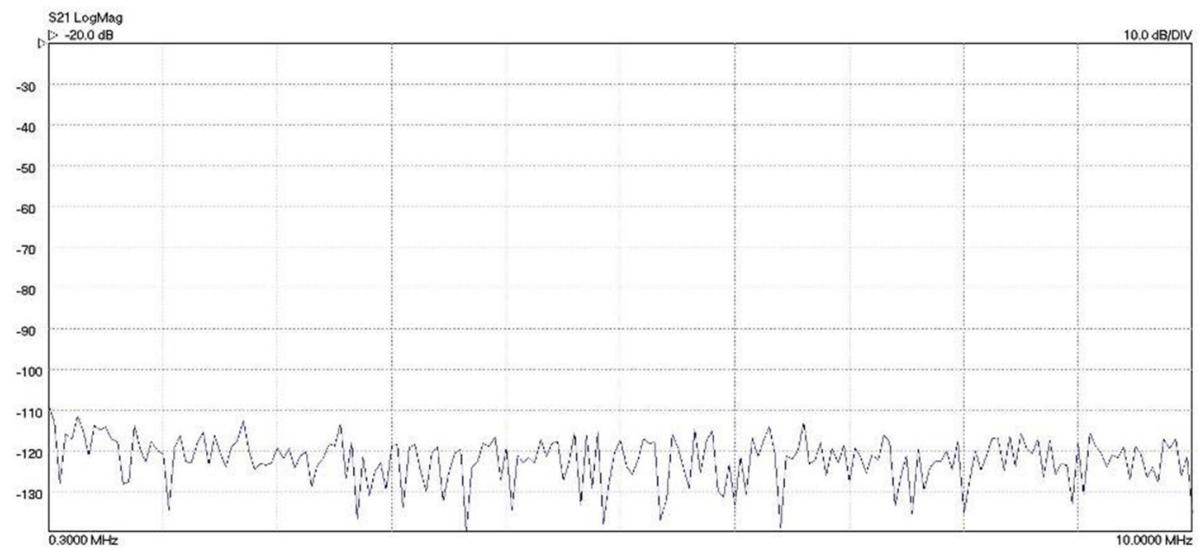
AM to PM utility	
Frequency range	0.3 to 6020 MHz or 8500 MHz
Input power sweep range	−20 to 0 dBm
Input power sweep step	1 dB (nominal)
AM to PM point calculation method	2nd order curve fit
Display format	Graphical, phase conversion (deg / dB)
Accuracy (Port 2 power +5 to −20 dBm)	1° (typical)

Signal generator utility	
Frequency range	0.3 to 6020 MHz or 8500 MHz
Output power	PicoVNA 106: −20 to +3 dBm PicoVNA 108: −20 to +10 dBm
Setting resolution	0.1 dB
Output power accuracy	±1.5 dB max
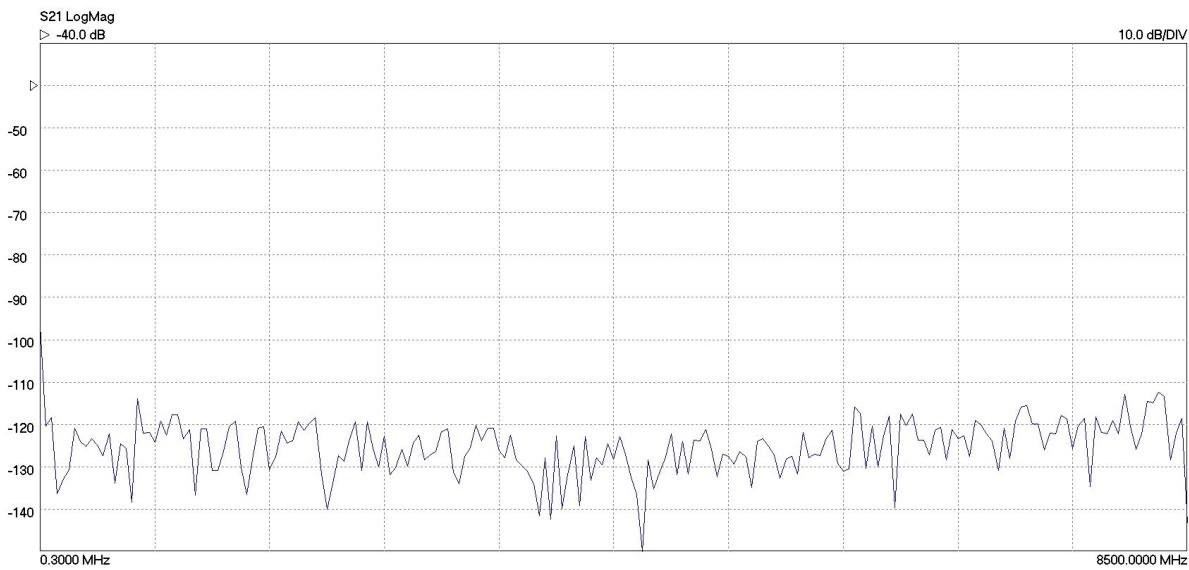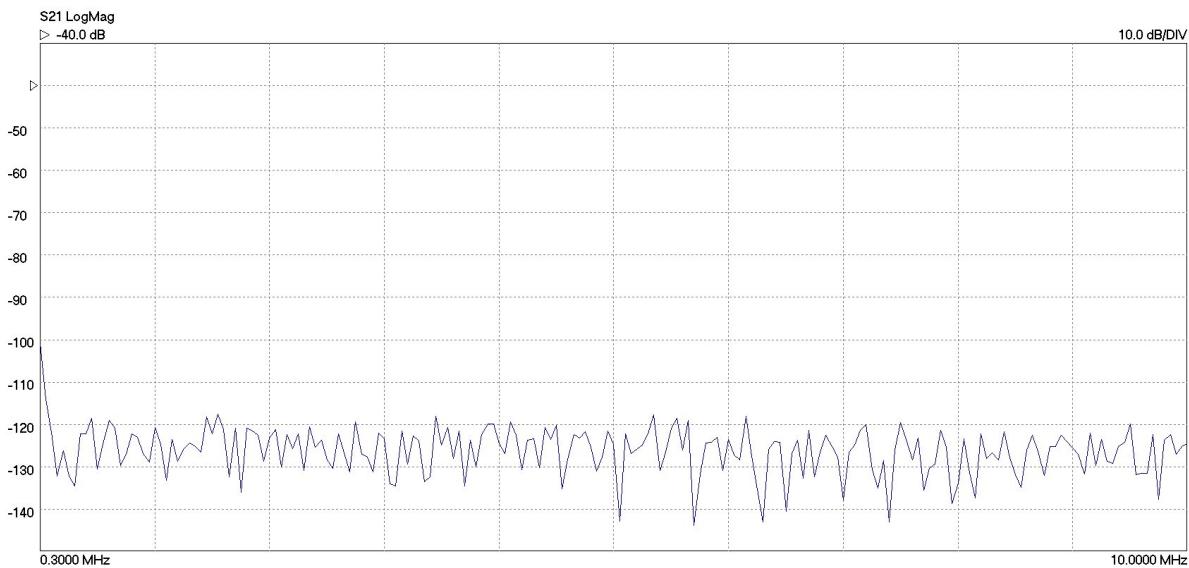
Group delay	
Range (180° maximum phase shift per frequency step)	$\tau = \frac{0.5}{\Delta f}$ where Δf is the aperture frequency
Aperture frequency	Frequency sweep step size
Accuracy	$\Delta \tau = \frac{PhaseError}{360.\Delta f}$

| Data handling	
Calibration data	Store / Recall on disk
Calibration kit data	Store / Recall on disk
Print measured data (graphics)	To any printer installed on host PC
Save measured data (graphics)	To disk
Measured data	Store on disk
Measured data (Touchstone format)	Store on disk
Measured data (Touchstone format)	Recall to memory trace from disk
Statement of Volatility: No user data, calibration data or user settings are stored on the device.	

| Miscellaneous	
PC data interface	USB
PC minimum requirements	Microsoft Windows 7, 8 or 10 2 GB RAM or more 200 MB hard disk storage on C: partition Display resolution of 1280 x 720 to run PicoVNA software
External dimensions (L x W x H)	286 x 174 x 61 mm
Weight	1.85 kg
Temperature range (operating)	+5 °C to +40 °C
Temperature range (storage)	−20 °C to +50 °C
Humidity	80% max. (non-condensing)
Power source	DC, 12 to 15 V PicoVNA 106: 1.85 A peak, 22 W max. PicoVNA 108: 2.1 A peak, 25 W max.

**Dynamic range (PicoVNA 106)**

Dynamic range 10 MHz to 6 GHz

Dynamic range 0.3 to 10 MHz

Typical system dynamic range (P_{test} = +6 dBm, BW = 10 Hz)

Dynamic range (PicoVNA 108)

Dynamic range 10 MHz to 8.5 GHz

Dynamic range 0.3 to 10 MHz

Typical system dynamic range (P_{test} = +10 dBm, BW = 10 Hz)

9   Troubleshooting guide
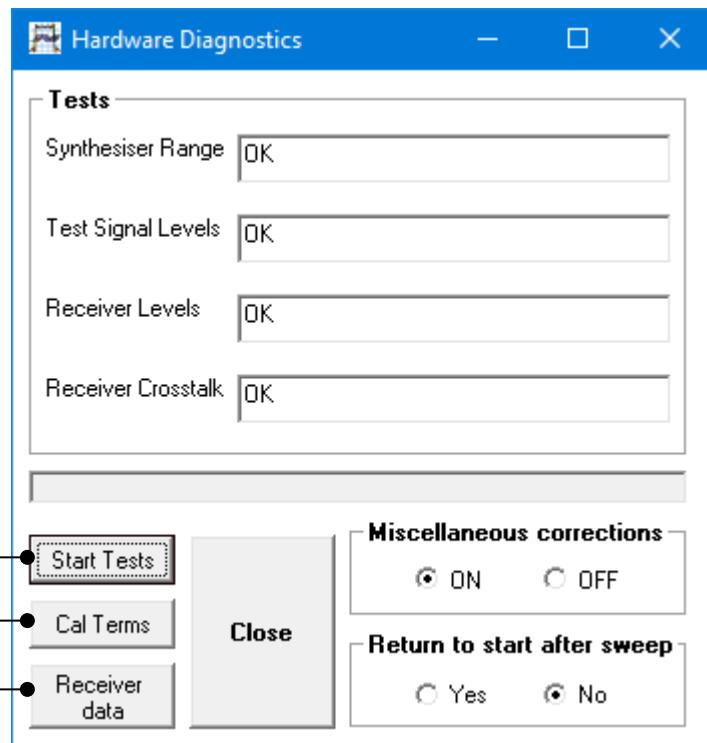
⚠️ **CAUTION**
The product and accessories contain no user-serviceable parts. Repair, servicing and calibration require specialized test equipment and must only be performed by Pico Technology or an approved service provider.

Symptom	Possible Cause	Solution
Instrument does not power up	• Power not applied • Incorrect supply	• Check DC connection • Check external supply
PicoVNA 2 or PicoVNA 3 software unable to communicate with the instrument	• Driver not installed • Link interrupted	• See Switching on • Restart instrument and software
Instrument sweeping but display not refreshing	• Data link interrupted	• Restart instrument and software
'Last Calibration not found' message on power up	• `C:\User\Public\Documents\PicoVNA2` (or `...PicoVNA3`) directory deleted or corrupted	• Restore folder. Set up display and calibrate. Exit the software using **File > Exit** menu command. This will save the current calibration in a file named `defaultcal.cal`.
Diagnostics Tests (under **Tools** menu) fail	• Data corruption	• Restart instrument and software. Ensure that test cable used is in good condition.
Error reading data files	• Invalid format • Too many lines • Leading space(s)	• Check for correct format / '#' line • 10 001 lines maximum • Remove leading spaces from data lines

Diagnostics tests
It is possible to run self-check tests on the instrument. This facility (Diagnostic Tests) is available from the **Tools** menu shown above. In order to complete the tests a low loss cable is required to link Port 1 to Port 2. The tests carry out the following checks.

- Synthesizers: test that they remain in lock over the frequency range
- Test signal: test the level range and step size
- Receiver levels: test that the receiver is operating at normal signal levels
- Receiver crosstalk: test that raw crosstalk remains below limit
- Receiver DC offset: test that this is at normal level

The Diagnostics Tests perform internal checks on key components

If any of the tests returns an error, check connectors and linking cable. If this does not resolve it, restart the instrument and the software. After pressing reset, wait until the front-panel channel activity indicators have stopped flashing to continue with the tests.

Calibration error terms and raw receiver data
The diagnostic tests dialog (figure above) also provides the facility for retrieving the calibration error terms and raw receiver data. The latter can be helpful for users wishing to carry out their own calibration procedure.

Back up/restore EEPROM
This facility allows the internal ROM (read-only memory) of the instrument to be backed up or restored. This facility should only be required by service or repair personnel.

10   Warranty

Pico Technology warrants upon delivery, and for a period of three years unless otherwise stated from the date of delivery, that the Goods will be free from defects in material and workmanship.

Pico Technology shall not be liable for a breach of the warranty if the defect has been caused by fair wear and tear, willful damage, negligence, abnormal working conditions or failure to follow Pico Technology's spoken or written advice on the storage, installation, commissioning, use or maintenance of the Goods or (if no advice has been given) good trade practice; or if the Customer alters or repairs such Goods without the written consent of Pico Technology.

UK headquarters:

Pico Technology
James House
Colmworth Business Park
St. Neots
Cambridgeshire
PE19 8YP
United Kingdom

Tel: +44 (0) 1480 396 395

sales@picotech.com
support@picotech.com

www.picotech.com

North America office:

Pico Technology
320 N Glenwood Blvd
Tyler
TX 75702
United States

Tel: +1 800 591 2796

sales@picotech.com
support@picotech.com

Asia-Pacific office:

Pico Technology
Room 2252, 22/F, Centro
568 Hengfeng Road
Zhabei District
Shanghai 200070
PR China

Tel: +86 21 2226-5152

pico.asia-pacific@picotech.com