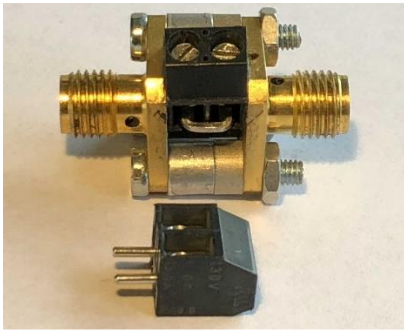
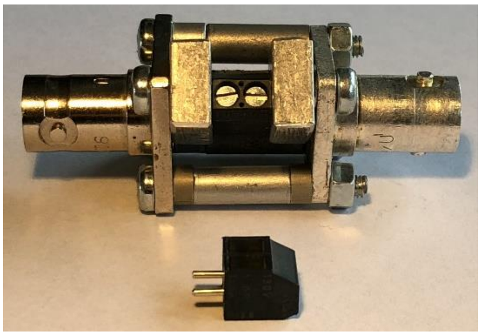
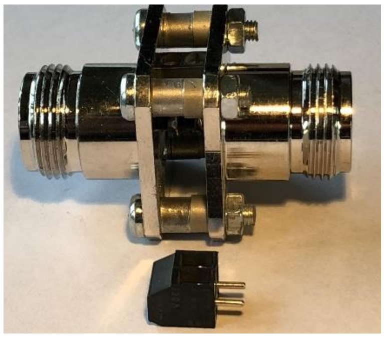
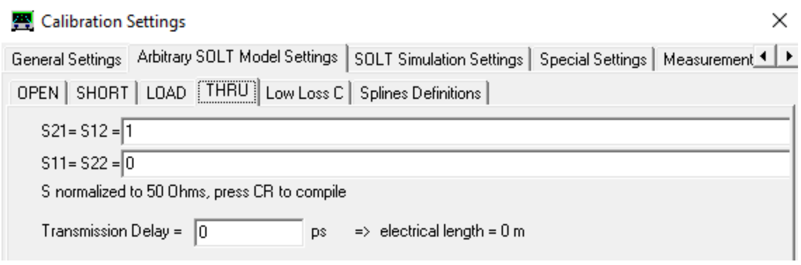
How to calibrate and measure a DUT like a toroid correctly

Preface:
This report is both a tutorial about what happens, when a calibration of the VNWA takes place, and how to take benefit of some smart features embedded in VNWA software.
Measuring a DUT like a toroid, an air coil or any other leaded component, creates difficulties measuring e.g. the self-resonance frequency of a toroid, and many reports has been seen how to solder the DUT to a bulkhead adaptor (even using test leads with banana clips) and measure S11 where the bulkhead adaptor capacitance lower the resonance frequency. Using the extension port delay of the VNWA to offset the delay in the bulkhead adaptor toward its rear where the center conductor is exposed, is of course improving the measurement accuracy, but such an adaptor has different delays when shorted and in open condition, not to mention the impedance transformation thru the bulkhead adaptor, which take place even at 50-ohm level.
Using a type of Test Adaptor like the SMA, N and BNC Test Adaptor family shown below, fitted with a 2wide screw terminal block for easy mounting a shorting bridge during initial setup and calibration, and later on for mounting the DUT wire leads.
It is a far better method, where the leaded DUT is mounted in series with center conductors of the two connectors for the Test Adaptor.
However, it requires a specific way of calibrating followed by some specific way of measuring and removal a small Shunt C of the Test Adaptor, and in such a clever way that everything is “taken out of the formula”. How that is done is going to be explained in details, and without using extension port delay, modifying calibration kit parameters and any other “funny” methods which is bound to fail. **In fact, getting away from the adaptor gender changer nightmare.**
That is what this report is all about.

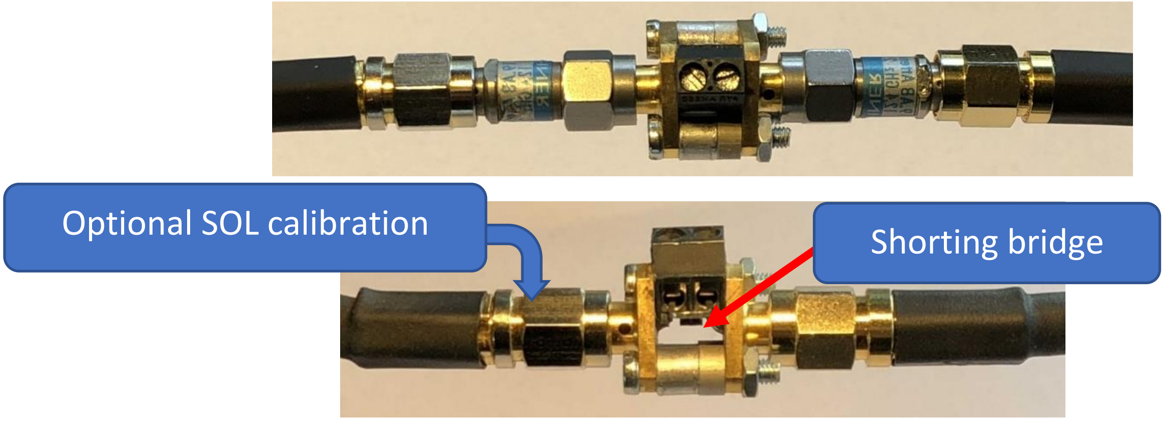




The smart features embedded in the VNWA software

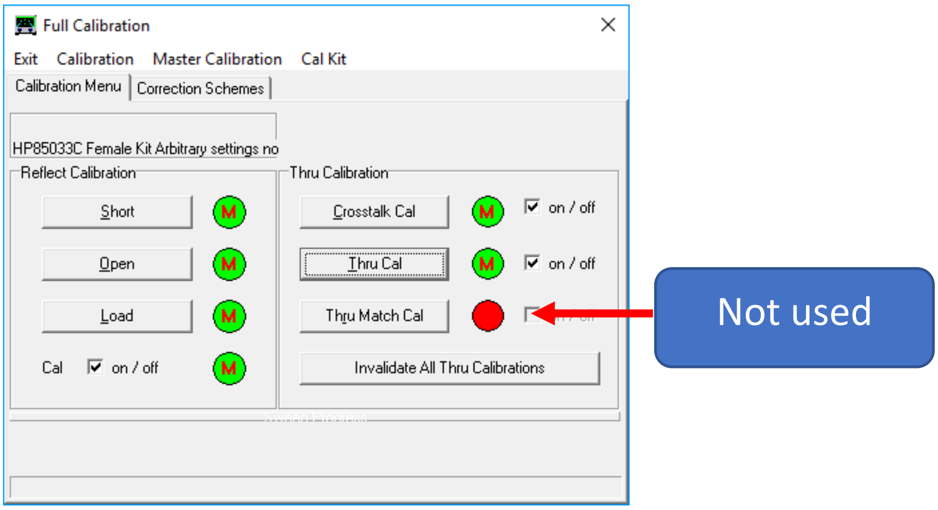
We will benefit from the smart feature in the VNWA software to convert a transmission measurement to S parameter in a Custom Trace with the expression t2s(S21). It requires only that we do a Thru calibration and to eliminate the very small open shunt capacitance, when the shorting pin is removed, by a Crosstalk calibration, and ensures correct measurement of the self- resonance frequency for the DUT, if e.g. a toroid.
Special attention to the calibration kit file settings is also mandatory , as transmission delay must be set to 0 ps and no other settings for S11=S22 and S21=S12 than the default settings. So, copy your e.g. SMA calibration kit file to a new name, and change these settings if needed as shown below.



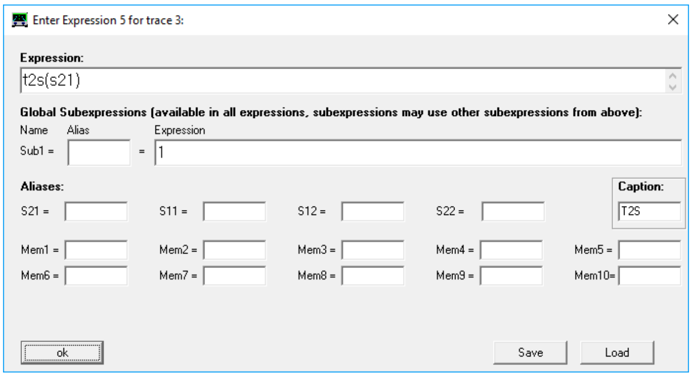
Mount the Test Adaptor with the shorting bridge between the two center conductors established.
For frequencies below 100KHz and above 100MHz insert 10 dB attenuators as shown below, as t2s(S21) expect pure 50 ohm source and load impedances, and that is not fulfilled for the VNWA TX and RX ports outside said frequency range.



As said before only a Thru and Crosstalk calibration required with the Test Adaptor as Thru calibration standard. For educational purposes we also do a SOL calibration at the end of the TX test cable as illustrated above.



Now create a Custom Trace with the Expression t2s(S21) and give it the Caption Name T2S



Enable a number of Custom Trace e.g. Trace 2 to Trace 6 and set the scale as illustrated and then run a sweep and see the RealZ and ImagZ are 0 across the entire frequency range, which mean it is a measurement of the Shorting Bridge.

The Shorting bridge has a series inductance and in my case of 1.5nH and it might be offset in the Cuctom Trace as described below.

How to figure out your Shorting Bridge or Shorting Wire inductance seek help on the following links

https://chemandy.com/calculators/round-wire-inductance-calculator.htm

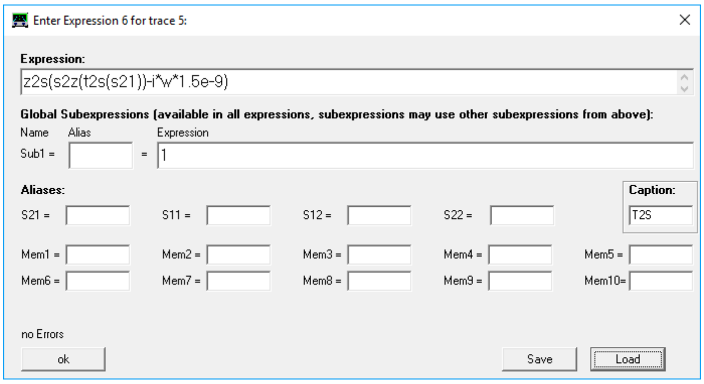
or

http://www.consultrsr.net/resources/eis/induct5.htm

or

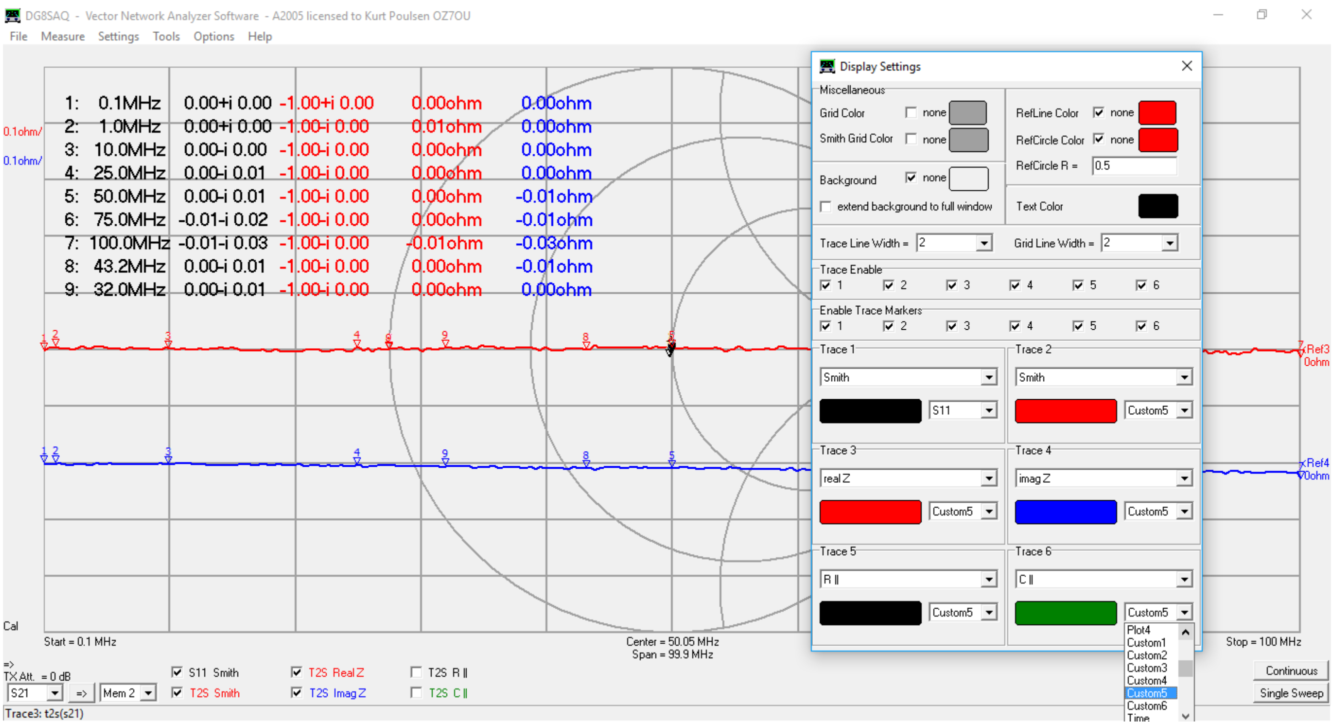
http://www.finetune.co.jp/~lyuka/technote/inductor/inductor-straight-flat.html

if you Shorting Bridge is not round as in my case.

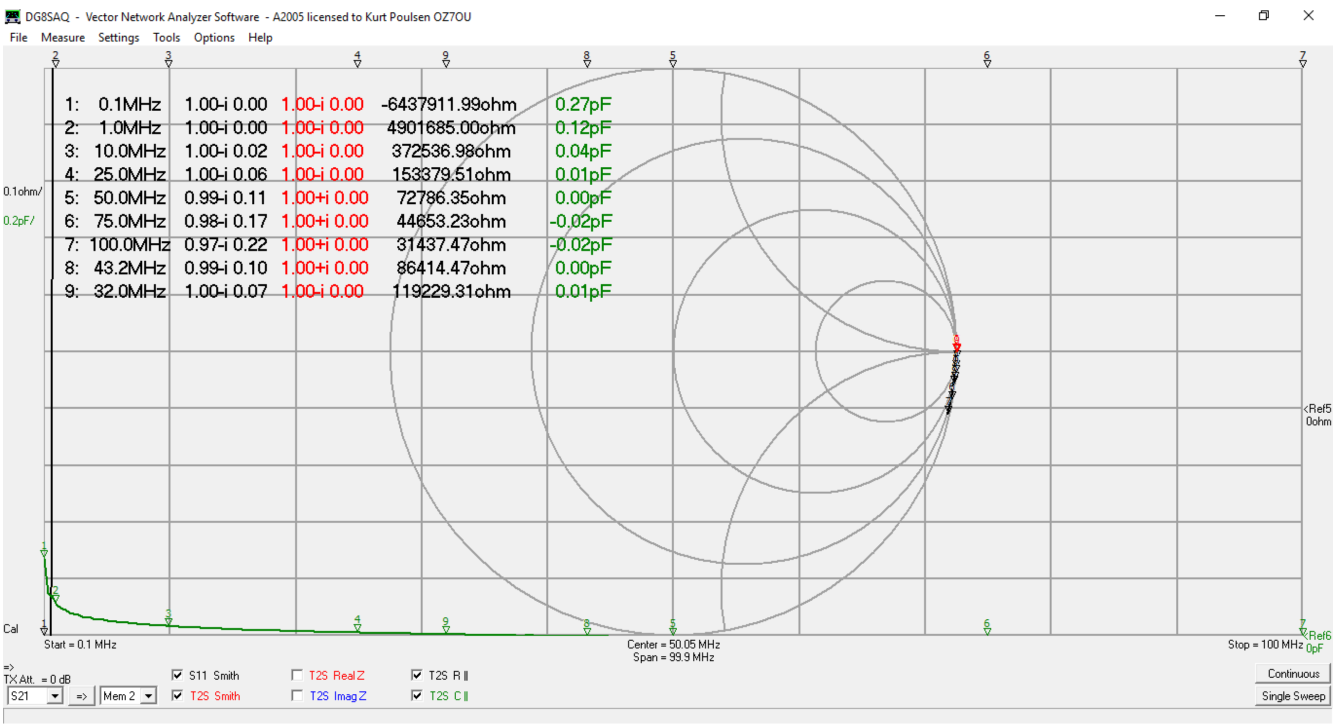


The t2s(s21) is converted to Z parameters with expression s2z and the impedance of the shorting bridge being 1.5nH is subtracted as i*w*1.5e-9.
The total expression is converted back to S parameter with the expression z2s in front of the outer brackets. Save the new Cuctom Trace with a new descriptive name e.g. "T2S Shorting Bridge compensated"

Below the sweep prior to Shorting Bridge compensation, else the Imag Z slant downwards as actually measured



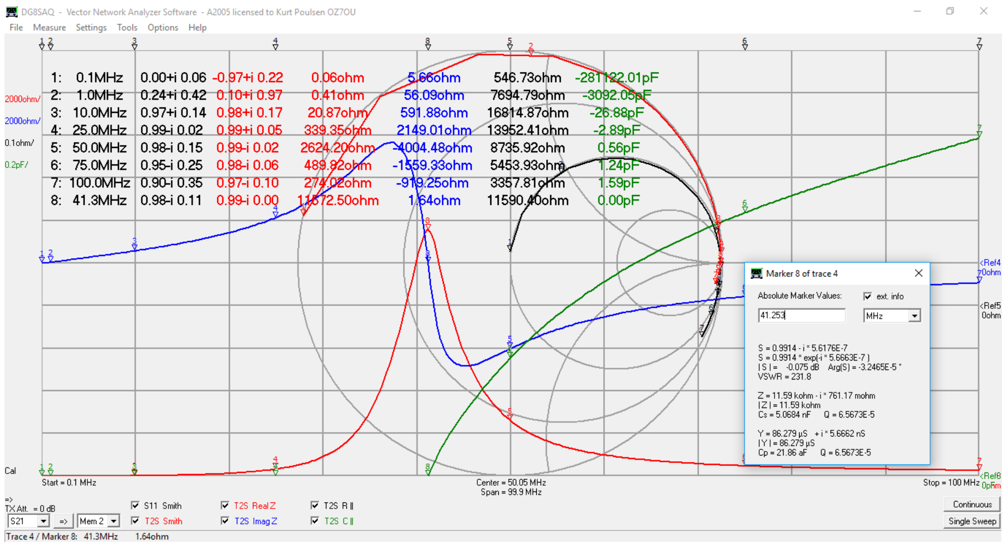
A sweep with Shorting bridge removed seen below and the CII is showing 0.00pF due to the Crosstalk calibration



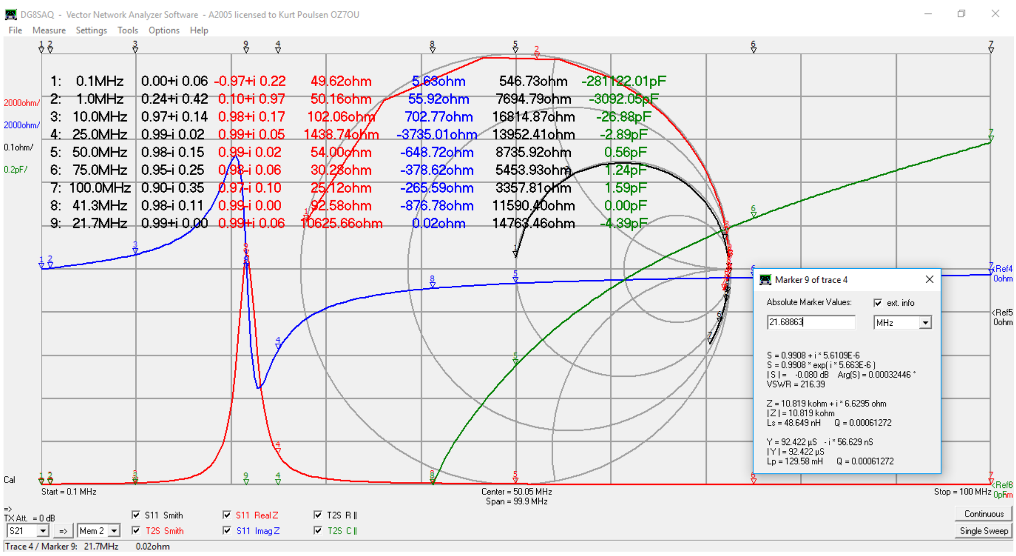
We are now ready to measure leaded components right away and below is a measurement of a toroid with 22 windings

The self-resonance frequency is 41.273MHz and a RealZ of 11572 Ohm and 0pF in parallel seen for marker 8. If we study the S11 and T2S Smith Charts the we see how the clever t2s(s21) works. Next, we will confirm we can trust the RealZ measurement by testing with leaded components as DUT bearing in mind that that any VNA has difficulties with accuracy approaching 10Kohm.

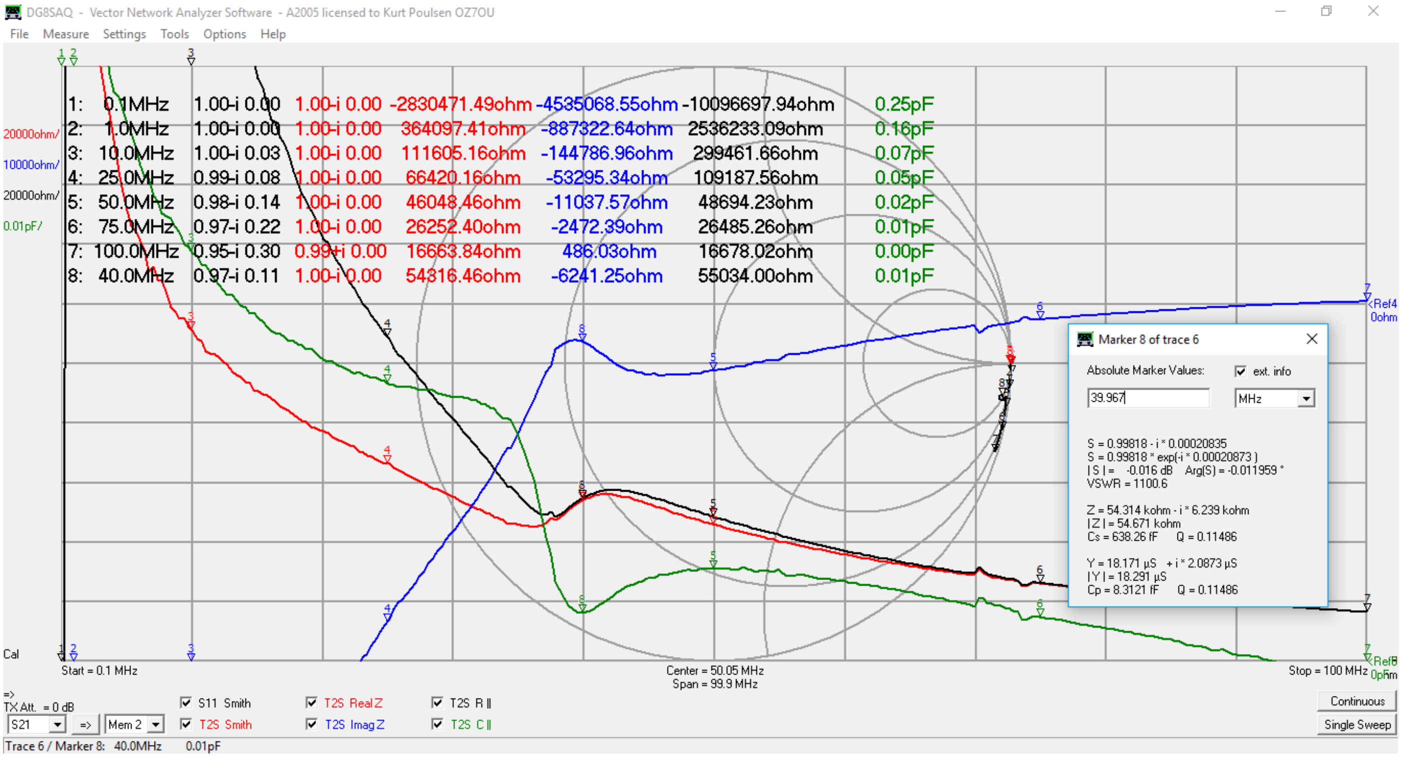
But first a few comments on S11 measurements



If we change trace 3 and 4 to S11 then we see the self-resonance lowered to 21.689MHz and to be able to measure the DUT accurate by S11, we must, in a Custom Trace, subtract both the serial impedance of the Test Adaptor itself, and the input impedance toward the RX port, at the calibration plane, where we connect the RX test cable to the Test Adaptor. This because the Test Adaptor is terminated with the input impedance of the RX port, seen thru the RX test cable. To find this input impedance we must first do a full SOLT calibration, and the VNWA then know the S parameter impedance to the RX cable as the S parameter expression SL. As the female Thru adaptor is removed after Thru and Thru match calibration, the calibration plane of the two ends of the TX and RX test cables are in amplitude and phase sync. At this point in time the Test Adaptor is inserted and been measured as a full 12term corrected measurement, done by pressing the F2 key on the PC keyboard. We save the measurement containing the S11, S21, S12 and S22 of the Test Adaptor as a s2p Touchstone file. From this s2p file we derive the S11 impedance of the Test Adaptor. Calculated by a Custom Trace we subtract from the S11 measurement of the DUT inserted in the Test Adaptor, the S11 for the Test Adaptor and the S parameter SL. At the same time is taken into account the shorting bridge inductance and the shunt capacitance of the open Test Adaptor and subtract these elements as well. It is a complicated process not worth the trouble compared to the S21 method here described.

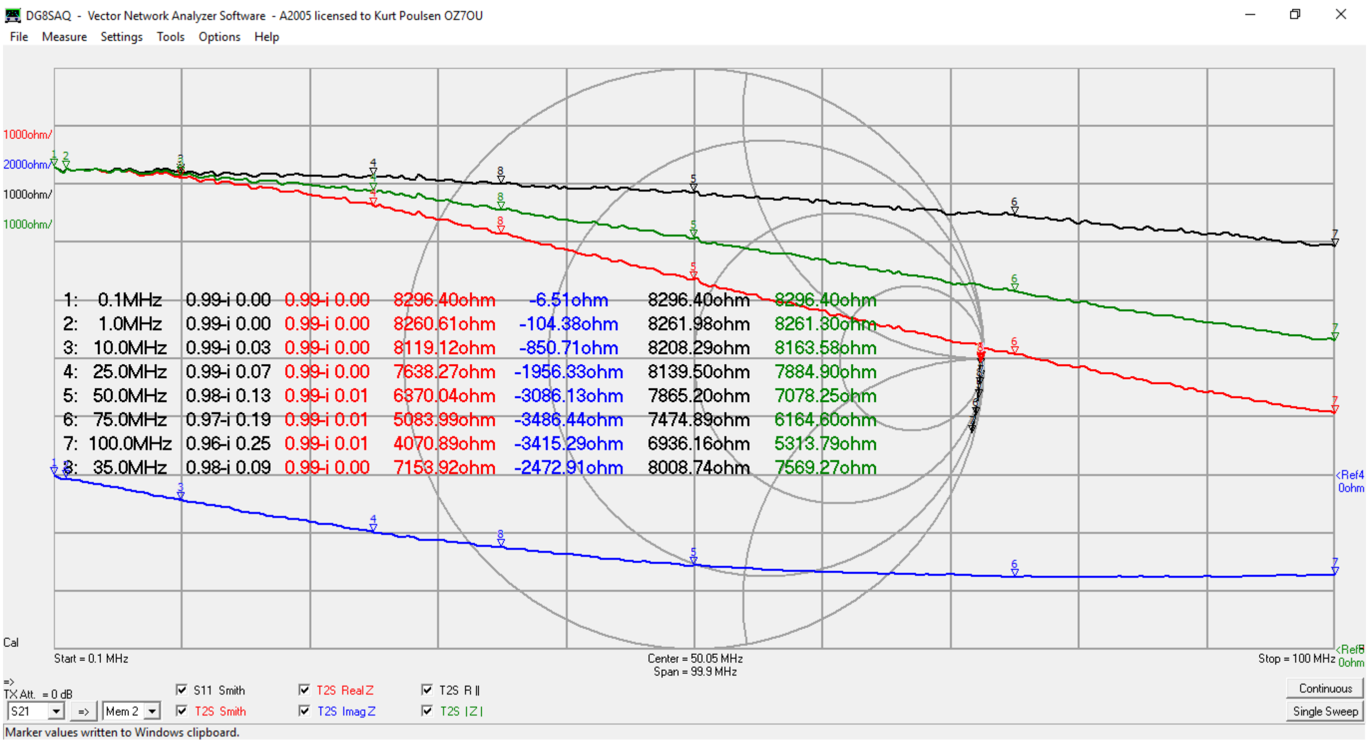


Letting only one lead of the toroid be connected to the TX side on the 2way terminal block and the other lead as far away from the RX port side of the Test Adaptor as possible, is show a resonance of 39.967MHz pretty close to the measured self-resonance of 41.253MHz. It will be a bit lower due the capacitance to open air of few fF which will lower the self-resonance slightly.

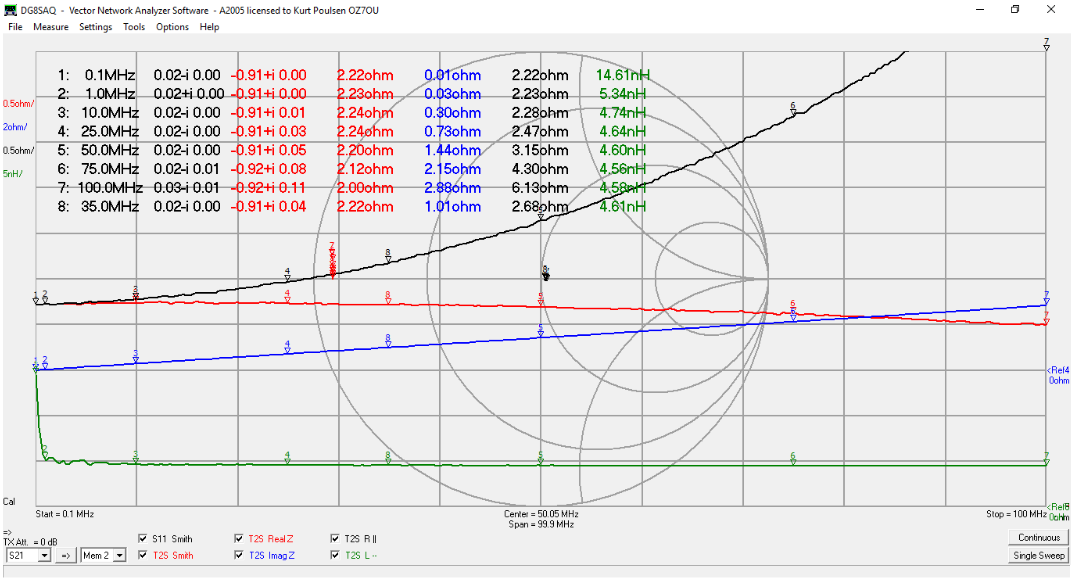


Now we will mount some ordinary leaded resistors from 2.2ohm to 18Kohm and see how the are measured. Remember that RealZ and ImagZ are the serial connection of these two components, and the RII and CII are parallel connection of these, so dependent of the real and imaginary part the value of the RealZ cannot be constant across the entire frequency range. A demonstration is shown for RealZ, RII and IZI below for a 8.2Kohm resistor

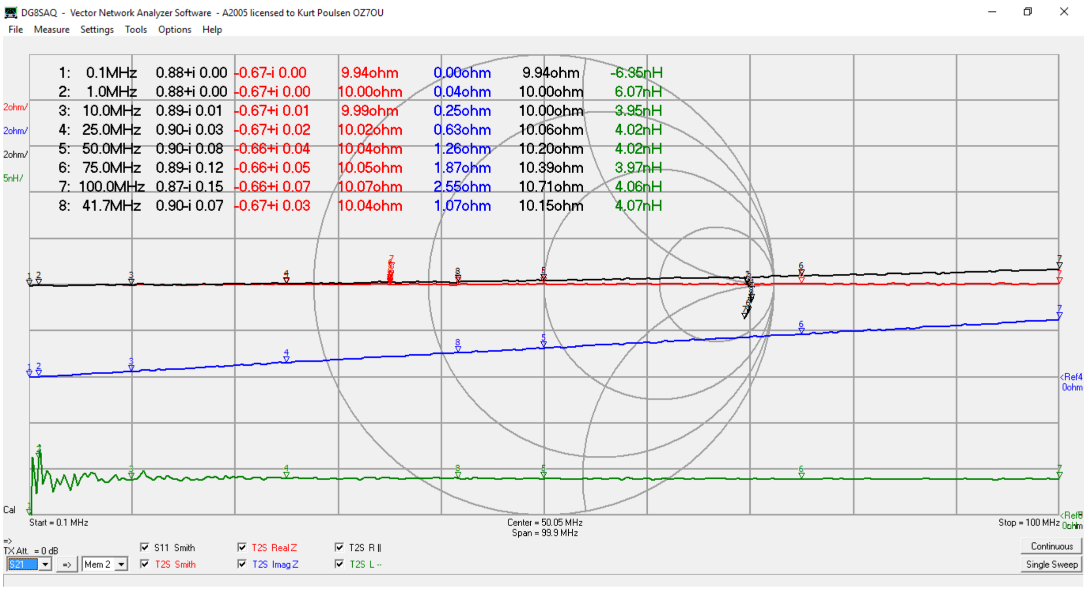
In the Appendix is SMD resistor tested ranging 1, 10, 100, 1K, 10K, 100K and 1Mohm. The results are after my own opinion excellent. (8.12Kohm by 4 wire measurement)



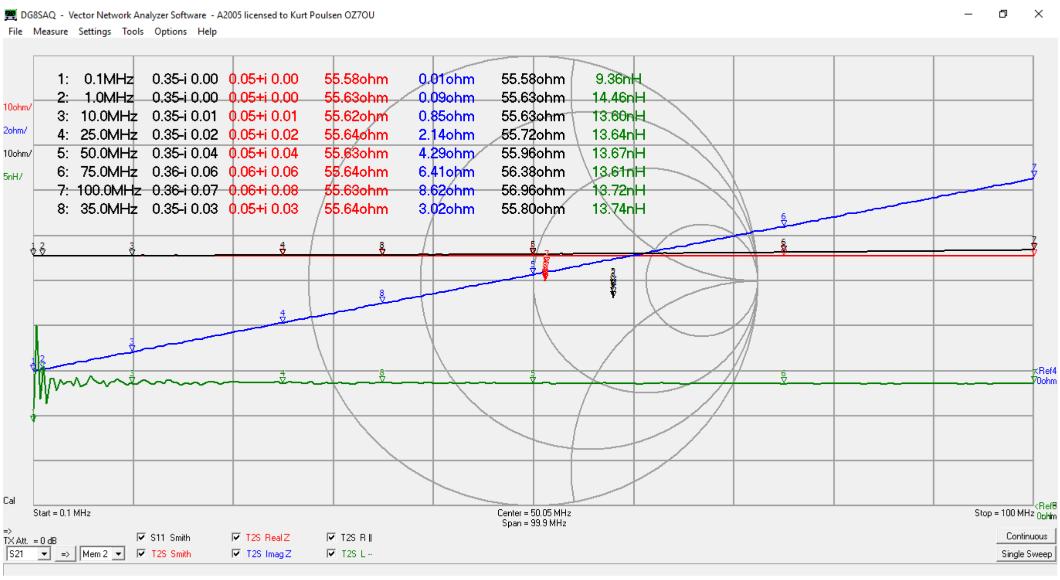
A mounted leaded 2.2ohm resistor is measured as RealZ pretty accurate and ImageZ show it is inductive. by 2.88ohm at 100MHz equals to 4.58nH and its 9mm 0.6mm diameter wire for the leaded resistor is 6nH. (2.24ohm by 4 wire)



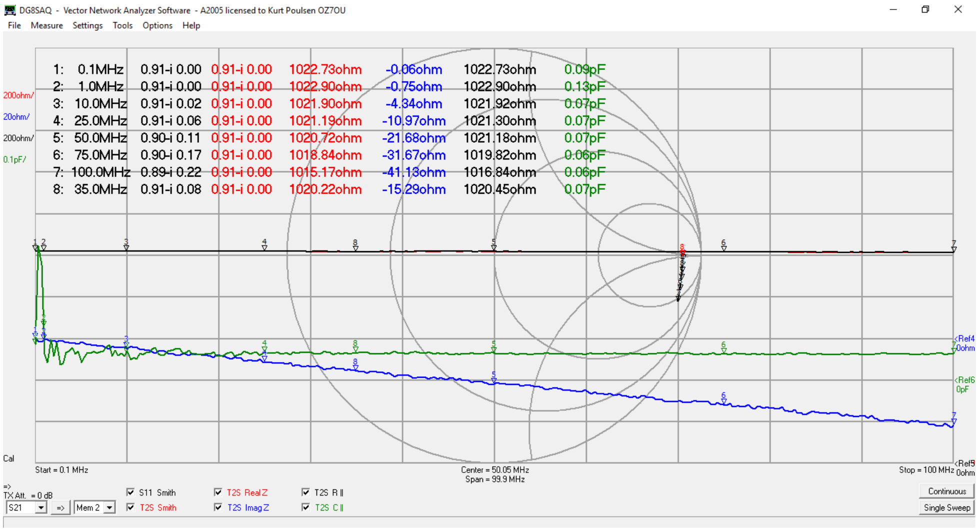
A 10ohm resistor mounted (9.9ohm by 4 wire measurement)



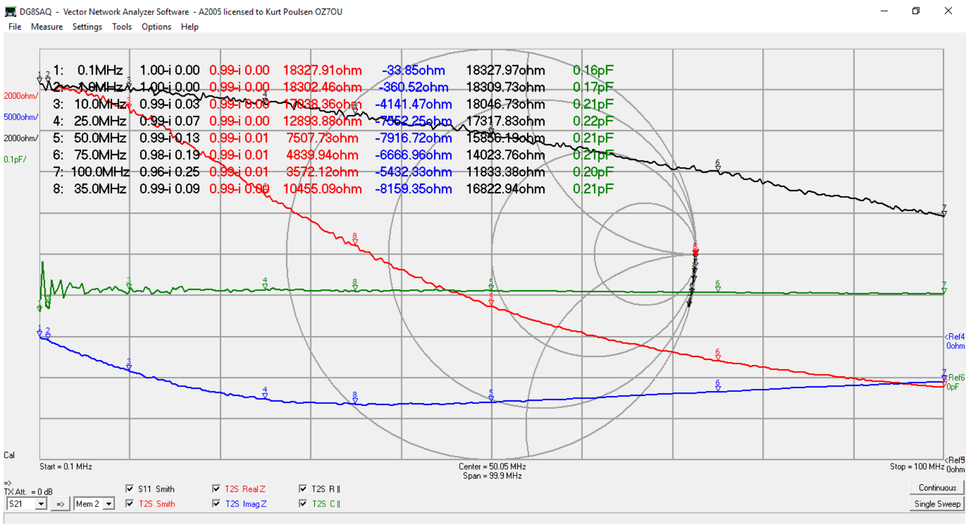
We will next mount a 56ohm leaded resistor and it look also reasonable correct. (55.2ohm by 4 wire measurement)



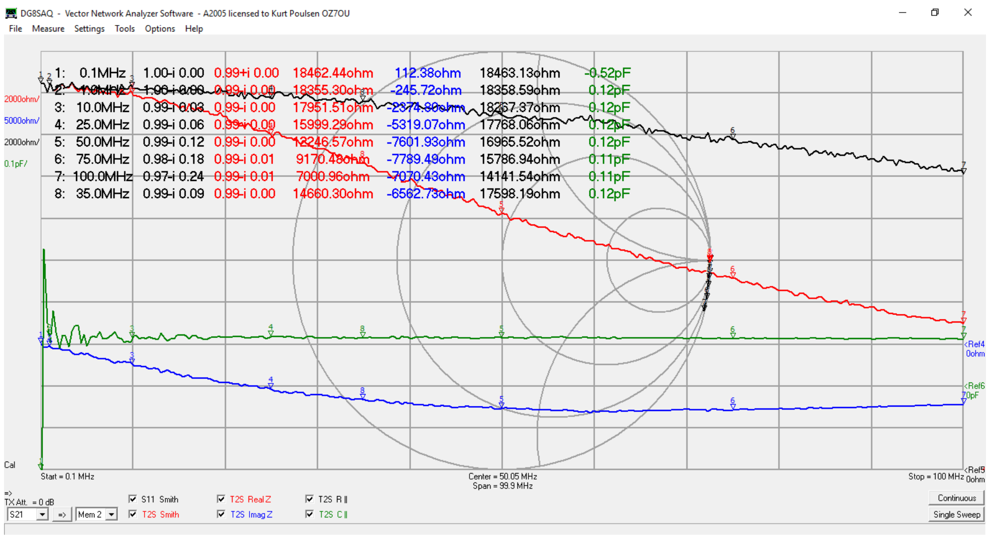
A 1Kohm leaded resistor fitted now turned capacitive (1.015Kohm by 4 wire measurement)



And a 18Kohm leaded resistor fitted next (17.99Kohm by 4 wire measurement)



Another 18Kohm leaded resistor measures quite differently so we are at the brink for the VNWA performance limit On the other hand it is also a matter how the resistor is designed. The used resistors are of unknown design. Such resistor a either made by a carbon layer, some are spiral grinded and other are metal layer resistors. (18.17Kohm by 4 wire measurement)

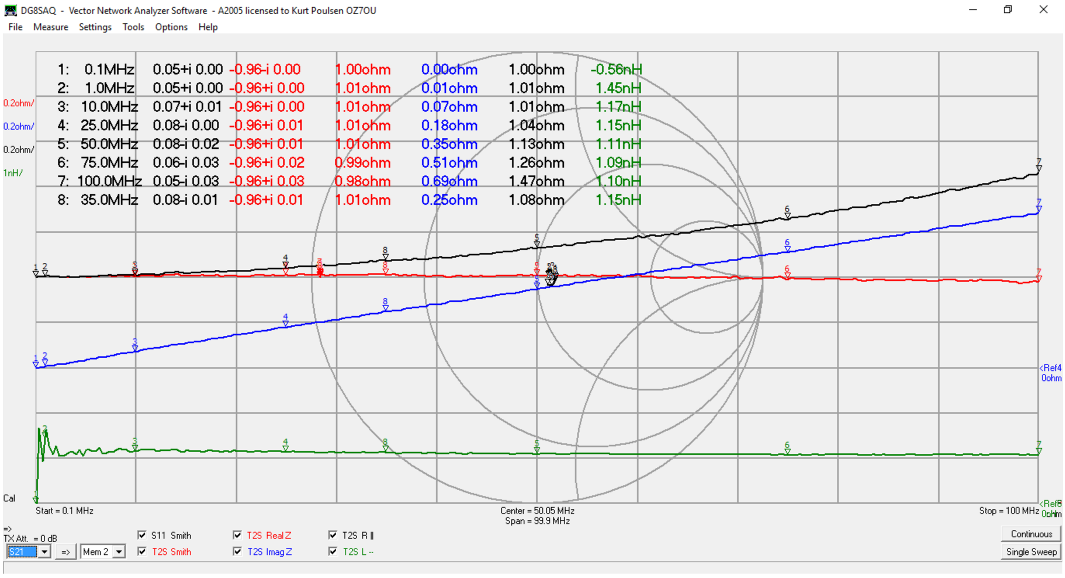


So as conclusion, this solution seems to be as good as we can expect it

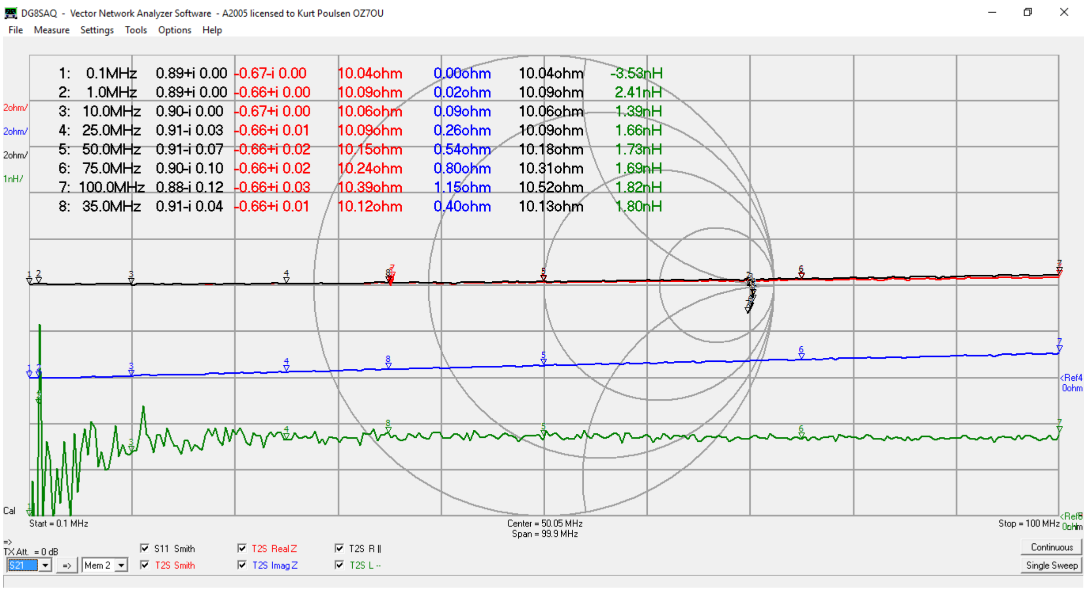
25.2.2019 Kurt Poulsen de OZ7OU See the APPENDIX on the next pages

APPENDIX 1% SMD 805 RESISTORS FITTED

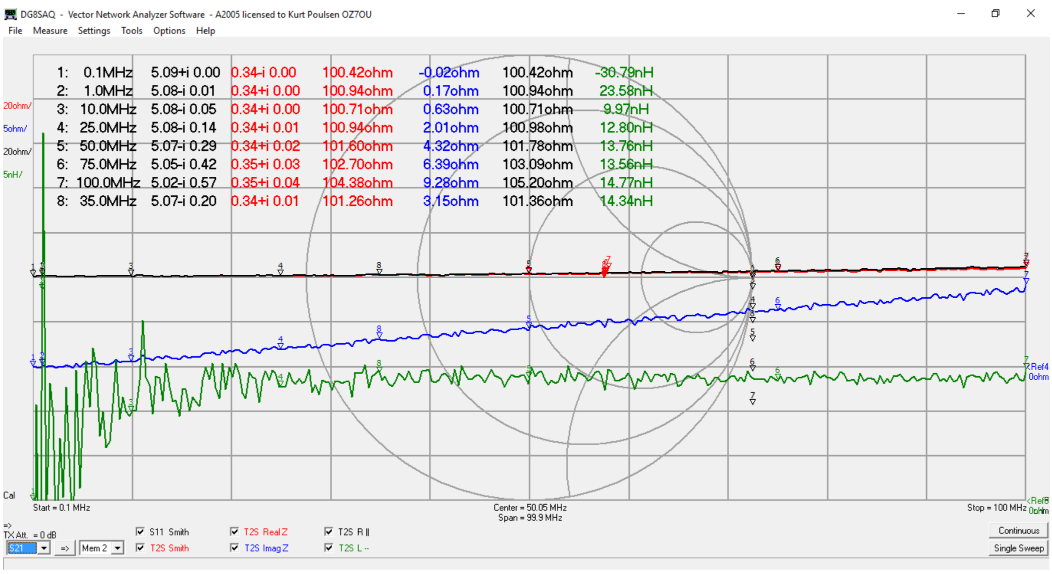
1ohm



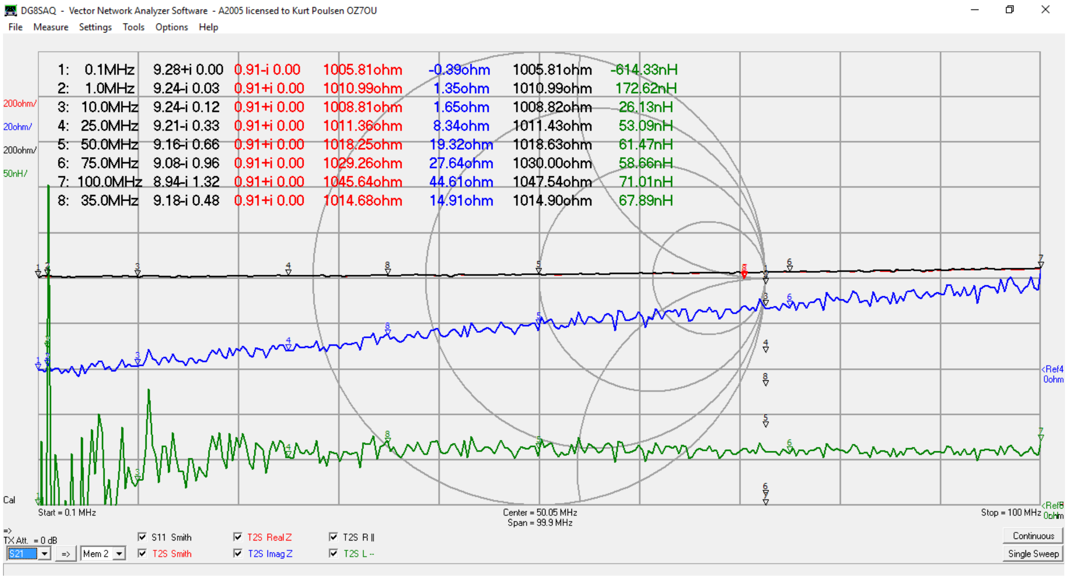
10ohm



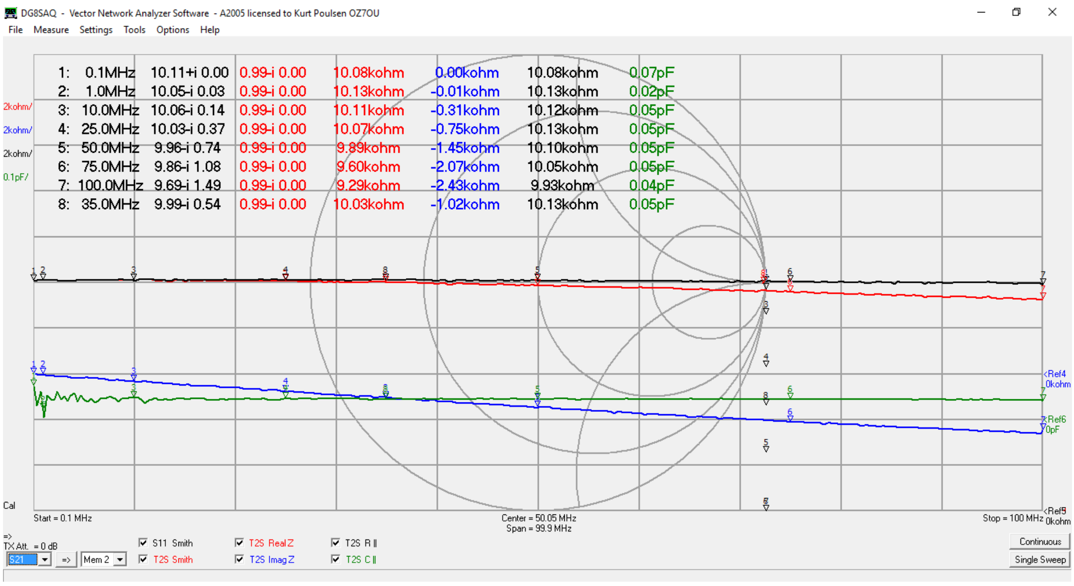
100ohm



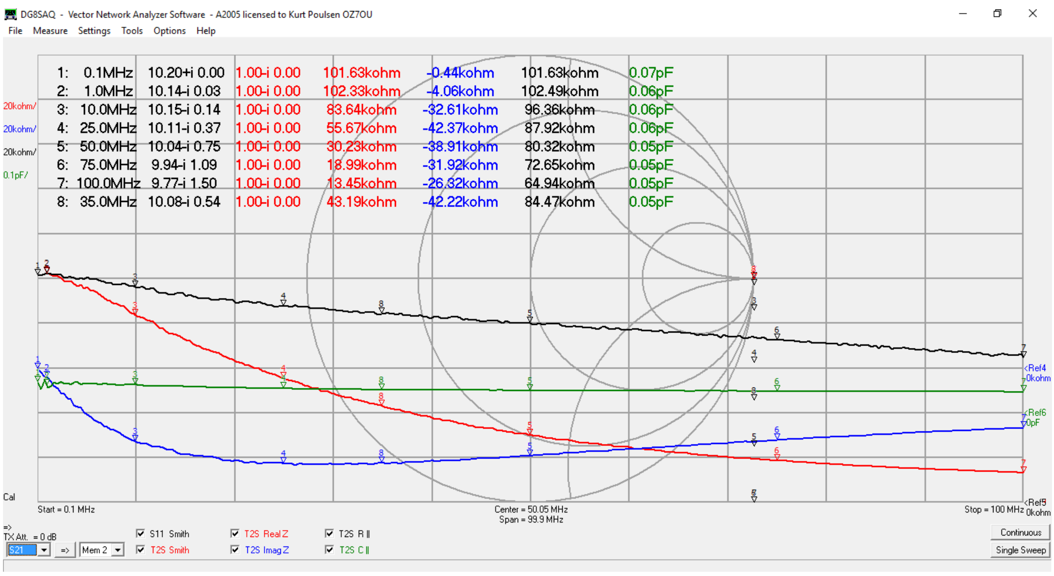
1Kohm



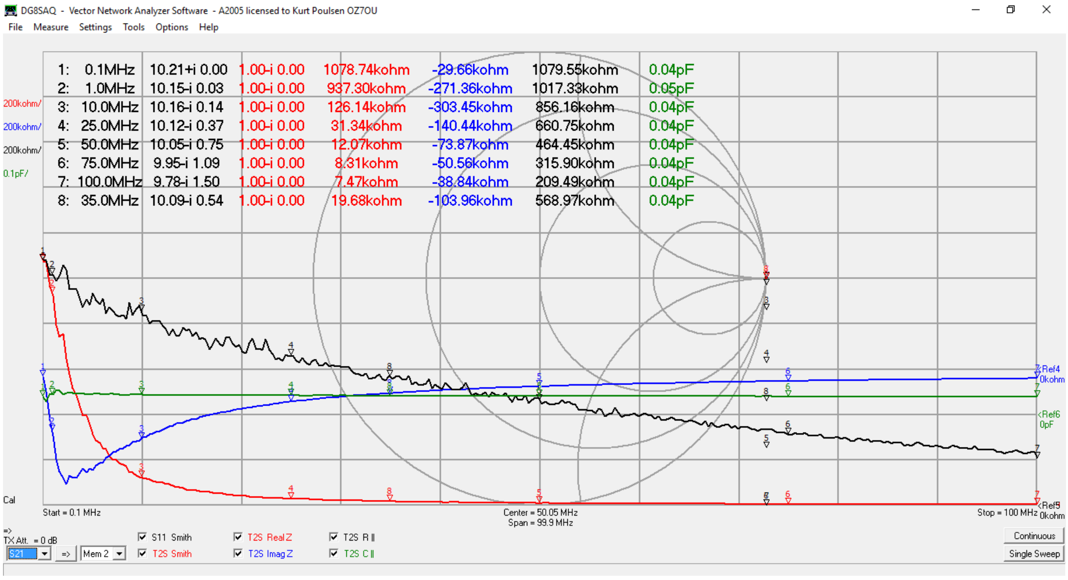
10Kohm



100Kohm



1Mohm



DG8SAQ - Vector Network Analyzer Software - A2005 licensed to Kurt Poulsen OZ7OU
File Measure Settings Tools Options Help
1: 0.1MHz 10.21+i 0.00 1.00-i 0.00 1078.74kohm -29.66kohm 1079.55kohm 0.04pF
2: 1.0MHz 10.15-i 0.03 1.00-i 0.00 937.30kohm -271.36kohm 1017.33kohm 0.05pF
3: 10.0MHz 10.16-i 0.14 1.00-i 0.00 126.14kohm -303.45kohm 856.16kohm 0.04pF
4: 25.0MHz 10.12-i 0.37 1.00-i 0.00 31.34kohm -140.44kohm 660.75kohm 0.04pF
5: 50.0MHz 10.05-i 0.75 1.00-i 0.00 12.07kohm -73.87kohm 464.45kohm 0.04pF
6: 75.0MHz 9.95-i 1.09 1.00-i 0.00 8.31kohm -50.56kohm 315.90kohm 0.04pF
7: 100.0MHz 9.78-i 1.50 1.00-i 0.00 7.47kohm -38.84kohm 209.49kohm 0.04pF
8: 35.0MHz 10.09-i 0.54 1.00-i 0.00 19.68kohm -103.96kohm 568.97kohm 0.04pF
200kohm/
200kohm/
200kohm/
0.1pF/
Cal
Start = 0.1 MHz
Center = 50.05 MHz
Span = 99.9 MHz
Stop = 100 MHz
Ref4 0kohm
Ref6 0pF
Ref5 0kohm
TX Att. = 0 dB
S21
Mem 2
S11 Smith
T2S Smith
T2S Real Z
T2S Imag Z
T2S R ||
T2S C ||
Continuous
Single Sweep