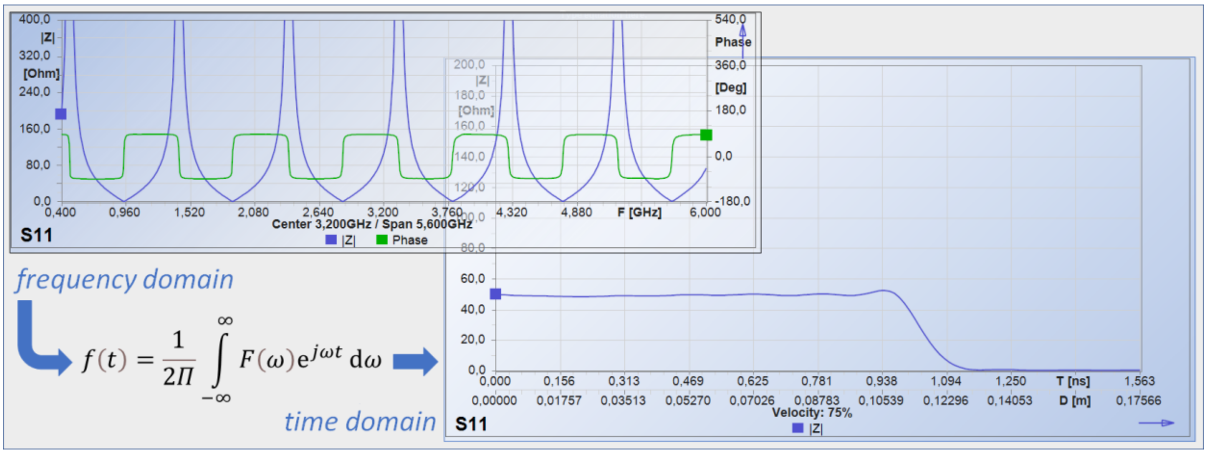
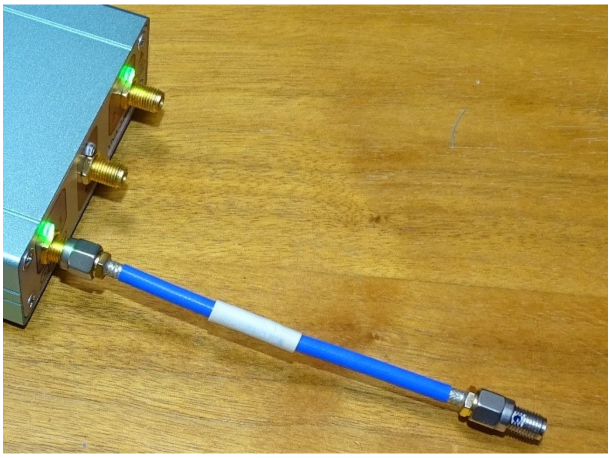
Application of Time Domain Reflectometry



Time Domain Reflectometry (TDR) is a technique that measures and displays the impedance of a network (cable, filter etc) over time. Traditionally this is done with a device that generates very fast pulses and injects them on the network, and measures the time and amplitude of reflected pulses.

This gives information about the impedance as a function of the time it takes to reflect. And, since the signals travel with (nearly) the speed of light, the time can be translated to a distance through a cable.



We can do the same kind of measurement with a VNA but in a roundabout way. A VNA measures the (reflected) impedance over frequency. We can use a Fourier transform to convert this into a series of impedances over time, just as a TDR instrument produces.

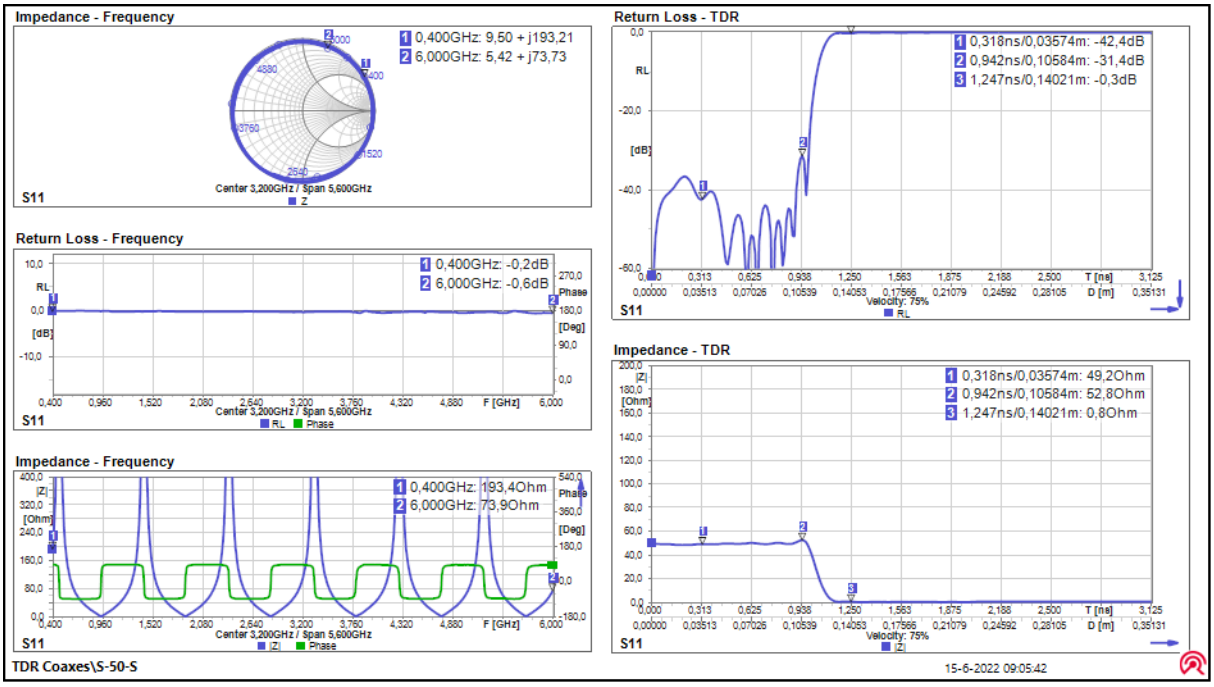
This article describes Frequency and TDR measurements of coax networks and the analysis of PCB trace impedances on a test PCB. These are some of the applications of TDR analysis.

The measurements were done with a MegiQ VNA-0460e Vector Network Analyzer.

A simple TDR measurement

The following graphs show a measurement of a piece of 50 Ohm coax terminated with a Short, as in the picture but with a Short at the end.

These graphs are all different representations of the same S11 measurement on this network:



On the left are three graphs of the Impedance over frequency:

- In the Smith chart the impedance is running circles around the perimiter.
- The Return Loss is almost 0dB because all energy is reflected by the Short at the end.
- In the Impedance graph the impedance varies wildly because the reflected signal off the Short termination adds or subtracts at different frequencies.

It is difficult to say something about the geometry of the network from those frequency graphs.

On the right are two TDR graphs that show the Return Loss and Impedance over time.

- The Return Loss TDR graph shows the Return Loss at different times.
- The Impedance graph shows how the Impedance itself develops over time.

At T = 0 the signal leaves the VNA port. At T = 1ns (marker 2) the signal that is reflected off the Short returns to the VNA port. The signal first travels through the 50 Ohm cable and the impedance then drops to (almost) 0 Ohm of the Short.

In a coax cable, time is distance since the signal travels at nearly the speed of light.

The second horizontal axis (at the bottom) converts the time to the distance in the cable.

The signal travels through the cable with the speed of light, multiplied by a 'Velocity Factor' that depends on the type of cable. This Velocity Factor is normally in the order of 60 to 90 percent of the speed of light, and this setting can be changed for the cable in use.

For Return measurements the distance scale accounts for the round trip of the signal from port to end and back to the port again. So the distance scale is the actual distance from the port to the impedance drop.

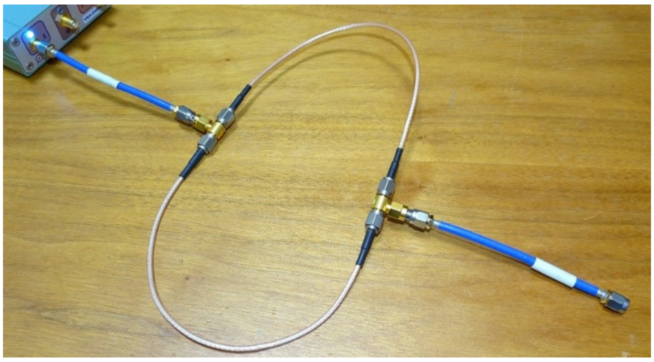
The VNA can, of course, not look beyond the end of the cable but in general it extends the final impedance to the end of the measurement.

The TDR transformation shows the real impedance at different positions in the network. There is no phase information in a TDR signal. This resembles the characteristic impedance of a coax cable, which is also a real number.

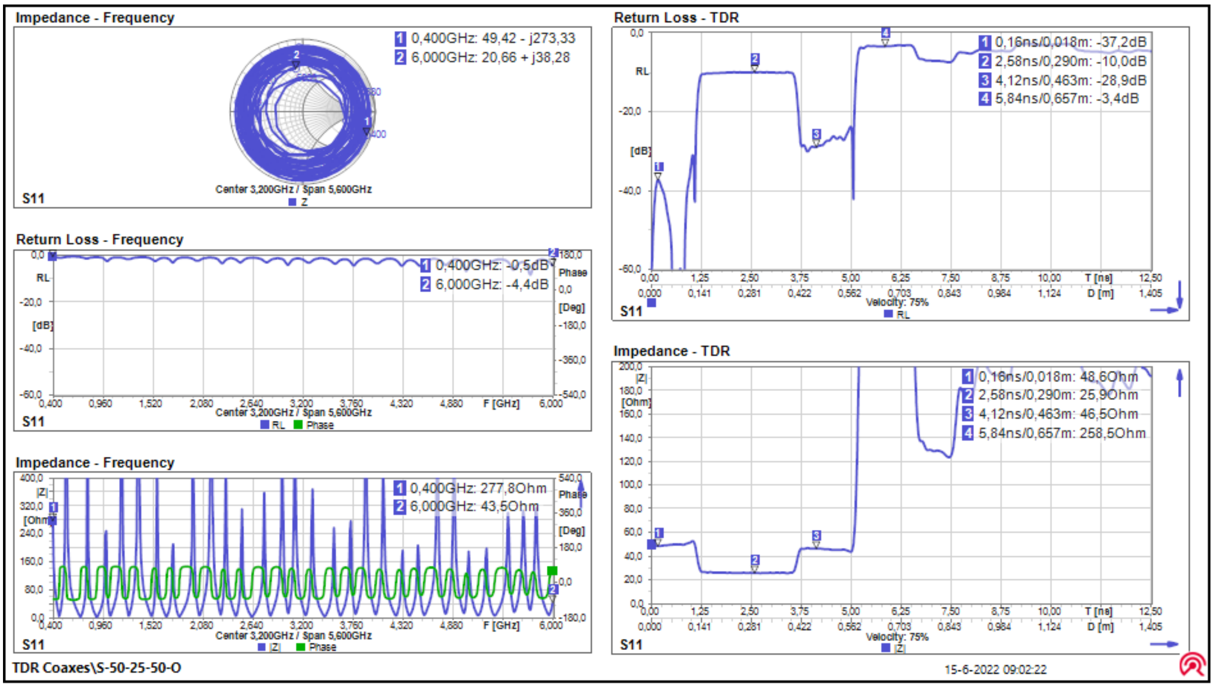
For this reason there is no Smith representation of a TDR signal.

Multiple impedance jumps

We can make a more interesting network with some coax creativity:



The signal travels through a piece of 50 Ohm cable, then through two parallel 50 Ohm cables (forming a 25 Ohm line) and back again to a single cable, ‘terminated’ with an Open.



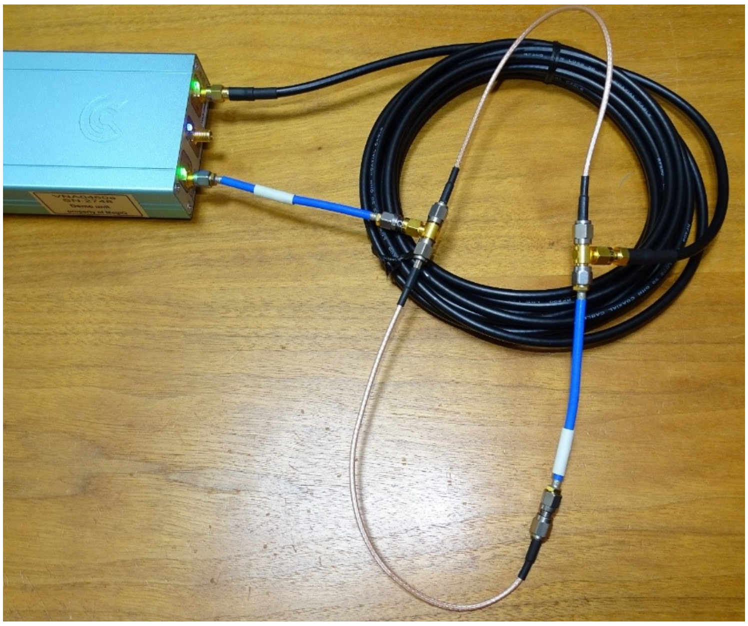
Again, the frequency graphs look spectacular but don’t give much information about the structure of the network.

In the TDR graphs on the right the impedances and jumps are clearly visible. It goes from 50 Ohm to the 25 Ohm of the two parallel cables, back to 50 Ohm and then to a high impedance at the end.

Two port measurement on a long cable

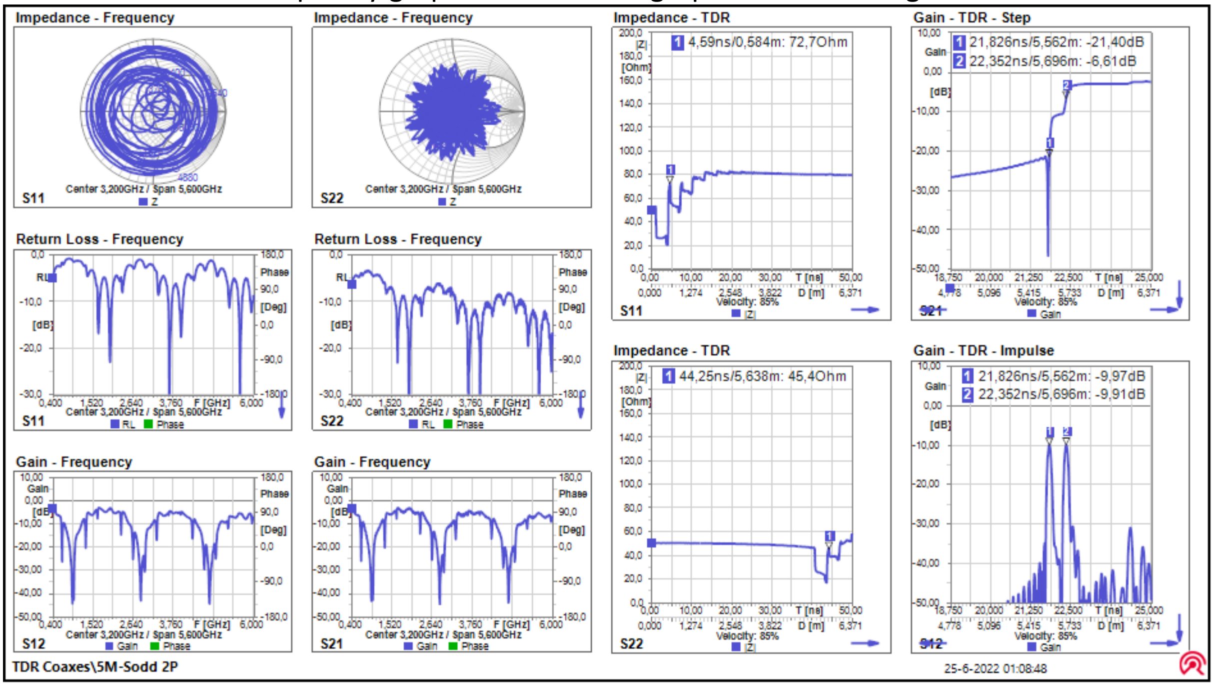
We connect a long 50 Ohm coax to the jumping network from above and do a two-port measurement.

The jumping network is made even more interesting with an additional piece of coax in one arm of the split network:



The ‘far end’ of the network is connected to Port 2 of the VNA so it is terminated with 50 Ohm. For Port 2 this is the ‘near end’.

On the left are the frequency graphs and the TDR graphs are on the right.



The S11 Smith chart on the left looks similar to before. The S22 Smith chart seems to have a better impedance because the mismatch is located at the end of the long coax, which attenuates the reflections.

The Gains S12 and S21 also vary wildly because of all the impedance jumps in the network. Note that the forward and reverse gain (loss) are identical, as there is no directivity in the network.

In the TDR graphs of the impedances S11 and S22 we see that the jumps are near Port 1 and far fom Port 2. The addition of an extra delay in one arm of the split part gives short extra jumps in the TDR impedance (marker 1).

In the TDR graphs of the Gain we see that the signal arrives at the other port after the delay of the network. The top-right graph reveals that the signal arrives in two steps.

This two step arrival is clearer with the Impulse mode of the TDR transorm. There are clearly two peaks in the arrival of the signal at the other end.

The dual peaks are caused by the uneven length of the two arms of the split network part.

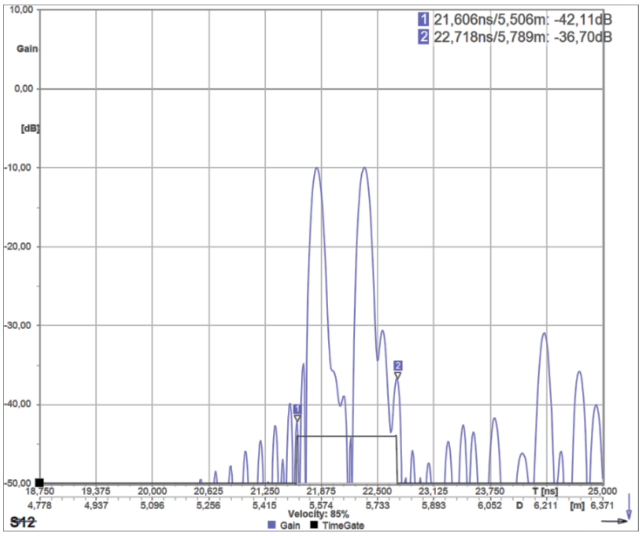
Distance To Fault detection

The TDR mode can also be used for analyzing a (long) cable with a fault.

In the TDR graph it is easy to see if there are impedance jumps, like a short or open in the cable, and how far from the VNA they are. A damaged coax can show a slight or large impedance variation along its length.

It is not necessary to terminate the cable at the far end for Distance To Fault detection.

Time Gating



With the TDR functionality it is possible to 'filter' the gain-frequency graph with a filter in time.

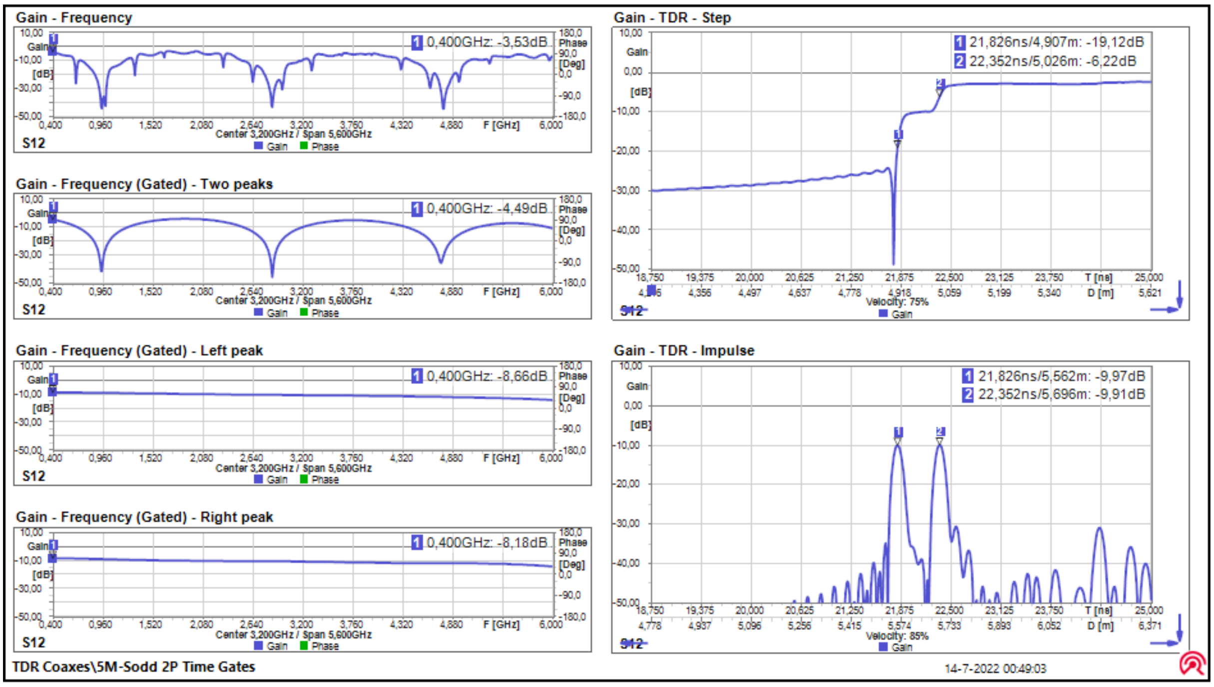
Effectively, the VNA software can do a TDR transformation of the frequency measurement, remove signal components outside (or inside) a certain time range, and then transform the signal back to a frequency graph.

This is called Time Gating.

The screen on the right shows the definition of such a Time Gate on the TDR transformed signal.

Marker 1 and 2 define a time-range and the filter is shown in black.

This screen shows the result of several Time Gates:



Left Top is the original Gain graph.

Next down has a Time Gate around both peaks.

Below that is the gain with a Time Gate around the first peak.

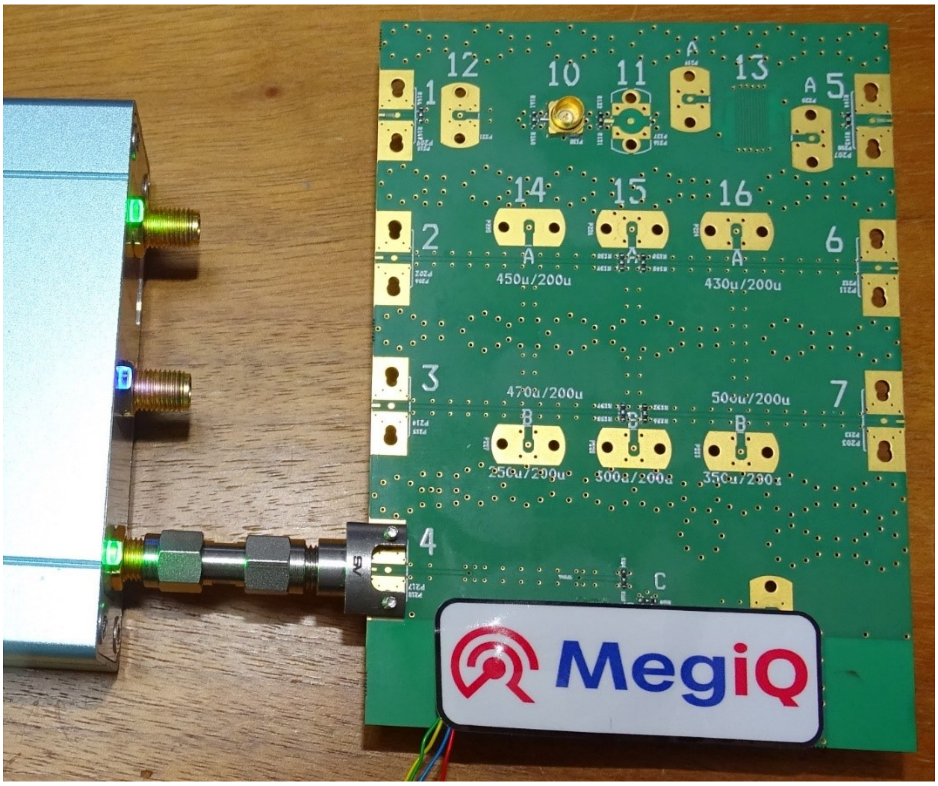
The lowest graph is the gain with a Time Gate around the second peak.

Analyzing PCB traces

We designed a PCB with different CPWG traces and SMA launches to investigate the impedances of these geometries.

The PCB is a 4 layer PCB with a top and bottom core of 254u Isola I-Tera material.

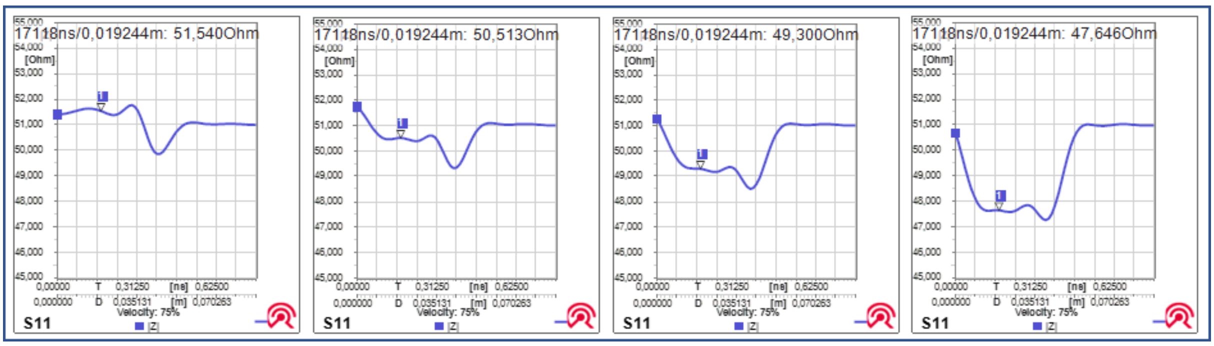
Circuits 2, 3, 6 and 7 are traces with different trace widths and a ground clearance of 200u. They are terminated with 50 Ohm (2 x 100 Ohm) near the center of the PCB.



The SMA connector is a solderless type that we moved to different positions. The SMA was deembedded from the measurements to see the impedances of the traces only.

We used the enhanced TDR mode of the VNA software to get more detail of these relatively short traces.

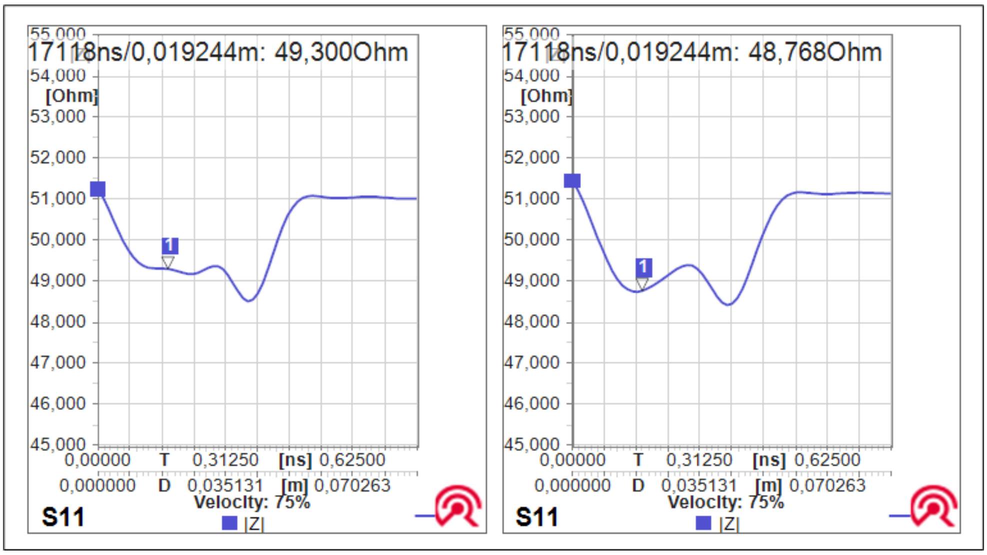
These graphs show the impedance of traces of respectively 430u, 450u, 470u and 500u width.



The impedance dip at the end of the trace is due to the layout of the termination network with a wider footprint that accomodates two resistors.
The Impedance decreases with wider track widths. The track of 450u show the best 50 Ohm match.

The effect of vias

Circuit 4 was made to investigate the effect of vias. It has a trace width of 470u with two vias to jump to the bottom layer and back up again.



These graphs show the impedance of the normal 470u trace (left) next to the impedance of the same trace with 2 vias.

The impedance is very similar to the regular 470u trace, with a slight drop because of the vias. This suggests that the vias have an impedance similar to the 470u trace.

Conclusions

Where regular VNA graphs of network measurements can be confusing or complicated, TDR analysis of these measurements can give a better insight in the physical geometry of a network.

TDR is also useful to get a better insight in local impedance effects of networks.

Time Gating can be used to isolate certain areas in a network for frequency representation.