How to measure very high impedances

A comparison between VNWA in various measuring modes and the VNWA with a RF-IV adaptor.

This article inspired by the problem Jim Brown K9YC had to measure on a couple of toroides into which a coax cable wound. He was not getting same results using the VNWA with RF-IV adaptor and other measurement result and questioned the RF-IV adaptor or the VNWA Software for systematic errors:

Quote:

I've gotten the RF-IV test fixture working and made some measurements in the range of 2-40 MHz, with parallel resonant circuits in the range 3K to 10K ohms, and Qs on the order of 1. Some of my results are inconsistent with careful point-by-point steady state measurements of similar DUTs, and I'm wondering if there might be systematic errors associated with the test fixture of the software?

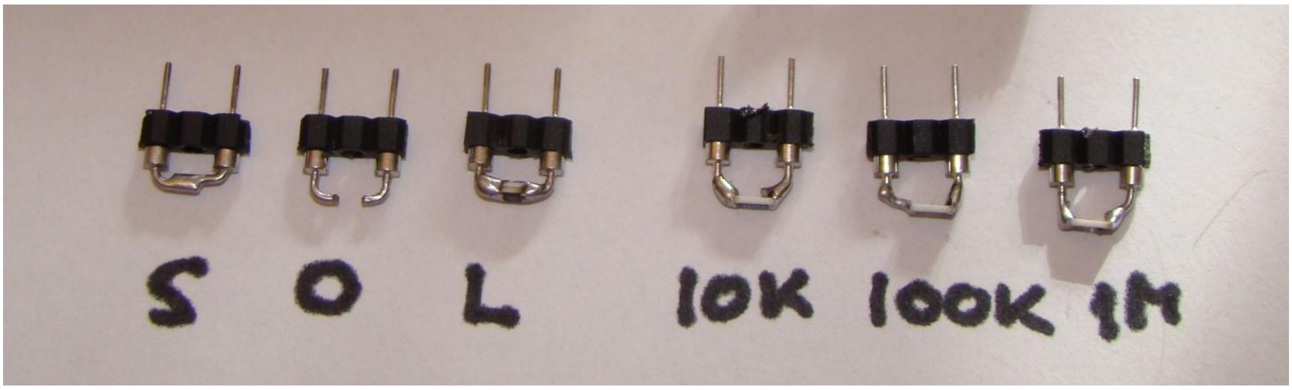
Unquote:

As of my opinion there is no such systematic errors and I have long been aiming of doing a write up on the subject. Below is described with examples which tricks can be used to obtain reliable measuring result and when one can trust the test setup is measuring what you expect to measure ☺

Various Calibration methods:

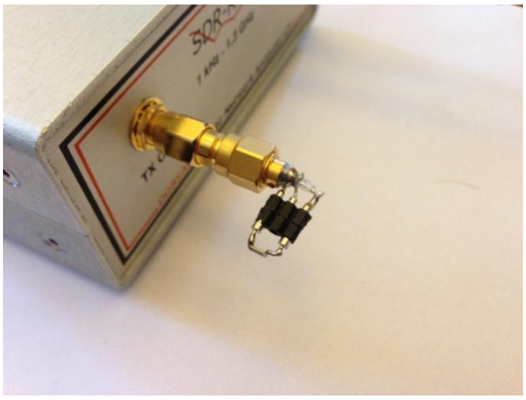
Traditionally "the beginner" calibrate VNWA directly at the TX port with a male calibration Kit and then the problem arises how to connect a devise to test fram now on called a DUT (Device Under Test). A DUT can many different components e.g. a Toroid coil or a SMD component.

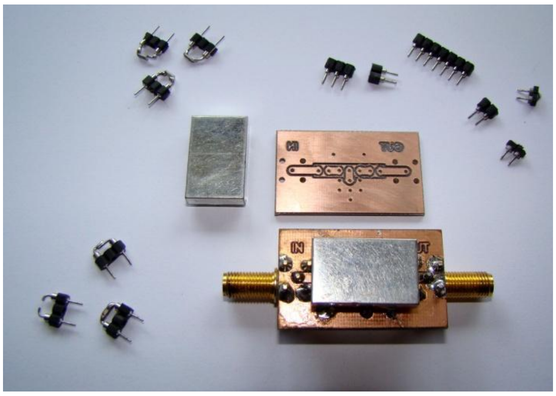
The kit shown is not used in the examples below, but just an illustration. For the examples is used the Amphenol Connex Male Kit consisting of a SMA Male Short and a Male Load obtained from SDR-Kits where the open is just the SMA Female Adaptor non terminated having a delay of 2x2.34pF=-4.67pS to enter in the calibration settings. The Short has a delay of 16.9pS and thus 2x16,9pS=-33.8pS to enter in the calibration setting. The Ampheno Connex SMA Load is 50 Ohm with 1% accuracy. In my case measured to 50.02 ohm but just use 50 ohm.



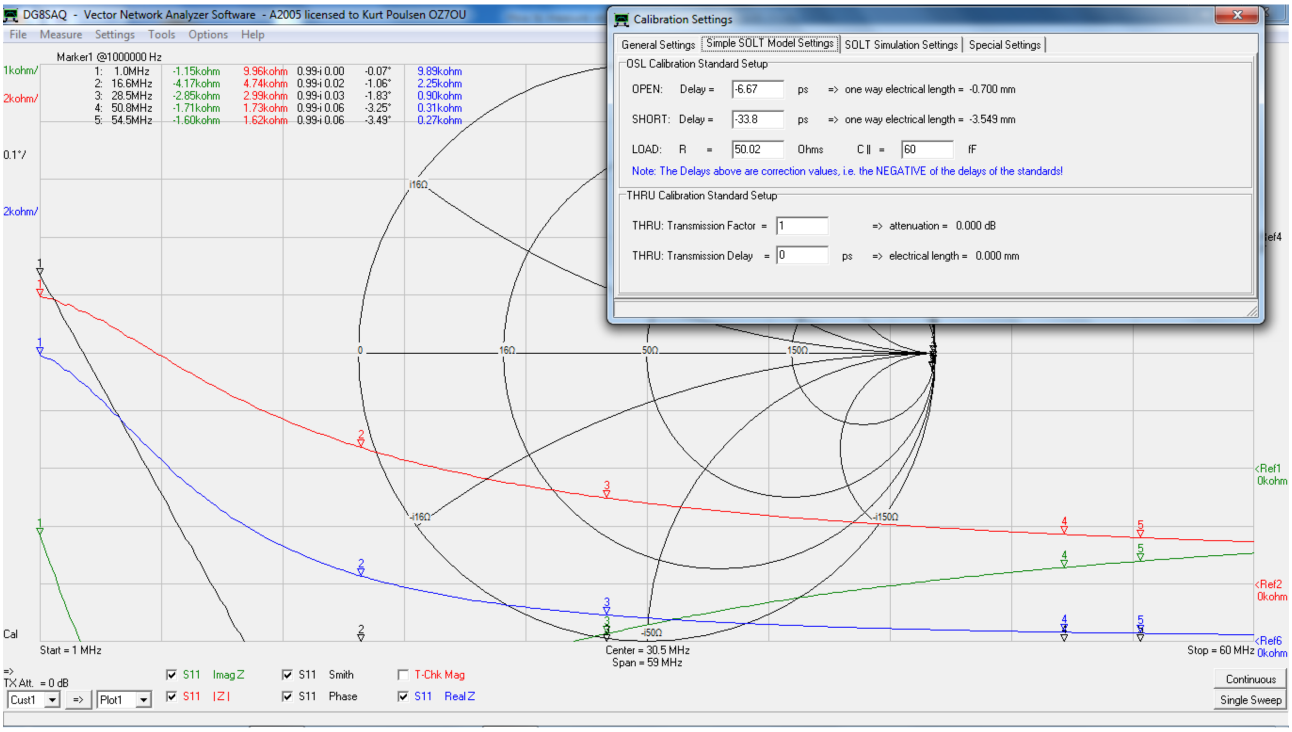
I have found it convenient to use a set of small adaptor which fits into DIL IC sockets and create Short Open and Load standard (SOL) as seen above. The Load consist of 2pc. 100ohm 0.1% SMD resistors soldered on top of each other. Using this method it is virtual possible to connect anything by soldering such an adaptor to the DUT as the calibration point is at the tips of e.g. the Open standard as defined to have 0 pS delay. The short is so "short" that it might as well be defined to be 0 pS long. (it is about 3pS long). Also seen is 3 pc. Test SMD resistors with values of 10Kohm, 100Kohm and 1Mohm to be used for testing and calibration as demonstrated below.

<u>Left below</u> is seen a Test setup where the Calibration with just described SMD Cal-Kit can be performed as soldered to a SMA Male connector, fitted with a very short semi rigid cable, is a 3 pin long DIL Socket terminal row such that SMD Cal kit and DUTs, soldered to the 3 pin long Male Male pin row, can be plugged in.
<u>Right below</u> is seen the parts used for a <u>universal test adaptor</u> based on the same principle which is a versatile unit for all sort of experiments and testing. Amongst such test is very accurate X-TAL testing not covered in this report, and to be seen later also testing of the Toroid earlier mentioned.

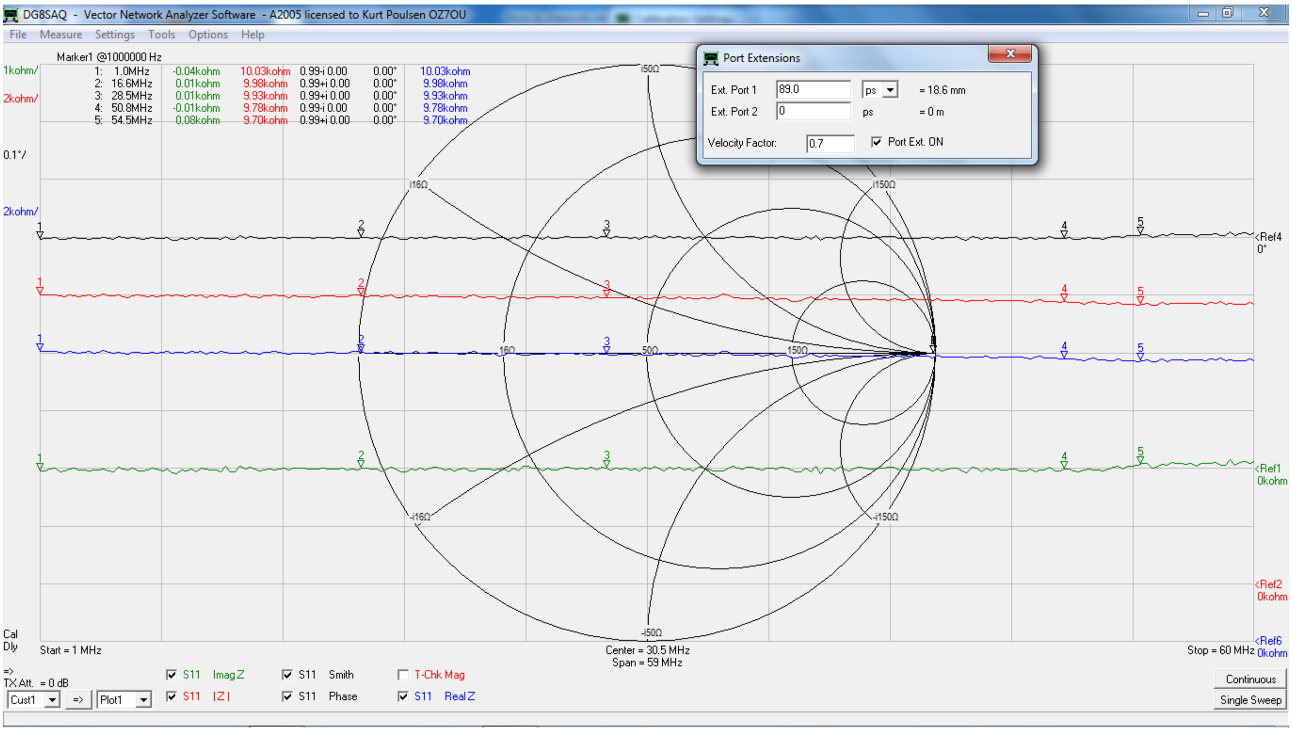




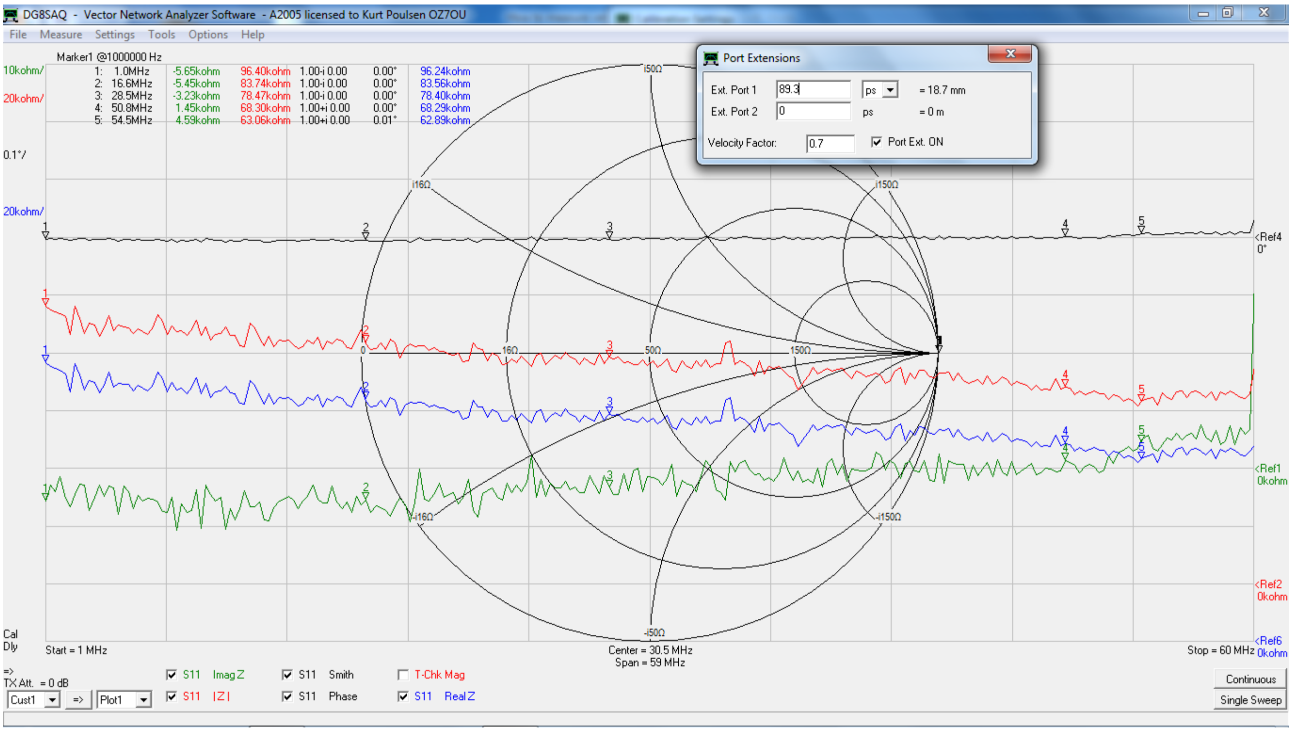
The first test is measurement of a 10Kohm SMD resistor, where the VNWA is calibrated with Amphenol Connex SMD Male Cal kit (Short and Load) with VNWA female TX port as Open standard (se data in the calibration setting in the picture below). The 10Kohm is seen in above left picture and the traces are quite misleading as there is influence from the SMA Male connector, the short Semi Rigid cable and the 3 pin adaptors. We shall now see how to correct for these influences.



Measuring a 10Kohm SMD resistor. We will now use the VNWA function Measure/Port Extensions (Press P) and trim Ext. Port1 until a S11 Phase Trace with 0.1degree/division (reference 0 degree at 7 divisions) is showing 0 degree (horizontal line) That is indicating we are measuring the pure resistive part

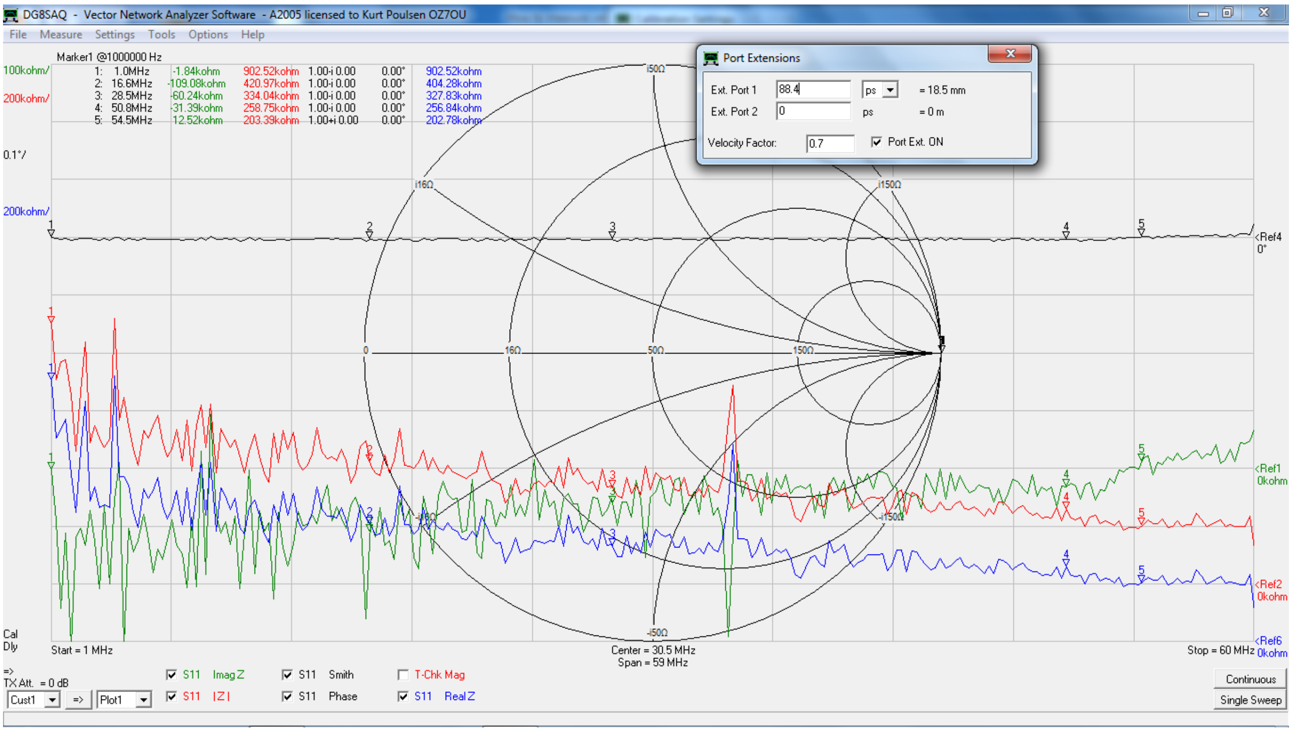


Measurement of the SMD 10Kohm Resistor with Port1 delay of 89.0pS . It can be seen the imaginary part ImagZ also is Zero across the frequency Span of interest (here 1 to 60MHz). The resistance measured fairly accurate to a drop off of 3% at 60MHz.



Measurement of the 100Kohm SMD resistor. The delay required delay now 89.3pS partly due to a fractional higher mounting, a little more solder used. The substrate capacitance might also be higher. All these small contribution is very easily observed as the VNWA is extremely accurate with respect to phase measurements and by all means a delicate instrument. The 100 Kohm resistor is dropping of more rapidly toward 60MHz (around 70Kohm) and in general the VNWA bridge cannot measure very accurate as its accuracy is highest around 50 ohm. However within less than 5% at 1 MHz. On the Smith Chart the resistor si simply indicated as Open on the horizontal line to the extreme right.

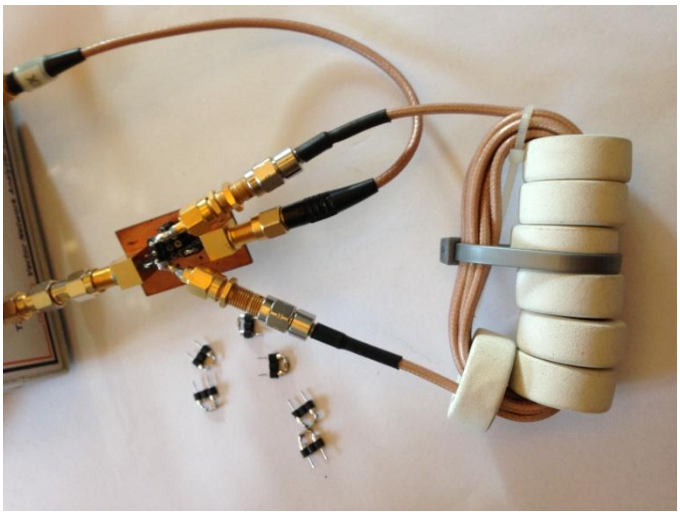
Below is shown the measurement for the 1Mohm SMD resistor.

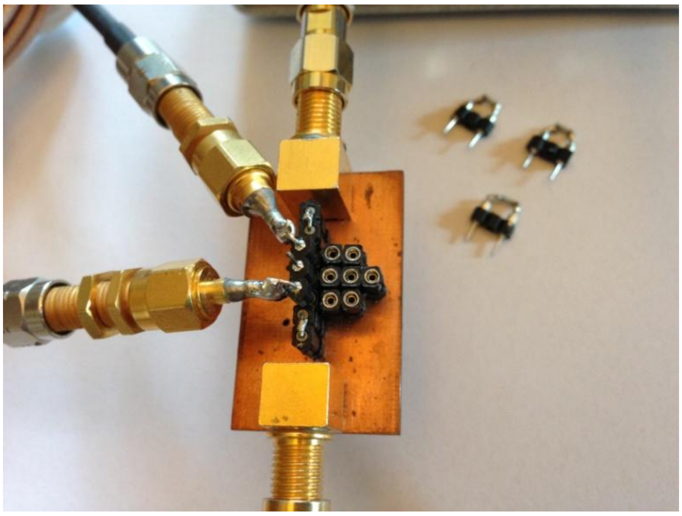


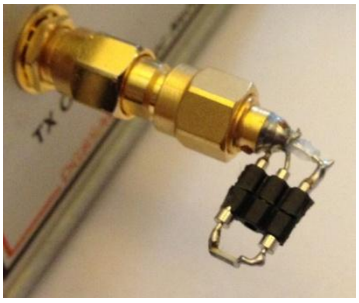
The measurements for the 1Mohm resistor demonstrates clearly that only at very low frequency the value are with around 10% and only 20% of the value at 60MHz. Whether the resistor really is 1Mohm at 60MHz is not known and a good question.

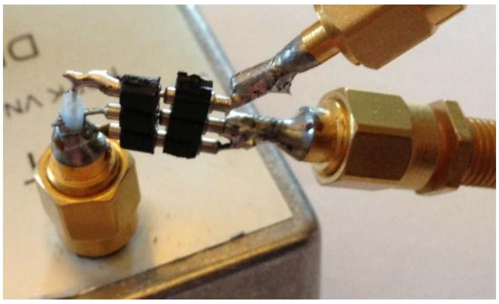
Now to some real measurement on a Toroid DUT.

Below left is seen the DUT which is similar to the "troubling DUT" of Jim Brown K9YC. However the ferrite material is far from that of Jim's but the surprises to be found below are identical. The aim is to measure the Q values for the coax windings throught the toroid's, measured from Screen to Screen (the inner conductor may be left open or shorted to screen as not having any impact on the measurements). The DUT is here fitted into the Universal adaptor. On the left picture in across the TX port (the normal way or also called method 1) and on the right picture in series from TX to RX port also called method 2.

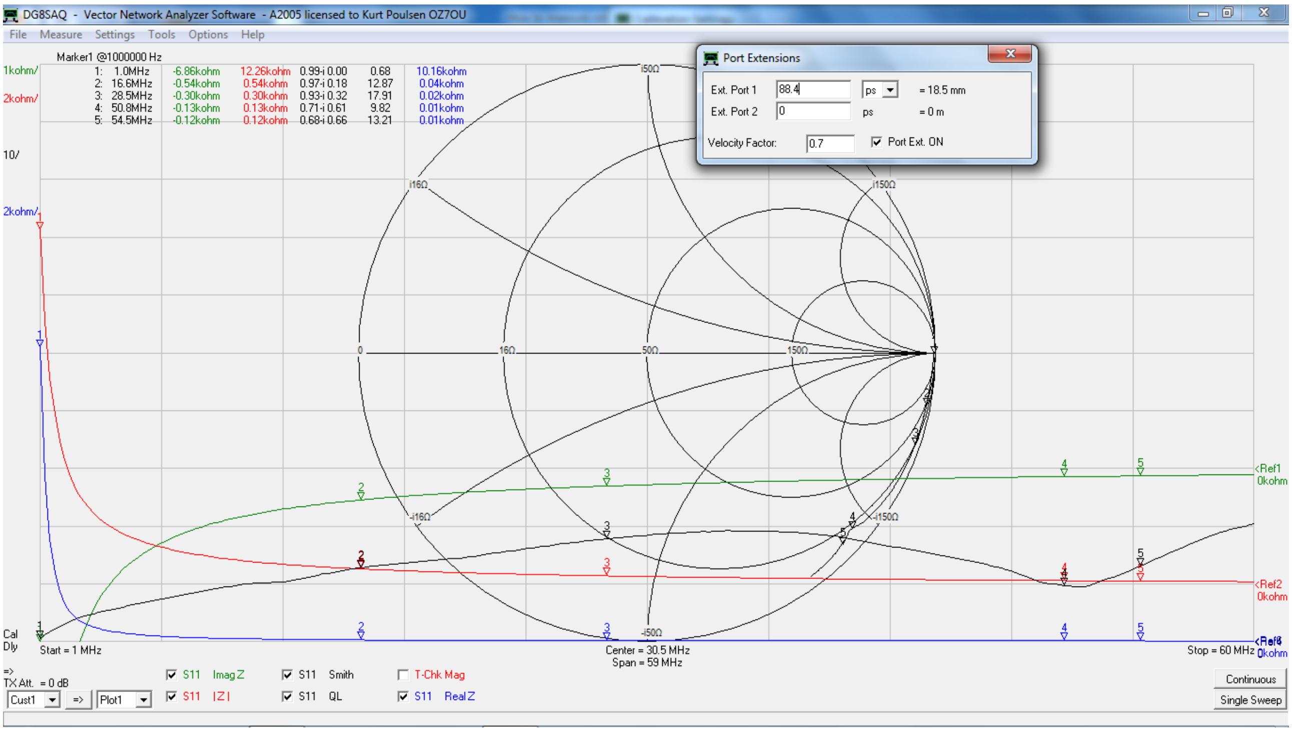




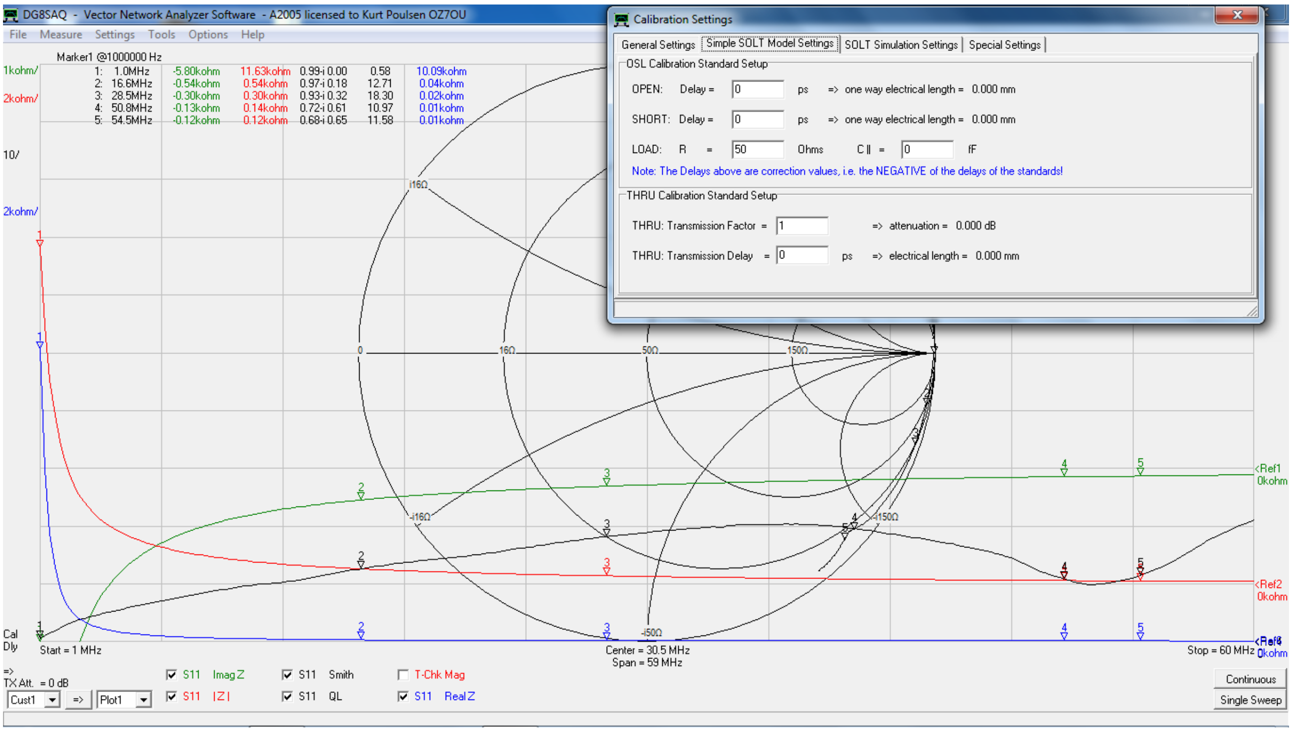




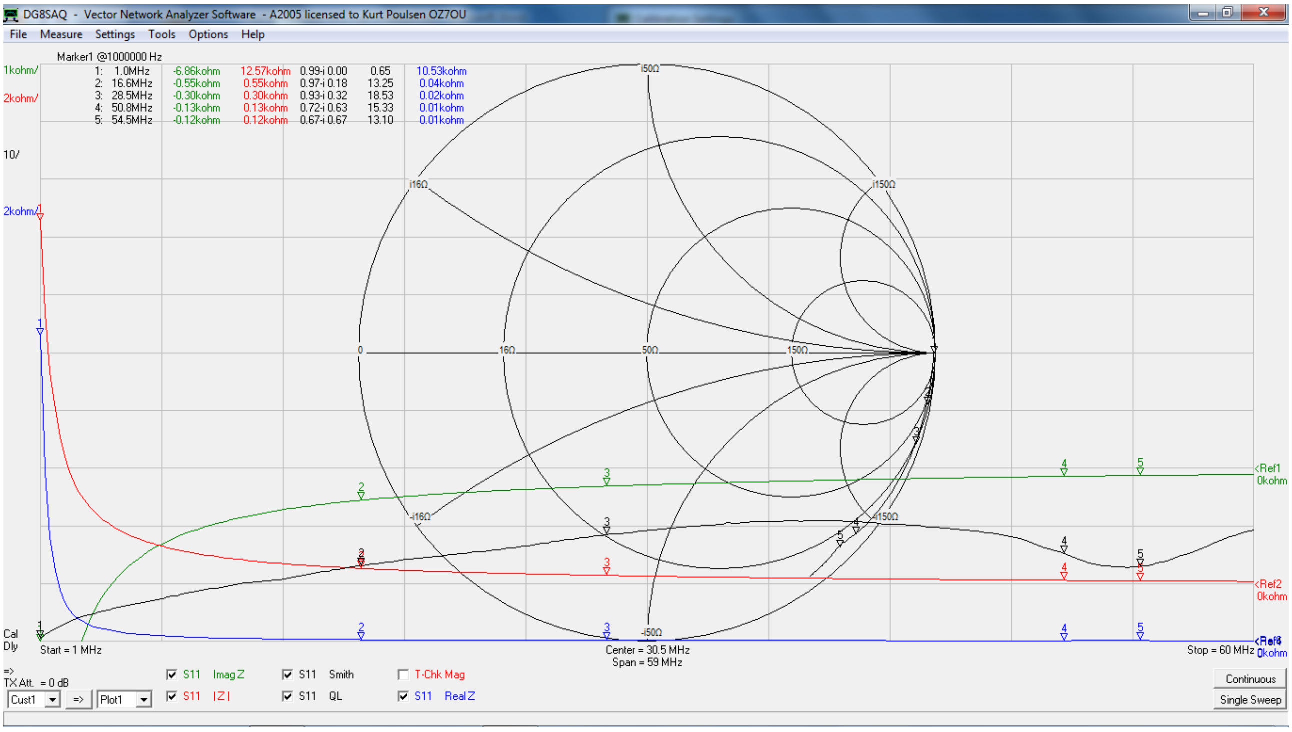
The first Toroid measurement will be done with the VNWA calibrated to the TX ports SMA Female Connector, just as it was done for the previous 3 SMD Resistor measurements. The right picture is for the RF-IV measurement but done identical for below measurements.



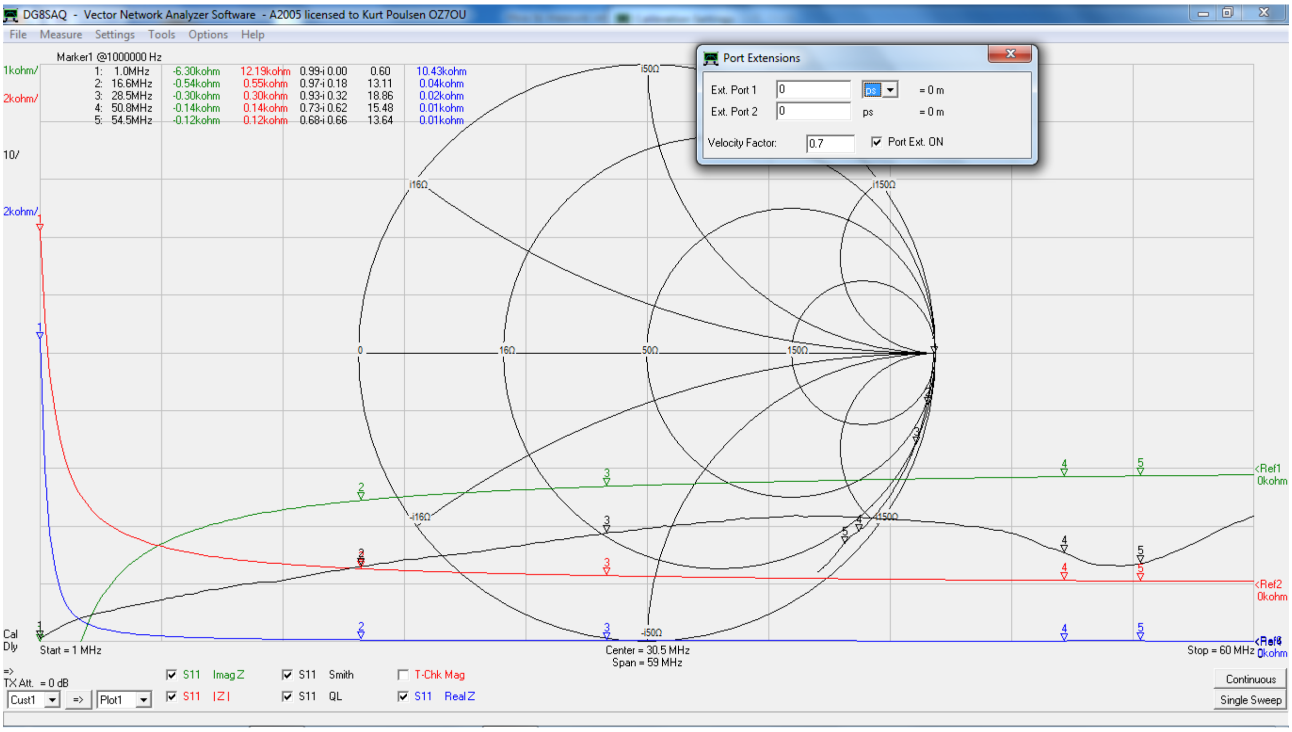
The Black trace is the Q values and it seem like there exist a resonance dip at marker 4. Can we trust that is true ??



But moving the Coil slightly the dip goes up in frequency. Before we further investigate let see if a calibration with the SMD Cal-Kit does change anything.

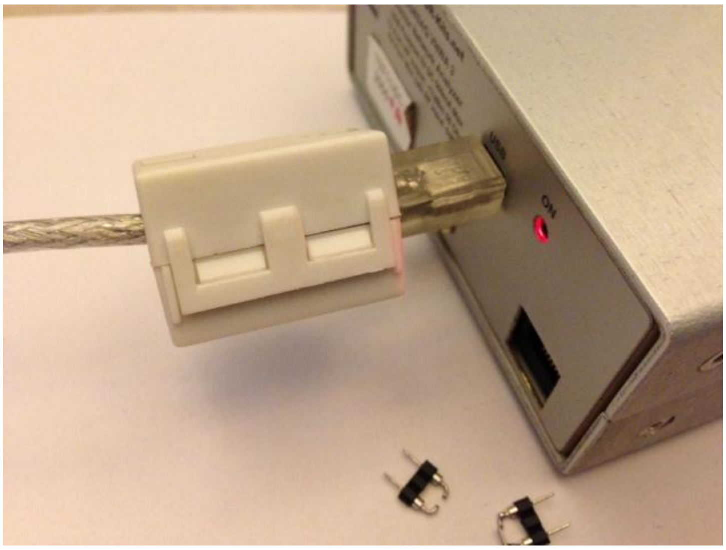


Using SMD Cal Kit to calibrate. Delay = 0pS. Below center frequency 30.5MHz reading are fairly stable and identical but the dip is shifting again…

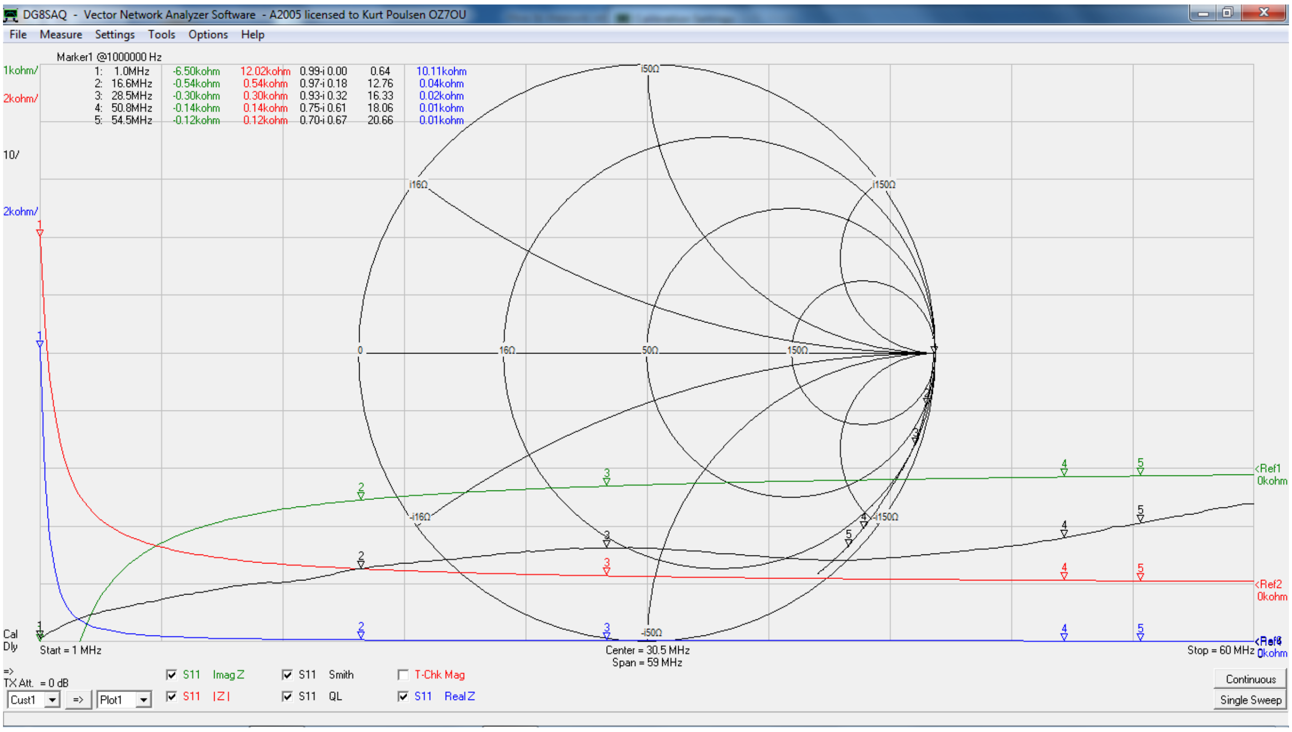


This measurement when the Toroid's is lifted with a long with wooden stick. The Q dip is moved…and value at 60MHz higher. This instability indicates "something is mutually coupling".

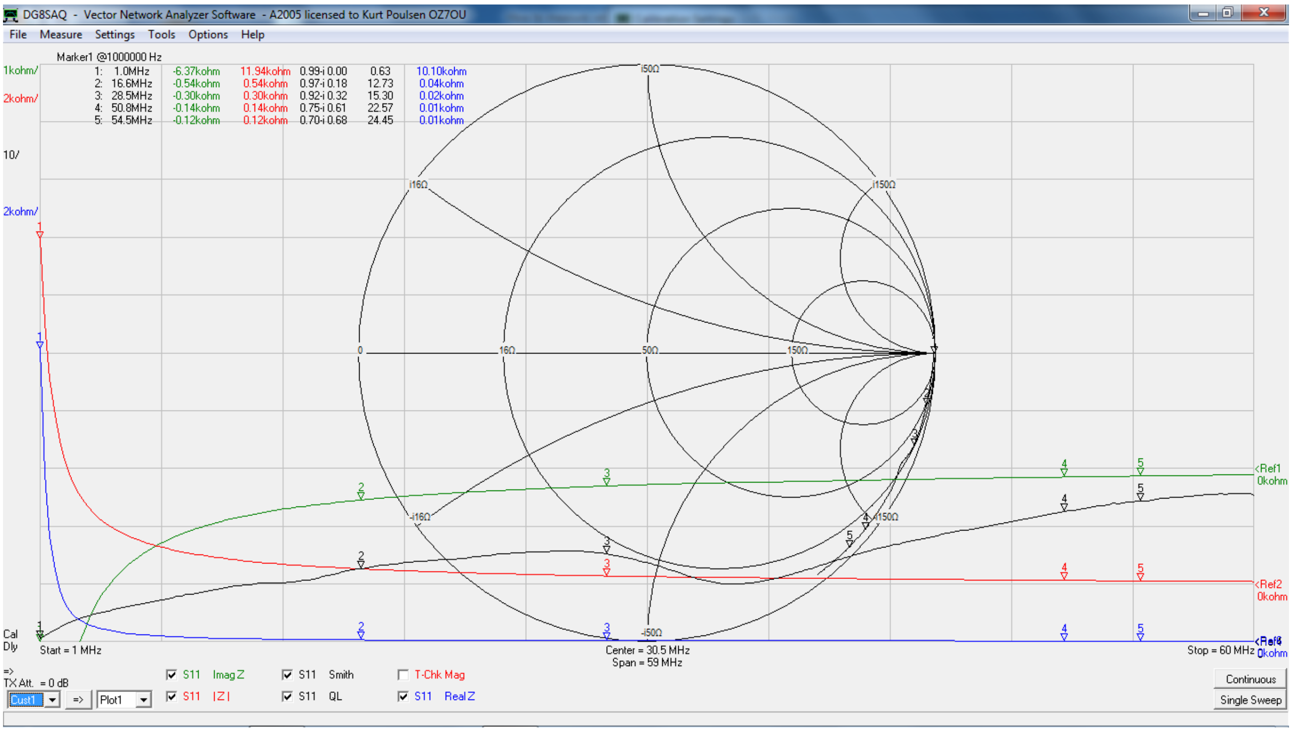
An Toroid Clamp inserted over the USB Cable



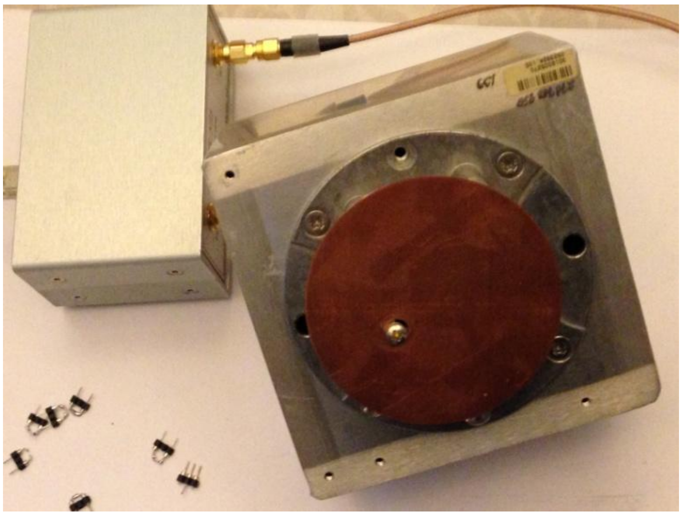
The suspicion to mutual Coupling is based on previous experiance with measurements on small and high Q coils. The reason is simply that the VNWA is a transmitter sitting in the center of an “antenna system” where the USB cable is the “left side” radiator and the DUT is the Right side radiator. It the DUT by any mean can radiate and the field been picked up by the USB cable (and the control cable for e.g. the RF-IV adaptor) the the measurements is distorted. It is most likely and primarily the electrostatic field which is causing this coupling.

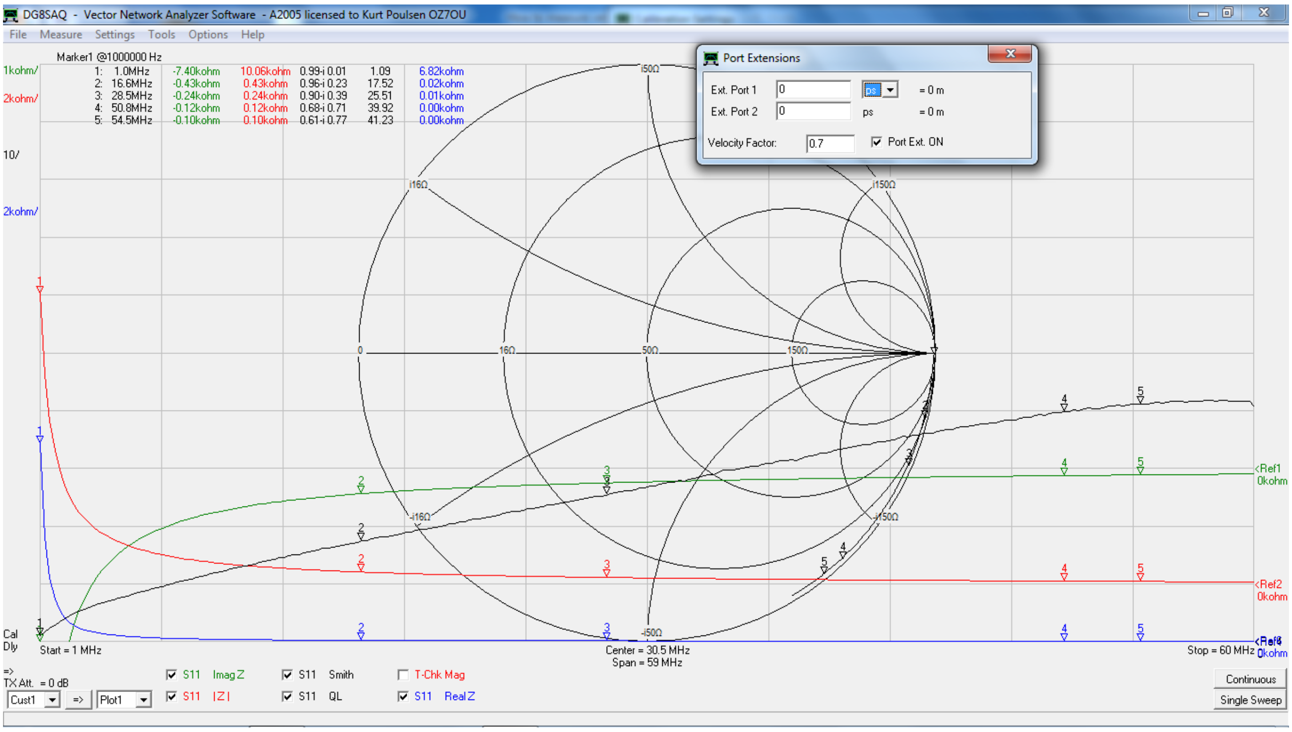


RF Choke clamped on USB cable. The Q dip is now moved downwards quite considerable.

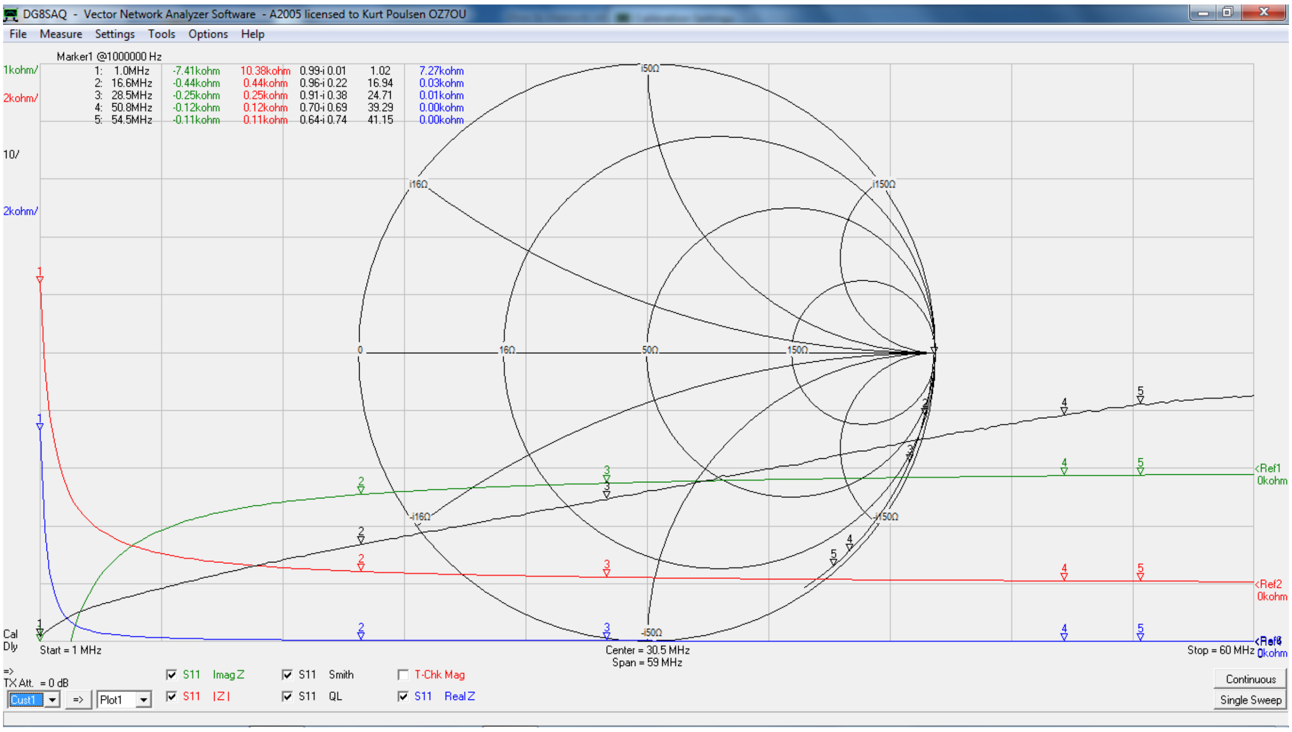


1 extra winding of the USB cable through the RF Clamp and the dip is changing again.
Now the DT is brough inside a Aluminium box with a SMA connect in the center of the buttom. Calbration doen with the SMA Cal-Kit inside the Box and thus identical calibrated measurements is done as before. Measuremetns done with and without the lid.





Open Lid

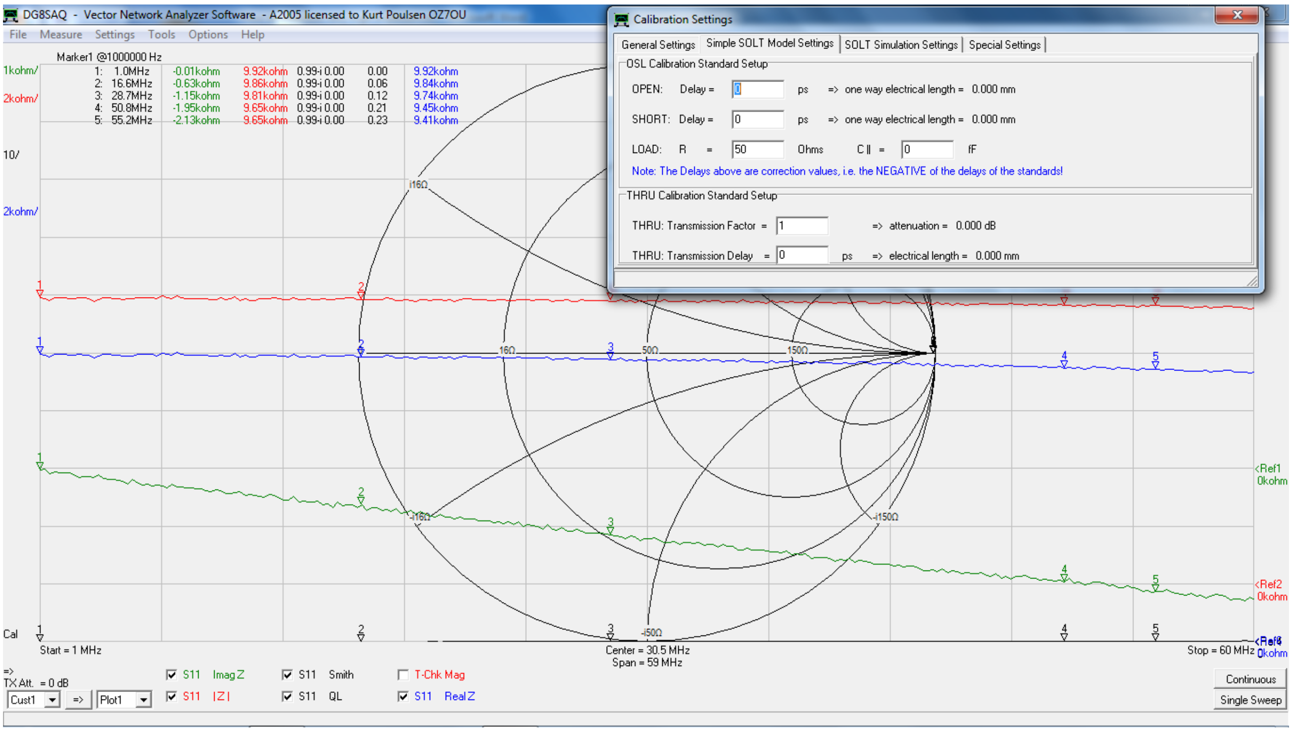


Closed lid.

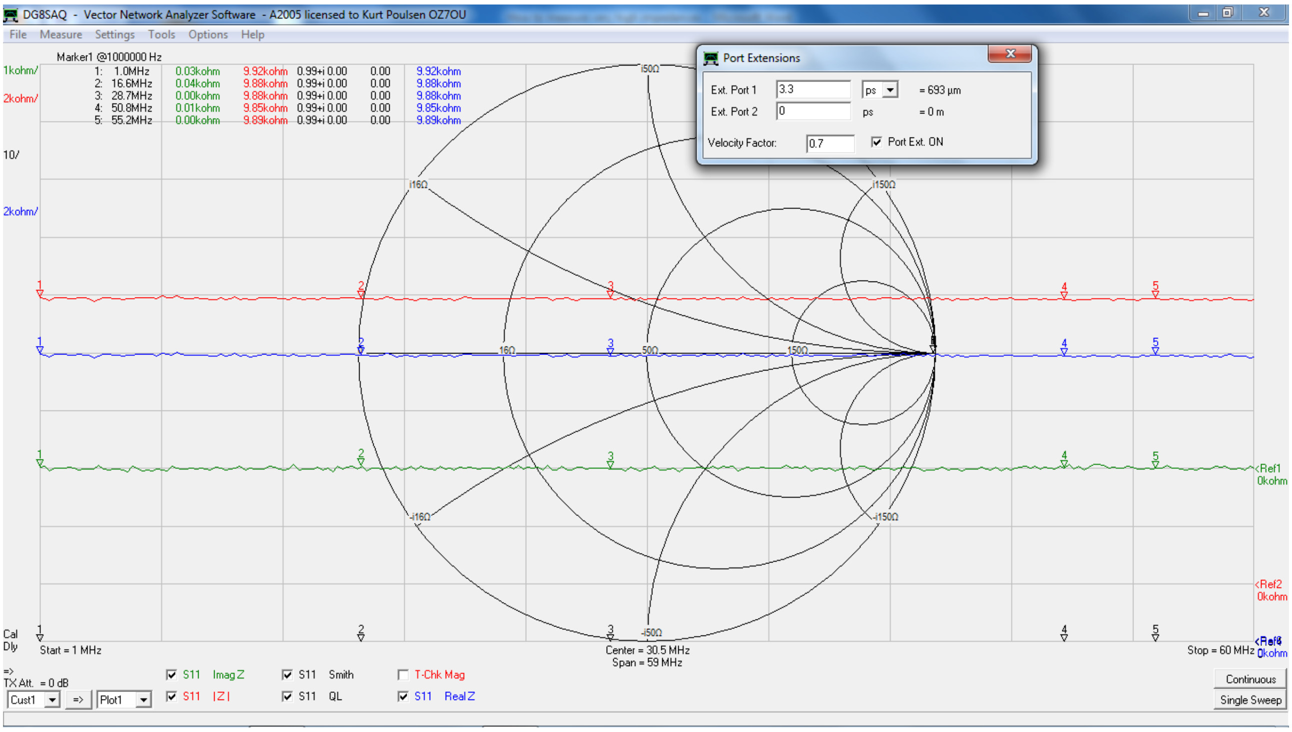
Thus the true Q values is measured for the DUT and being the same with and without the lid.

Case solved……………………………….

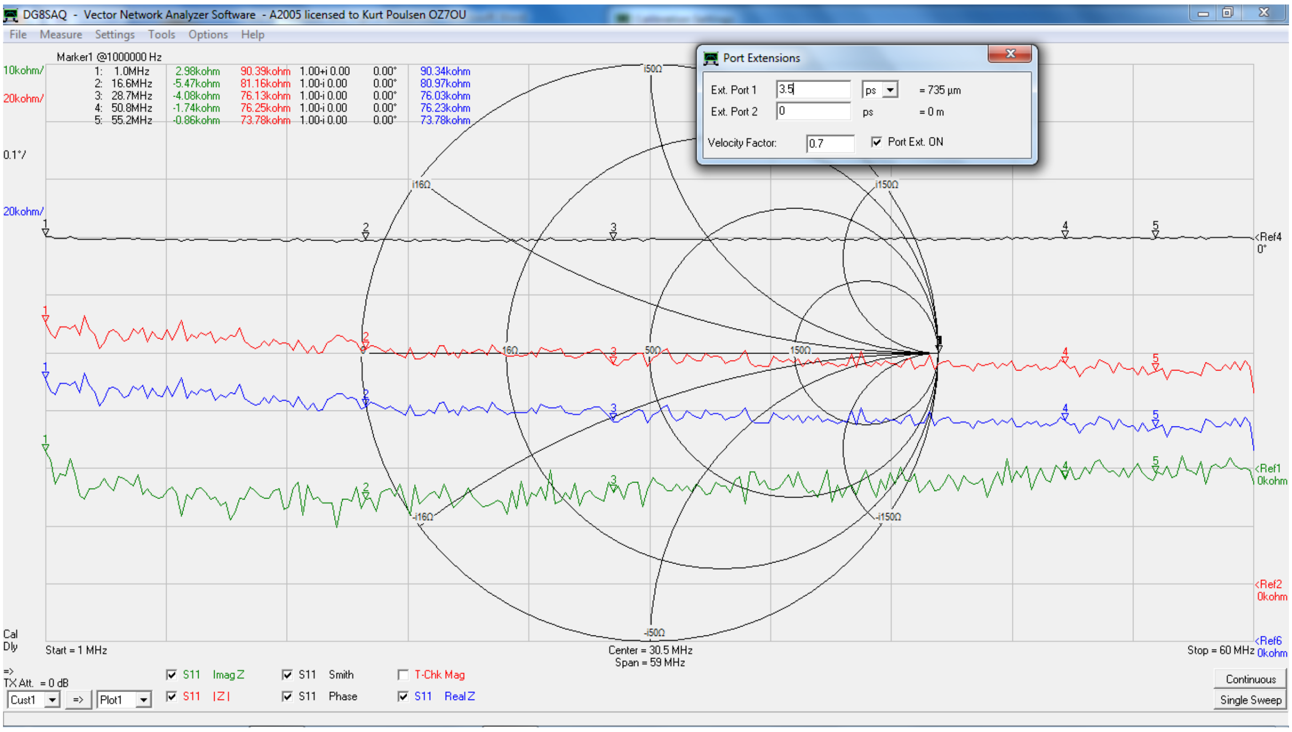
What about method 2 and high impedance measurements in addition to Q measurements ??
Calibration is done by using the universal adaptor and placing the SMD Cal - Kit in the series position from TX port to RX port. Remember to do a S21 Thru and Thru Match calibration as well using the Short SMA adaptor.



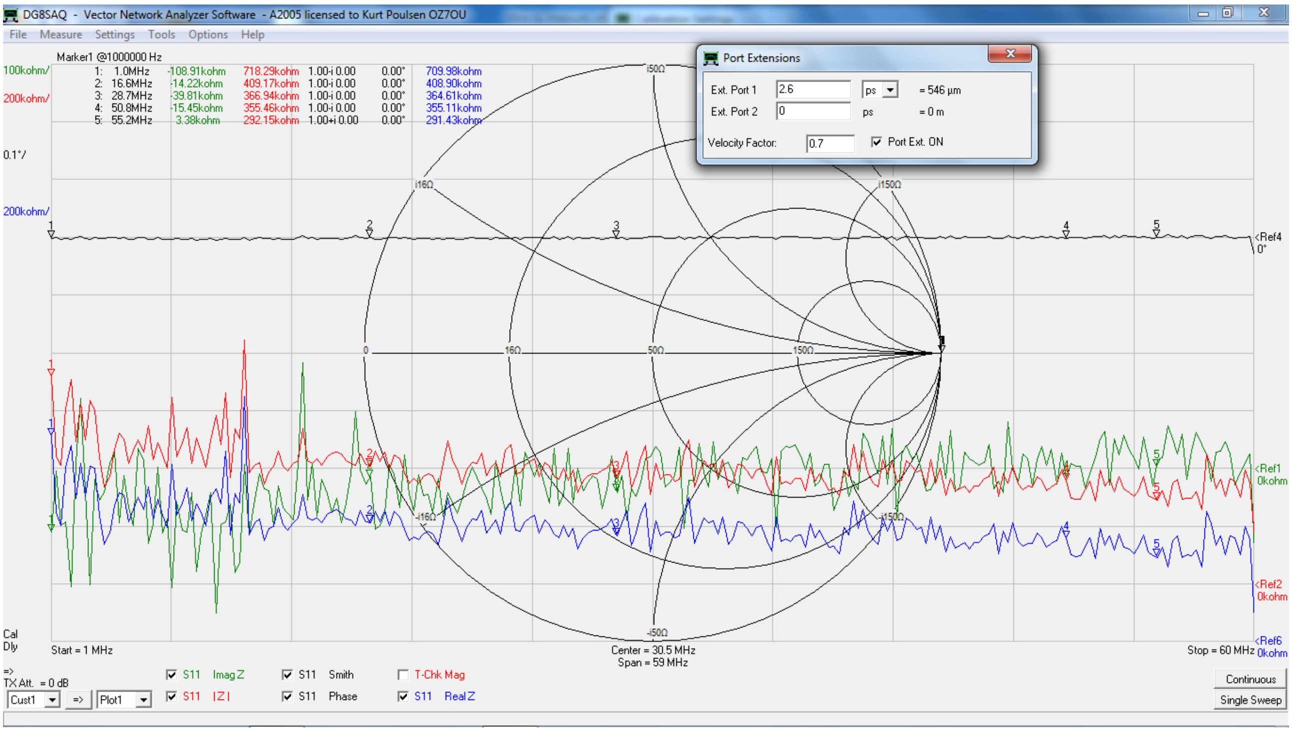
Measurement of the 10 Kohm SMD resistor without any Ext.Port1 delay. See the calibration settings above



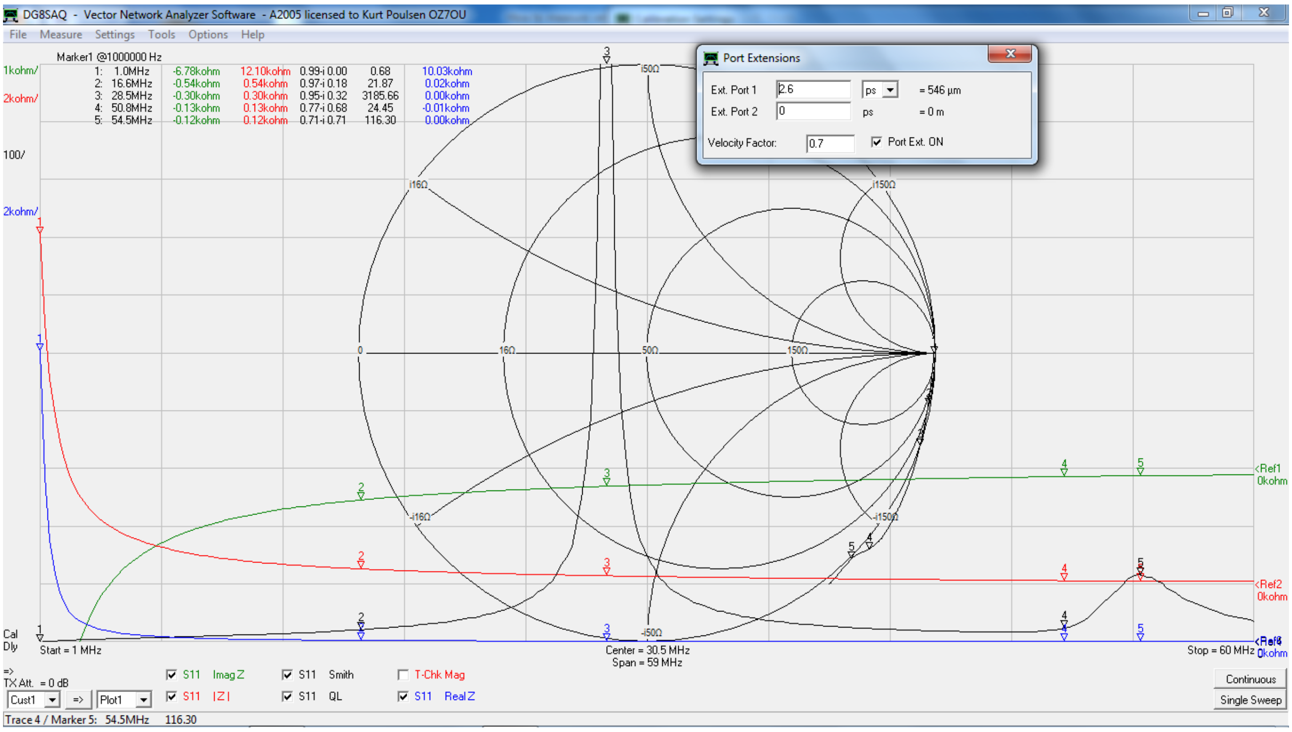
Measurement/Port Extension/ext. Port1 enabled and the 3.3pS represent the additional parasitic capacitances. Accuracy within 1% to 60MHz.



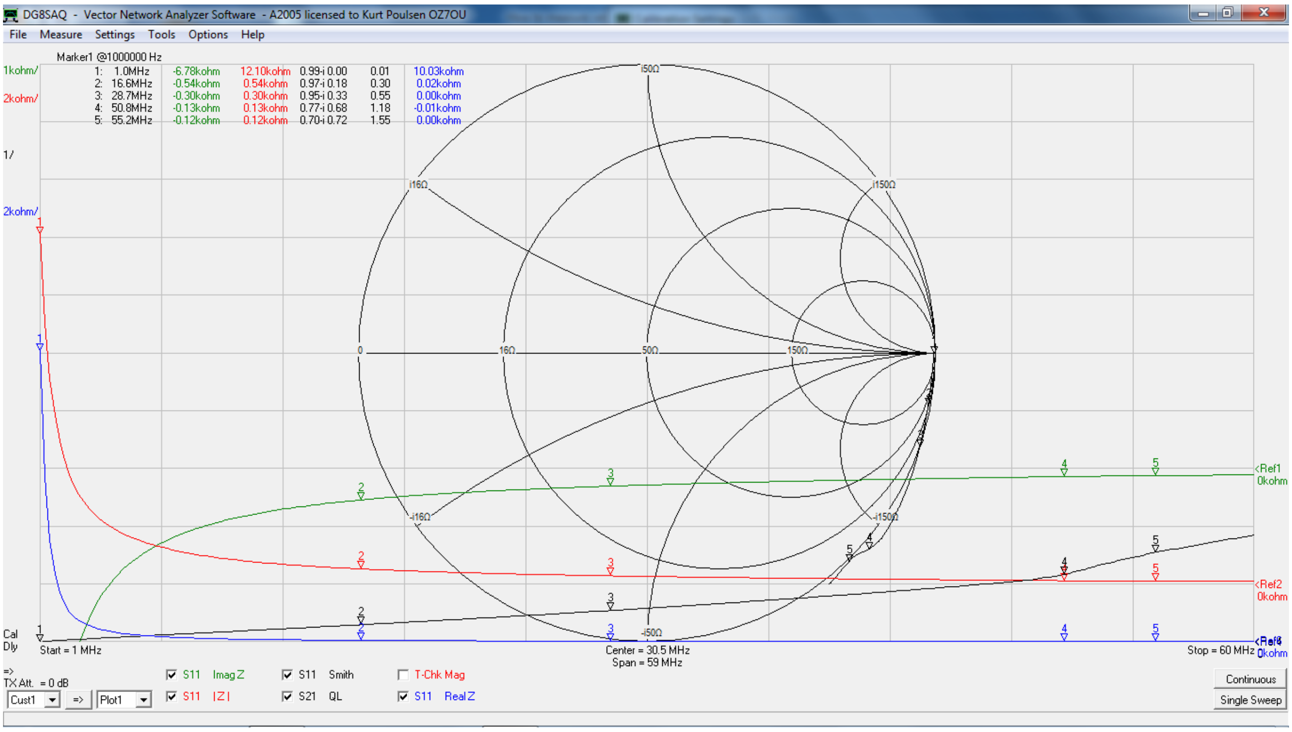
Measurements of the 100Kohm SMD resistor and by comparing to the measurement of Method 1 a much flatter trajectory of |Z|, ImagZ and RealZ



Measurements of the 1Mohm SMD resistor shows the same shortcoming as for method1

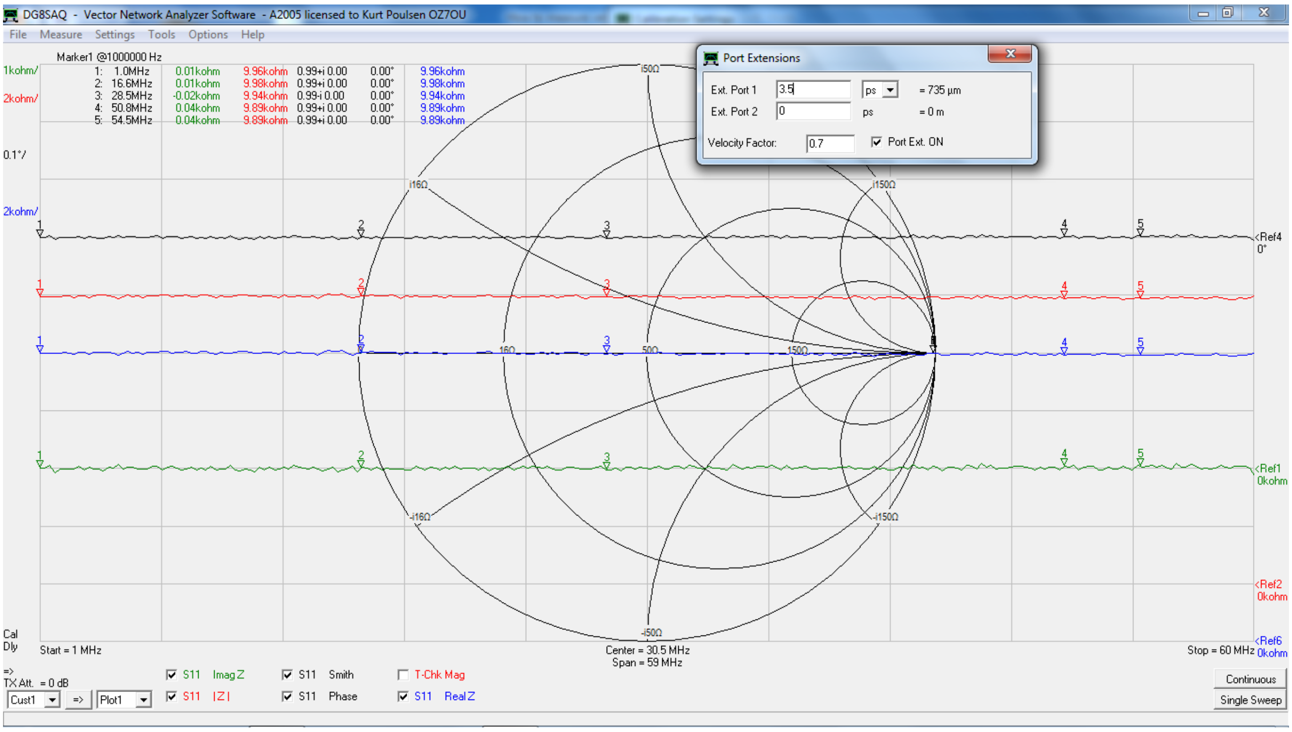


Enabling a S11 Q trace is giving wrong data as it is not a tradition S11 reflect measurement.

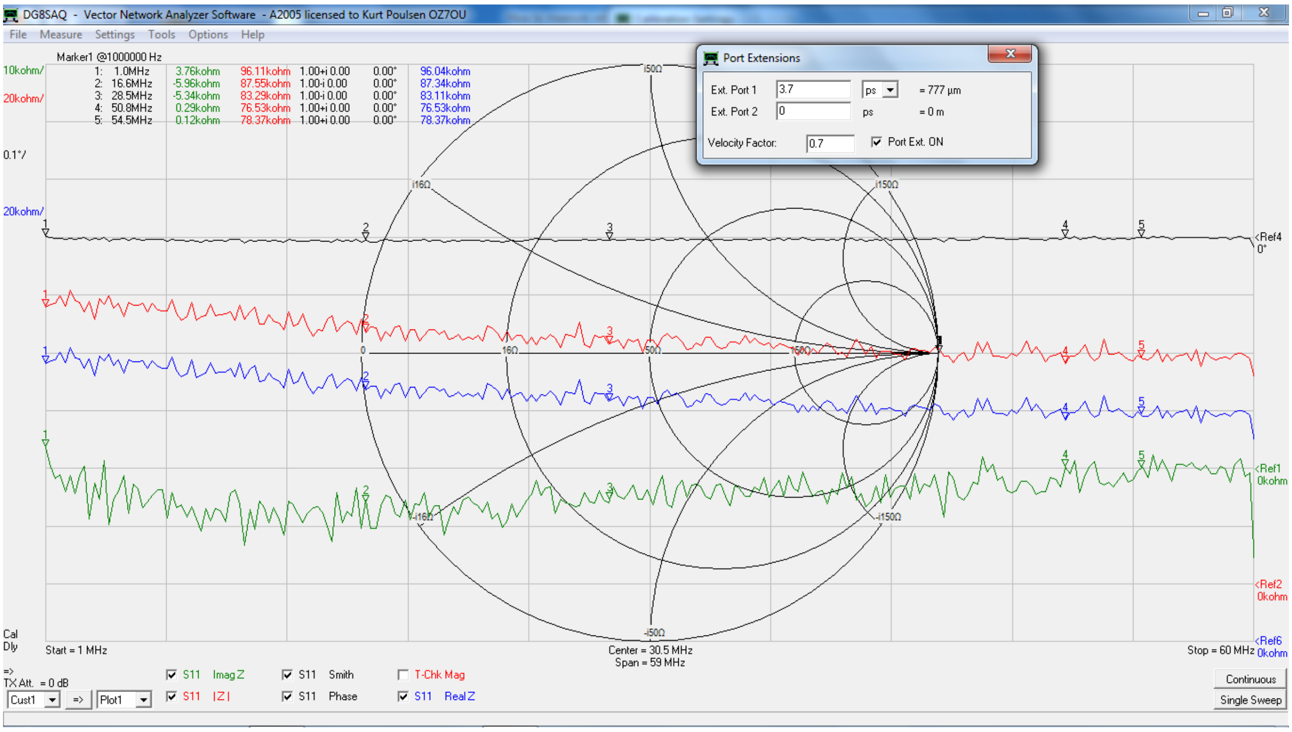


Neither does a S21 Q trace make any sense.

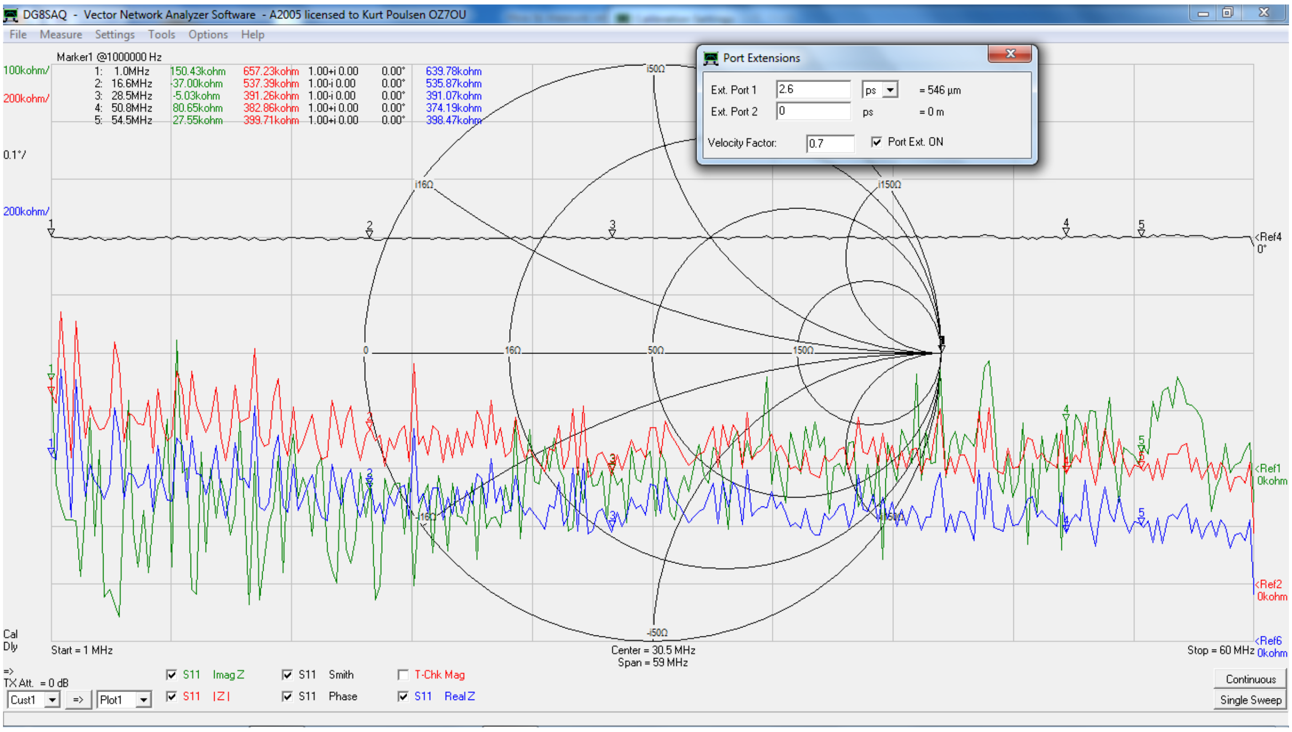
Doing an ordinary SMD Method 1 calibration in the Universal test adaptor provides following results.



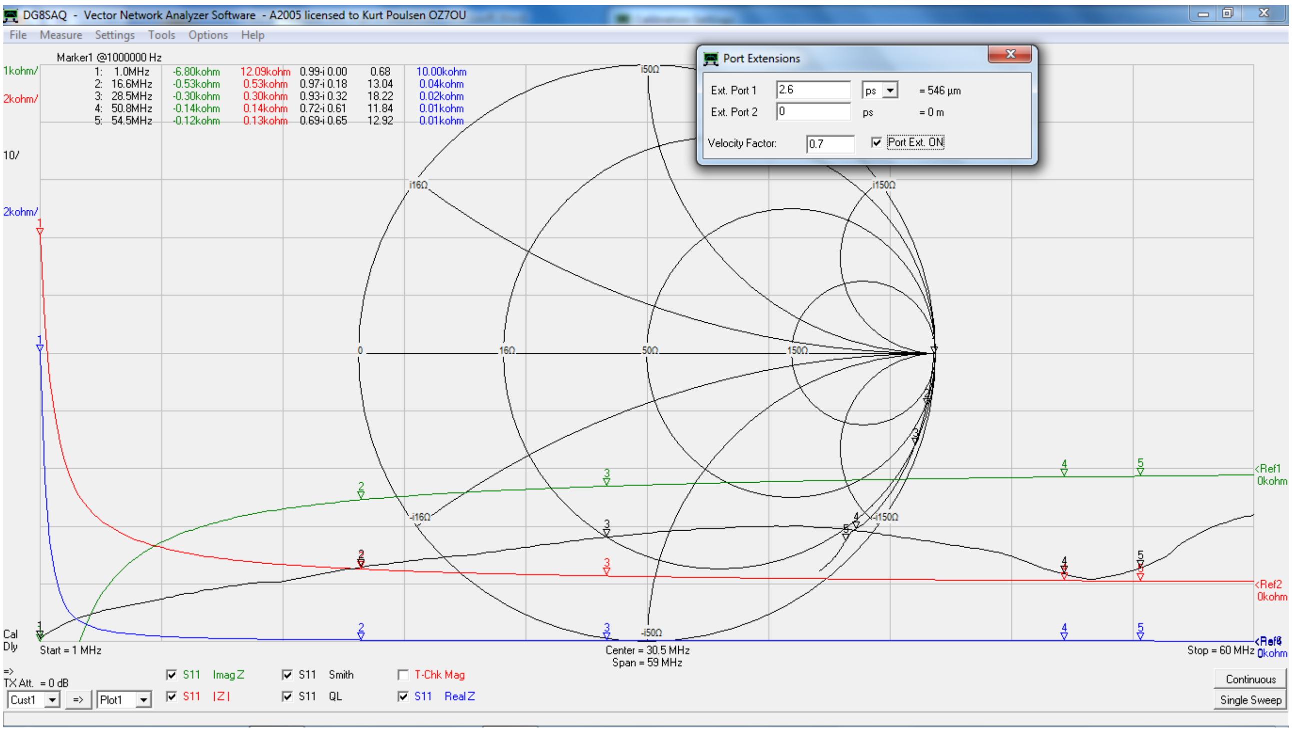
Measurements of the the 10Kohm SMD resistor is identical to the first method1 measurements done at the TX port



Measurements of the 100Kohm SMD resistor is identical to the first method1 measurements done at the TX port



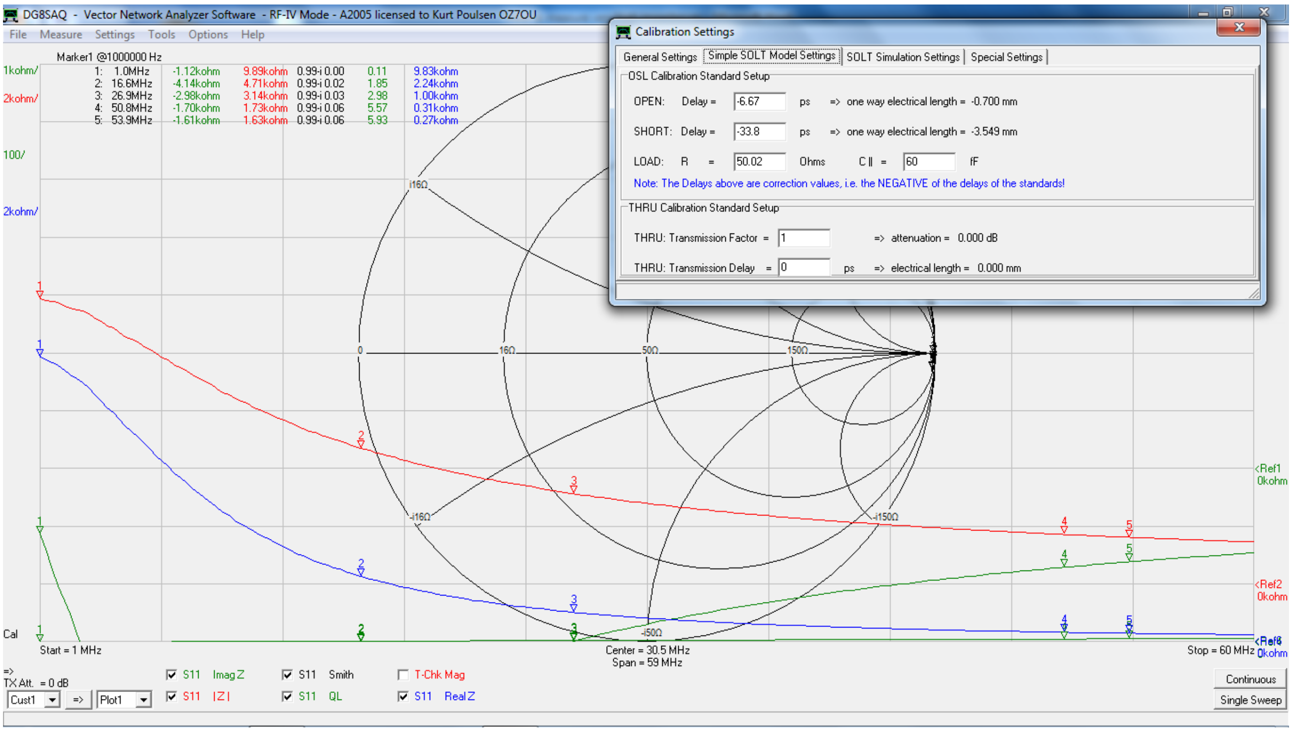
Measurements of the 1Mohm SMD resistor is simular to the first method1 measurements done at the TX port. The better performance is probably just a lucky coincidence.



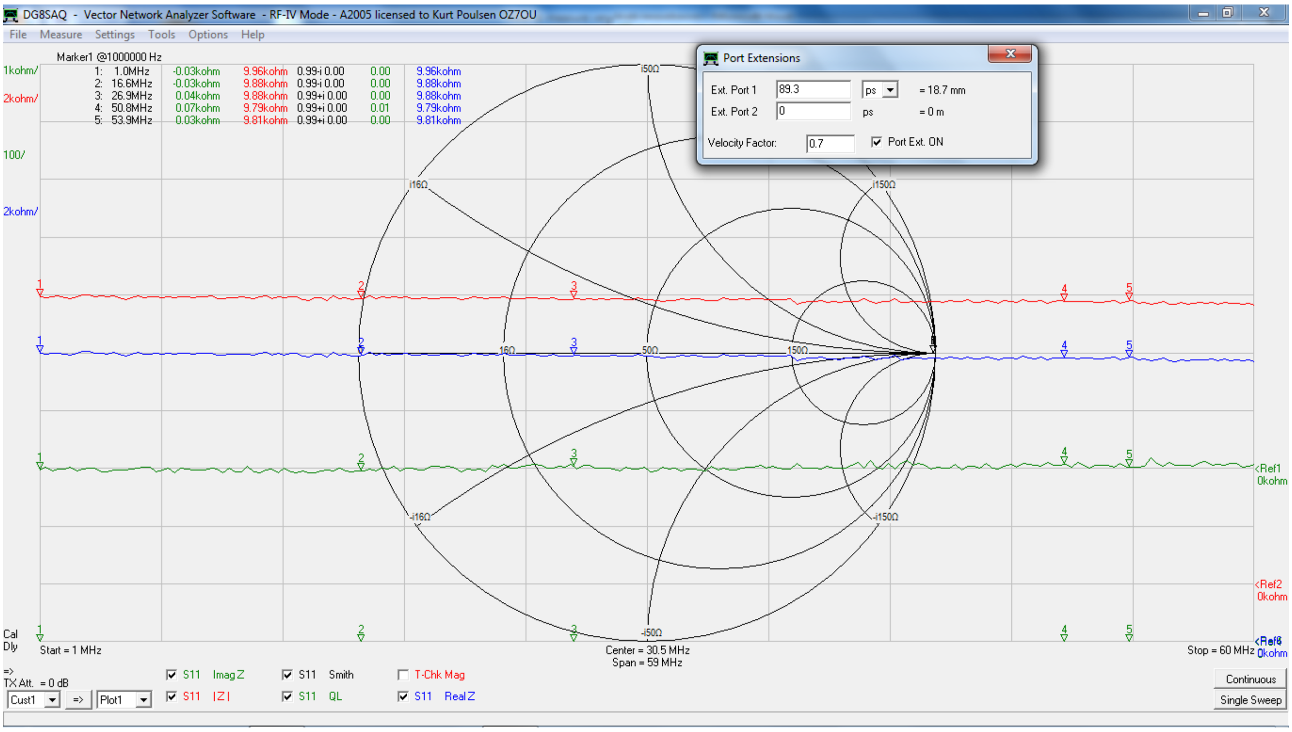
This Toroid measurement is identical to previous Method1 measurements. Screened measurements not possible.

RF-IV Measurements.

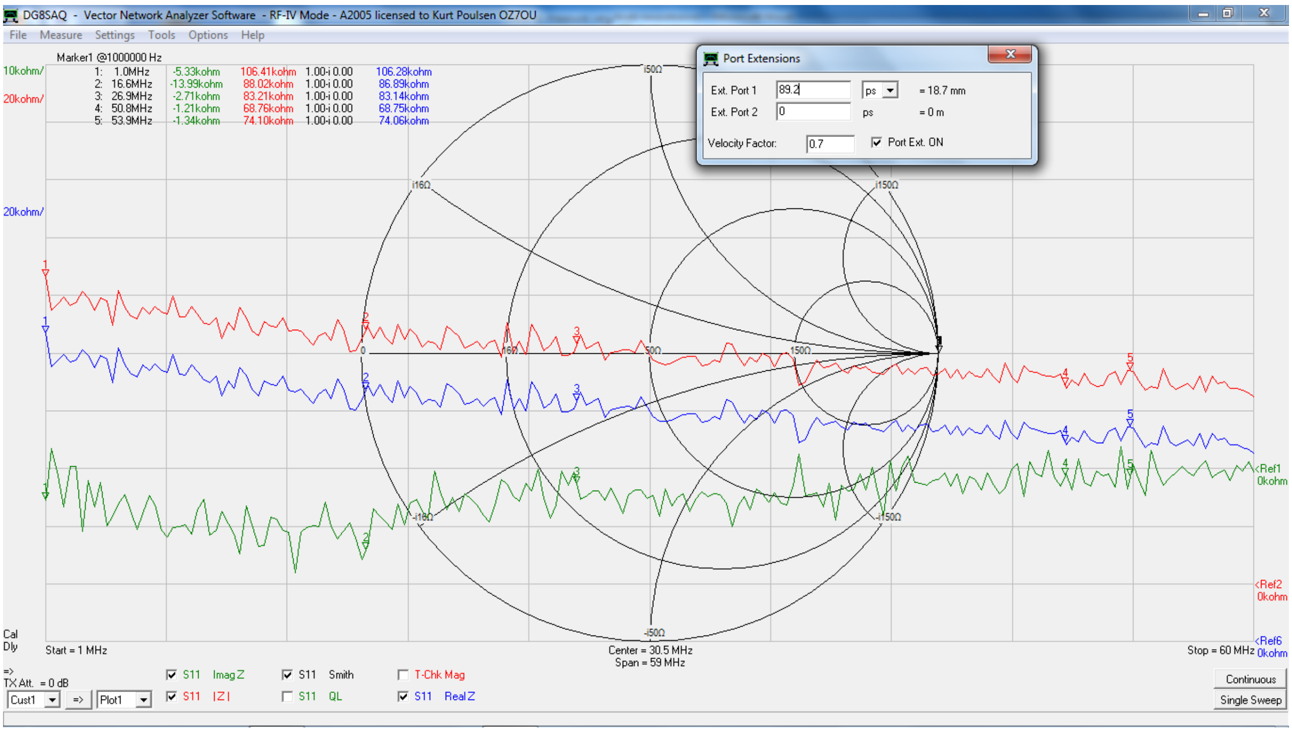
The first calibration done by using the previous described Amphenol Connex Cal Kit with DUT SMA female on the RF-IV adaptor as Open standard. Then the 3 SMD resistors measured as per ther left picture followed by the Toroid as seen on Right picture.



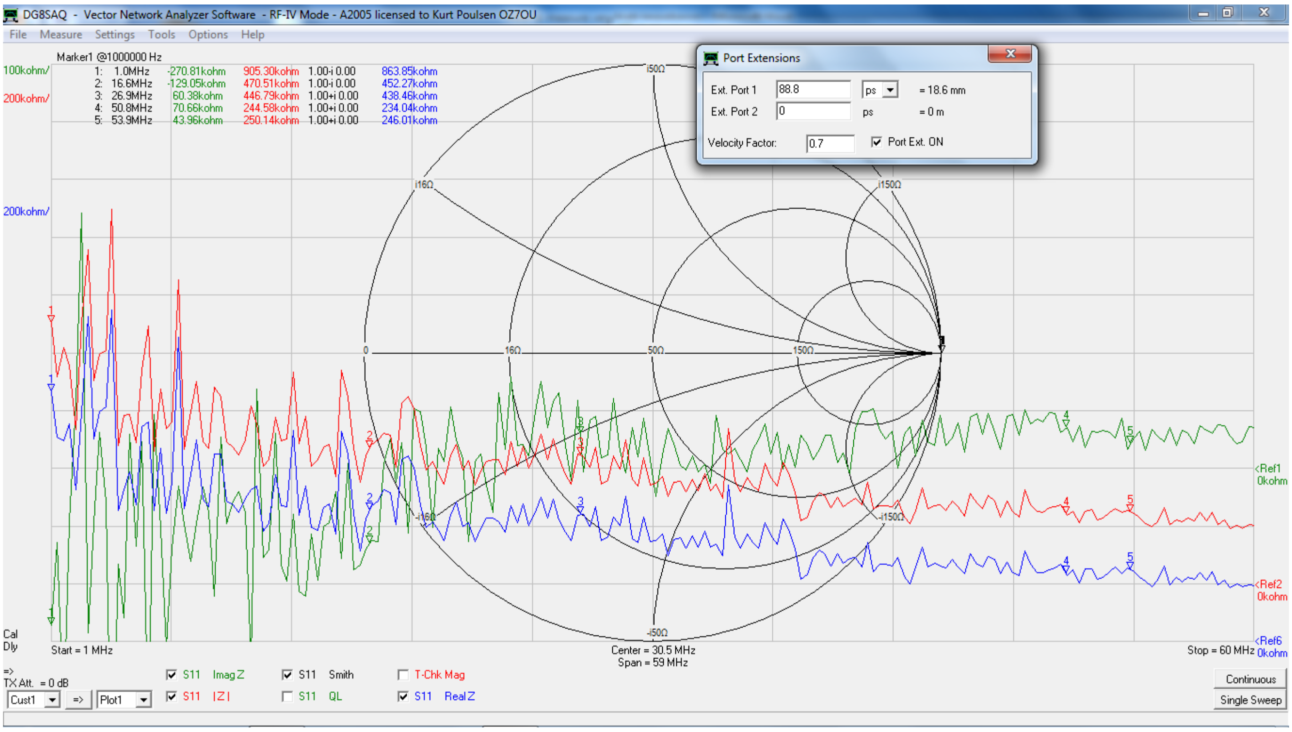
RF-IV measurements of the 10Kohm SMD resistor before application of Ext. Port1 delay. Observe the calibration data



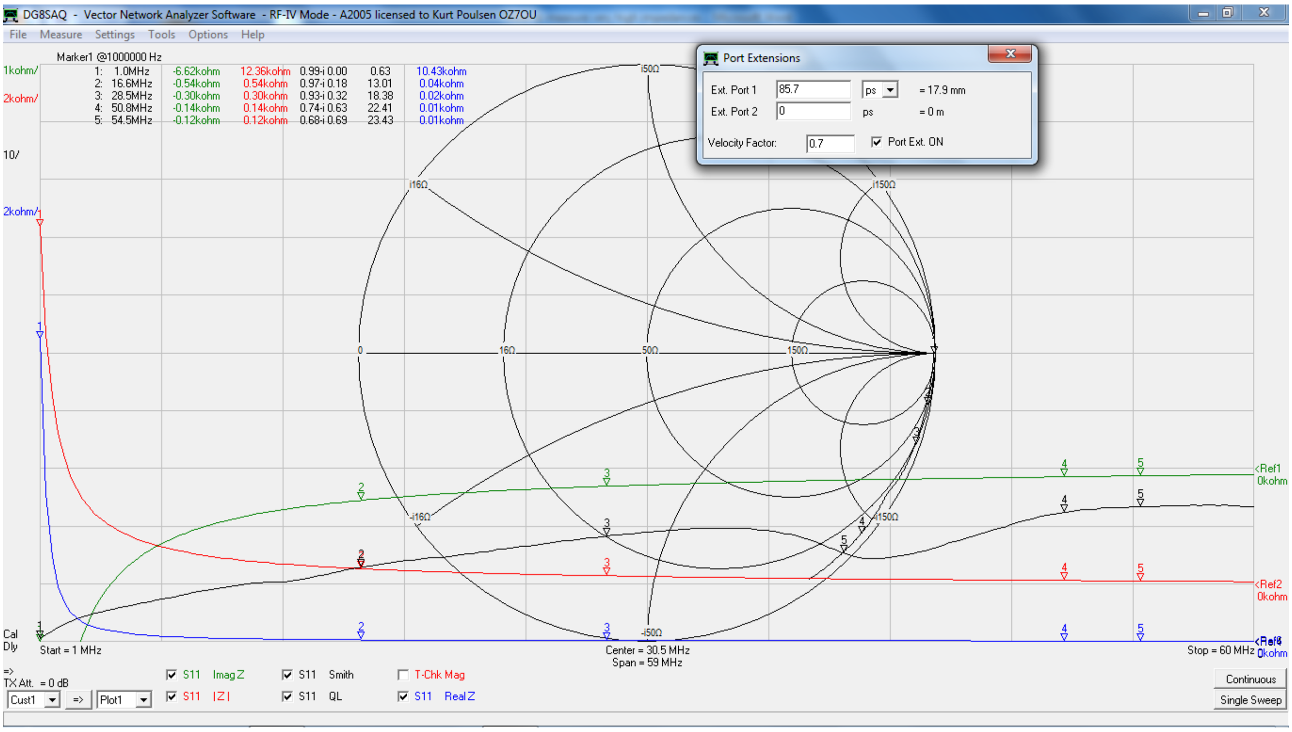
RF-IV measurements of the 10Kohm SMD resistor after application of Ext. Port1 delay. Not any better than for VNWA Method 1 or 2. But the stability over time is definitely obtained as the VNWA Bridge is temperature sensitive requiring frequent calibration.



RF-IV measurements of the 100Kohm SMD resistor after application of Ext. Port1 delay. Not better than by using VNWA method 1.

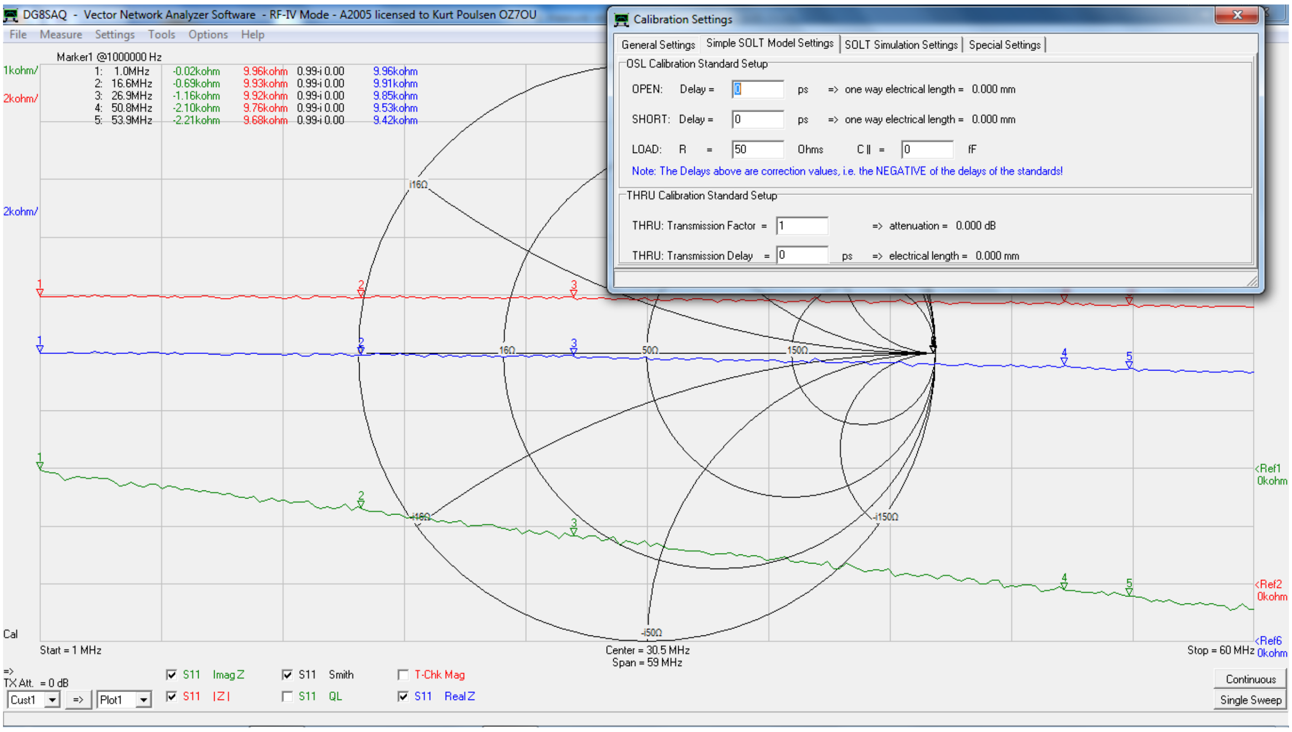


RF-IV measurements of the 1Mohm SMD resistor after application of Ext. Port1 delay. Not better than by using VNWA method 1.

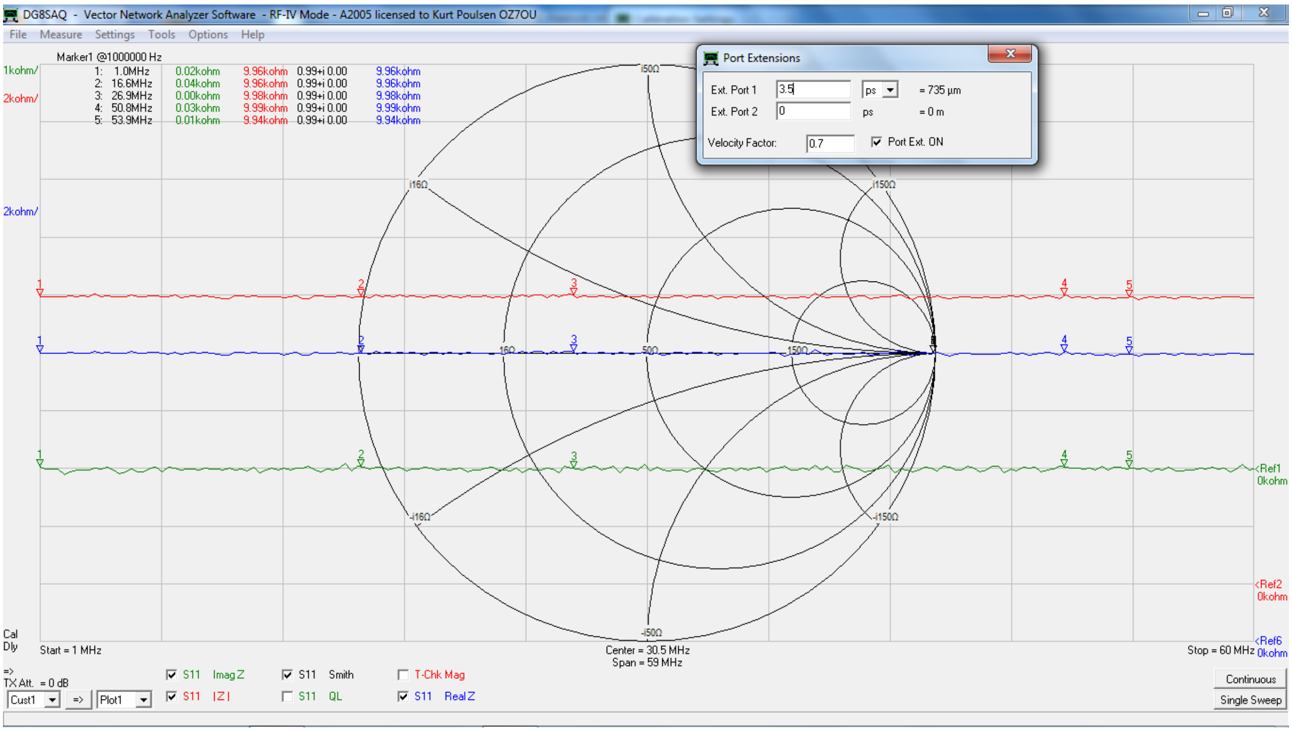


Toroid measurements identical to VNWA method 1. The USB cable was not fitted with the Toroide Clamp. As the Detector out has a 20/21dB lower measurement level such that the Q dip based on the mutual coupling may differ due to this fact. The Q values below 30MHz are identical.

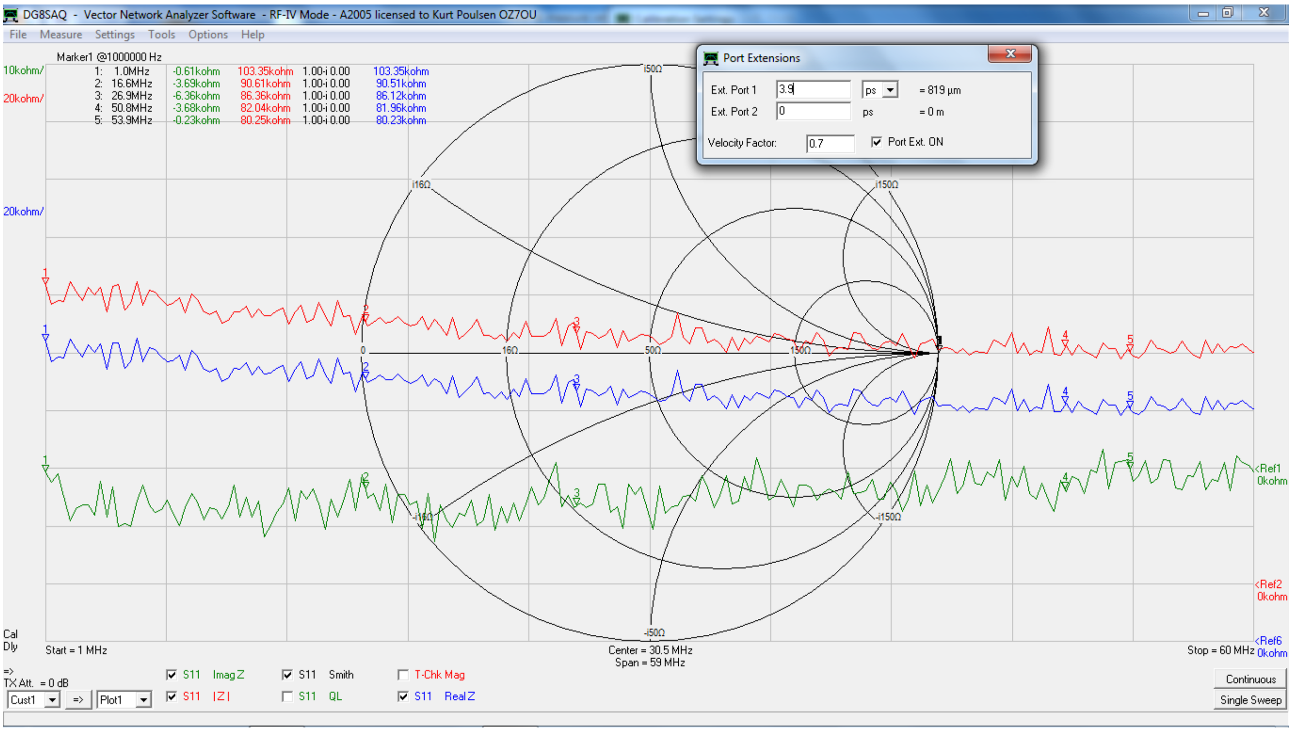
Now SMD calibration Kit used for the RF-IV adaptor.



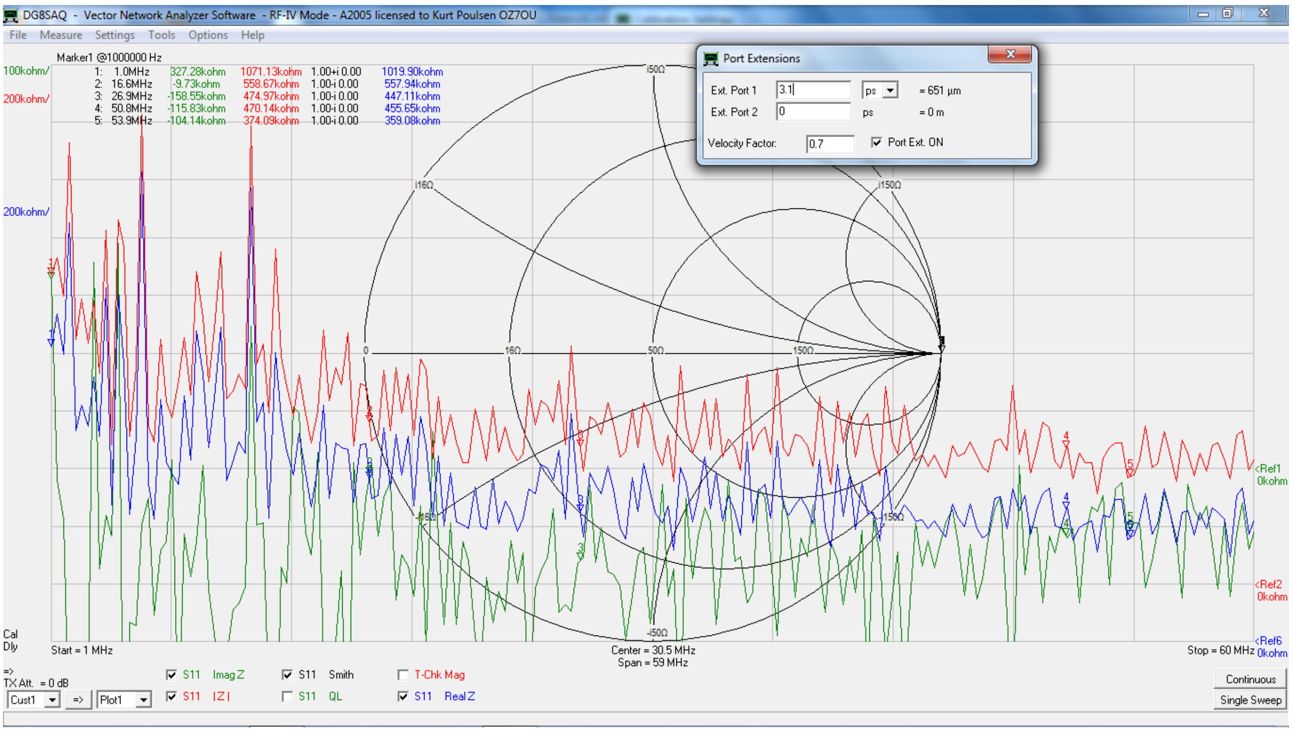
RF-IV measurements of the 10Kohm SMD resistor before application of Ext. Port1 delay.



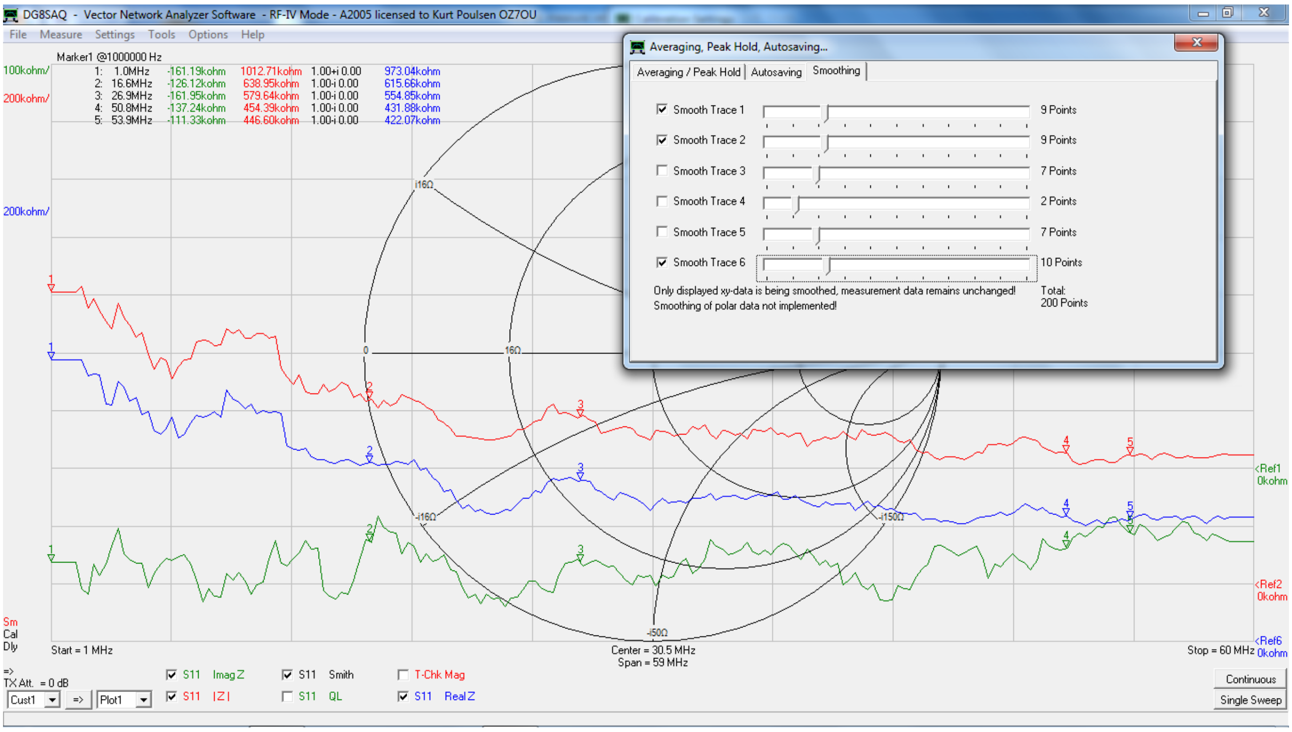
RF-IV measurements of the 10Kohm SMD resistor after application of Ext. Port1 delay. The best results so far.



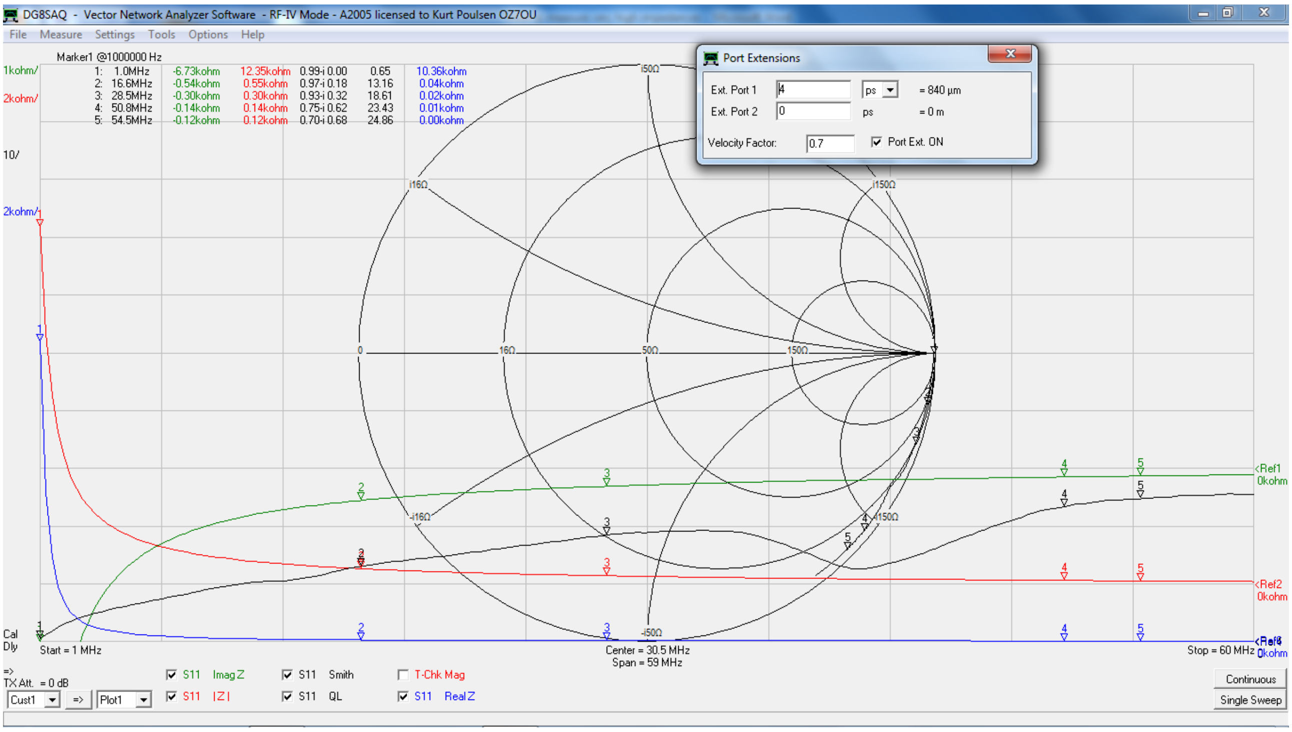
RF-IV measurements of the 100Kohm SMD resistor after application of Ext. Port1 delay. The best results so far.



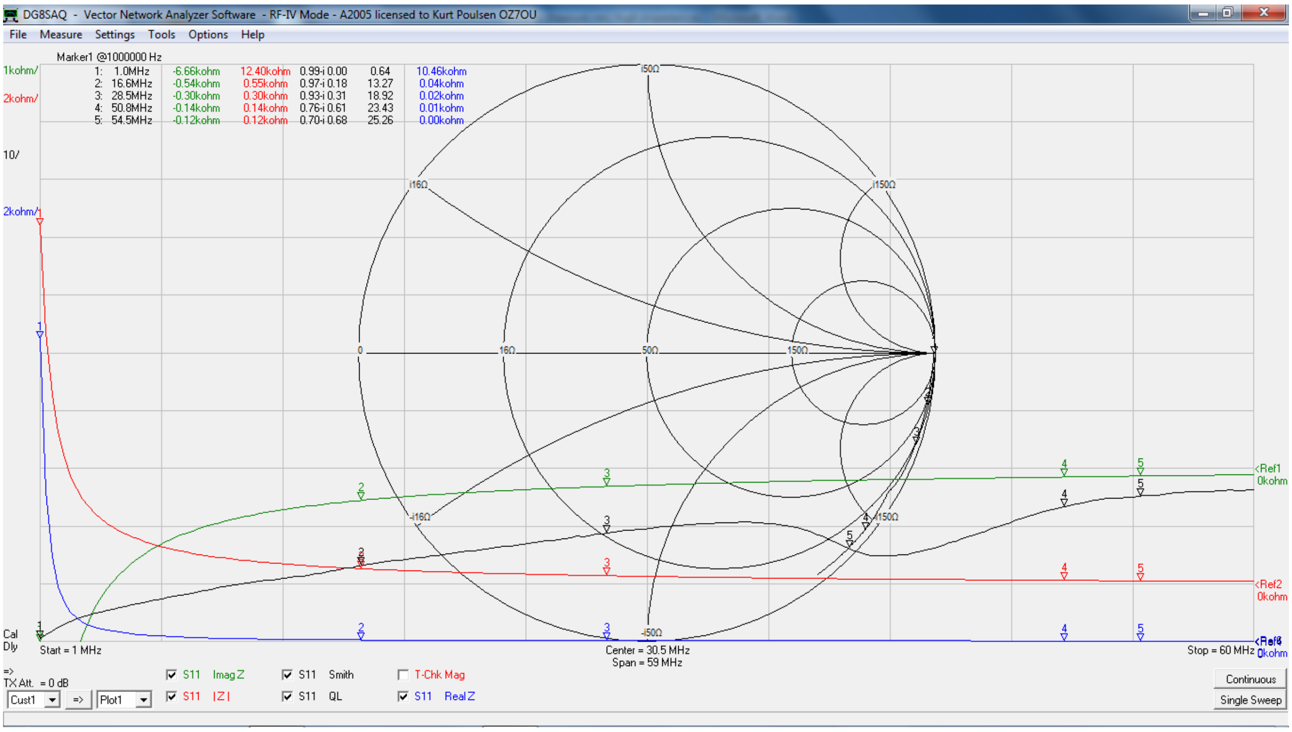
RF-IV measurements of the 1Mohm SMD resistor after application of Ext. Port1 delay. Maybe the best results so far but very noisy due to the low output from Detector Out.



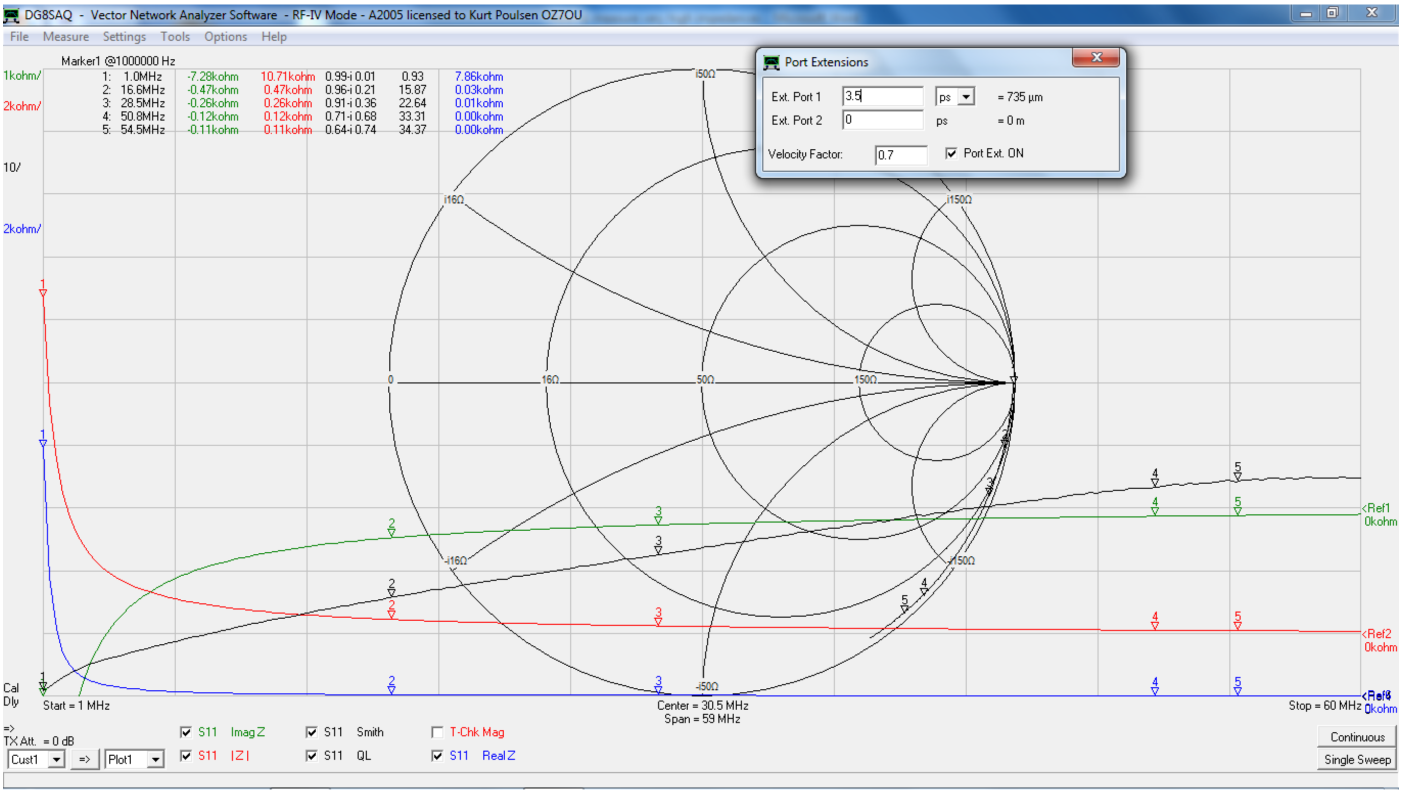
Application of Smoothing can be beneficial.



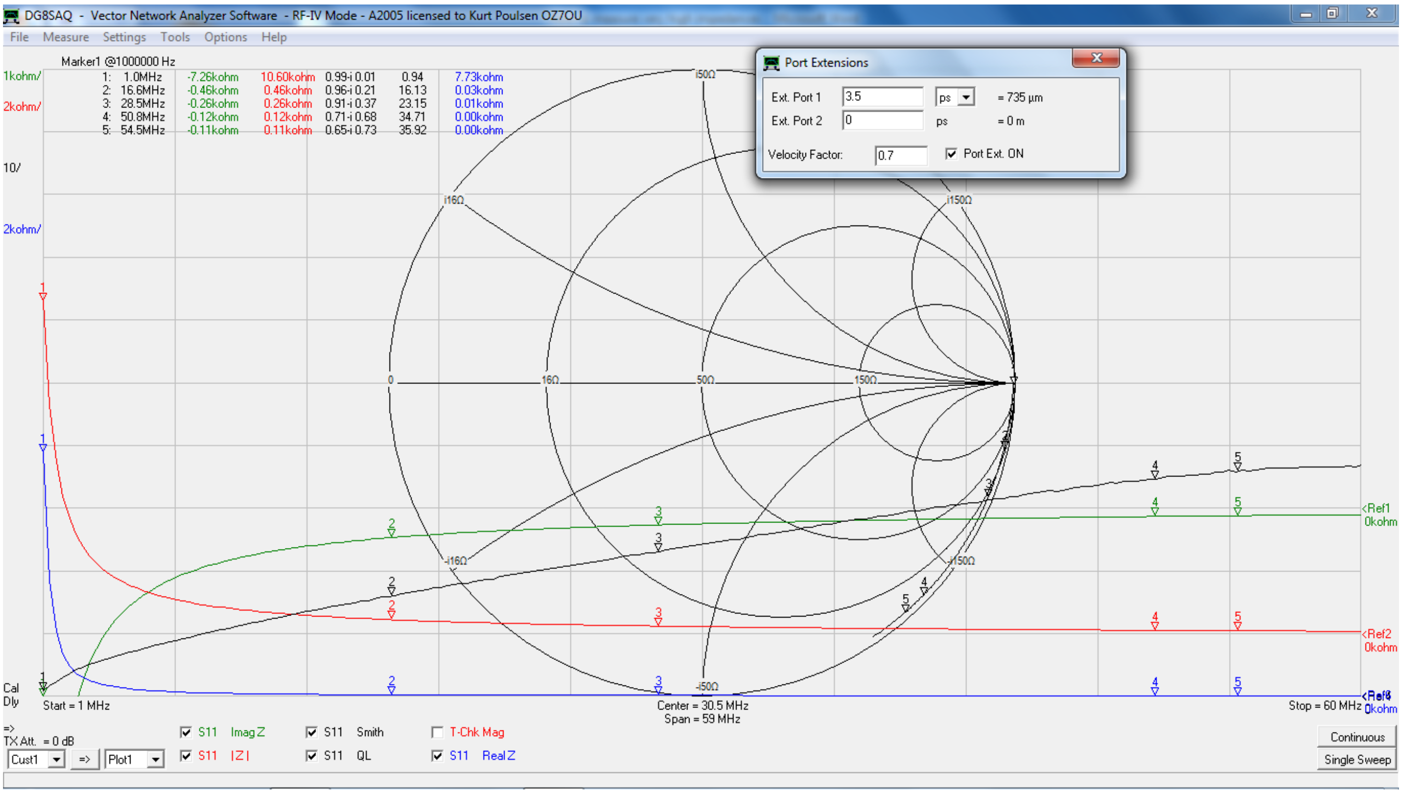
Toroid measurements identical.



At the end of a 20cm long test cable calibrated with the SMD cal kit to investigate if coupling was reduced



Toroid in screen box no lid



Toroid in screen box with lid

Summary:

RF-IV is not measuring more accurate than VNWA in mode1 and mode2. The benefit is More stability over time and temperature. The WNWA is less accurate in theory than RF-IV when errors are introduced. See the Video on YouTube discussing this topic. Search for DG8SAQ or TheKurtPoulsen.
The most important issue to monitor when measuring on large physical items which by any means can radiate or has a large air capacitance which by an electrostatic field can couple to wires connected to the VNWA such as the USB cable and the control cable for an external test set or the RF-IV Test adaptor. The cure is Screening or using enclosures for the DUT. Not necessarily fully closed but preventing electromagnetic/electrostatic coupling (faraday enclosure technique). That comment is highly valid for measuring on antennas outdoors and the DUT that **Jim Brown K9YC** is designing these days a valuable device for VNWA measurements on Wire antennas feed with coaxial cables.

Kurt Poulsen de OZ7OU marts 31 2013
Revised April 2 2013