

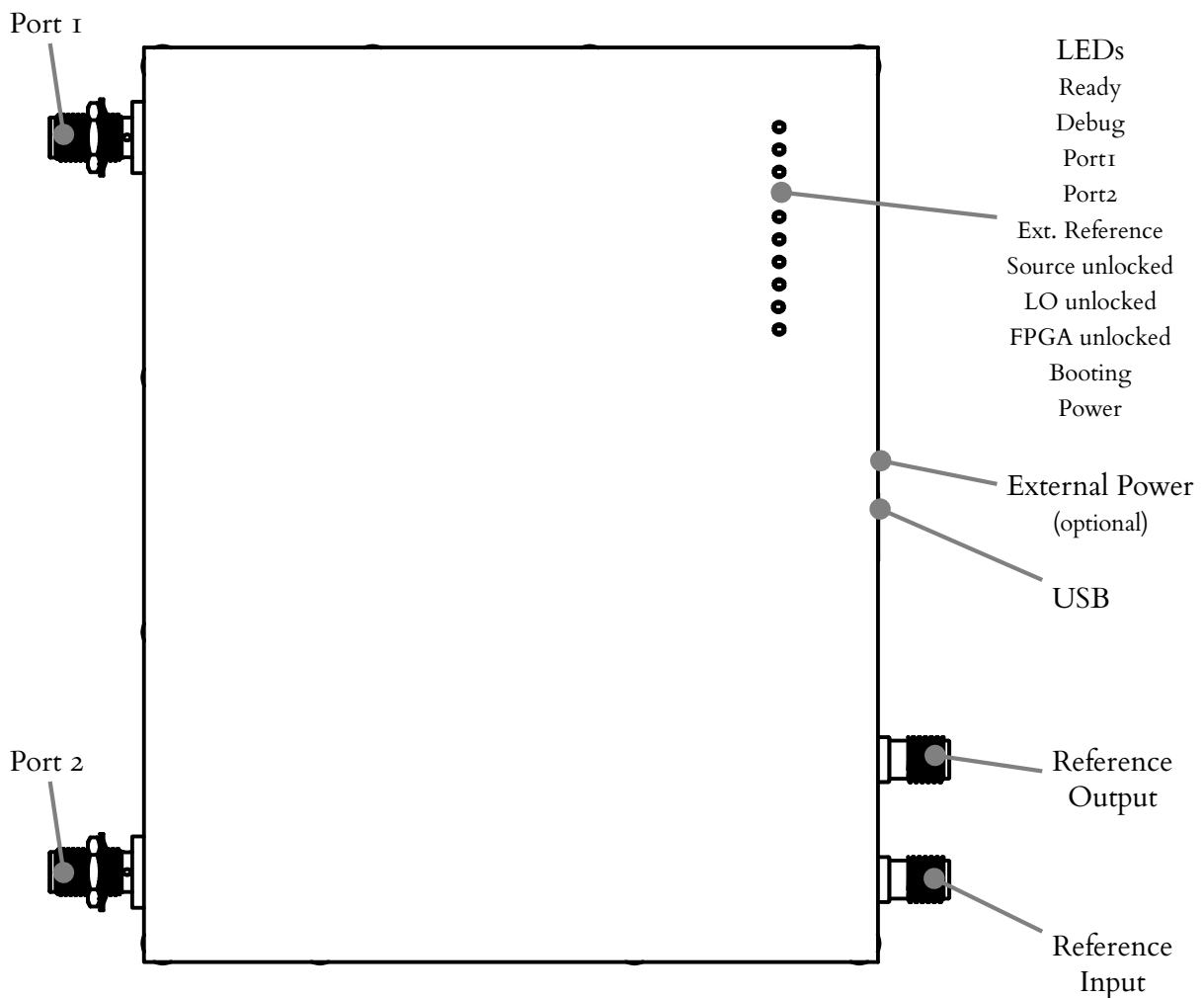
VNA User Manual

November 19, 2020

Contents

1	Overview	2
1.1	USB	2
1.2	External Power	2
1.3	RF ports	2
1.4	LEDs	3
1.5	Reference Output	3
1.6	Reference Input	3
2	Getting started	3
2.1	GUI element types	4
2.2	Common GUI elements	4
2.2.1	Reference Toolbar	5
2.2.2	Device Log Dock	5
2.2.3	Device Menu	5
2.2.4	Window Menu	6
3	Vector Network Analyzer	6
3.1	Sweep Toolbar	7
3.2	Acquisition Toolbar	7
3.3	Calibration	7
3.3.1	Introduction	7
3.3.2	Types	8
3.3.3	Calibration Kit	8
3.3.4	Measurements	9
3.3.5	Enabling a calibration	10
3.3.6	Saving/Loading	12
3.3.7	Viewing error terms	12
4	Signal Generator	12
5	Spectrum Analyzer	12
5.1	Acquisition Toolbar	13
5.2	Tracking Generator Toolbar	14
6	Amplitude Calibration	14
6.1	Source Calibration	14
6.2	Receiver Calibration	16
7	Troubleshooting	16

I Overview



I.1 USB

The VNA uses a USB-C connector as the power supply and for data transmission. The hardware supports the USB power delivery standard¹, requires 5 V and draws up to 1.2 A of current.

The implemented USB device is limited to USB 2.0 Fullspeed and data transmission will work with any USB 2.0 or 3.0 port (no USB-C required). However, the current consumption exceeds the specifications for USB 2.0 and 3.0 ports and the VNA may be unable to fully boot when no external power is applied USB host limits the current.

I.2 External Power

Input jack for external DC power (5 V, 1.5 A, positive center pin). If a power source is connected, no current is drawn from the USB port anymore.

I.3 RF ports

RF connector to connect the DUT. Both ports are identical and the device architecture support full S-Parameter measurements (S_{11} , S_{21} , S_{12} and S_{22}).

¹Work in progress, the device will not negotiate USB-PD yet



The RF ports have no input protection, do not apply a signal with more than +10 dBm of power.

1.4 LEDs

Ten LEDs indicate the status:

Ready (green) Indicates fully booted VNA, ready to take measurements

Debug (green) Not used at the moment

Port 1 (green) Active output signal on port 1

Port 2 (green) Active output signal on port 2

Ext. Reference (green) External reference in use

Source unlocked (red) The source PLL failed to lock (it may turn on briefly during a sweep, this is not a problem)

LO unlocked (red) The 1. LO PLL failed to lock (it may turn on briefly during a sweep, this is not a problem)

FPGA unlocked (red) The FPGA clock PLL failed to lock

Booting (red) Indicates boot process, also used for error codes

Power (green) USB power valid

1.5 Reference Output

Optional reference output port (user selectable 10 MHz or 100 MHz). The output power is approximately +3 dBm.

1.6 Reference Input

High impedance reference input port. When applying a 10 MHz input signal, it can be used to overwrite the internal TCXO.

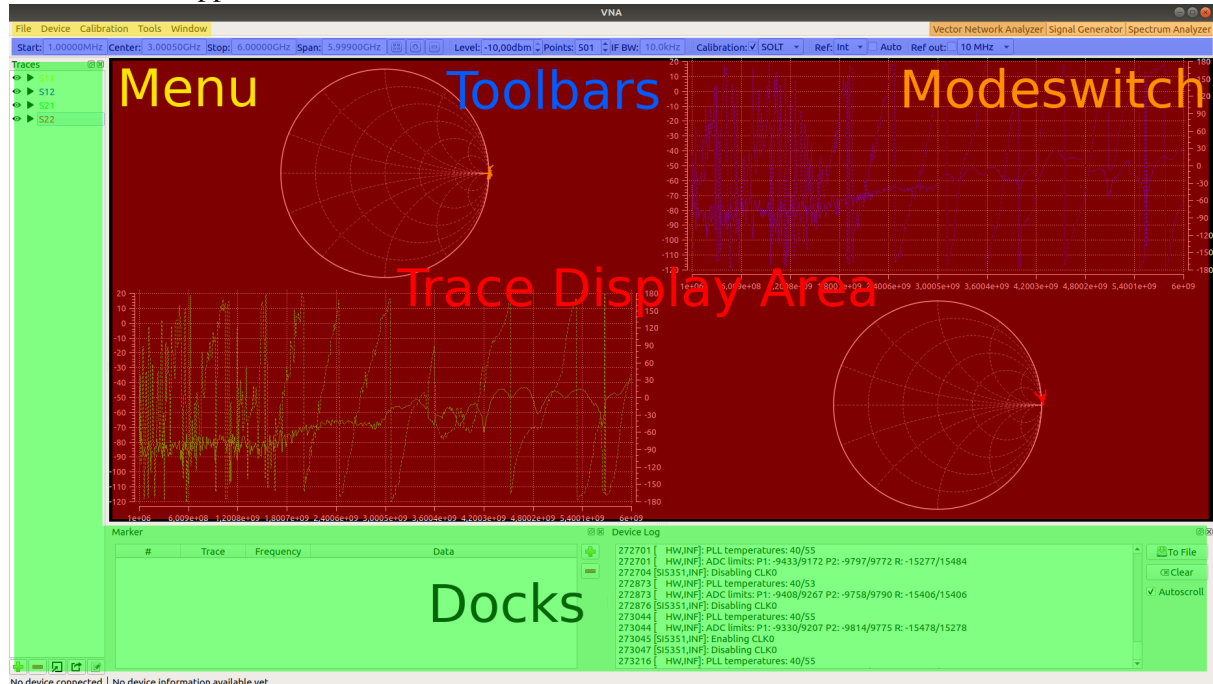


Due to the high impedance input, the external input may detect a valid signal when picking up external radiation. If this is a problem, either terminate the reference input connector or disable automatic reference switching.

2 Getting started

1. Connect the VNA to a computer using the USB port. After a couple of seconds, only the "Power" and "Ready" LEDs should stay on. If the "Ready" LED does not turn on or the "Booting" LED indicates an error code, there is a problem and the device will not function properly. See section 7 for possible solutions.

2. Start the PC application to connect to the VNA. The window should look similar to this:



2.1 GUI element types

The VNA application is made up of six areas containing different types of control:

- The **Trace Display Area** shows the measured data in various diagrams.
- The **Toolbars** provide access to commonly used device settings. They can be rearranged or disabled (see section 2.2.4).
- The **Menu** at the top left handles less common settings or more complex actions (often with additional popup windows).
- The **Docks** mostly provide access to display related settings such as traces and markers. They can be rearranged or disabled (see section 2.2.4).
- The **Statusbar** at the bottom show some basic informations about the connected device.
- The **Modeswitch** at the top right allows changing the VNA operating mode. Although it is primarily designed as a vector network analyzer, the hardware architecture allow some other operating modes with certain limitations.

Depending on the current operating mode, the available toolbars, docks and menu entries change. It is also possible to rearrange the docks and toolbars.

2.2 Common GUI elements

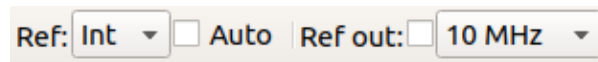
Certain control elements are always available, regardless of the selected mode. They control settings of the VNA that are not specific to any of the operating modes.

Entering values

Most entry fields support SI prefixes. To set a new value, type in the number followed by an SI prefix (e.g. to set 3.2 GHz press , , , ,). The accepted prefixes vary depending on the input (e.g. pico is a valid prefix for a capacitance while it will not be accepted for a frequency).

2.2.1 Reference Toolbar

The reference toolbar controls the external reference output as well as the input.



The reference can be set to "Int" (internal TCXO), "Ext" (external 10 MHz signal) or to automatic mode. In automatic mode, the reference will switch to the external input when a signal is detected, otherwise it will use the internal TCXO.

The external reference output may either be disabled or set to 10 MHz or 100 MHz.

2.2.2 Device Log Dock

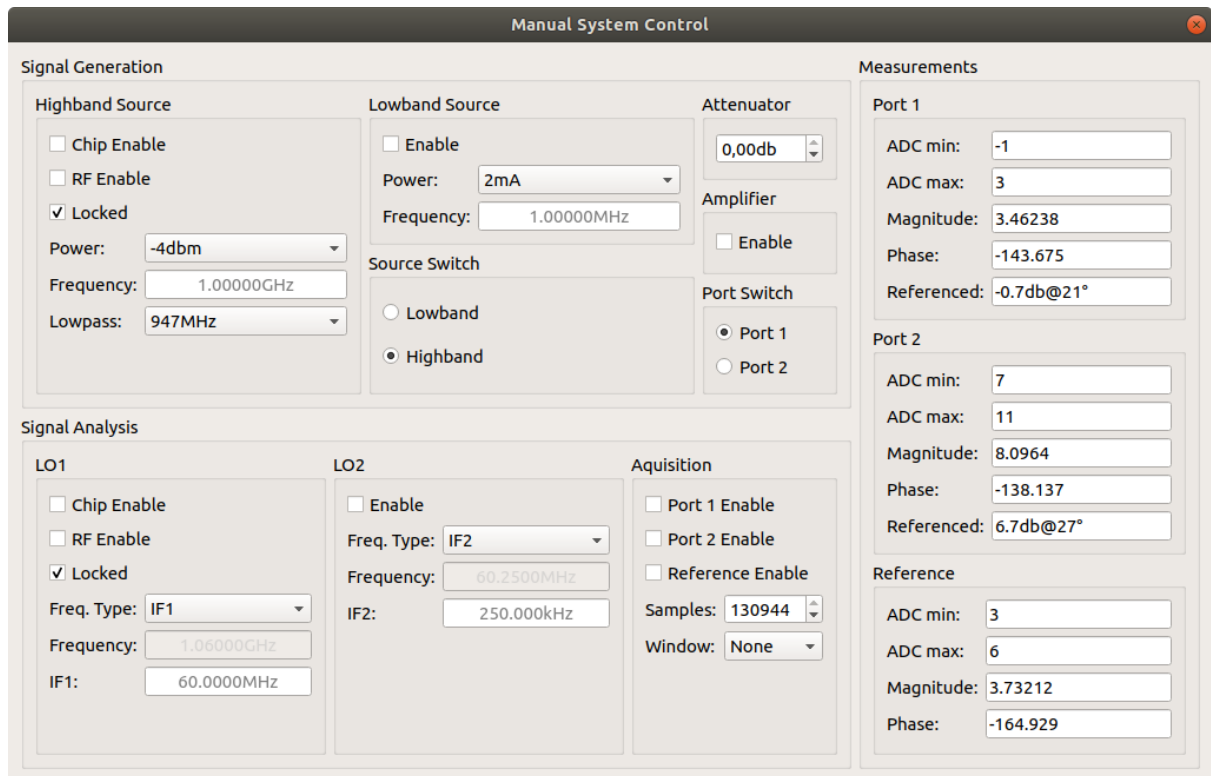
This dock shows the debug output of the VNA (the same messages as on the internal UART port). It may help to identify problems, otherwise it is not required for operation.



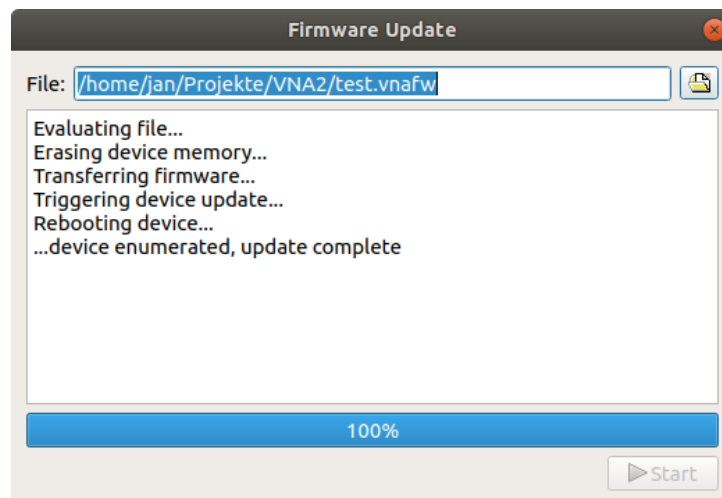
2.2.3 Device Menu

The device menu controls the connection state, allows low level hardware access and to perform firmware updates:

- **Update Device List:** Scans the USB port for connected devices. Clicking this action simply updates the list of devices, no connection is established.
- **Connect to:** Select which VNA to connect to. Different devices are identified by their serial number.
- **Disconnect:** Disconnect from the VNA.
- **Manual Control:** Starts the manual control dialog in which all hardware settings are accessible (mostly used for testing purposes):



- **Firmware Update:** Load a new microcontroller firmware and FPGA configuration into the VNA. Do not disconnect power while updating the firmware!



2.2.4 Window Menu

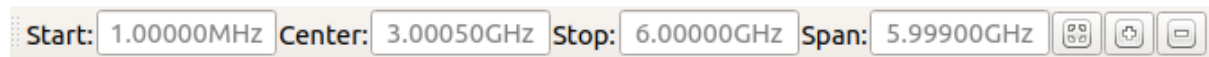
The window menu allows hiding not needed toolbars and docks. It also contains some application preferences.

3 Vector Network Analyzer

In this operating mode, the VNA takes S-parameter measurements. A source signal is generated and alternately applied to the RF ports. The incoming signal at both RF ports is measured, resulting in the four S-parameters S_{11} and S_{21} (when the source signal is routed to port 1) as well as S_{12} and S_{22} (when it is routed to port 2).

3.1 Sweep Toolbar

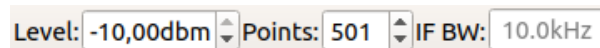
This toolbar sets the swept frequency range.



The start/stop and center frequency as well as the span can be set directly.

Additionally, the sweep toolbar contains buttons for zooming in/out around the center frequency and a preset to set the sweep to the full frequency range.

3.2 Acquisition Toolbar



- **Level:** The amount of power used for stimulus generation. The dynamic range decreases when using smaller values. It is recommended to use the highest available settings when measuring passive networks. When measuring active devices (e.g. amplifiers), decrease the stimulus power in such a way that the input power into any port does not rise above -10 dBm to stay within the linear range of the VNA.
- **Points:** Amount of measurement points in one sweep. More points provide finer frequency resolution but also increase sweep time.
- **IF BW:** Bandwidth of final IF measurement. Low bandwidths increase the sweep time but improve the noise floor. At higher frequencies (roughly above 3 GHz), the dynamic range is limited by the isolation between the ports and decreasing the IF bandwidth does not improve the noise floor anymore.

3.3 Calibration

This section is about the VNA calibration which is used to remove the effect of connectors and cables (as well as imperfections from the VNA itself). For the amplitude calibration see section 6.

Some general knowledge about the different calibration types is assumed, this manual only explains how to use them with the VNA.

3.3.1 Introduction

This section contains some implementation details of the calibration. It can be skipped but understanding them can be helpful when using the calibration.

To apply a calibration three things are required:

1. **Calibration kit:** It contains the definition of the calibration standards. When the calibration error terms are calculated, these definitions are taken into account.
2. **Measurements:** Raw (uncorrected) measurements of the calibration standards. Depending on the type of desired calibration, different measurement are required.
3. **Calibration type:** The calibration type determines which errors are corrected by the calibration and how the error terms are derived from the measurements.

For the most accurate results, the calibration should be performed with the same settings (span, number of points, stimulus level, ...) as the intended measurement. However, it is possible to change these settings after the calibration. The calibration will be interpolated/extrapolated when a different span is used.

3.3.2 Types

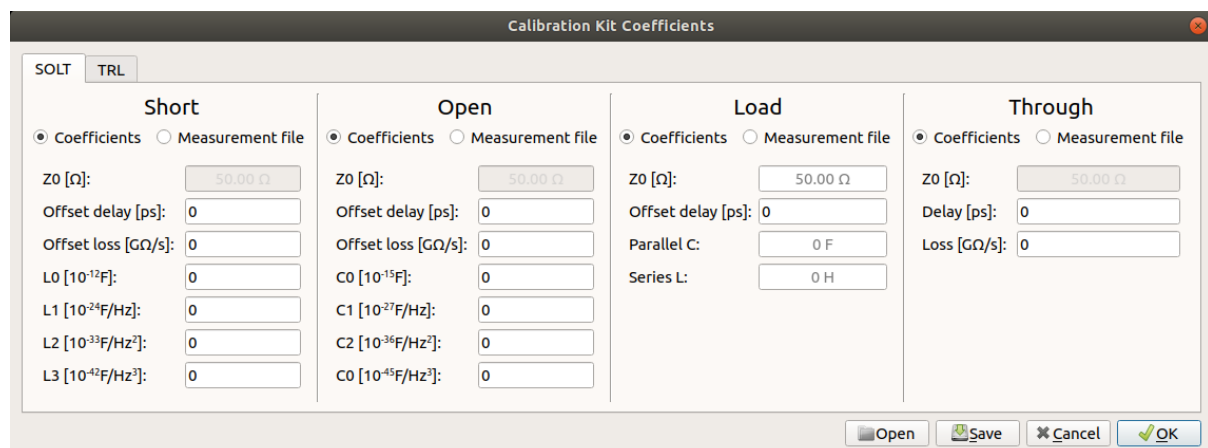
Several different calibration types are available:

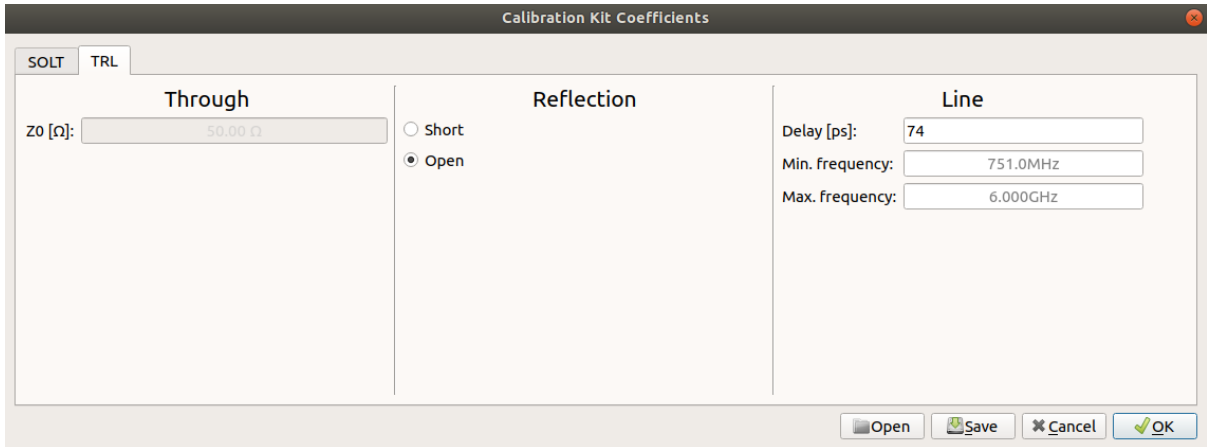
Type	Applied corrections	Required measurements
Port 1	Removes influences of cables and setup at port 1 only	Port 1 open Port 1 short Port 1 load
Port 2	Removes influences of cables and setup at port 2 only	Port 2 open Port 2 short Port 2 load
SOLT	Full two-port calibration, removes influences at both ports and also corrects transmission measurement	Port 1 open Port 1 short Port 1 load Port 2 open Port 2 short Port 2 load Through Isolation(optional)
Normalize	Only corrects for losses and phaseshift in through measurements. While this is not as accurate as SOLT, it is useful e.g. when measuring only the frequency response of a filter because it requires far less calibration measurements.	Through
TRL	Full two-port calibration but with different (less accurately defined) standards than SOLT	Port 1 open/short Port 2 open/short Through Line

3.3.3 Calibration Kit

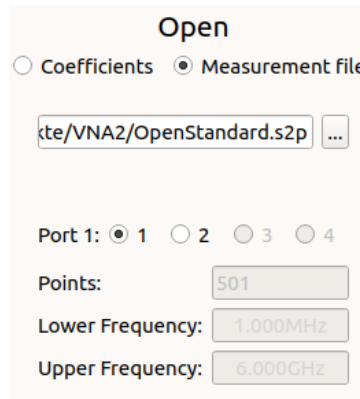
The calibration kit contains the calibration standard definitions used in the calibration. It can be edited through the menu: **Calibration** >> **Edit Calibration Kit**

The calibration kit coefficients are split into two tabs, one for the SOLT standards and one for the TRL standards. If a calibration kit is saved, all standard definitions (SOLT and TRL) are stored, regardless of which tab is currently active. The type of calibration selects which standard definitions are used in the actual calibration.





SOLT standards can either be specified by parameters (preferred way, valid for all frequencies) or by providing measurement data of the standard, here shown as an example with the open standard:



A touchstone file with the measurements is required. If the file contains data from more ports than required (for open, short and load 1-port measurements are needed, for the through 2-port measurements), the correct port(s) has to be selected. If any standard is defined by a measurement, the usable frequency range of the calibration kit is limited to the smallest common range of all measurement.

Example: The open standard is defined by a measurement file containing data from 10–500 MHz. The load standard is defined by a measurement file containing data from 50–800 MHz. In this case the calibration kit can only be used in the range of 50–500 MHz.



When saving the calibration kit, only the (relative) filenames of any used measurements are saved. For future use, the measurement files have to be kept in the same folder relative to the calibration kit file.

3.3.4 Measurements

The calibration measurements can be found in **Calibration >> Calibration Measurements**. It contains all possible measurements, regardless of the currently active calibration:

Type	Prerequisites	Statistics	Timestamp
Port 1 short	Short standard connected to port 1, port 2 open	Not available	
Port 1 open	Open standard connected to port 1, port 2 open	Not available	
Port 1 load	Load standard connected to port 1, port 2 open	Not available	
Port 2 short	Port 1 open, short standard connected to port 2	Not available	
Port 2 open	Port 1 open, open standard connected to port 2	Not available	
Port 2 load	Port 1 open, load standard connected to port 2	Not available	
Through	Port 1 connected to port 2 via through standard	Not available	
Isolation	Both ports terminated into 50 ohm	Not available	
Line	Port 1 connected to port 2 via line standard	Not available	

To take a measurement, select the corresponding line and press .



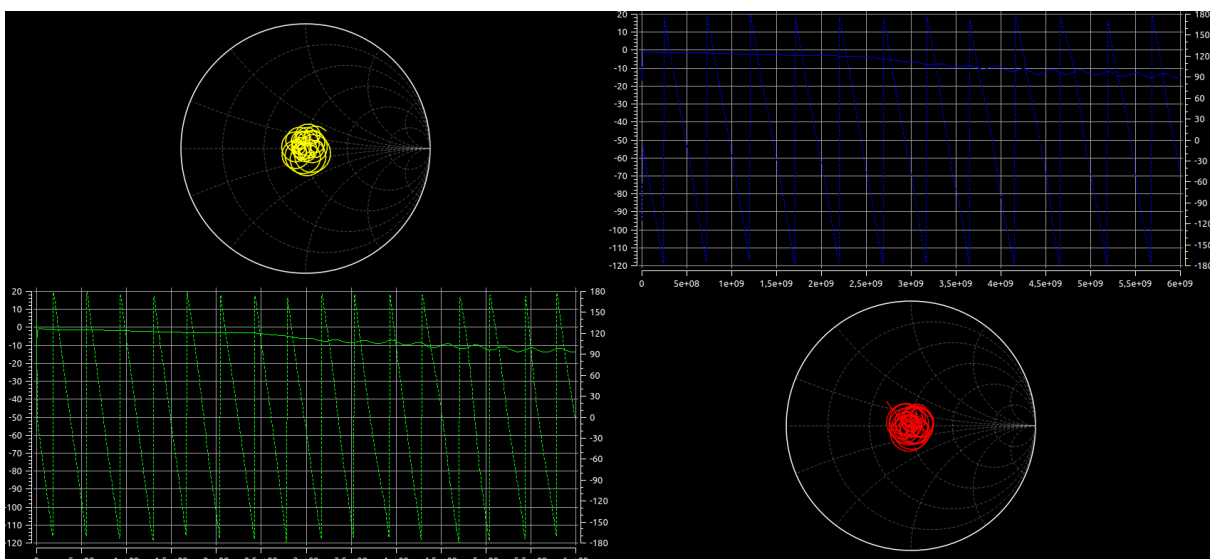
All measurements required by a calibration type must have the same start and stop frequencies as well as number of points. Do not change the span inbetween measurements.

3.3.5 Enabling a calibration

Either select the desired calibration type in the calibration menu or choose it in the calibration toolbar and enable the checkbox. If all required measurements have already been taken, the calibration is activated immediately. If some measurements are missing or have been taken with different span settings, applying the calibration is not possible. In that case, the calibration measurement dialog (see section 3.3.4) opens, this time only showing the necessary measurements required for the selected calibration type.

Example: After starting the application, the following steps are necessary to perform a SOLT calibration.

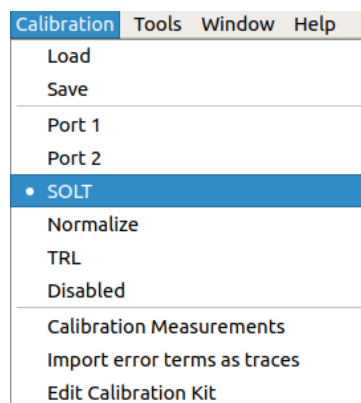
1. Edit the calibration kit to match the standards used in the measurements or open a saved calibration kit file.
2. Change the span and acquisition settings to match the intended measurement. At this point no calibration is active yet, the measured data (here with both port directly connected) is inaccurate:



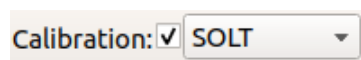
3. Select **Calibration** >> **Calibration Measurements** and take the required measurements. In this case, the measurement "Isolation" (optional for SOLT) has not been taken, as well as the "Line" measurement (not required for SOLT)

Type	Prerequisites	Statistics	Timestamp
Port 1 short	Short standard connected to port 1, port 2 open	501 points from 10.0000MHz to 6.00000GHz	19.11.2020 19:33:13
Port 1 open	Open standard connected to port 1, port 2 open	501 points from 10.0000MHz to 6.00000GHz	19.11.2020 19:32:41
Port 1 load	Load standard connected to port 1, port 2 open	501 points from 10.0000MHz to 6.00000GHz	19.11.2020 19:33:52
Port 2 short	Port 1 open, short standard connected to port 2	501 points from 10.0000MHz to 6.00000GHz	19.11.2020 19:33:28
Port 2 open	Port 1 open, open standard connected to port 2	501 points from 10.0000MHz to 6.00000GHz	19.11.2020 19:32:55
Port 2 load	Port 1 open, load standard connected to port 2	501 points from 10.0000MHz to 6.00000GHz	19.11.2020 19:34:09
Through	Port 1 connected to port 2 via through standard	501 points from 10.0000MHz to 6.00000GHz	19.11.2020 19:34:32
Isolation	Both ports terminated into 50 ohm	Not available	
Line	Port 1 connected to port 2 via line standard	Not available	

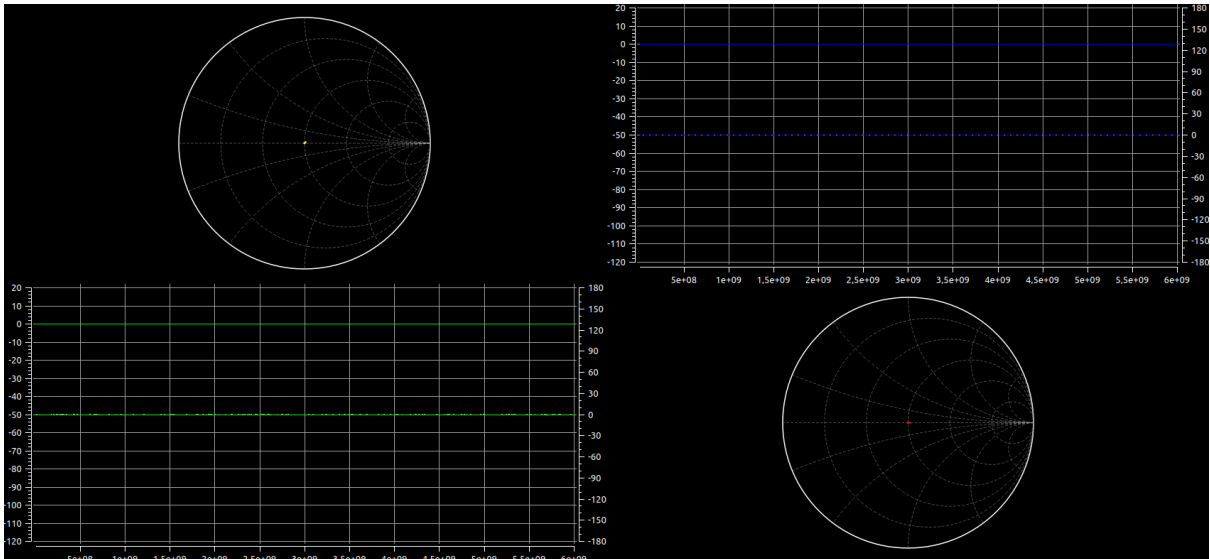
4. Close the "Calibration Measurements" window and activate the SOLT calibration by selecting **Calibration** >> **SOLT**:



Alternatively, the calibration can be activated by choosing "SOLT" in the toolbar and enabling the calibration checkbox:



5. The calibration is active and connecting both ports directly results in a corrected measurement:



3.3.6 Saving/Loading

Once a calibration is active, it can be saved by selecting **Calibration** \gg **Save**. All raw measurements are saved together with the calibration type and the calibration kit (saved in an additional file with same filename as the calibration).

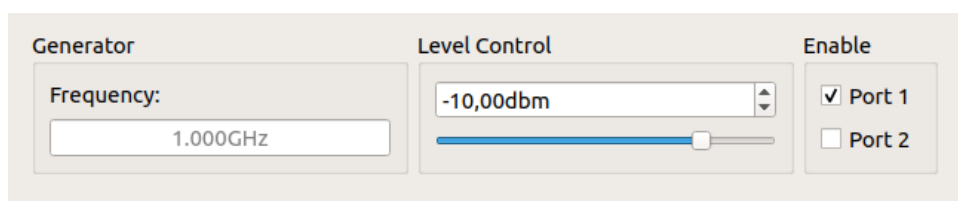
Similarly, a saved calibration can be opened by selecting **Calibration** \gg **Load**. It is applied immediately after opening.

3.3.7 Viewing error terms

The error terms calculated from the calibration measurements can be imported by selecting **Calibration** \gg **Import error terms as traces**. This feature is mostly intended to debug calibration problems and is not normally required. The nomenclature follows "Network Analyzer Error Models and Calibration Methods" by Doug Rytting.

4 Signal Generator

In the signal generator mode, measurements are stopped and the VNA only outputs a CW signal.



The hardware is not optimized for signal generation which means that the output level is not very accurate, especially at higher frequencies (also see section 6). Also, the signal will contain higher levels of harmonics than one would normally expect from a signal generator.

5 Spectrum Analyzer

Although the VNA hardware is not designed to be used as a spectrum analyzer, the general hardware architecture of a spectrum analyzer is similar enough to that of a VNA to implement basic two-channel spectrum measurements. This is in no way on the same performance level as a dedicated

spectrum analyzer but for simple measurements it might suffice if no other equipment is available. The main differences to a real spectrum analyzer are:

- **No input attenuator or pre-amplifier:** This means that the measurement range is essentially fixed to approximately -110 dBm to -10 dBm.
- **No amplitude calibration:** The displayed signal level is not very accurate, especially at higher frequencies (also see section 6).
- **No image rejection filters:** This is probably the most severe limitation, because it means that for every real signal several other signals will show up in the spectrum that are not actually present at the input. Most of the images can be filtered out by signal identification but some will remain (at lower amplitude) in the reported data.
- **Highest resolution bandwidth is quite low:** The sweep speed is too slow to cover the complete frequency range of 1 MHz to 6 GHz in an acceptable time.

Most control elements (Frequencies, Span, Traces, Marker, ...) are identical to the vector network analyzer mode.

5.1 Acquisition Toolbar

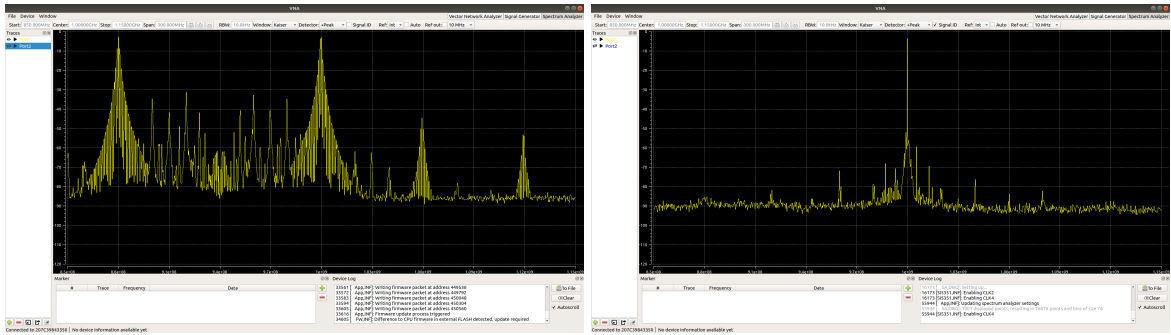


- **RBW:** Resolution bandwidth. Lower values allow differentiating between signals at closer frequencies. Lower values also result in a reduced noise floor but significantly increase sweep time. For low RBWs, a faster DFT acquisition method is available. Instead of tuning the LOs to look at each frequency point by itself, several points can be measured at once by performing a DFT of the final IF. Due to limitations in the hardware and the available processing power, the DFT is limited to 96 points and can only cover up to 30 kHz at a time. Whether the DFT is used (and at which RBWs) can be selected in [Window >> Preferences](#)
- **Window:** Window type used in the DFT of the final IF. If in doubt, use Flat Top.
- **Detector:** For every displayed point, several measurements are taken. The detector type determines which one of these measurement will be displayed:

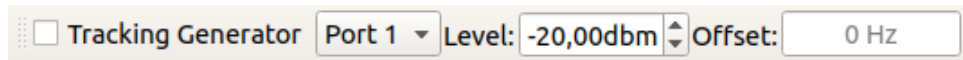
Detector	Displayed data
+Peak	Highest amplitude
-Peak	Lowest amplitude
Sample	Only uses the middle measurement
Normal	Highest amplitude on odd points, lowest amplitude on even points
Average	Average all measurements for each point

- **Signal ID:** Signal identification. This can help to determine whether a displayed signal is actually present or the result from internal imaging. When enabled, the VNA changes the LO frequencies for every measurement point and observes how the final IF signal is affected by that. This removes almost all of the mirror images but at the cost of increased sweep time.

The following example shows the effect of signal ID. For both measurements the only signal at the input was a 1 GHz tone with a level of -10 dBm. On the left, signal ID is turned off, resulting in a lot of extra tones. On the right, signal ID has removed most of these tones:



5.2 Tracking Generator Toolbar



A tracking generator at either port is available in the spectrum analyzer. If the tracking generator is active at a port, measurements from that port are still available but meaningless. The tracking generator also includes an optional frequency offset. To get accurate results, a Source/Receiver Calibration (section 6) should have been performed when using the tracking generator.

DFT acquisition is not available when the tracking generator is active. Also, due to hardware limitations, the tracking generator is unable to reach every frequency exactly. For narrow spans this could result in "drops" in the spectrum where the signal of the tracking generator is outside of the RBW filters passband. The frequency resolution is frequency dependent. A warning message appears if this could be a problem with the selected span and stop frequency.

6 Amplitude Calibration

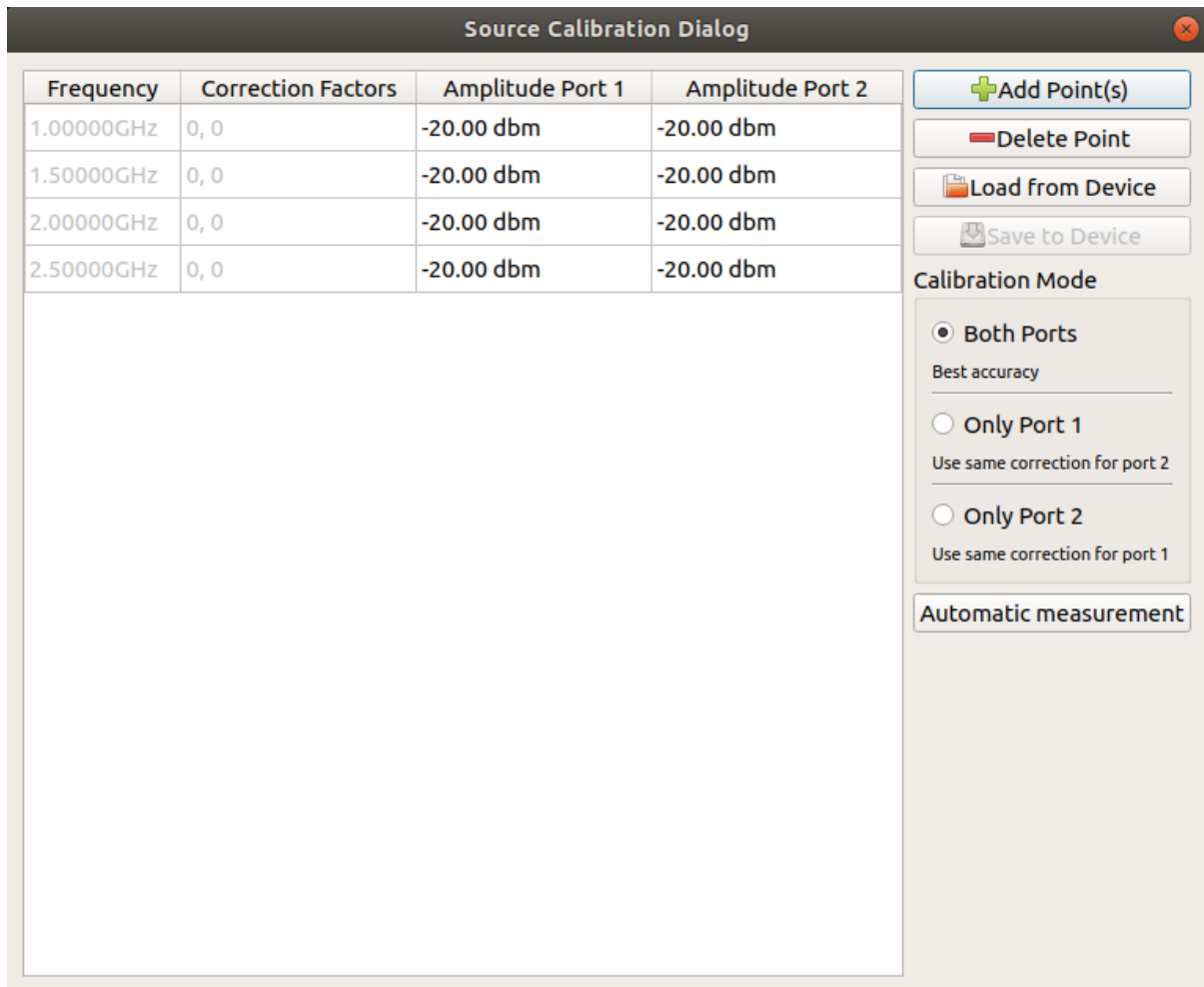
This section is about calibrating the source output level and spectrum analyzer level. It does not affect VNA measurements at all. For the VNA calibration, see section 3.3.

Both the internal signal source and the receiver paths used in the generator or spectrum analyzer mode have no means of ensuring accurate amplitudes (as imperfections are removed by the VNA calibration, the hardware is not optimized for absolute amplitude accuracy). In order to improve the accuracy of both the generator and the spectrum analyzer (especially with enabled tracking generator), frequency dependent amplitude calibrations are available. They are permanently stored in the device and are only required to be performed once. The **Source Calibration** corrects the output of the (tracking) generator, while the **Receiver Calibration** corrects the measurement of the spectrum analyzer.

For both calibrations, other test equipment is required, ideally covering the whole range of 1 MHz to 6 GHz (a calibration of only the partial frequency range is also possible but signals/measurements outside the calibrated range will be inaccurate). The Source Calibration requires a way to measure the output of the VNA (e.g. a spectrum analyzer or power meter), the Receiver Calibration requires a signal source (e.g. a signal generator). Once either calibration has been completed, the VNA can also infer the other one with reasonable accuracy.

6.1 Source Calibration

Select **Device** >> **Source Calibration**. A window showing the current source calibration opens:



These are the necessary steps:

1. **Set up the calibration frequencies:** Add or remove points according to your needs. Ideally, they should be evenly spaced across the range to calibrate, maybe with a slight emphasis on higher frequencies (signal levels generally vary more at higher frequencies). Additionally, it is advisable to set one point at 25 MHz and one just below (at 25 MHz a band is switched, resulting in an amplitude discontinuity). Up to 64 points can be used.
2. **Select the calibration mode:** Either calibrate both ports separately (best accuracy but more work) or assume that they are identical and use the measurement at one port for both.
3. **Perform the calibration:** For each frequency and port, select the corresponding cell in the table. The VNA will generate a signal at the selected frequency and port with (what it thinks are) –20 dBm. Use external equipment to determine the actual output level and enter the measured value into the selected cell.
4. **Save the calibration:** Once all measurements have been taken, the "Save to Device" button becomes available. There is no way to save intermediate results, you have to calibrate all frequencies you have chosen in step 1.

If the Receiver Calibration is already done, it is also possible to infer the Source Calibration from that. Press **Automatic measurement** and connect both ports of the VNA directly to each other. This connection should be as ideal as possible (short, low loss cable) as every imperfection directly translates into calibration errors. During the automatic calibration, the VNA uses the already established frequency points from the Receiver Calibration and measures the output amplitude by itself to determine the coefficients of the Source Calibration.

6.2 Receiver Calibration

Select **Device** > **Receiver Calibration**. The Receiver Calibration works almost identically to the Source Calibration. The only difference is in step 3:

3. **Perform the calibration:** For each frequency and port, select the corresponding cell in the table and apply a signal with known level at the selected frequency and port. The signal level should be in the range of -40 dBm to -10 dBm. Higher signal levels might already compress in the receiver while lower levels unnecessary increase calibration errors due to noise. The VNA tunes its receiver to the selected frequency and measures the amplitude. Apply the signal for at least 2 s and enter its actual amplitude into the selected cell while the signal is still active.

7 Troubleshooting

If there was an error in the boot process, the "Booting" LED will blink an error code repeatedly:

Error Code	Meaning	Possible solution
1	Failed to detect FLASH memory	Hardware failure, check soldering
2	Invalid FLASH content	Perform firmware update
3	Failed to configure FPGA	Check FPGA bitstream generator settings
4	Hardware initialization failed	Verify that FPGA bitstream and uC firmware are created from the same release