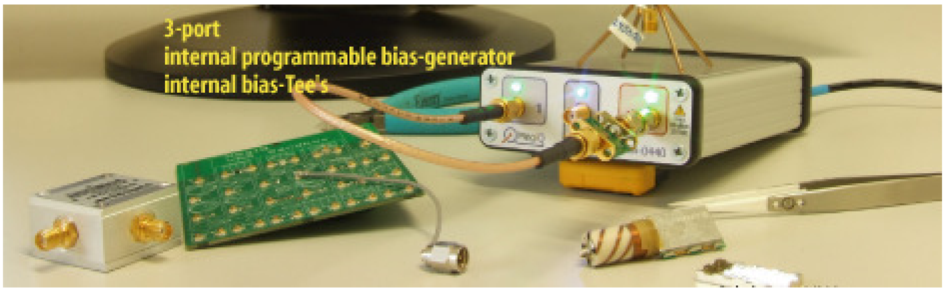
MegiQ VNA0440e measurements on the VNA Sandbox

This document shows VNA0440e measurements on the circuits contained on the MegiQ VNA Sandbox. The circuits on this board are designed to show the many possibilities of the VNA0440e.



Introduction to the measurement setup

VNA0440e

The VNA0440e is a professional 4GHz Vector Network Analyzer and comes with a calibration at the SMA ports. This allows you to directly measure impedances and gains at the connectors without any user calibration. Further calibration is only required when measuring on-board or connectorized devices. The device is very stable and does not need any warm-up time.

The VNA0440e also has a built-in Bias Voltage and Current generator. It allows Frequency, Power and Bias Voltage and Current sweeps to be combined in any combination. This makes it possible to do several different characterizations on active components in its purest form, without additional components or programming of external V/I sources.

The software contains a unique Session Manager to easily store several measurements in a Session File. It makes it easy to build a trail of experiments and retrace your steps. Since all calibration and measurement data are stored you can go back to an earlier measurement and continue measuring from there, changing cursor positions, choose another graphical representation etc.

The graphs below are made with the report generator of the VNA0440e software. We printed them in black here to give a feel of the actual screen. Both screen and reports can be set to white or other backgrounds with different trace colors.

We varied the choice of graphs and the settings of the graphs for zooming, markers and trace labels to show the possibilities of the software for a clear presentation of the measurements and to assess the accuracy of the measurements.

VNA Sandbox

The MegiQ VNA Sandbox is a circuit board with many different experiments to demonstrate the features of VNAs in general and the VNA0440e in particular. It comes with a printed tutorial showing how to measure and explaining the results you see. It can also be used as a reference to verify the correct operation of a test setup.

The VNA Sandbox is based on UFL connectors that are also used to measure consumer miniature RF circuits like mobile phones, Wifi access points etc. it contains a dual calibration kit for quick calibration, which is supported by the VNA0440e software. This reduces a full 2-port calibration from 12 steps to only 4 steps. The lights on the front panel of the VNA0440e will guide you through the calibration process.

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The board contains several 1-port impedances, 2-port passive circuits like attenuators and filters, two antennas and several active circuits that are measured using the bias generator.

Other Calkits

Also available from MegiQ are a universal UFL dual Calkit that allows calibration for different print layer thicknesses, and a Balanced Calkit for measurements on differential circuits and antennas. The Calkits come with custom SMA adapters and cables necessary for the measurements.

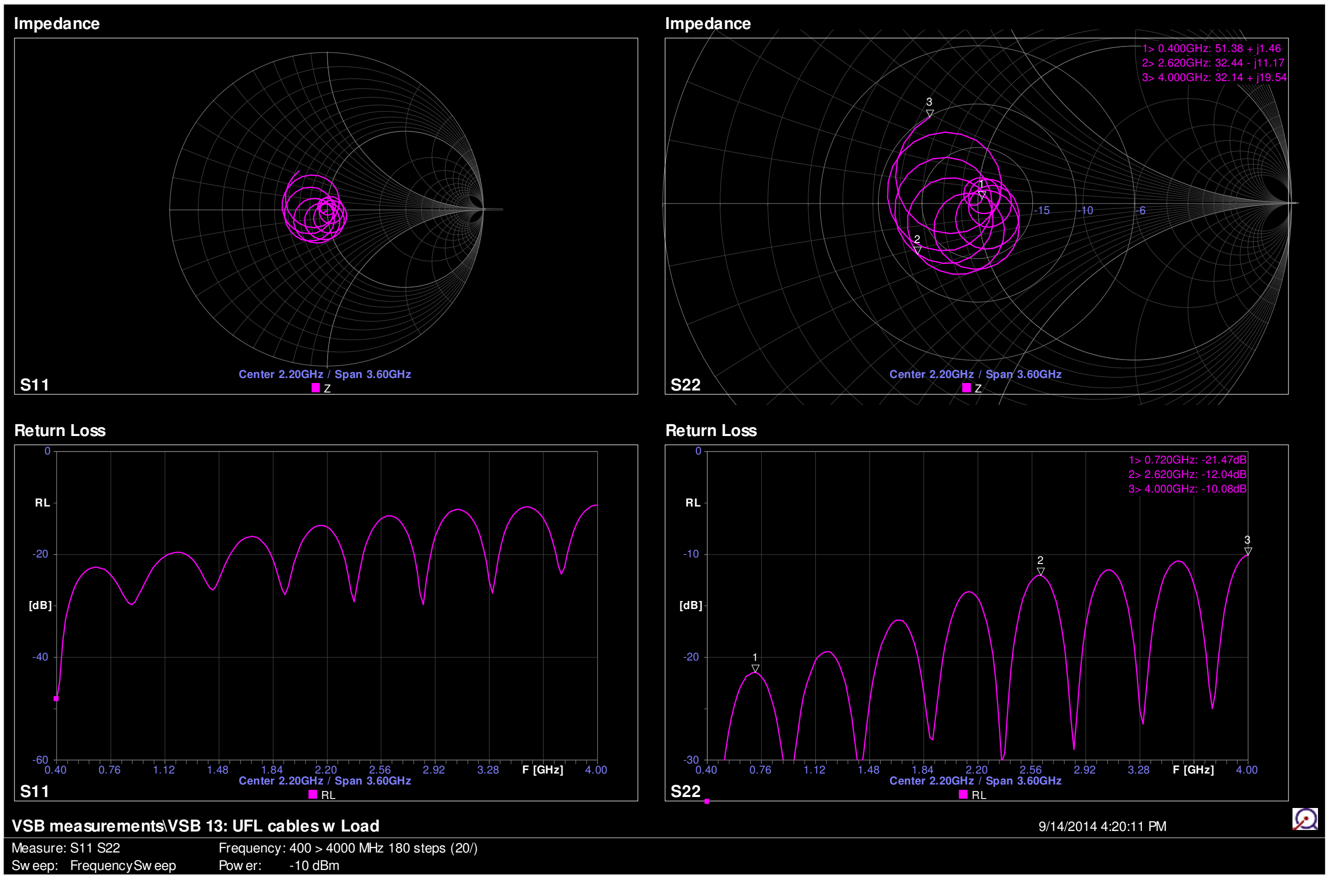
UFL connections

The MegiQ VNA Sandbox uses miniature UFL connectors and cables. These connectors and cables are ideal for measuring small RF devices in the microwave range, but they have the drawback that they are not so well matched at all frequencies.

These UFL and cable mismatches are calibrated and normalized away by the VNA0440e, but some artifacts remain in the higher range between 3 and 4 GHz. The same artifacts are also seen on other high end VNAs. Note that the VNA0440e itself features SMA front panel connectors.

UFL Cable

Here are the bare impedances of two single UFL cables measured with the Port Calibration of the VNA0440e.



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Double UFL cable in series

When two cables are connected in series, as in the test setup with the VNA Sandbox, the UFL impedances are getting quite a bit off.

The total impedance and gain varies quite a bit over the frequency range and the return loss is quite low on some frequencies. This should be taken into account when applying these cables in an RF application.

The Group Delay is shown in the bottom left S12 Gain graph. It can be used to estimate the length of the two cables in series.

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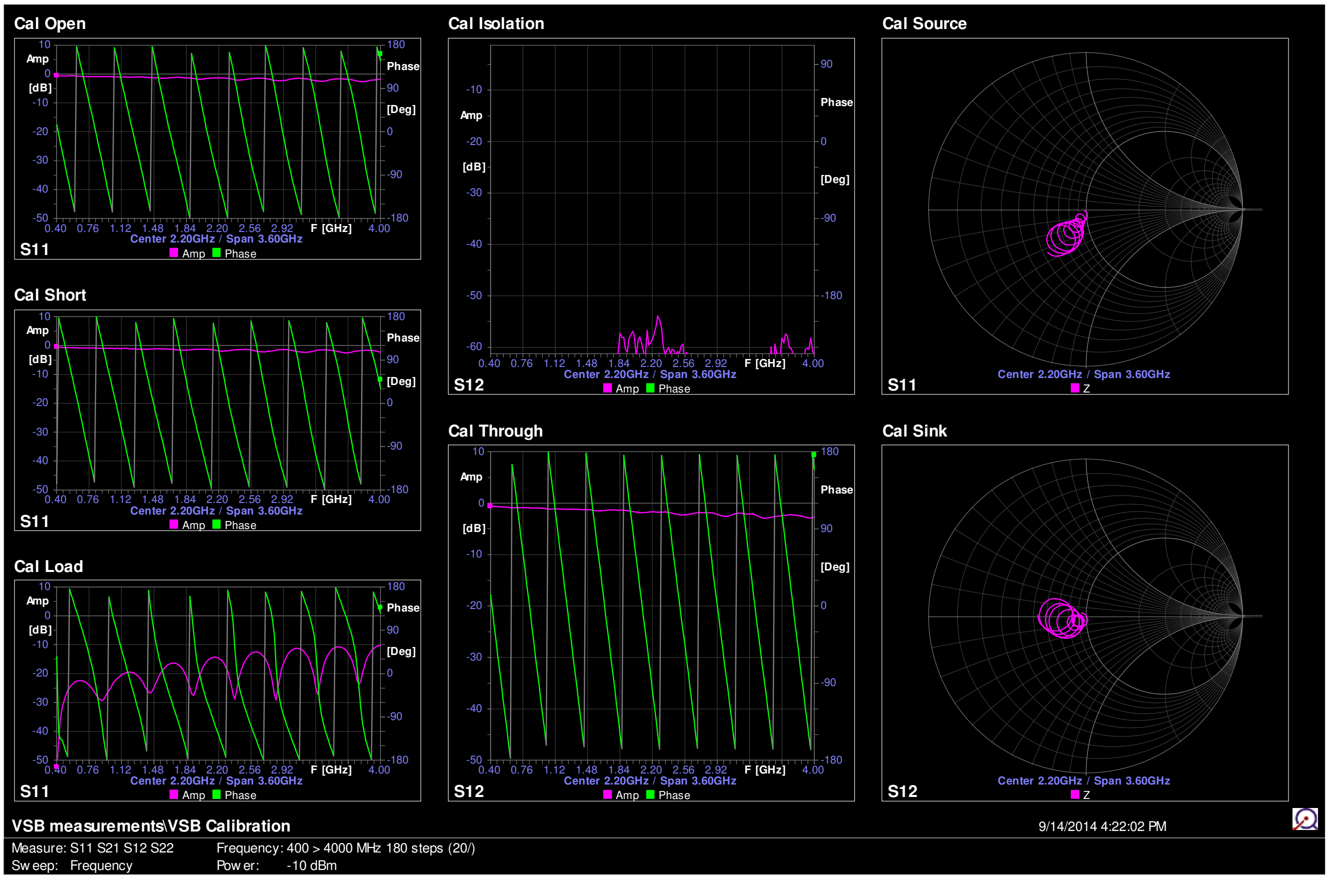
Calibration

The VNA0440e has ‘Port Calibration’ for direct measurements on cables and connectorized antennas, without further user calibration. The UFL measurements above were made with Port Calibration.

For measurements through cables and fixtures the measurement must be calibrated with reference impedances at the very point where the device under test is to be connected. A double set of calibration references is included on the VNA Sandbox which speeds up the calibration process for 2-port measurements.

For a 2-port measurement we have to make reference measurements with an Open, Short and Load (50Ohm) on each port, and an Isolation and a Through connection between them.

This graph shows the calibration signals of one half of the 2-port calibration on the VNA Sandbox.



From the Open-Short-Load calibration (the three graphs on the left), the VNA0440e calculates the impedance at the reference plane of the calibration. This is the Source impedance with which the circuit under test is excited.

During the Through-calibration the VNA0440e also measures the impedance that is connected to the Source. This is the Sink impedance that will terminate the circuit under test.

The ‘imperfect’ Source and Sink impedances – they are not perfectly 50 Ohm – cause errors in the measurements, both for impedance and for gain results.

The 6 calibrations for each of the 2 ports allow the VNA0440e to perform a 12-term normalization (Full Normalization) on the measurement to remove these measurement impedances from the results.

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The results then show the device’s characteristics as if it were measured with pure 50 Ohm source and termination impedances.

We see that there is a significant amount of crosstalk between the UFL cables (Isolation measurement). This crosstalk is also eliminated in the normalization process.

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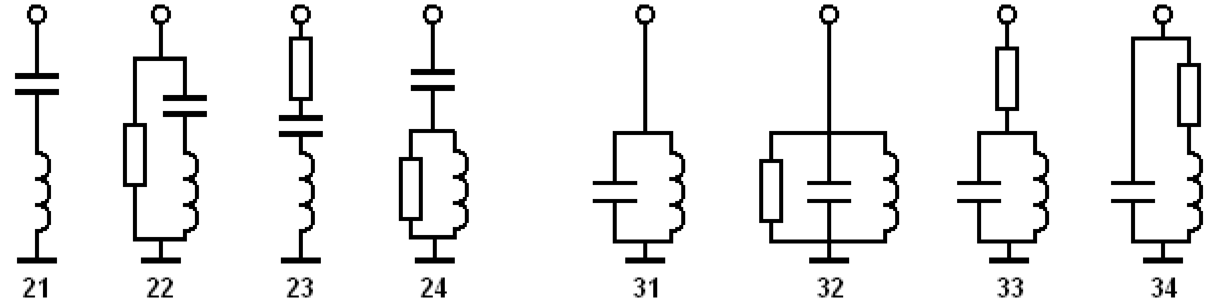
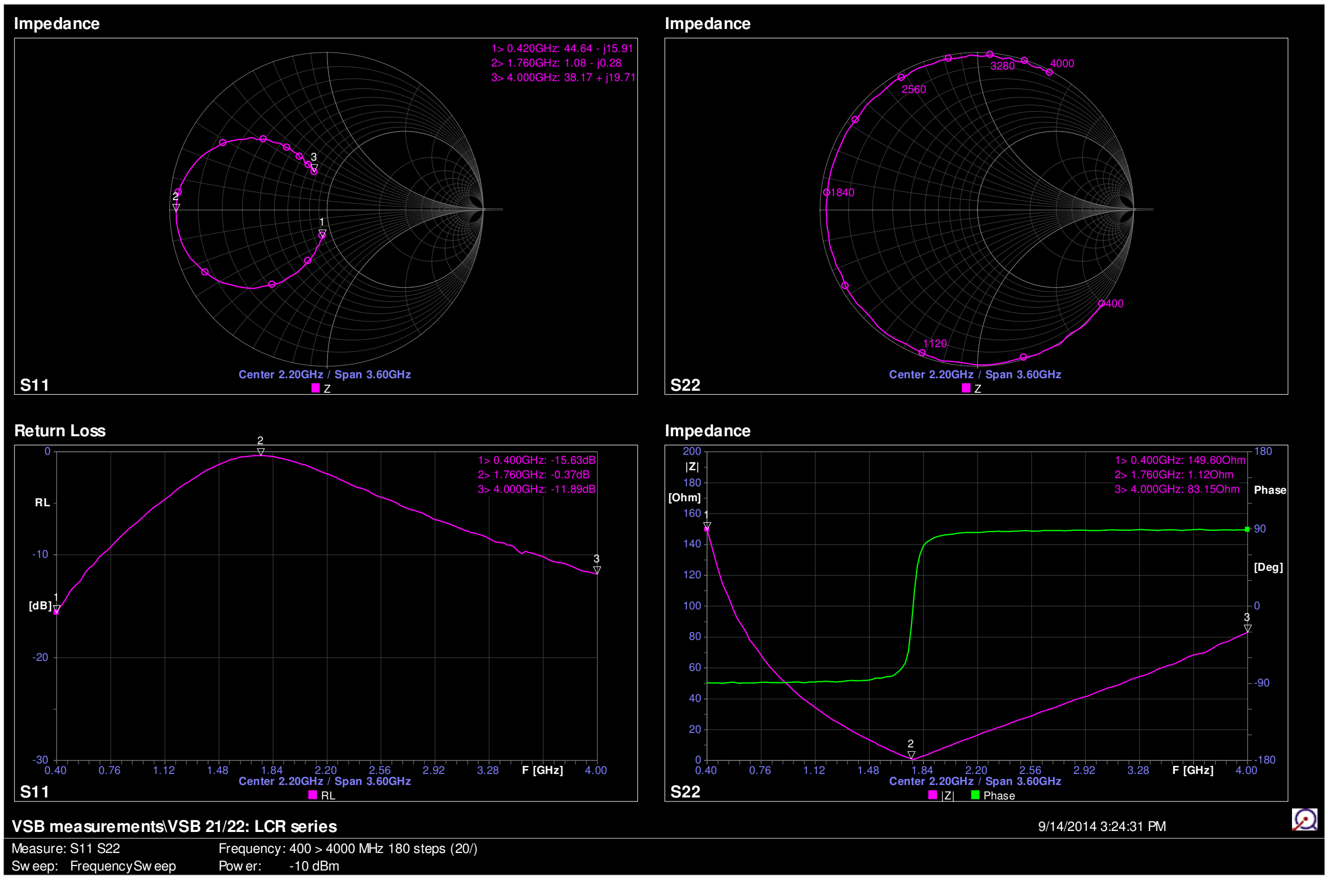
1-port circuits

These are measurements (in pairs) of different series and parallel resonance circuits combined with a resistor.



Series resonance circuits 22 and 21



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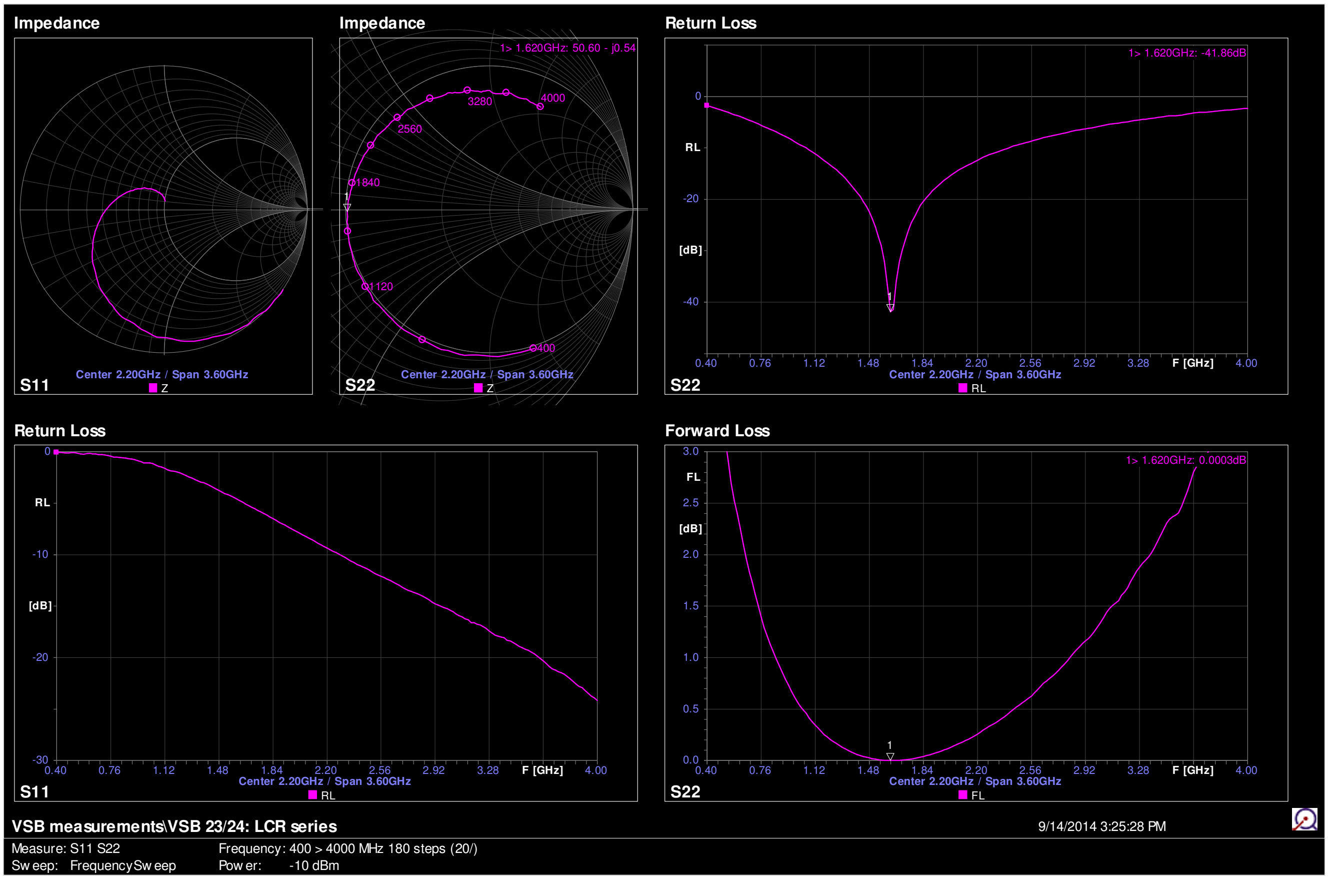
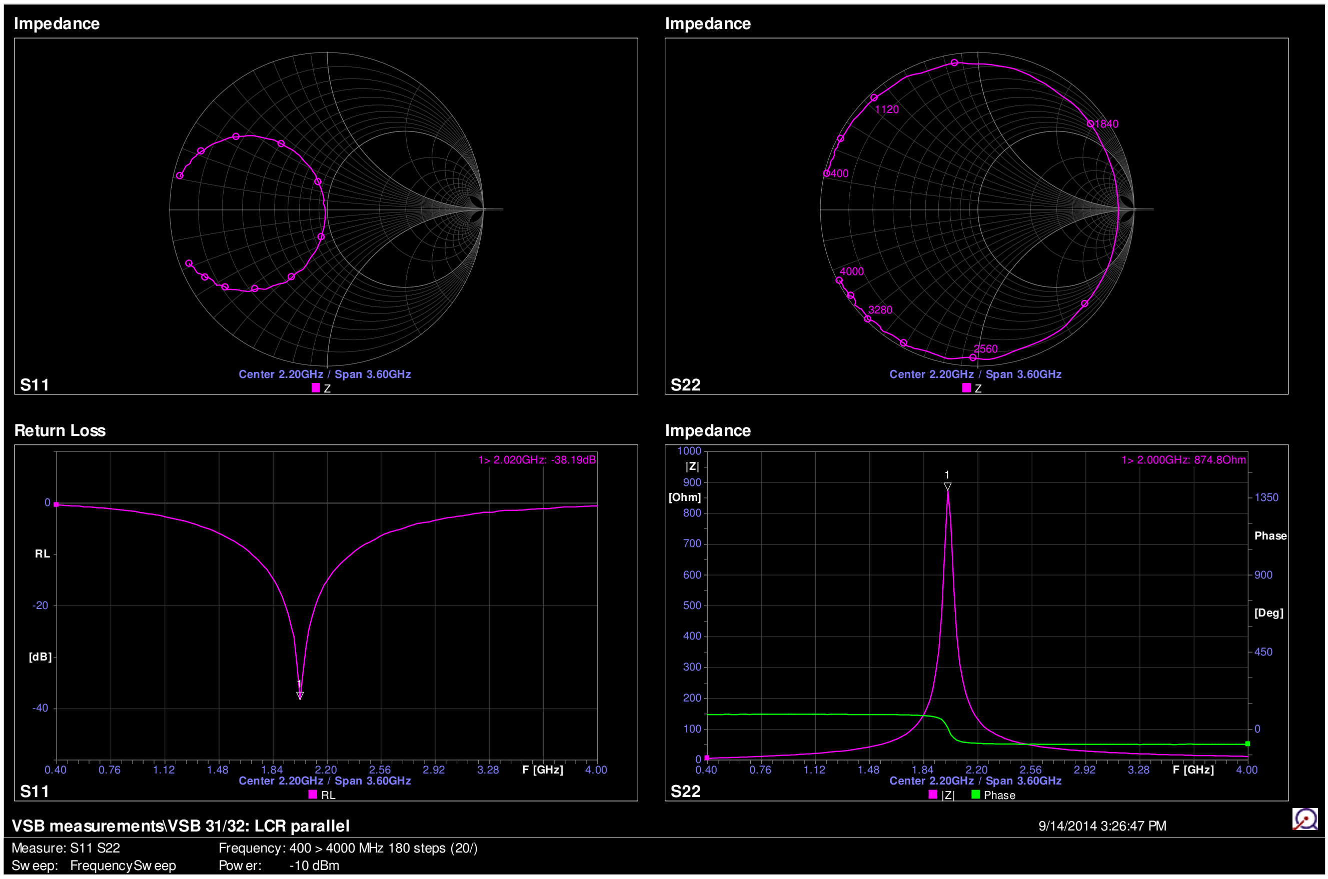
Series resonance circuits 24 and 23



Parallel resonance circuits 32 and 31



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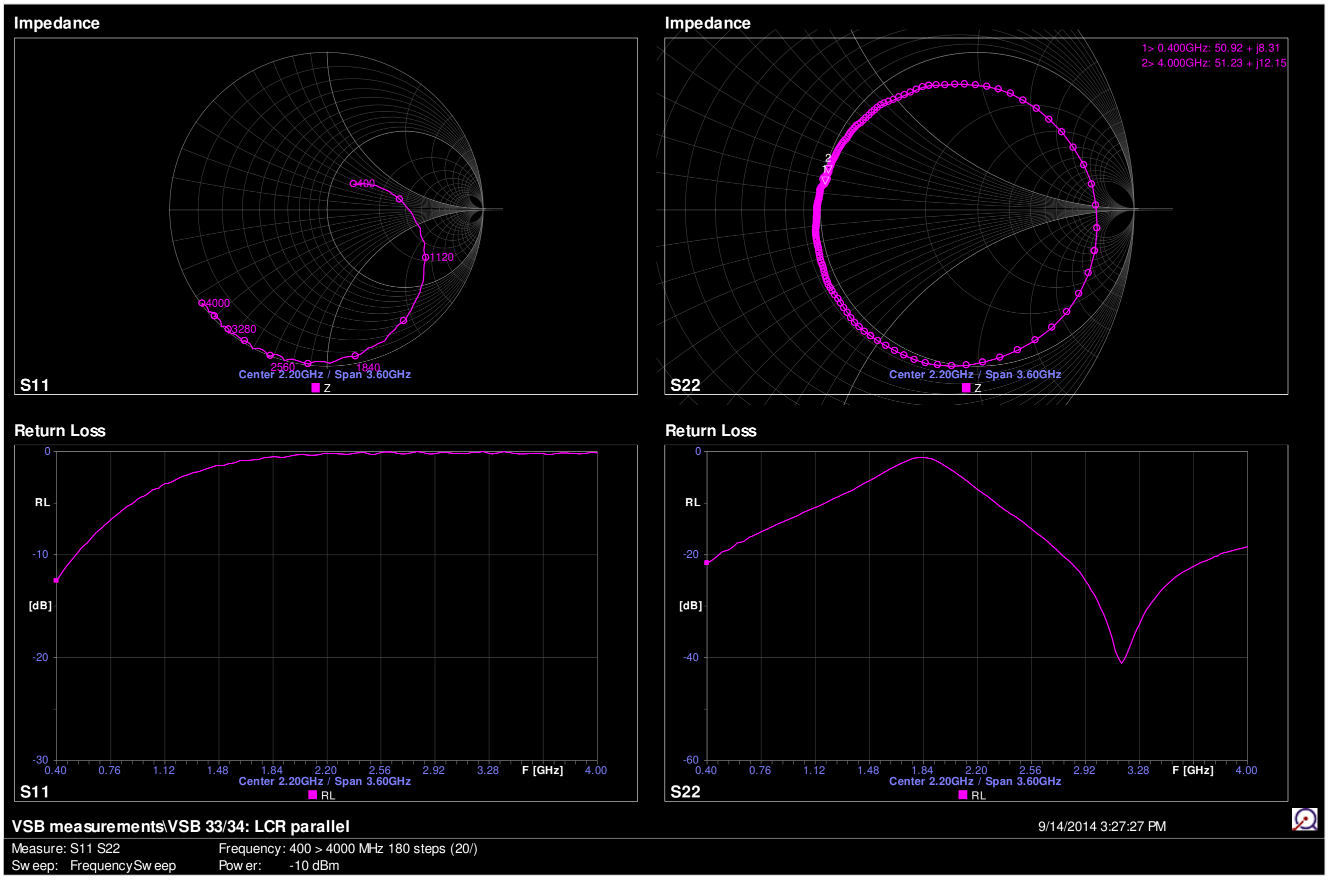
Parallel resonance circuits 34 and 33



Notice that the frequency indications in the Smith chart give a much better insight in the circuit's behaviour than the bare lines that other VNAs show. These markers are a unique feature of the VNA0440e software. In the right Smith chart the measure point markers are turned on.

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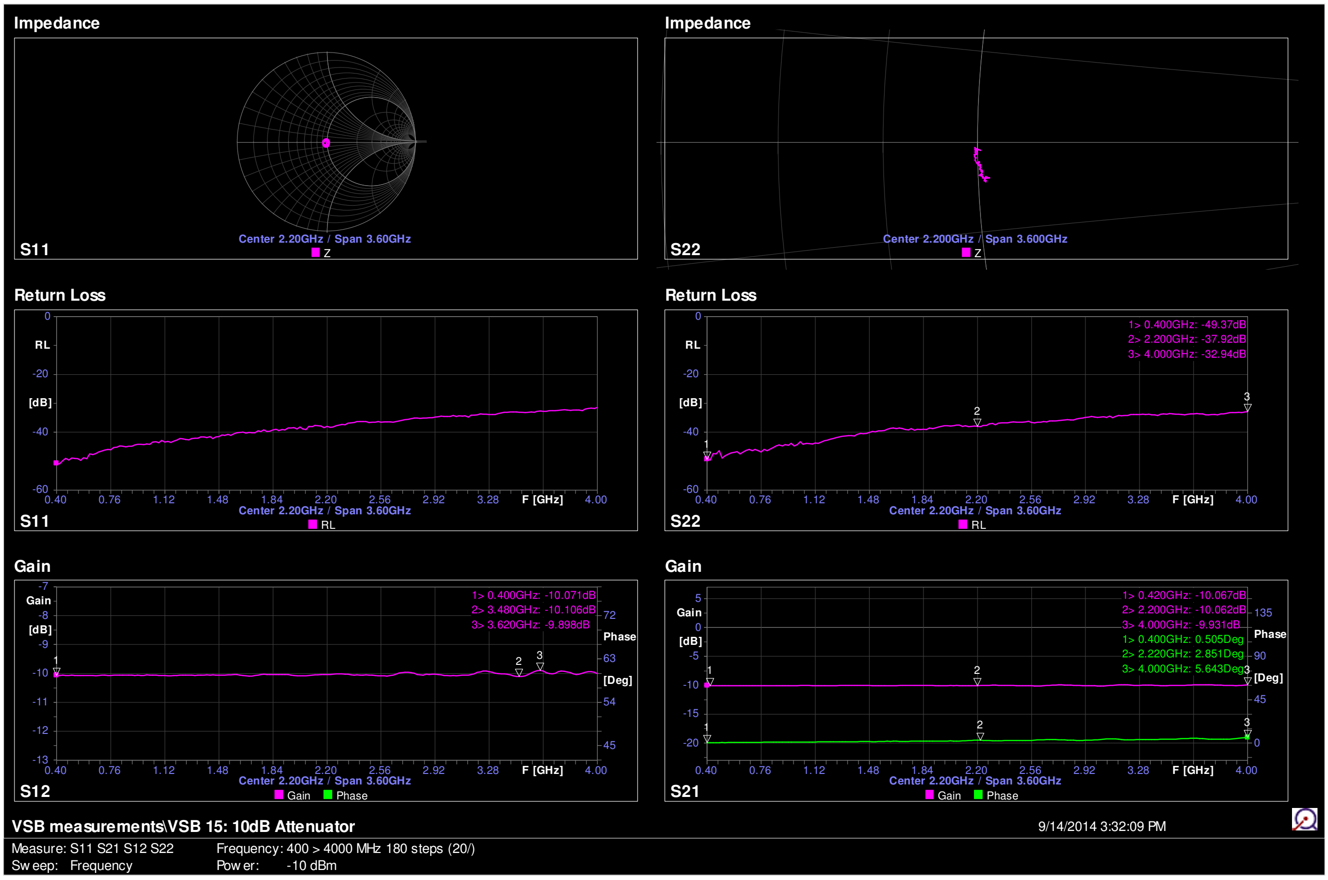
2-port passive circuits

10 dB Pi attenuator



A simple resistor network has very accurate attenuation and matching over the whole band, with only 0.2 dB variation in attenuation.

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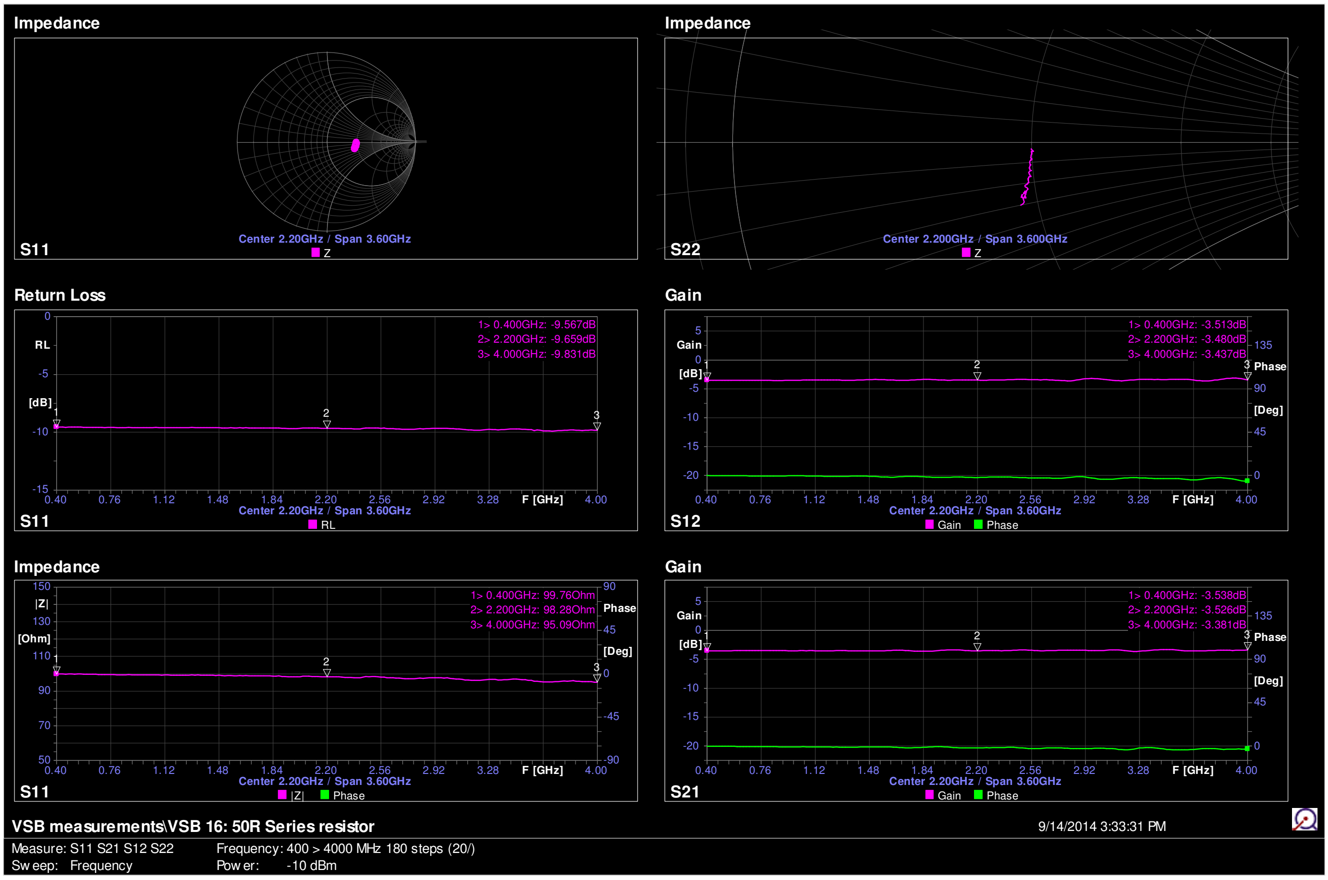
50 Ohm series resistor.



In series with the system impedance of 50 Ohm we measure (nearly) 100 Ohm in total. The circuit has about 3.5dB attenuation.

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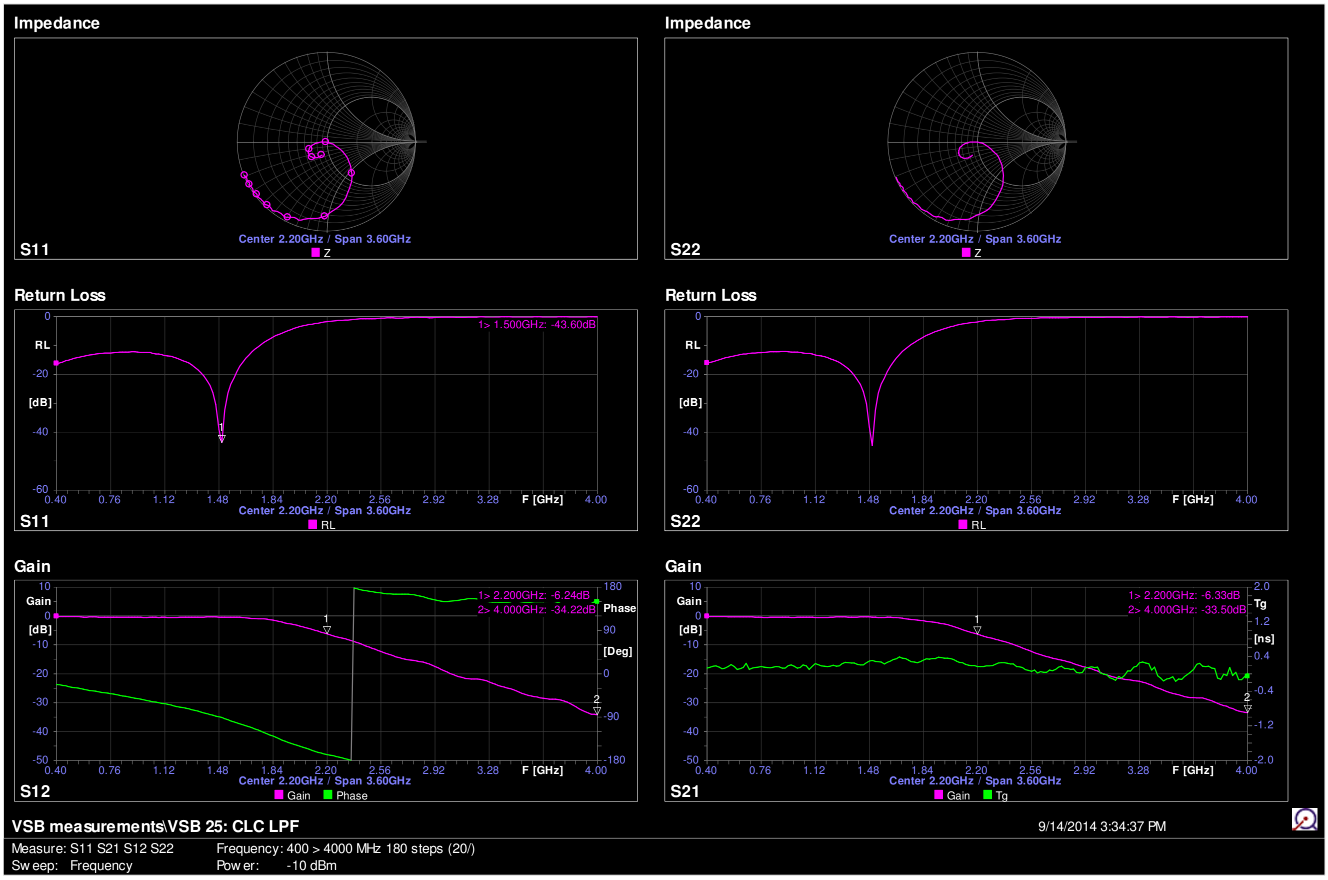
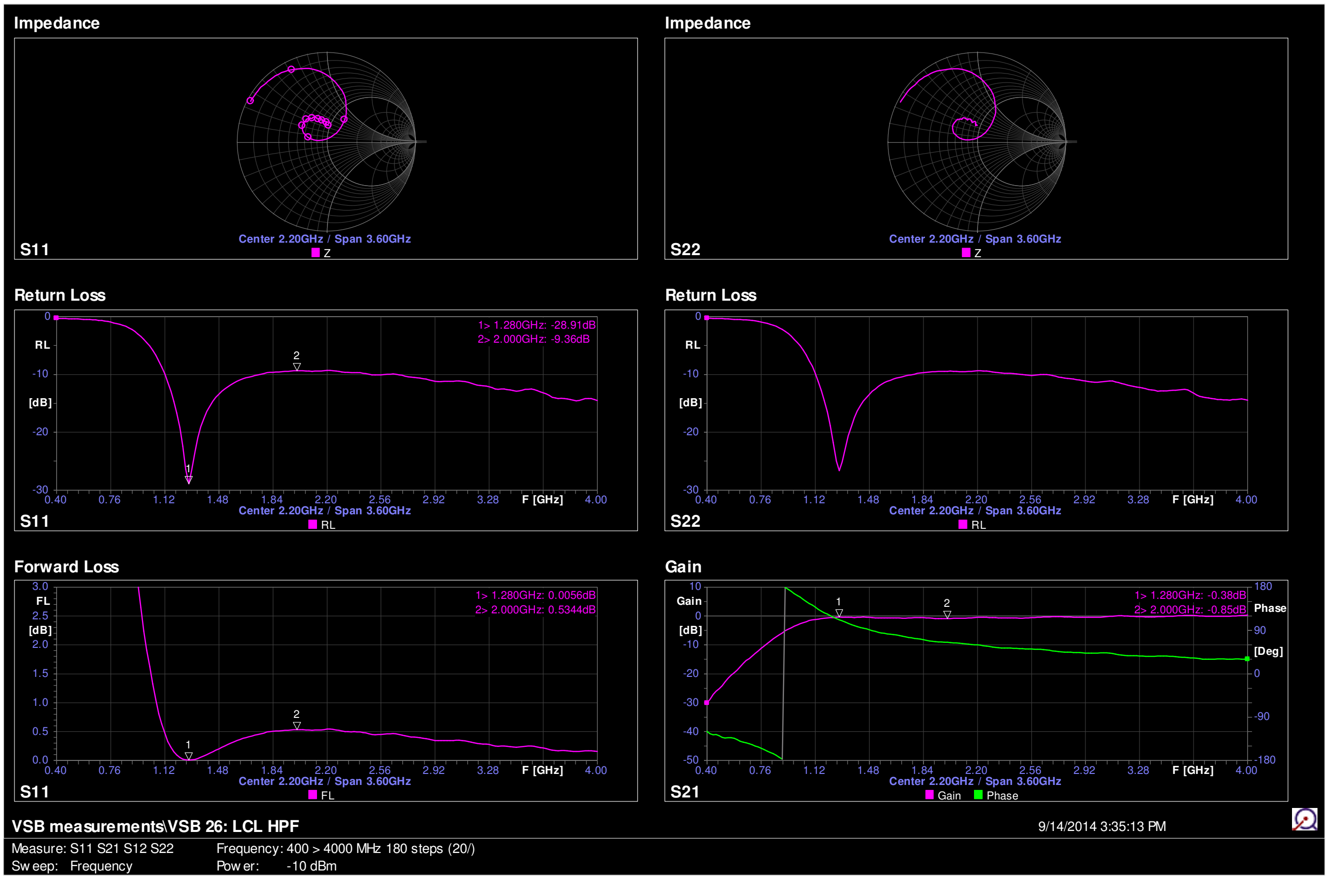
Filters

3rd order low pass filter



3rd order high pass filter



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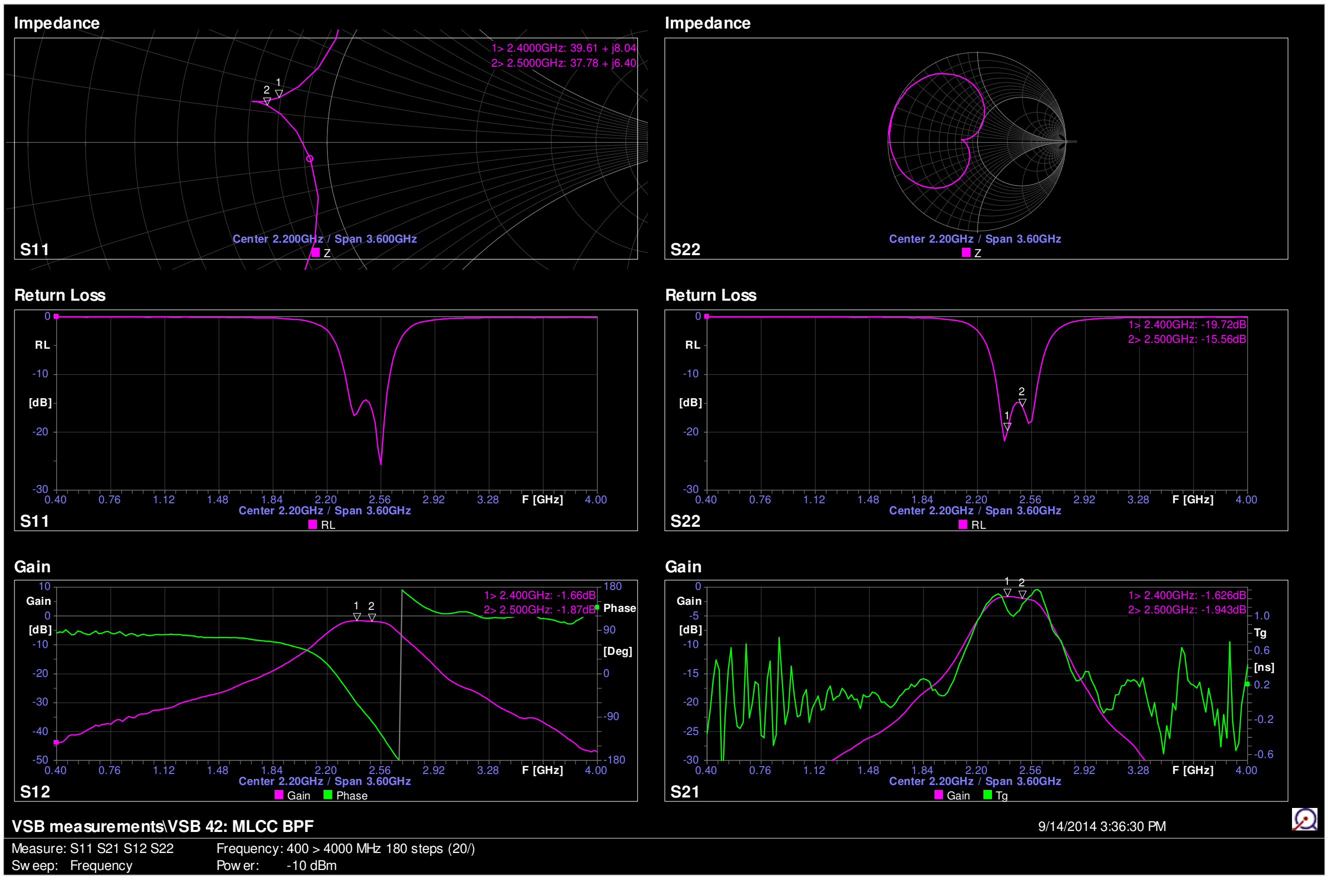
Wifi MLCC band pass filter



This filter has a 0.3dB variation in Insertion Loss and a good Return Loss in the Wifi – Bluetooth – Zigbee band from 2.4 GHz to 2.5 GHz. The fairly high Group Delay (Gain S21, green trace) may distort signals and cause symbol errors in an application.

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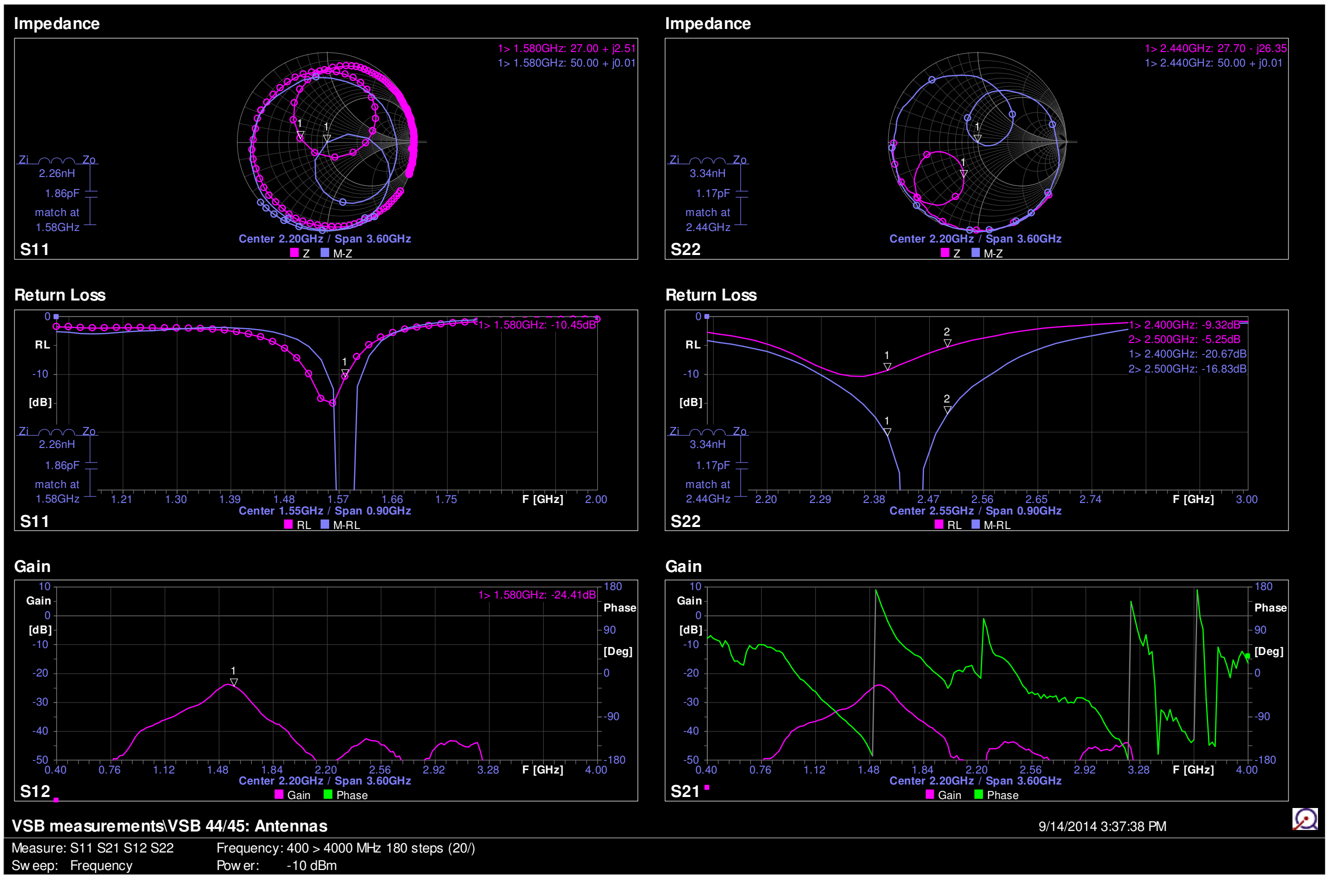
Antennas

The VNA Sandbox contains two ceramic antennas, one for GPS at 1.575GHz and one for Wifi at 2.5GHz. They are measured here in a 2-port configuration which also shows the coupling between them. The coupling is of course not optimal since the antennas are made for different frequencies.

The antennas are not very well matched and tuned here. The VNA0440e has the unique possibility to calculate matching circuits and plot the results after matching. The matching results are simulated in real-time during measurements.



Notice that the GPS antenna on the left has a very narrow bandwidth. To visualize this in the Smith chart we turned measure-point markers on to show how fast the impedance sweeps around the resonance circle. The VNA0440e can of course also make a much narrower sweep at this frequency.

The Wifi antenna is matched to full Wifi band with a very good return loss. These matching results are generally well replicated with real-life components in the circuit.

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Active 2-port circuits

The built-in bias generator of the VNA0440e make it possible to measure active circuits like varactors, PIN diodes and amplifiers in its purest form without biasing components. The bias generator is Voltage and Current controllable and sweepable and with a range of +/-14V and 100mA it has ample voltage and current to measure a wide range of devices.

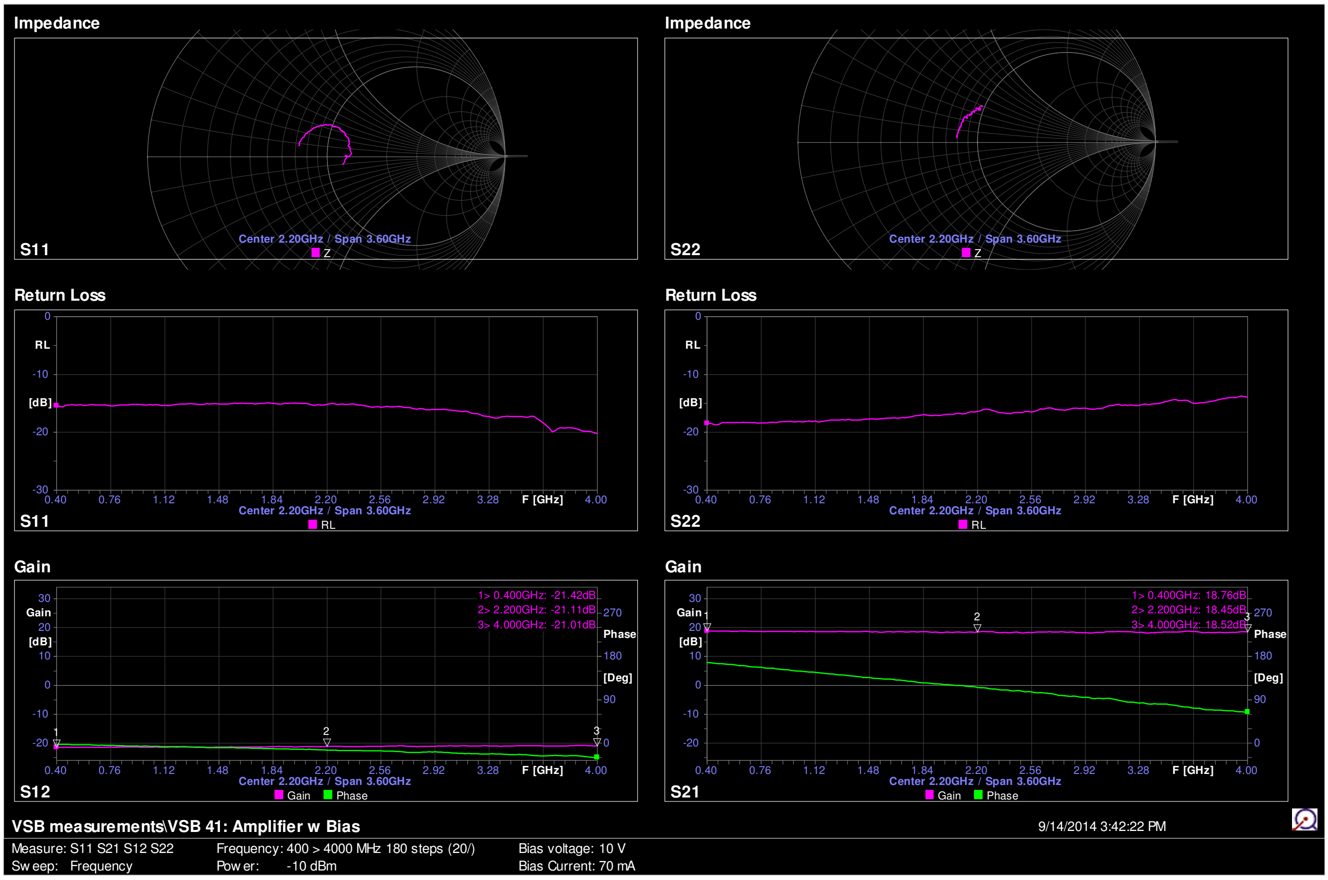
The VNA0440e bias circuit has three configurations for each port:

- Open
- Bias On
- Return to Ground

The Return to Ground setting allows the Bias Current through a component to return to ground without additional components.

Wideband amplifier

In this measurement the amplifier supply is generated by the bias generator (70mA current source). There are no additional components on the chip.



The amplifier has a steady gain of 18.5dB which varies by only 0.25 dB up to 4 GHz. The reverse gain is about -21dB, which shows that the amplifier is stable. The return loss is also around a nice 15dB over the frequency range.

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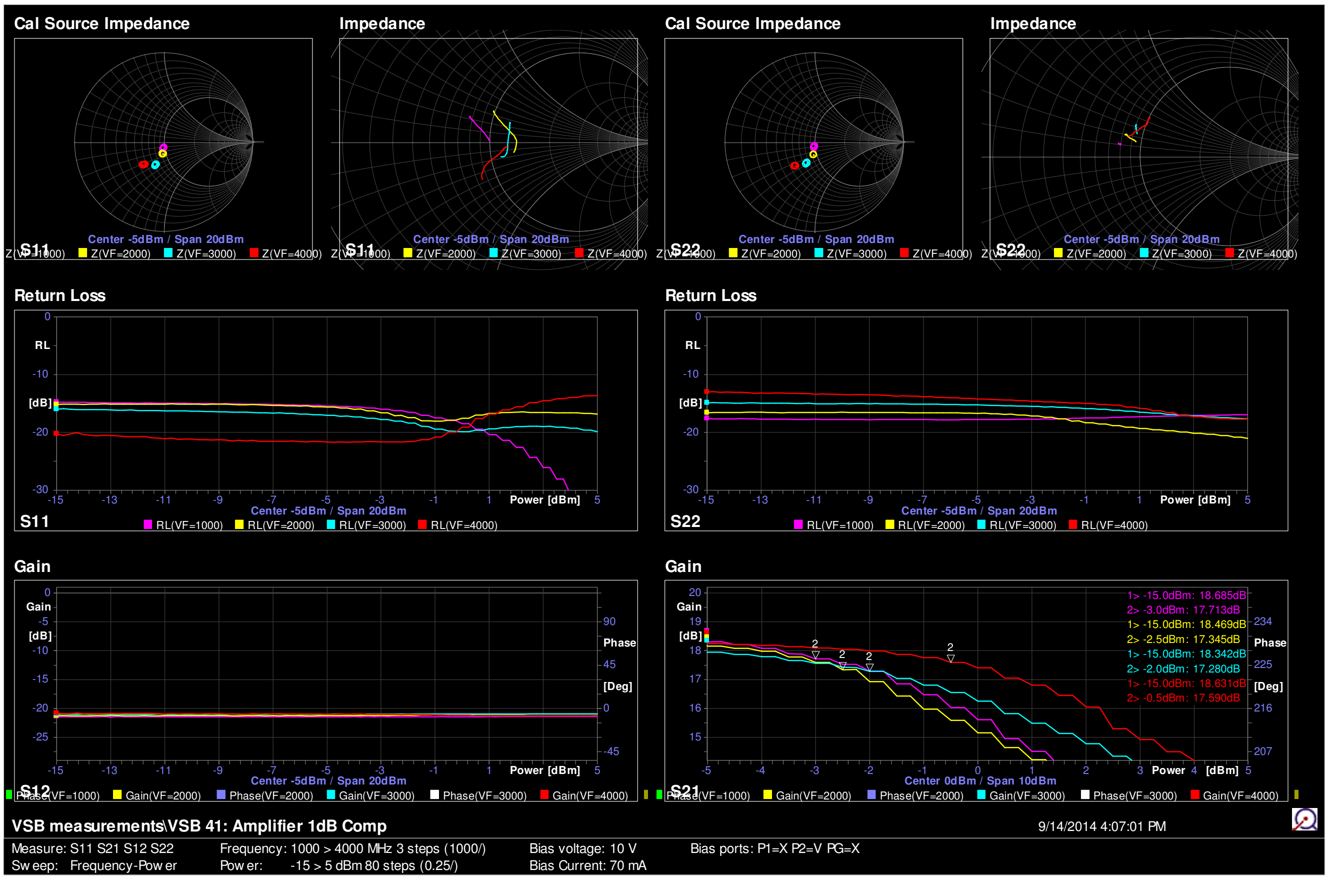
1dB Compression Point

We can combine a power sweep with frequency stepping to determine the 1dB compression point at different frequencies.



We determine the level at which the gain decreases by 1dB by setting a marker at the low frequency gain (outside the zoomed graph) and finding the point at which this gain is 1dB lower. The compression point is measured at 1, 2, 3 and 4 GHz.

Notice that the decline in input return loss at 3GHz (RL S11, red trace) causes input power to be lost and moves the compression point to a higher input power level (Gain S21, red trace).

We could combine this sweep with a stepping of the bias current (2-parameter sweep) to determine the 1dB compression points at different amplifier currents, but this would yield very busy graphs with many traces.

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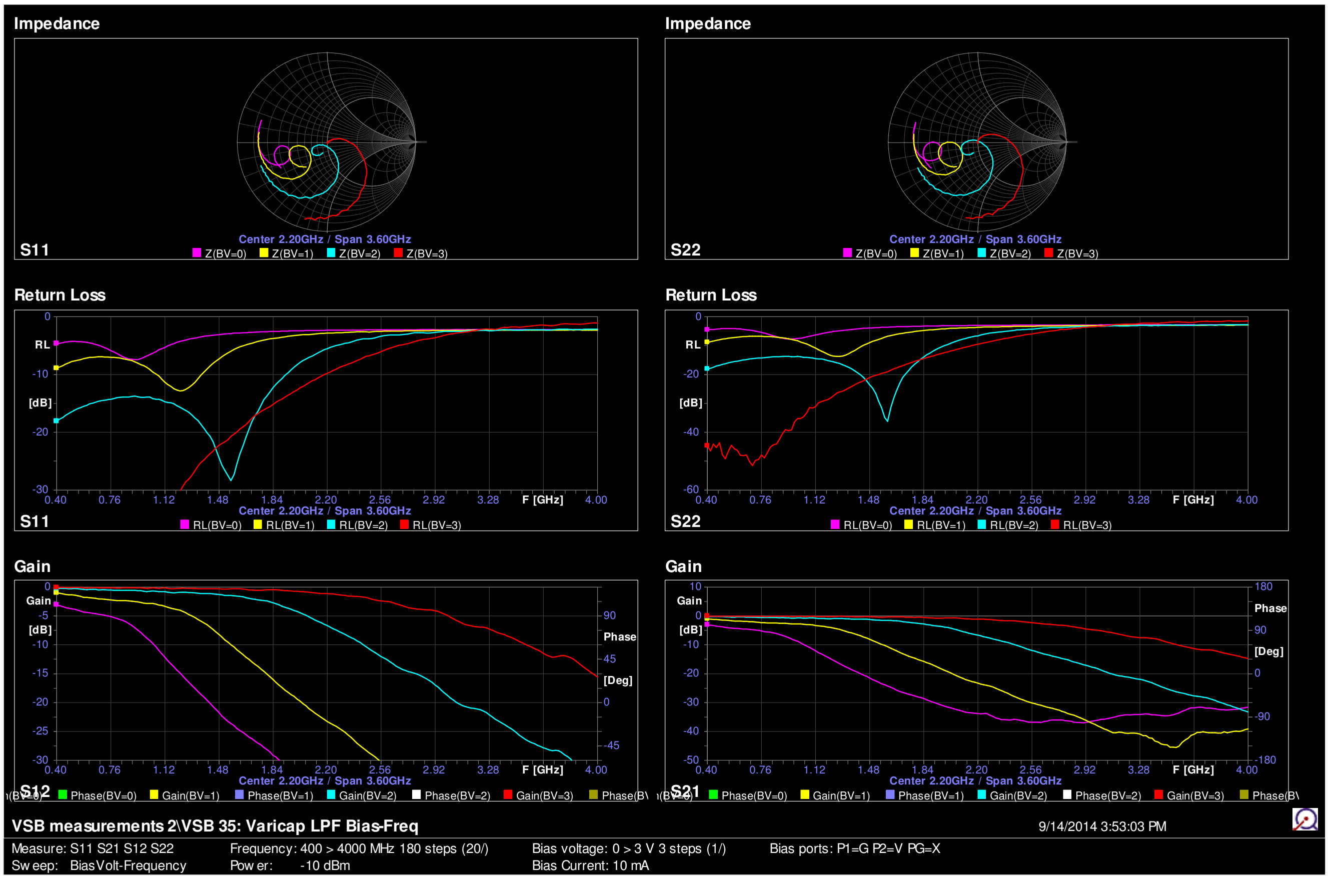
Tunable low pass filter

The Bias Voltage and Current can also be combined with the Frequency sweep to make parametric measurements, like Frequency sweeps while stepping Bias Voltage, or Bias Voltage sweeps while stepping Frequency.

This graph shows a Pi low pass filter with two varactor diodes, at several varactor voltages.



Notice how the impedance in the Smith chart swirls around at different points with different voltages.

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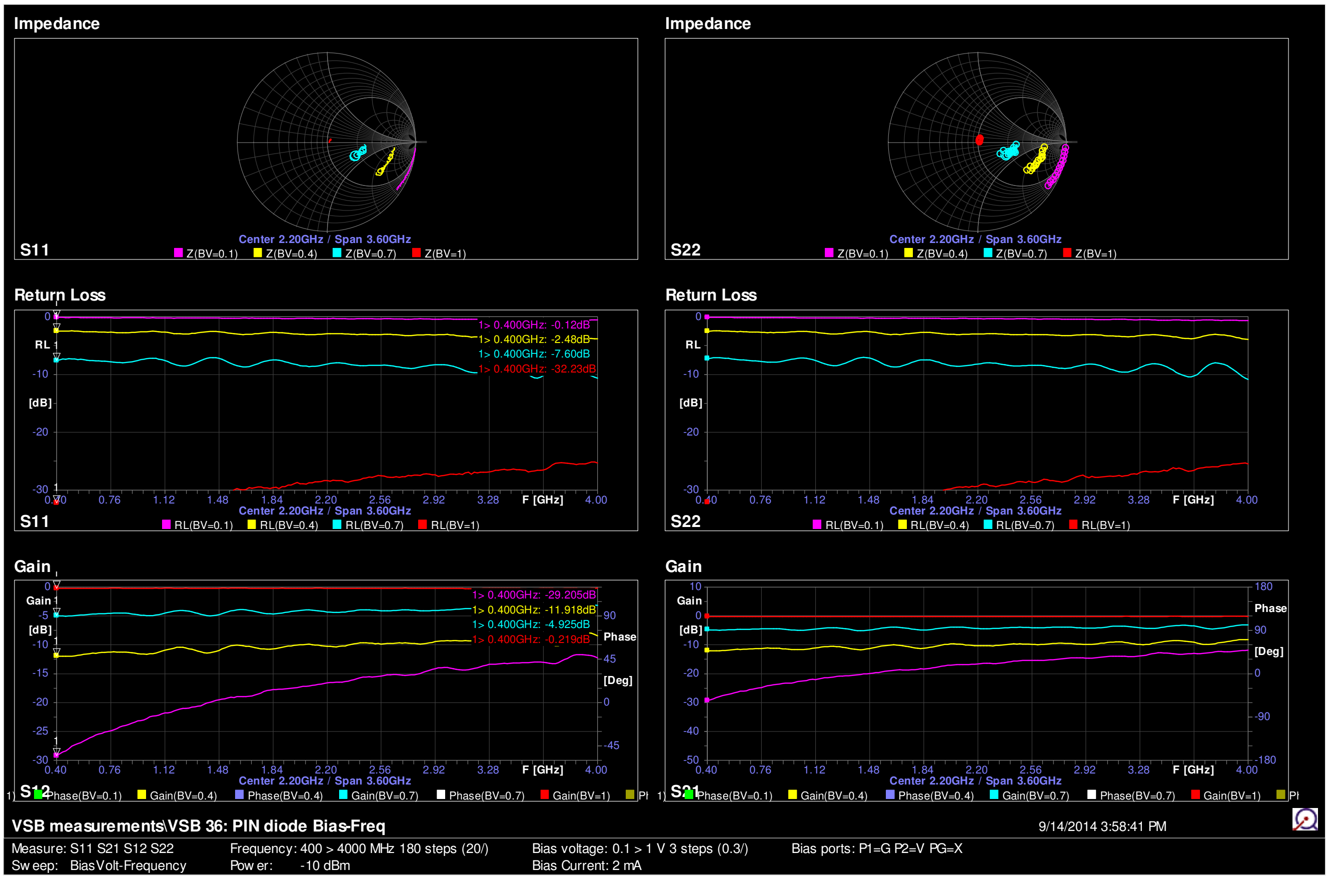
PIN diode Voltage-Frequency sweep

We can make two different parametric sweeps with the bias voltage: Voltage-Frequency sweep and Frequency-Voltage sweep.

This is a Voltage-Frequency sweep of a PIN diode: the VNA0440e sweeps through the frequency range at 4 different bias voltage settings.



At the highest voltage (red traces) the PIN is turned ON and it is a good bypass, connecting the 50 Ohm measuring source directly to the 50 Ohm termination impedance. When the voltage gets lower (towards the purple traces) the PIN becomes a series resistor. The attenuation is highest at the lower frequencies.

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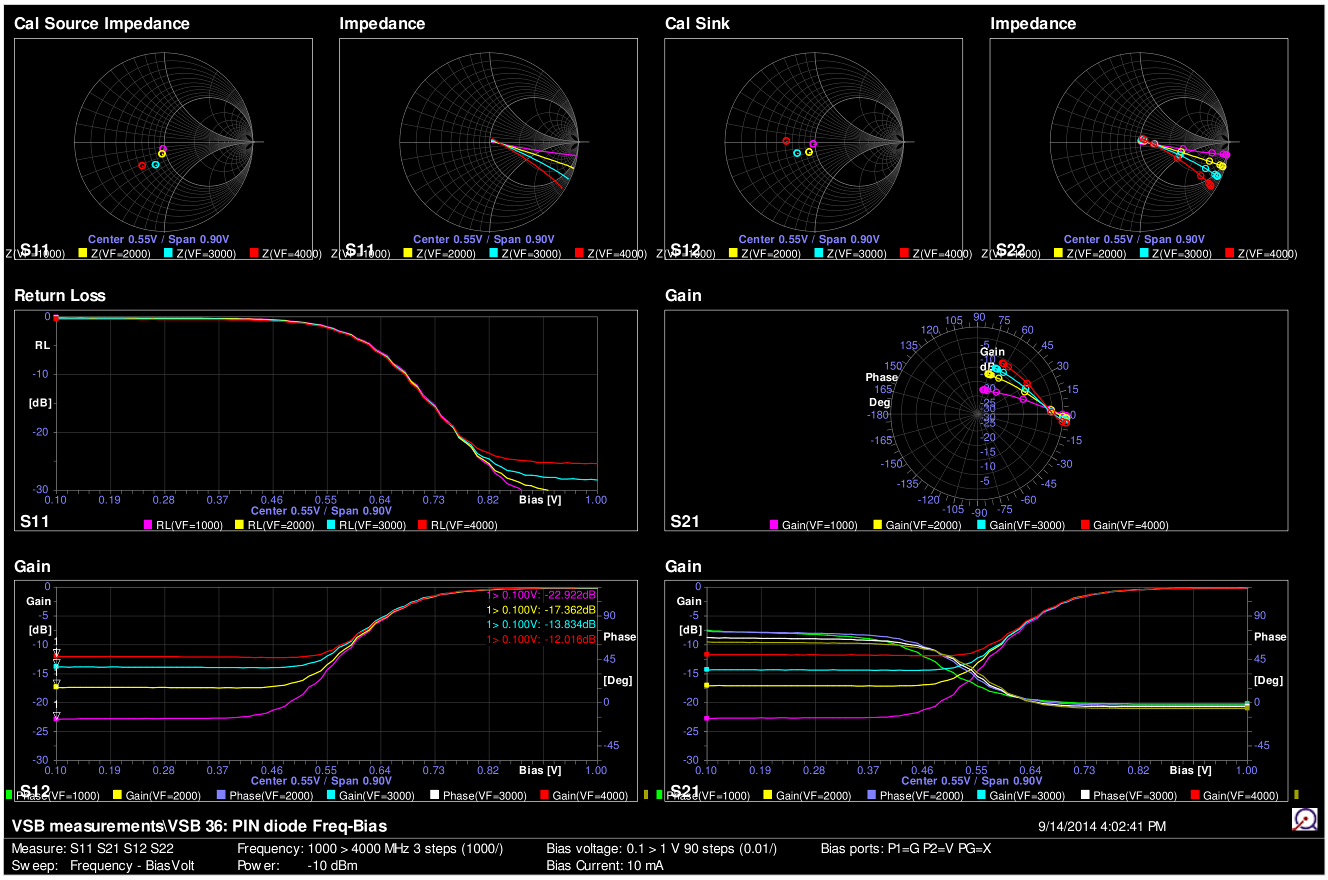
PIN diode Frequency-Voltage sweep

To see the switching behaviour we sweep the bias voltage of the PIN diode at 4 different frequencies: 1, 2, 3 and 4GHz.



We can see how the impedance and attenuation develop over bias voltage, at each of the frequencies.

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