

## How to calibrate and measure a DUT like a toroid in shunt mode

### Preface:

There are 4 basic measurement methods to be used with the VNWA.

1. By ordinary S11 reflection methods where the DUT is measured at the TX reference plane after a SOL calibration.
2. Where the DUT is inserted between the RX and TX port after a Thru only calibration, a Thru calibration and that only and by custom trace converted from S21 to S11
3. Where the DUT is inserted between the RX and TX port after a SOLT calibration at the insertion point, without a Thru Match calibration. This method called virtual ground measurements. But required special calibration kits consisting of 10mm pin pin adaptor onto which a 50ohm SMD resistor soldered as load and pins shorted for short
4. Where a T Adaptor is inserted in the TX to RX port path and the DUT is measured at the reference plane of the T-adaptors third leg after a SOL calibration.

This report is dealing with method 4, as it is highly accurate for low impedances which is important for Q measurements of a coil and toroid. The shunt method allows also, when used with test adaptors as seen below, to verify the calibration and demonstrate the ability to measure accurate even for high impedances up to 10Kohm

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 have 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 lowers the resonance frequency. Using the extension port delay of the VNWA to offset the delay in the bulkhead adaptor toward its rear end, 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 takes place even at 50-ohm level.

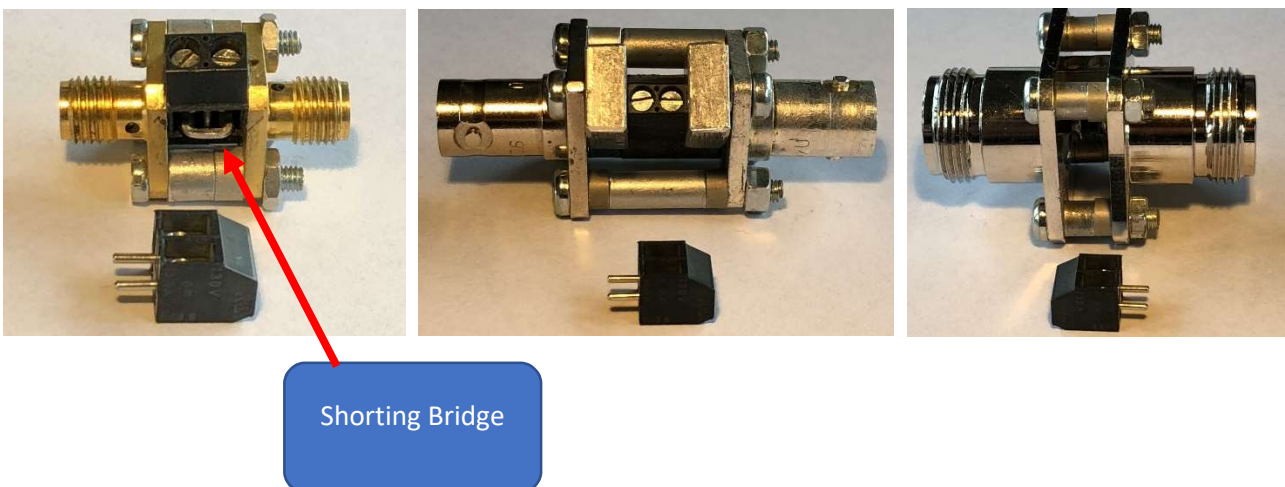
Using a type of Test Adaptor like the SMA, N and BNC Test Adaptor family shown below, fitted with a 2wide screw terminal block for easy mounting a shorting bridge during initial setup and calibration, and later on for mounting the DUT wire leads.

It is a far better method to use such test adaptors, and in this report, we will focus on measuring with highest accuracy the low ohmic values by using the shunt T method. It is of utmost importance when we want to measure Q values, to determine the serial resistance of e.g. a toroid or choke with precision.

However, it requires a specific way, after a standard SOL reflection calibration, that we remove the Test Adaptors S11 impedances from a S11 measurement of the DUT, by using custom traces. We must at first characterize the Test Adaptor, so it can be "taken out of the formula". How that is done is going to be explained in details in the following section so we **in fact, are getting away from the adaptor gender changer nightmare.**

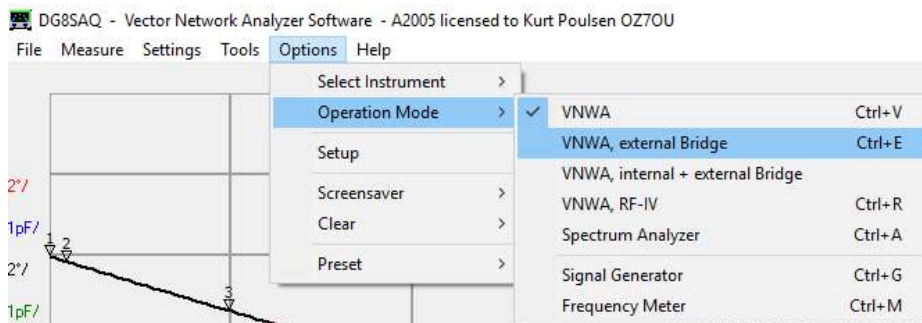
**That is what this report is all about.**

As an appendix 2 to this report is shown the complicated process if we should characterize the test adaptor when using the method 2, the S21 transmission method

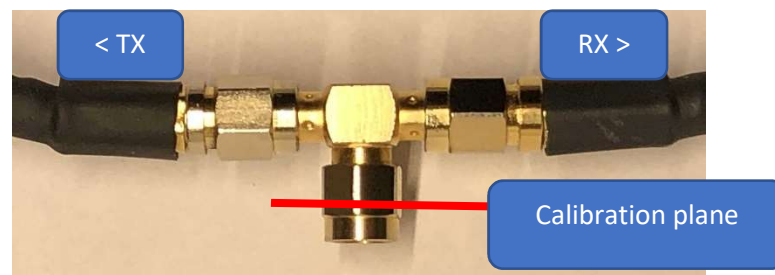


## The measurements using the T Adaptor Method

At first the VNWA must be switched to External Bridge mode

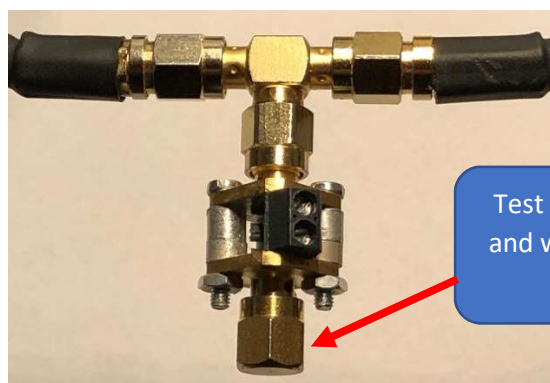
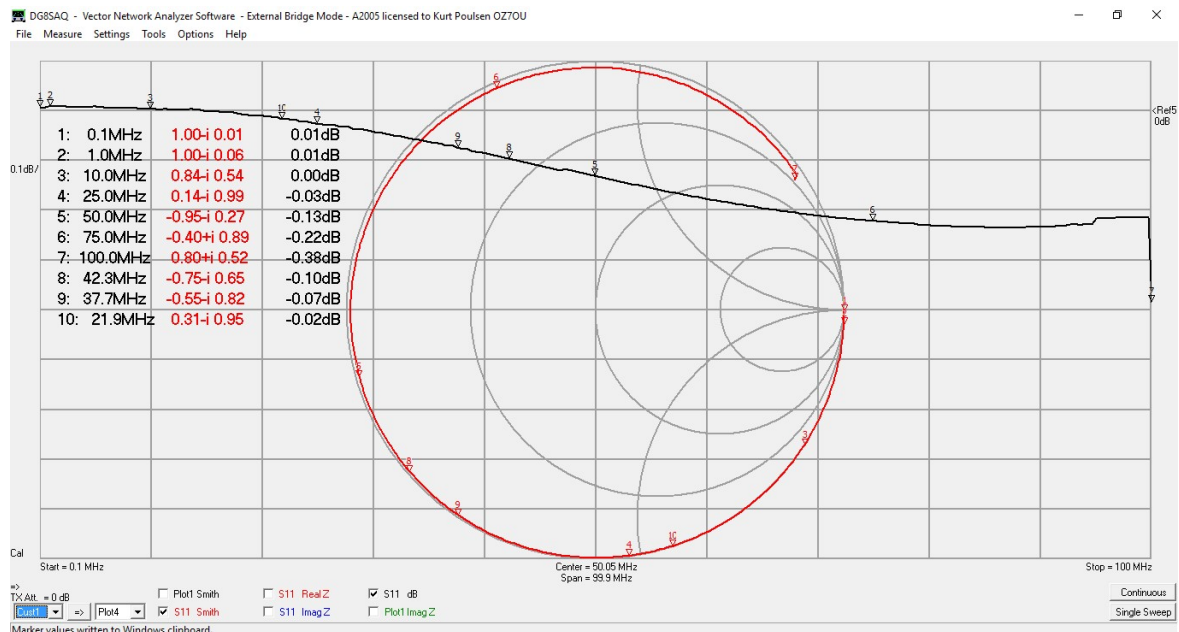


And a T adaptor fitted as shown below

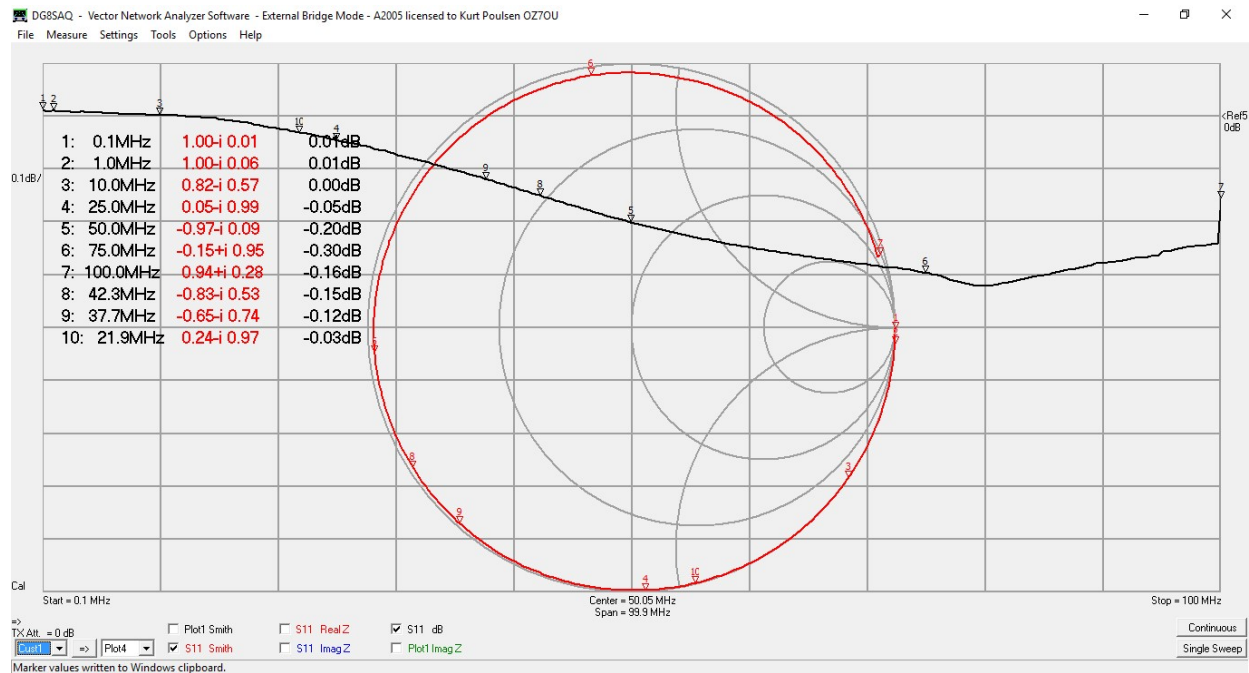


Perform a SOL calibration at the reference plane

A sweep of a 95cm long semi rigid cable with female SMA fitted to the Calibration plane, which show a perfect trace, and to be used as reference later on. Exported as a s1p file with the name "semirigid 95cm 0.1 to 100MHz"



The same 95cm semi rigid cable connected to the 2 wide terminal block of the test adaptor using a female bulkhead adaptor to which two 1 cm wires soldered to center conductor and ground, and a sweep performed. The meauremetn exported a a s1p file named “semirigid 95cm fitted to TA 0.1 to 100MHz”



As seen the sweep look very like the sweep when the semirigid cable is fitted to the calibration plane.

The whole idea is to measure the S parameter of the test adaptor, when the shorting bridge is fitted and also when it is removed and open, and then by a custom trace subtract these S parameters from the S11 measurements to come when a DUT is mounted in the 2wide terminal block. The shorting bridge has an inductance of 1.5nH which is also can be subtracted by the custom trace, if so desired, else just consider it a 2x2mm lead length of the DUT inserted into the 2wide terminal block.

NOTE!! Most likely you do not have a SMA, BNC or N male short to terminate the test adaptor, so you may just consider it as part of the test adaptor.

How such a custom trace look like we are going to see right away.

The screenshot shows the 'Enter Expression 2 for trace 6' dialog box. The 'Expression' field contains the formula  $z2s(s2z(s_m)-z_{TA\_s})$ . Below this, there is a table of 'Global Subexpressions' with columns for Name, Alias, and Expression. The table lists four subexpressions: Sub1 (Alias: z\_TA\_s, Expression:  $s2z(Mem1)-i*w*1.5e-9$ ), Sub2 (Alias: y\_TA\_o, Expression:  $s2y(Mem2)$ ), Sub3 (Alias: s\_m, Expression:  $y2s(s2y(S11)-y_{TA\_o})$ ), and Sub4 (Alias: , Expression: 1). At the bottom, there are fields for 'Aliases' (S21, S11, S12, S22, Mem1, Mem2, Mem3, Mem4, Mem5, Mem6, Mem7, Mem8, Mem9, Mem10) and a 'Caption' field (TTA). Buttons for 'ok', 'Save', and 'Load' are at the bottom.

Name	Alias	Expression
Sub1 =	z_TA_s	$s2z(Mem1)-i*w*1.5e-9$
Sub2 =	y_TA_o	$s2y(Mem2)$
Sub3 =	s_m	$y2s(s2y(S11)-y_{TA\_o})$
Sub4 =		1

In Mem1 is imported the S parameters of the test adaptor with shorting bridge fitted and in Sub1 with the Alias  $z_{TA\_s}$  we convert Mem1 from S parameter to Z parameter with the expression  $s2z(Mem1)$  and subtract at the same time the impedance of the 1.5nH shorting bridge  $i*w*1.5e-9$  **but normally not relevant only shown here to demonstrate it is possible so as standard set it to 0.0 in the custom trace. We may later benefit from this possibility**

In Mem2 is imported the S parameters of the test adaptor when shorting bridge is removed, and in Sub2 with Alias y\_TA\_o Mem2 is converted from S parameter to Y parameter by the Expression s2y(Mem2)

As the open adaptors shunt C is in parallel with the DUT we subtract it from the S11 measurement in Sub3 with the Alias s\_m (s parameter measured) by the expression y2s(s2y(S11)-y\_TA\_o) where S11 is converted to Y parameter by s2y(S11) from which we subtract Sub2 y\_TA\_o and convert the difference back to S parameter by y2s in front of the outer brackets.

Finally in the main expression z2s(s2z(m\_s)-z\_TA\_s) the S11 measurement is converted to Z parameter with the expression s2z(m\_s) from which we subtract the test adaptor impedance from Sub1 z\_TA\_s and convert the difference back to S parameter by the expression z2s in front of the outer brackets.

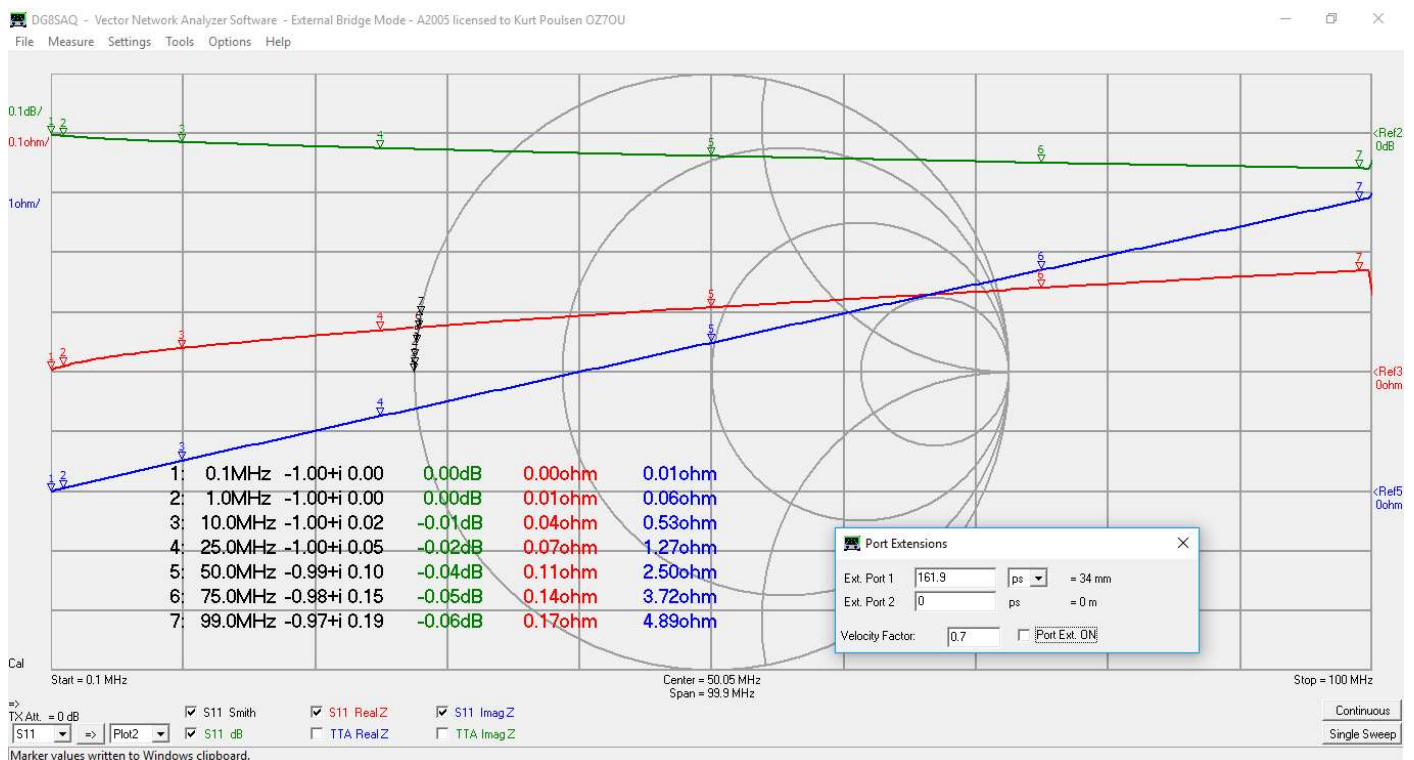
That is the process required to measure the DUT accurate, which will be proven in the following with one single further observation to deal with. If we subtract the shorting bridge impedance in the custom trace it will act like the DUT is placed physically forward along the path from the calibration plane to the Ops shorting male adaptor at the end of the test adaptor and the forward delay we have to enter in the Extension port delay of the VNWA, to offset this subtraction (which can be of interest to investigate) is easy to find as to be shown in the following.

Are there any impractical condition to consider?? Yes there is, as we shall consider to use adequate number of points when measuring a toroid coil as Q values are needing adequate number of points, at the low frequencies so about 600 50ms points seems a good choice.

Likewise we must consider the fact, that the two measured S parameters of the test adaptor are for a fixed frequency span and fixed number of point, which is a bit non flexible. We can with the VNWA Optimizer find a mathematical expression which allow a free choice of frequency span and number of points within the frequency range of which the two S parameters of the test adaptor are measured.

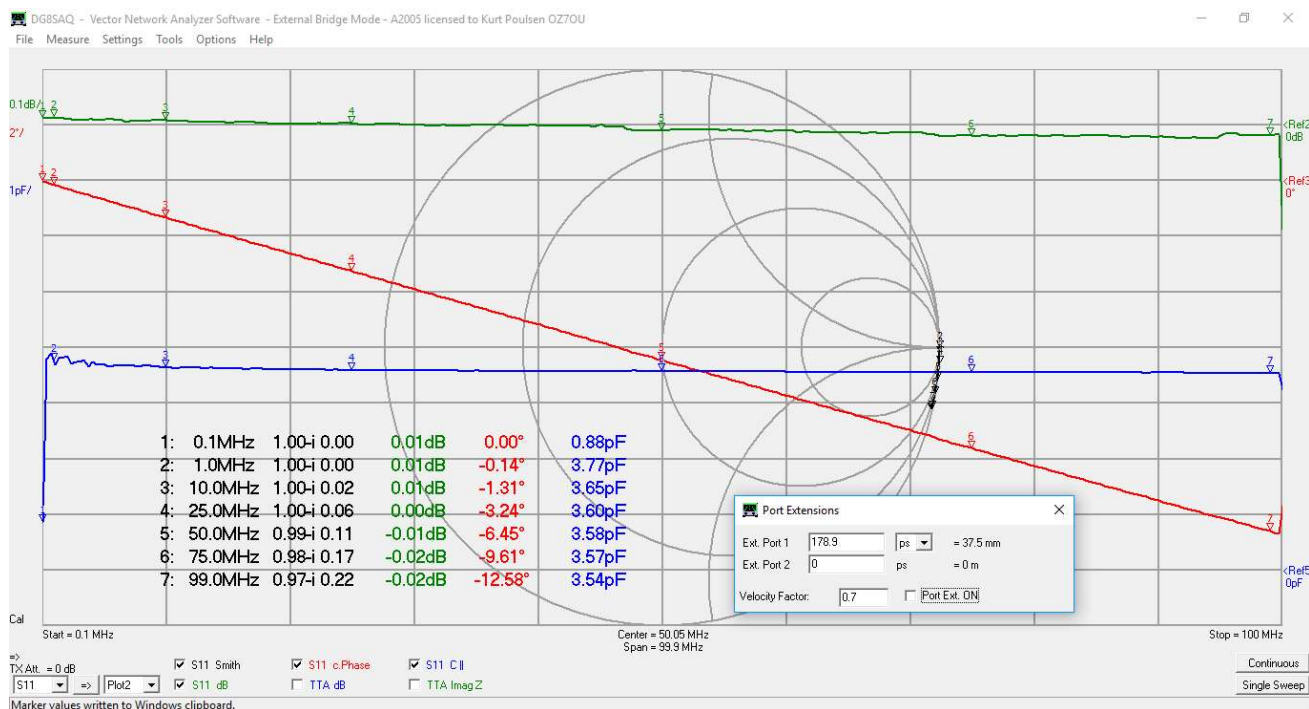
These S parameter expressions are then substituting the (Mem1) and (Mem2) within the brackets, but at first, we shall prove the basis concept, using a frequency span of 0.1 to 100MHz and 300 100ms points. This will demonstrate the comments about number of points, when measuring a Toroid coil and displaying Q values.

The measurement of the test adaptor with shorting bridge was exported a s1p file named "S11 of TA Short T method 0.1 to 100MHz 300 100ms points" and next imported to S11. As seen the RealZ increases nonlinear with frequency and the inductive part ImagZ is neither linear with frequency which can be seen if Ext. Port delay is activated, with 161.9ps and the Imagz then "horizontal" with 0 ohm up to some 25MHz and slightly dropping by a small fraction to 100MHz





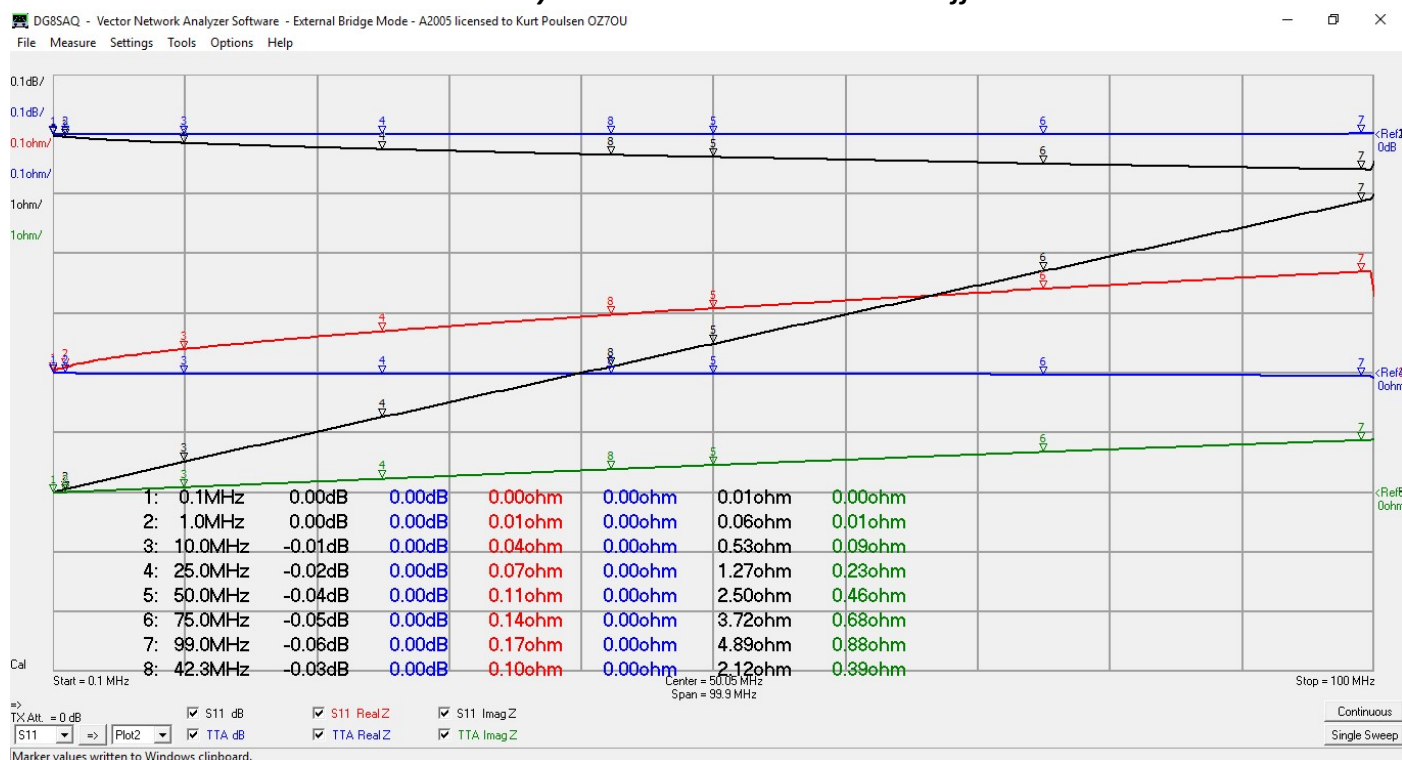
The measurement of the test adaptor, with shorting bridge removed and exported as a s1p file named "S11 of TA open T method 0.1 to 100MHz 300 100ms points" now imported to S11. The measurement shows a shunt C of about 3.6pF. Enabling a Ext. Port delay of 178.9ps and tune shunt C tuned to 0pF at 50MHz results in -0.05pF at 99MHz and +0.19pF at 1MHz. The reason why the two Ext port delays - short and open - is not identical, is simply that the test adaptor is not a 50ohm transmission line system which the Ext. Port delay assumes.



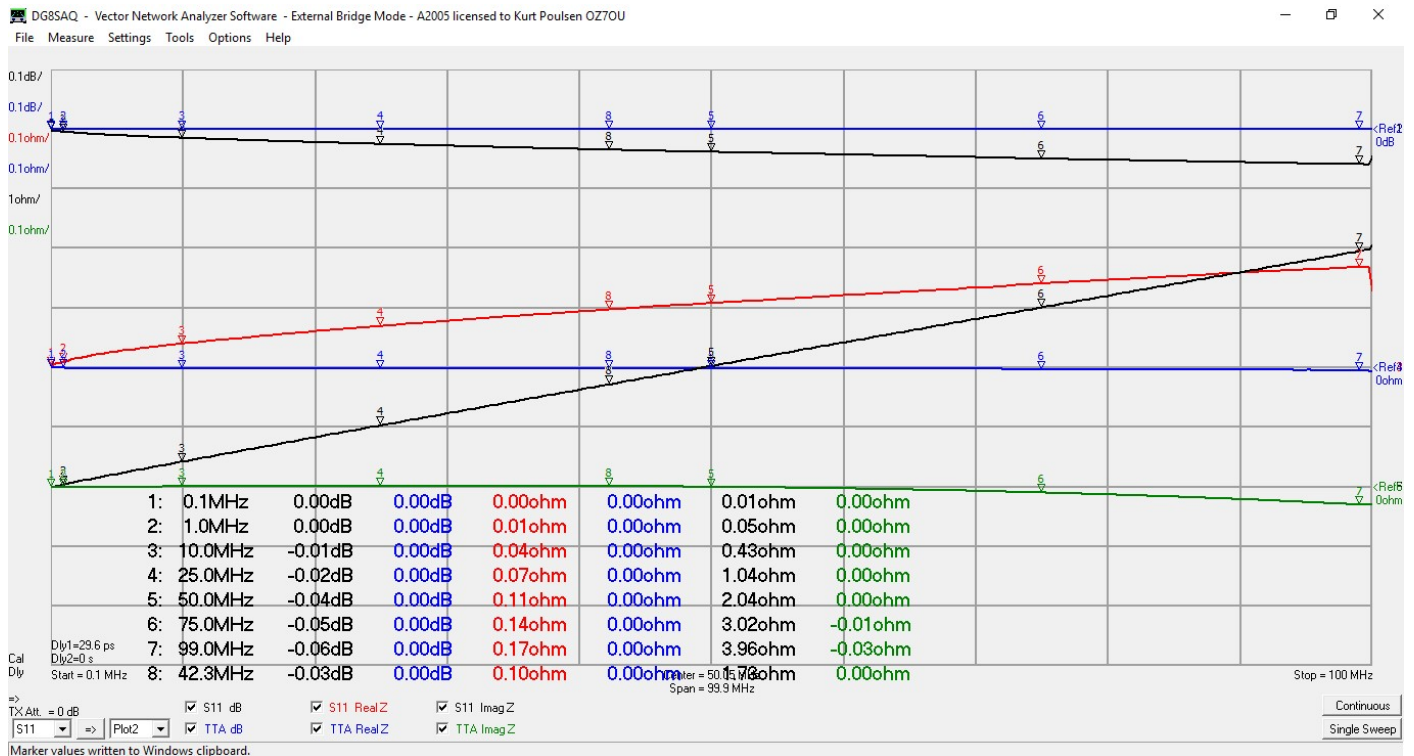
### Does the custom trace work??

**Yes, it does.** After creation of the Custom trace and enable a sweep with the shorting bridge in place we see following traces for the S11 and TTA custom traces. Remark the custom trace is as shown above with the shorting bridge inductance subtracted.

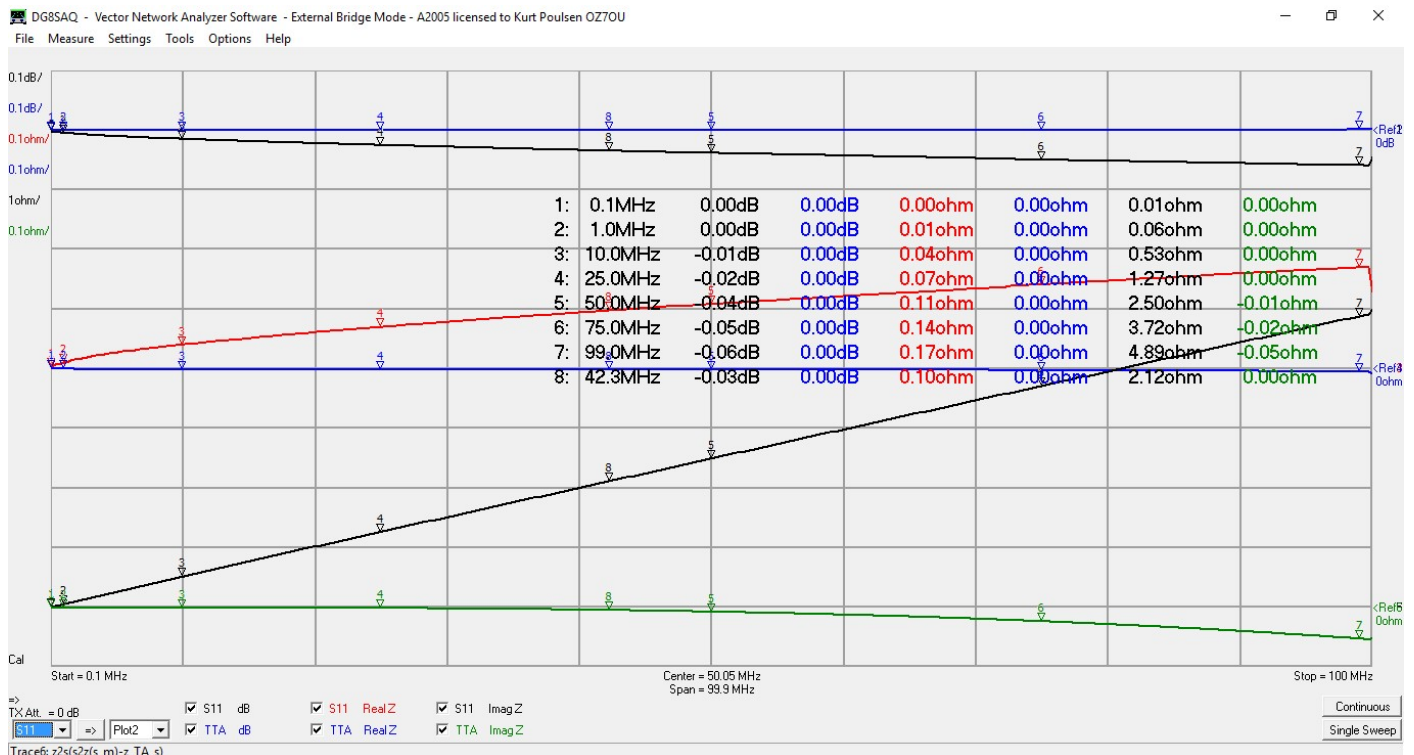
The return loss trace2 is 0dB, the RealZ Trace4 is 0 ohm and the ImagZ has a negative inductance introduced (ImagZ positive) due to the subtraction of the shorting bridge inductance in the custom trace. Adding an Ext. Port delay we can find what we must have enabled to offset the subtraction **if we subtract the inductance at all, which is not normal to do as earlier commented and only introduced to demonstrate the effect.**



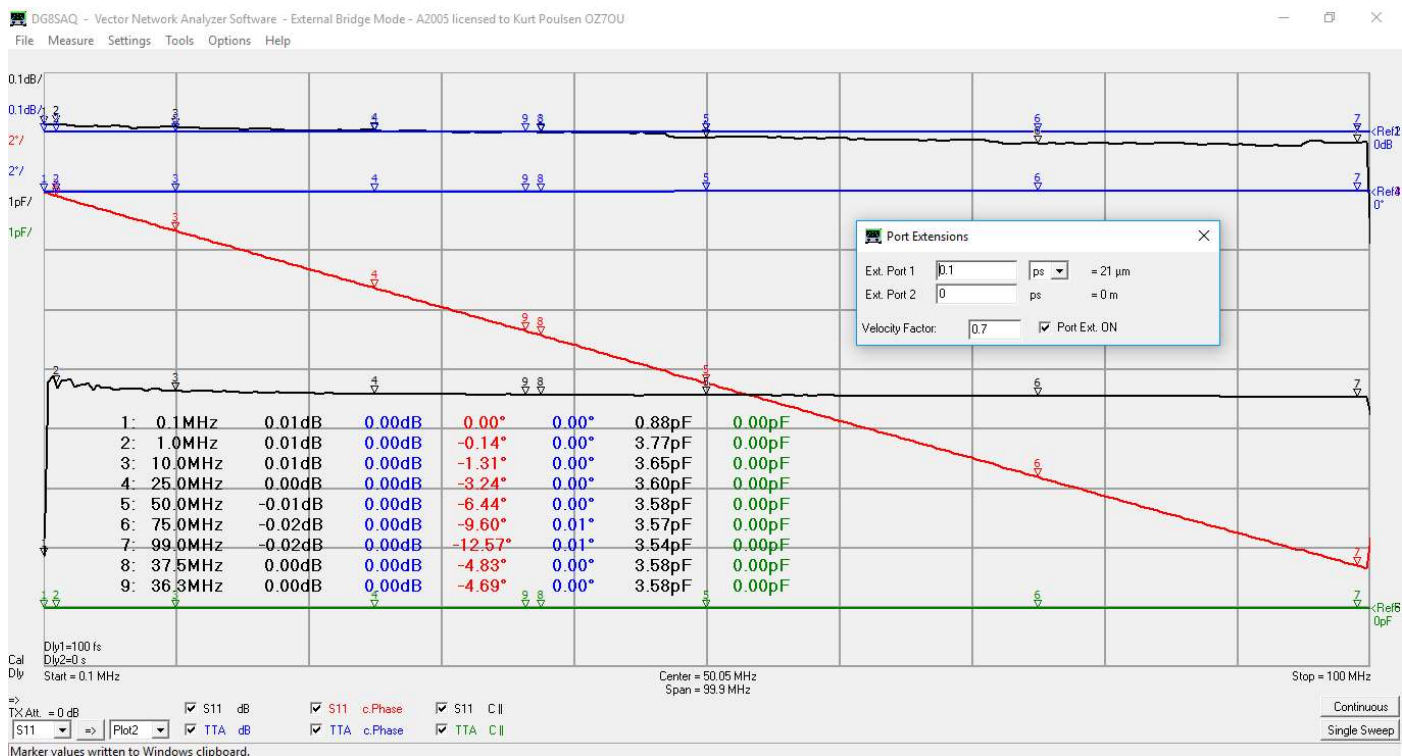
As seen for trace 6, with ImagZ changed to 0.1ohm/div, the required Ext. Port delay is 29.6ps, and the frequency dependency causes an error at 99MHz of 0.03ohm which is fully acceptable.



When the custom trace does not subtract the shorting bridge inductance (set to 0.0), the ImagZ traces is “straight” with the insignificant error at 99MHz of 0,05ohm

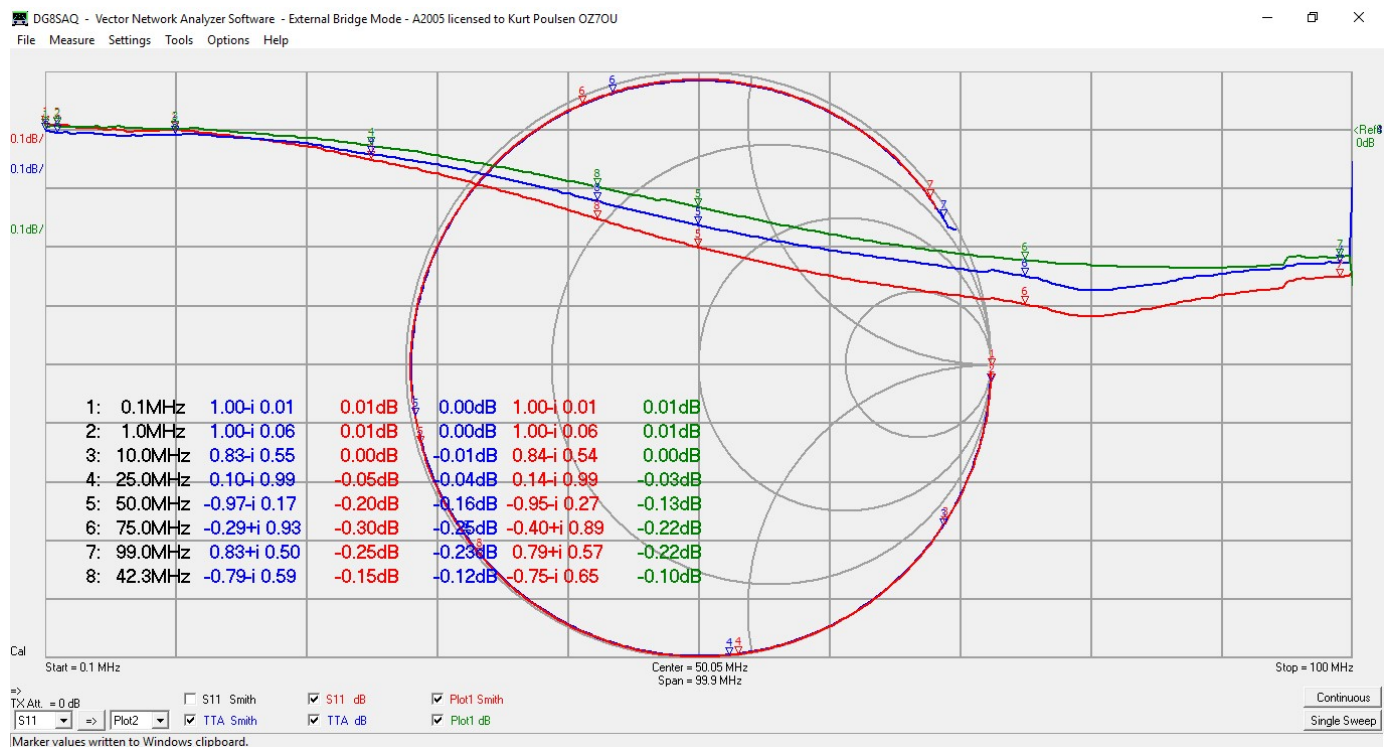


When importing the exported s1p file for the test adaptor named “S11 of TA open T method 0.1 to 100MHz 300 100ms points” and applying an extension port delay of 0.1ps all TTA traces turn to 0. That is another reason why the shorting bridge inductance as standard shall not be subtracted, as then shorted and open test adaptor is in sync with respect to Ext. Port delay as not needed.



The 95cm semi rigid cable sweep, when fitted as a DUT with 2x1cm pin pin adaptor leads soldered to a SMA Bulkhead adaptor, is also corrected with the custom trace.

With respect to the insertion loss in dB, the green trace6 for Plot1 is the sweep when mounted directly to the calibration plan. The blue TTA trace 2 is the corrected trace by the custom trace, and the red trace3 is the uncorrected sweep Imported into S11. The two Smith chart traces are by the red Plot1 trace for the sweep at calibration plane and the Blue TTA trace2 as treated by the Custom Trace. The Ext. port delay of 29.6ps does not changed anything worth mentioning and the two sweeps displayed in the Smith chart are so to speak identical.



Conclusion so far:

Despite the task to characterize your test adaptor and create the custom trace and determine the Ext. Port delay not to use ☺, it is quite easy to get going, in particular if you save the setup to a zipped instrument state file, as then everything is memorized such as trace settings, custom Trace Mem1 and Mem2 content. However, a SOL calibration might be an idea if you have done other task and might use other test cables or swapped those you have.

From scratch the procedure is:

Import the s1p file for the test adaptor with shorting bridge fitted to Mem1 named

“S11 of TA Short T method 0.1 to 100MHz 300 100ms points”

Import the s1p file for the test adaptor with shorting bridge removed to Mem2 named

“S11 of TA open T method 0.1 to 100MHz 300 100ms points”

Open any number of the Custom Trace but leave one S11 trace enabled e.g. Smith Chart, else no sweep possible

Start measuring

### Creating a mathematical model for the test adaptor

To freely select frequency span and number of points it is beneficial to create two expression for the test adaptor to substitute the content of Mem1 and Mem2 in the custom trace.

For that purpose, import at first the s1p file for the test adaptor with the shorting bridge fitted to S11. You may do a measurement from 0.03 to 100MHz of 0.03 to 500MHz to have more options or any other frequency span you fancy. Next open the VNWA Optimizer.

The way the optimizer work is that you enter some variables given an Alias and an estimated value not far from what is expected in this case an inductor  $l$  of 10nH and a resistor  $r$  of value 1 ohm. By clicking on optimize the Optimizer does a best fitting to S11 and save it to a trace called  $s_{11}$  or just as it is named “Opt.Expr.” in the drop-down list, so you just study the S11 trace and the  $S_{11}$  trace to see how good a fitting is obtained. Let give it a try although we know there is frequency dependency of the test adaptors impedance.

Optimizer - Model Fitting Tool

File Load Save Model Settings Optimize

Optimizer Splines

Expression to be globally fitted to S11 Simulation stored to s\_11

☐ in restricted frequency range 0 MHz to 0.0013 MHz

z2s(i\*w\*l+r)

Name	Alias	Subexpression (available in main expression, subexpressions may use other subexpressions from below)
Sub1		1
Sub2		1

Variable	Alias	Real Value	Delta	Optimize
x1	l	1.000000000000E-008	1.0E-009	<input checked="" type="checkbox"/>
x2	r	1.000000000000E+000	1.0E-001	<input checked="" type="checkbox"/>
x3		1.000000000000E+000	0.0E+000	<input type="checkbox"/>
x4		1.000000000000E+000	0.0E+000	<input type="checkbox"/>
x5		1.000000000000E+000	0.0E+000	<input type="checkbox"/>
x6		1.000000000000E+000	0.0E+000	<input type="checkbox"/>

Figure of Merit = 1150 (should be as small as possible)

21:26:21 : Model loaded from VNCommon.ini

Right-click to load a descriptive text or picture!



Quite natural the Optimizer find the average of the RealZ to be 0.1039 ohm and the inductance to be 7.91nH including the shorting bridge. So, the model needs to be more sophisticated. Notice the figure of Merit to see how it improves when better models are created. The Delta exponent setting are normally two decades smaller than for the value e.g. E-011 versus E-009.

**Optimizer - Model Fitting Tool**
✕

File Load Save Model Settings Optimize

Optimizer | Splines

Expression to be globally fitted to S11 Simulation stored to s\_11

☐ in restricted frequency range 0 MHz to 0.0013 MHz

$z2s(j\omega l+r)$

Name	Alias	Subexpression (available in main expression, subexpressions may use other subexpressions from below)
Sub1 =		= 1
Sub2 =		= 1

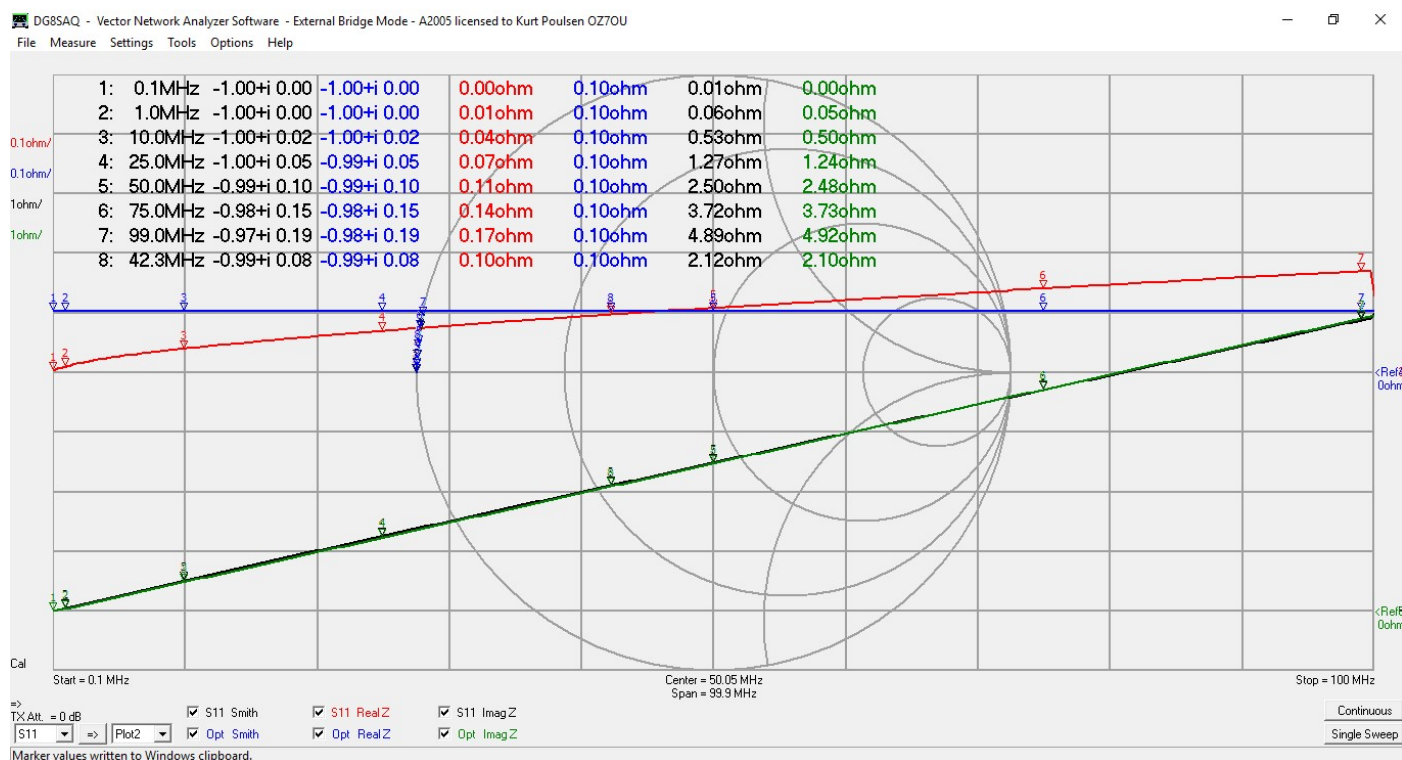
Variable	Alias	Real Value	Delta	Optimize
x1 =	$l$	= 7.907561161933E-009	1.0E-011	<input checked="" type="checkbox"/>
x2 =	$r$	= 1.039049161325E-001	1.0E-003	<input checked="" type="checkbox"/>
x3 =		= 1.000000000000E+000	0.0E+000	<input type="checkbox"/>

Figure of Merit = 0.00111 (should be as small as possible)

# function calls = 45

21:26:21 : Model loaded from VNCommon.ini

Right-click to load  
a descriptive text  
or picture!



By a little cut and try a perfect model and match is obtained with a figure of Merit=4.81E-5 hard to do better  
 Save the model for later use e.g. for a different frequency span.

So the expression to enter instead of Mem1 in the custom trace is by substituting the Alias in the main expression  
 $z2s(i*w*L+dL*f+R*sqrt(f)+dR*f^2)=z2s(i*w*8.1128E-009-2.7369E-018*f+1.397E-005*sqrt(f)+3.4075E-018*f^2)$

Optimizer - Model Fitting Tool

File

Load

Save Model

Settings

Optimize

Optimizer

Splines

Expression to be globally fitted to

S11

Simulation stored to

s\_11

☐ in restricted frequency range
 

0

 MHz to 

0.0013

 MHz

$z2s(i*w*L\_TA+R\_TA)$

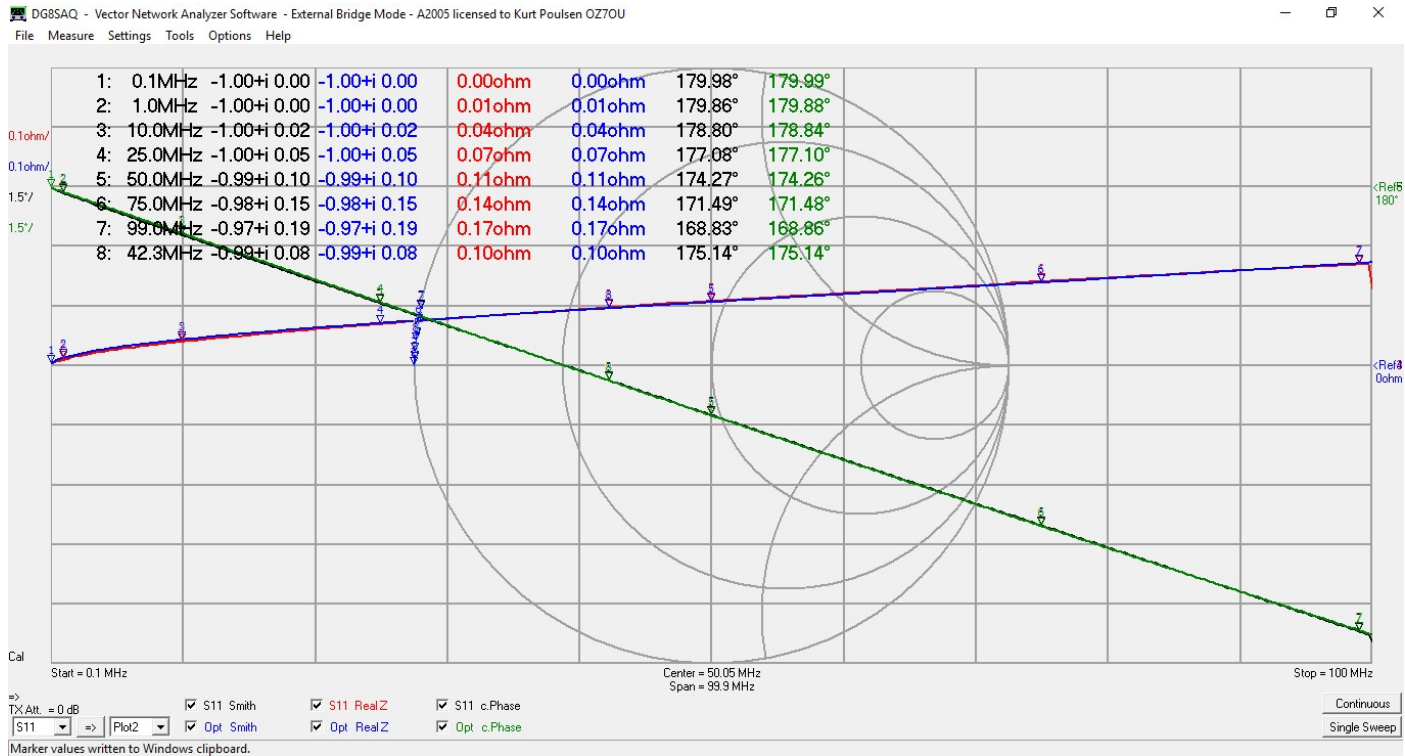
Name	Alias	Subexpression (available in main expression, subexpressions may use other subexpressions from below)
Sub1 =	R_TA	$R*sqrt(f)+dR*f^2$
Sub2 =	L_TA	$L+dL*f$
Sub3 =		1
Sub4 =		1
Sub5 =		1

Variable	Alias	Real Value	Delta	Optimize
x1 =	L	8.112847773185E-009	1.0E-011	<input checked="" type="checkbox"/>
x2 =	R	1.397042578775E-005	1.0E-007	<input checked="" type="checkbox"/>
x3 =	dR	3.407549357774E-018	1.0E-020	<input checked="" type="checkbox"/>
x4 =	dL	-2.736948117015E-018	1.0E-020	<input checked="" type="checkbox"/>
x5 =		1.000000000000E+000	0.0E+000	<input type="checkbox"/>

Figure of Merit = 4.81E-5 (should be as small as possible)  
 # function calls = 68

Right-click to load  
 a descriptive text  
 or picture!

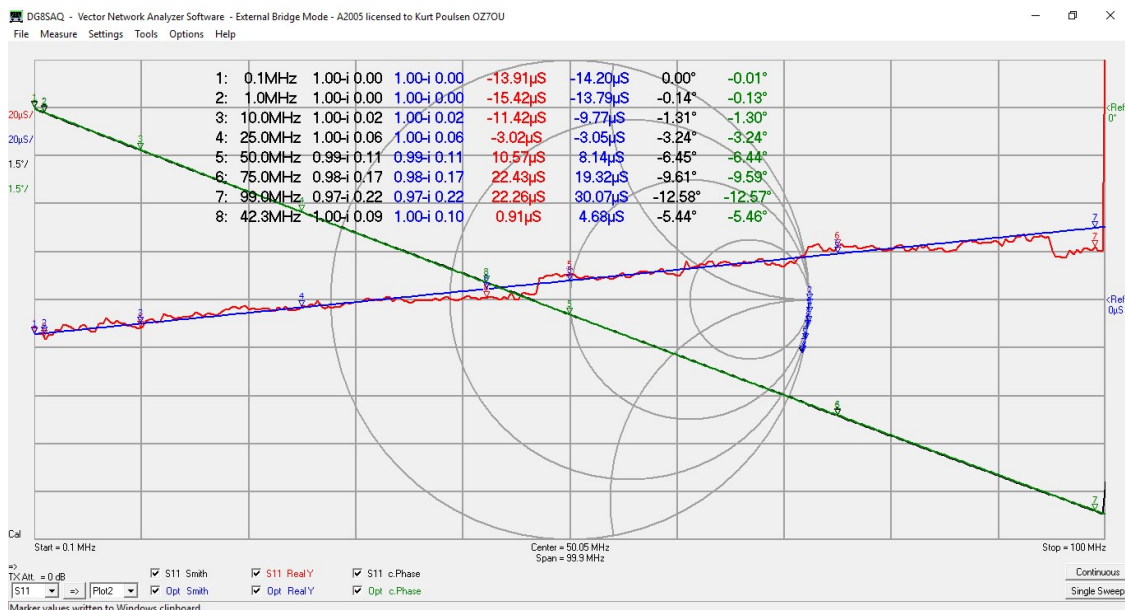
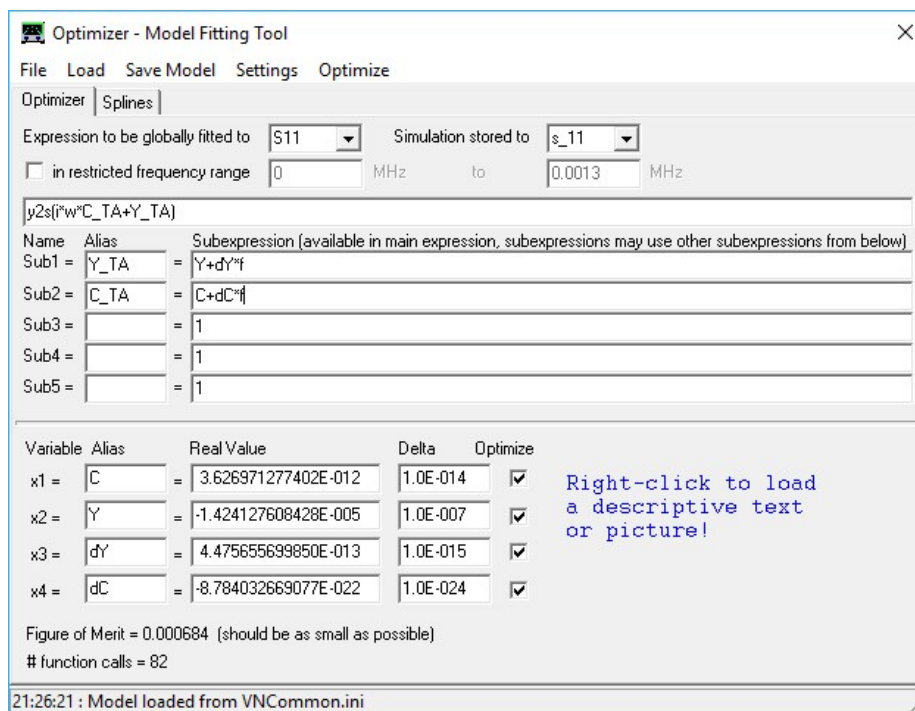
21:26:21 : Model loaded from VNCommon.ini



Same procedure performed by the s1p for the test adaptor with shorting bridge removed

The expression to enter instead of Mem2 in the custom trace is

$y2s(i*w*C+dC*f+Y+dY*f)=y2s(i*w*3.627E-012-8.784E-022*f-1.4241E-005+4.4757E-013*f)$



After modification of the Custom Trace there is no longer need for any import to Mem1 and Mem2

A small refinement has been added as Lx now represent the inductance of the shorting bridge, which just might be considered as 2mm of the DUT leads and thus set to 0.0e-9 else if we want to subtract it because short leads/wires are added for measuring the DUT, we can then enter the inductance accordingly.

Cx are added to subtract additional shunt capacitance introduced due to e.g. added leads/wires for measuring the DUT.

How to figure out your Shorting Bridge or extra lead/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.

Enter Expression 2 for trace 4:

Expression:  
 $z2s(s2z(s_m)-z\_TA\_s)$

Global Subexpressions (available in all expressions, subexpressions may use other subexpressions from above):

Name	Alias	Expression
Sub1 =	$z\_TA\_s$	$s2z(z2s((i*w*8.1128E-009-2.7369E-018*f+1.397E-005*sqrt(f)+3.4075E-018*f^2))-i*w*Lx$
Sub2 =	$y\_TA\_o$	$s2y(y2s((i*w*3.627E-012-8.784E-022*f-1.4241E-005+4.4757E-013*f))+i*w*Cx$
Sub3 =	$s_m$	$y2s(s2y(S11)-y\_TA\_o)$
Sub4 =	$Lx$	$0.0e-9$
Sub5 =	$Cx$	$0.0e-12$

Aliases:

S21 =  S11 =  S12 =  S22 =

Mem1 =  Mem2 =  Mem3 =  Mem4 =  Mem5 =

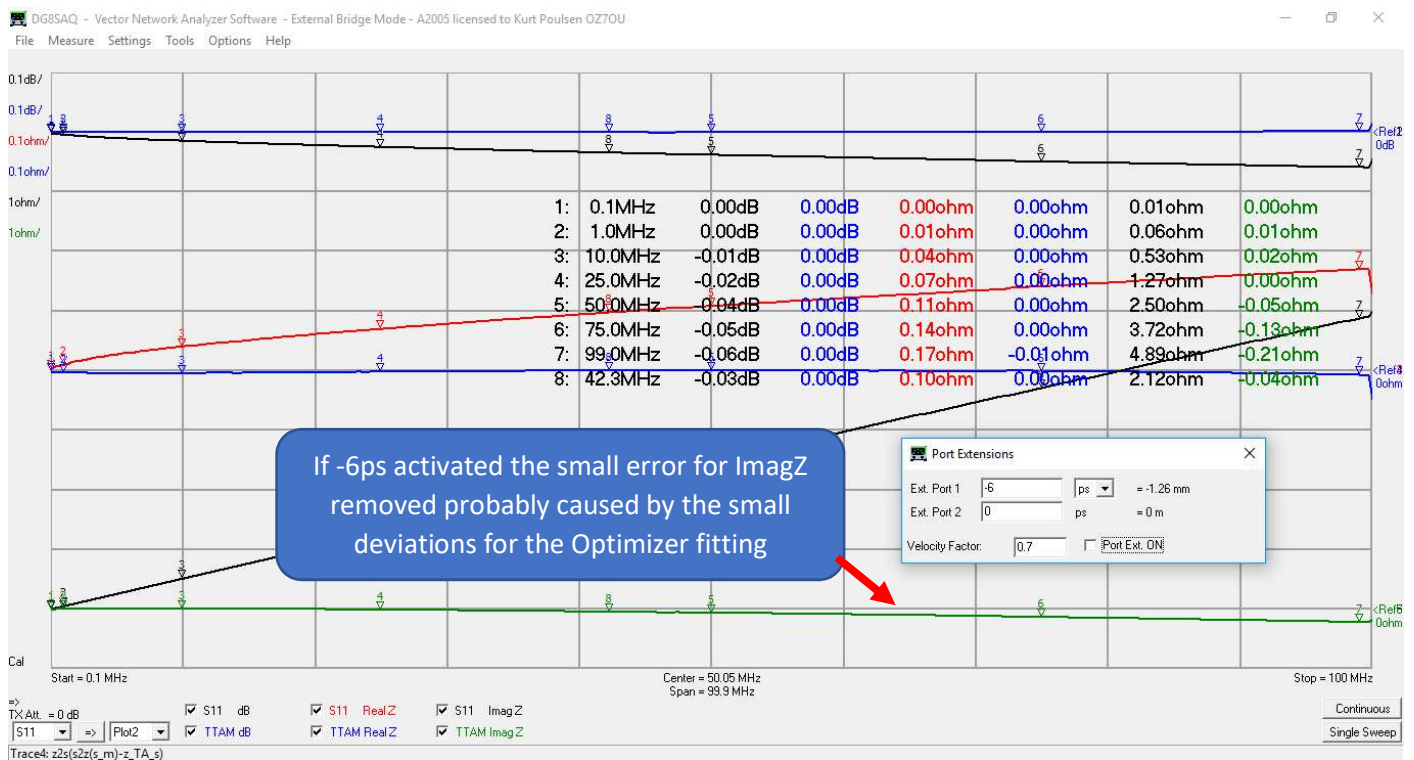
Mem6 =  Mem7 =  Mem8 =  Mem9 =  Mem10 =

no Errors

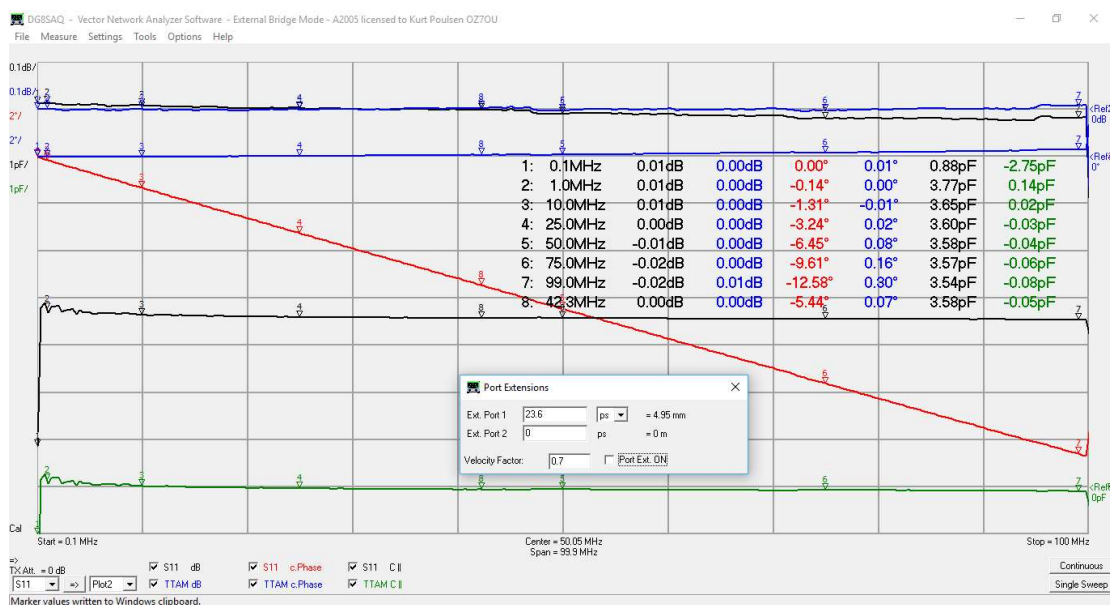
Caption:

ok Save Load

The custom trace still works as before here for the s1p file for the test adaptor with shorting bridge imported to S11

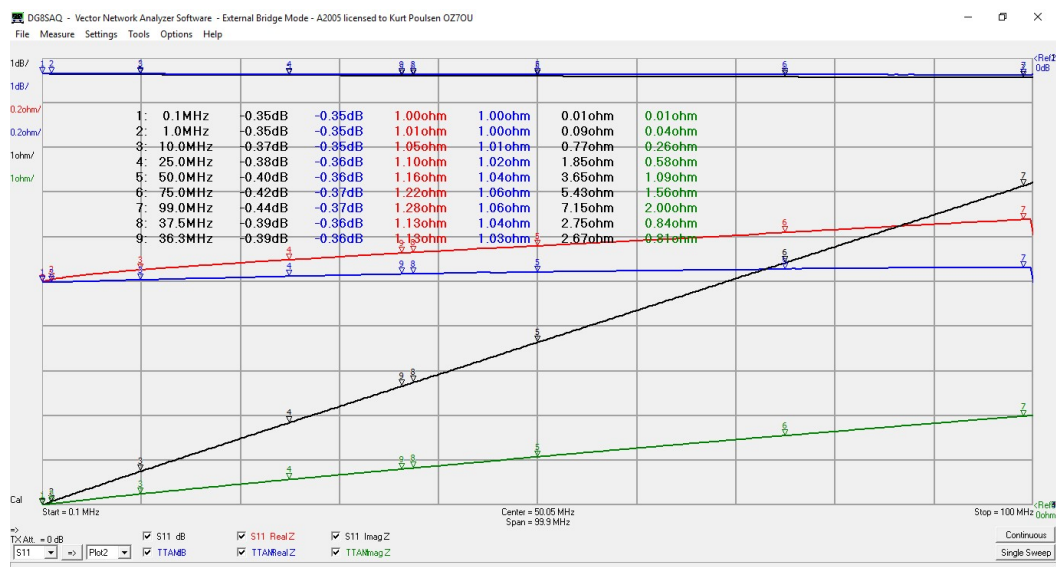


The custom trace also works as before for the s1p file for test adaptor with shorting bridge removed imported to S11

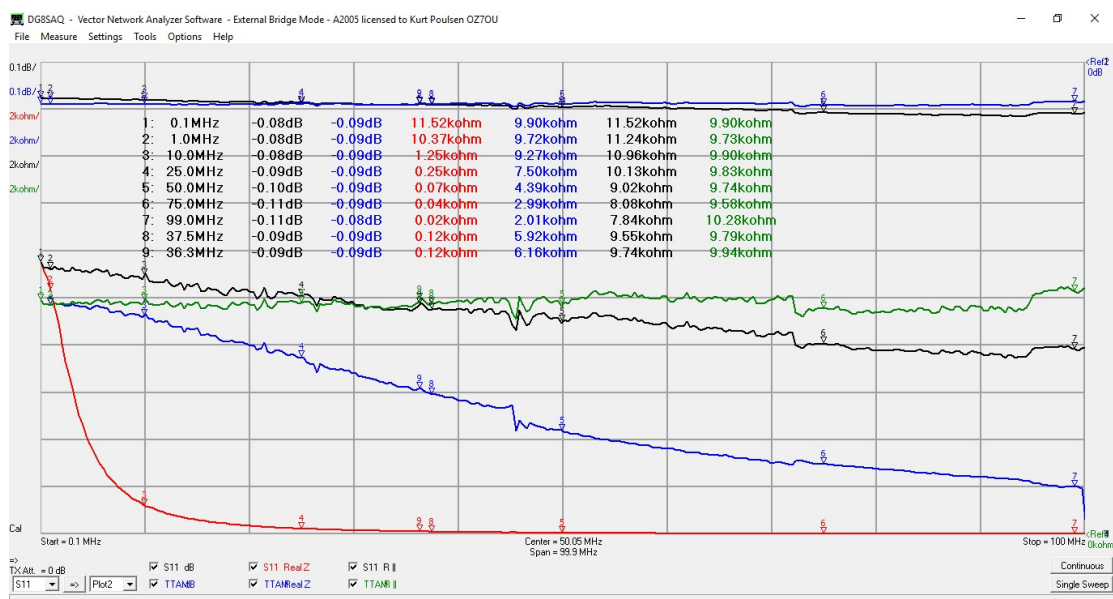




In the Appendix 1 test are made for measuring some SMD resistors from 1 to 10Kohm done before the mathematical custom trace was created, So here a sniff test with the mathematical custom trace for 1ohm and 10Kohm. The ImagZ are due to the pin pin lead length of 2x10mm, to which the SMD resistor are soldered. 1 0hm at 1.06ohm at 100MHz.



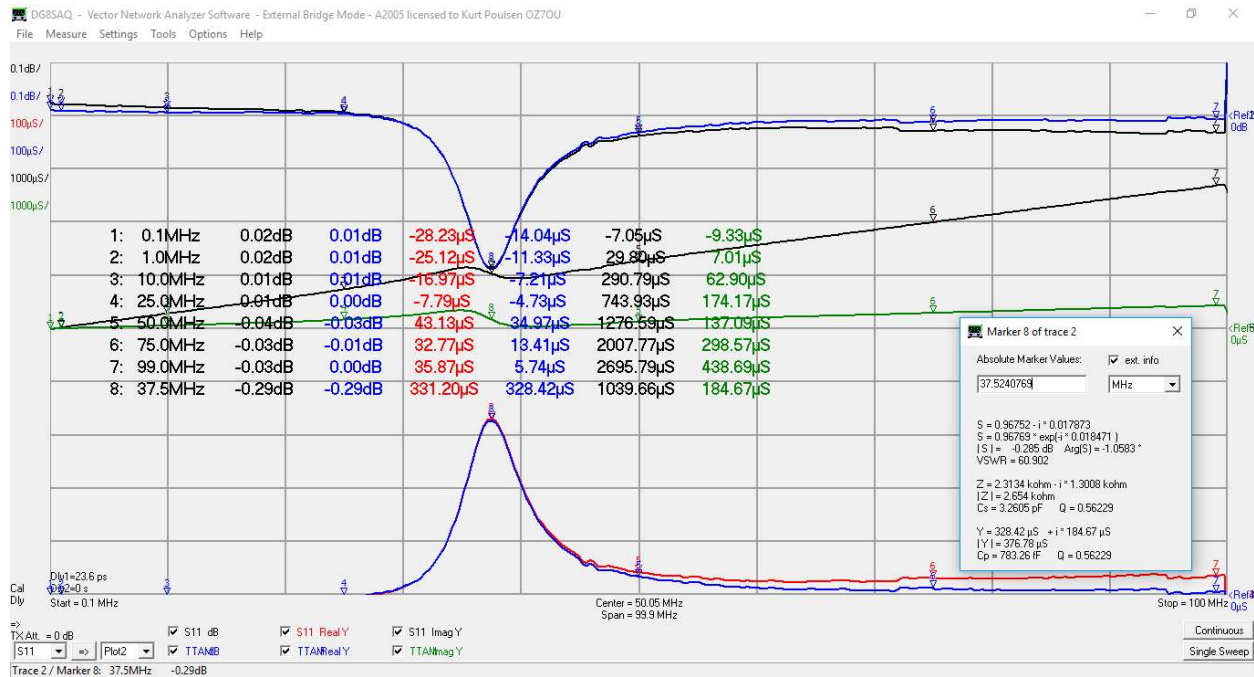
The only reliable measurement is TTAM RII and is within 3% to 99MHz, so the measurements at 10Kohm are excellent even the Shunt measurement technique as earlier noted does not promises such accuracy.



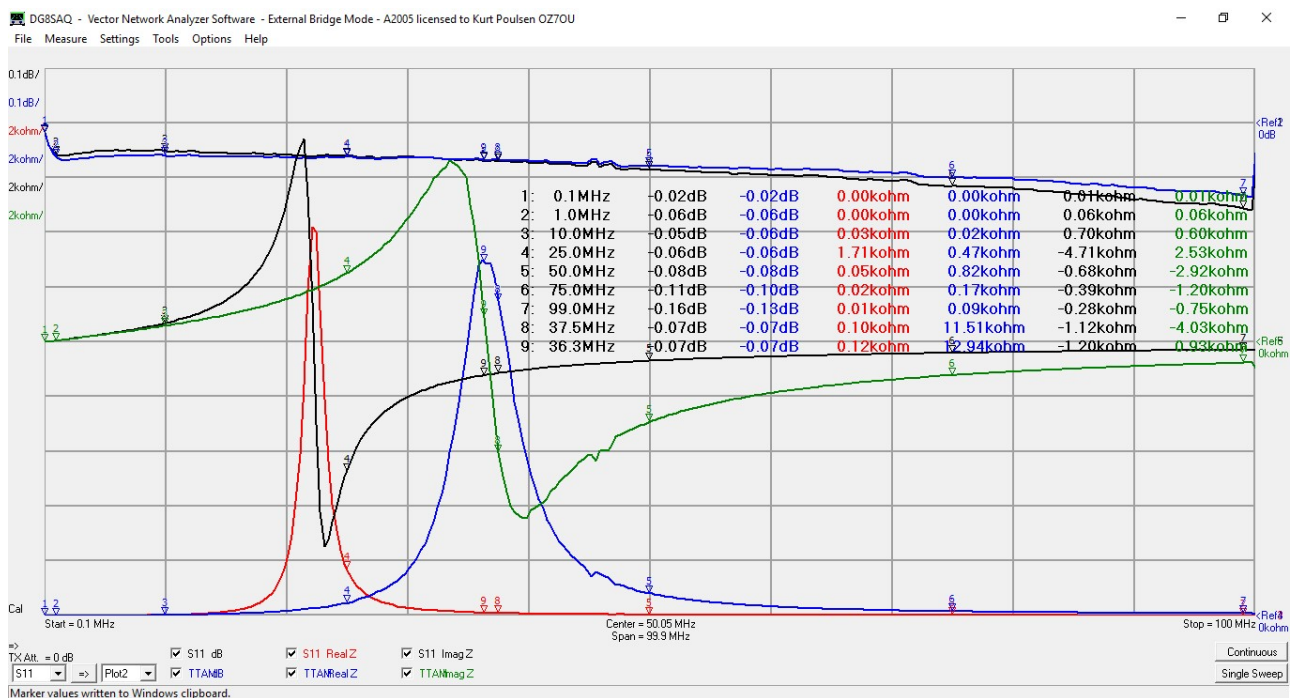
## Finding the self-resonance of a 22-winding toroid



One of the toroid wires are connected to the TX side of the 2wide terminal block and the other wire left into open air away from the 2wide terminal block. A distinct dip in the 0.1dB/div S11 trace indicate the self-resonance frequency of 37.52MHz

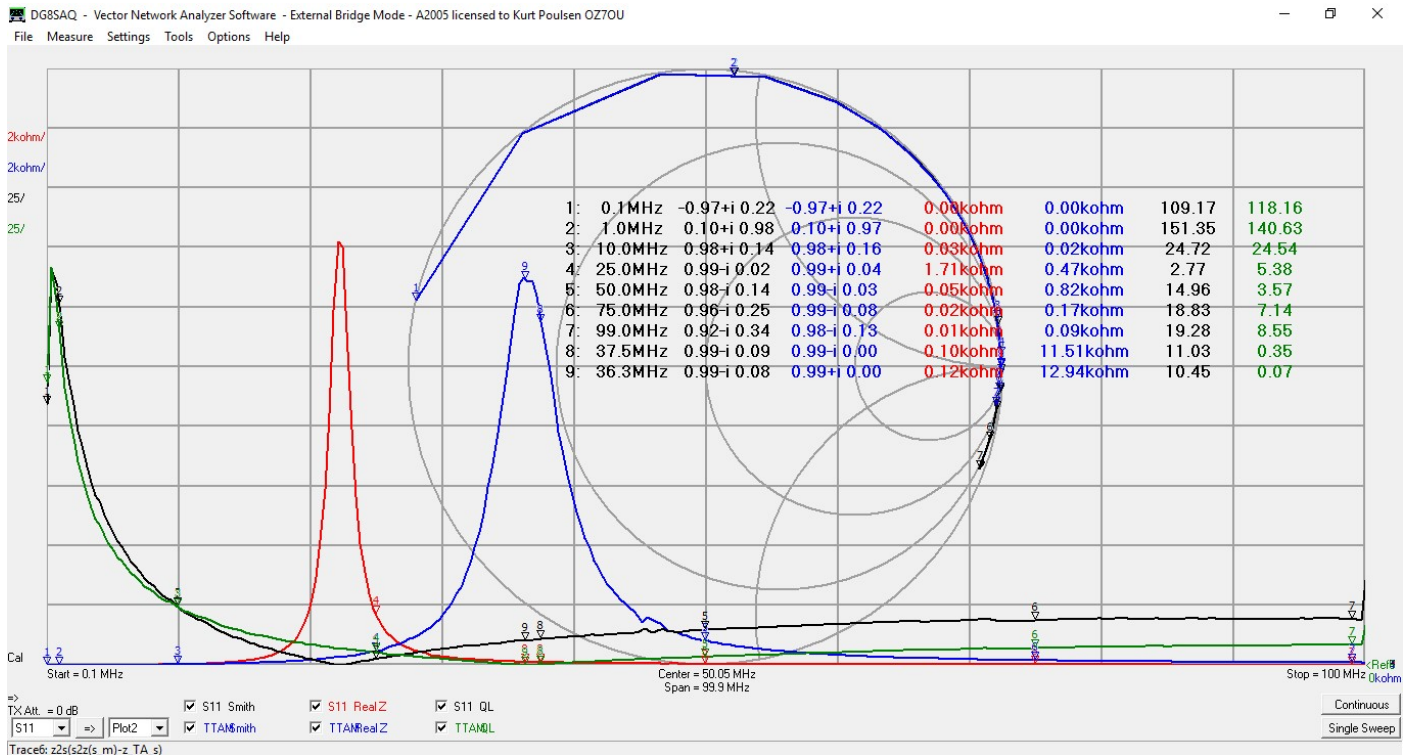


Measurement of the toroid mounted as DUT in the 2wide terminal block show a resonance frequency 36.3MHz. The shift to a lower frequency is caused by a capacitance increase of 0.13pF, which can be explained by an increase in the capacitance between the two wires of the toroid, now closer to each other than during above measurements. Anyway, it is probably not possible to hit better measurements results than as done here. Self-resonance is not a stable condition as influence by external “nearby” item such as mounted towards a wall in a plastic case or worse in a metal case

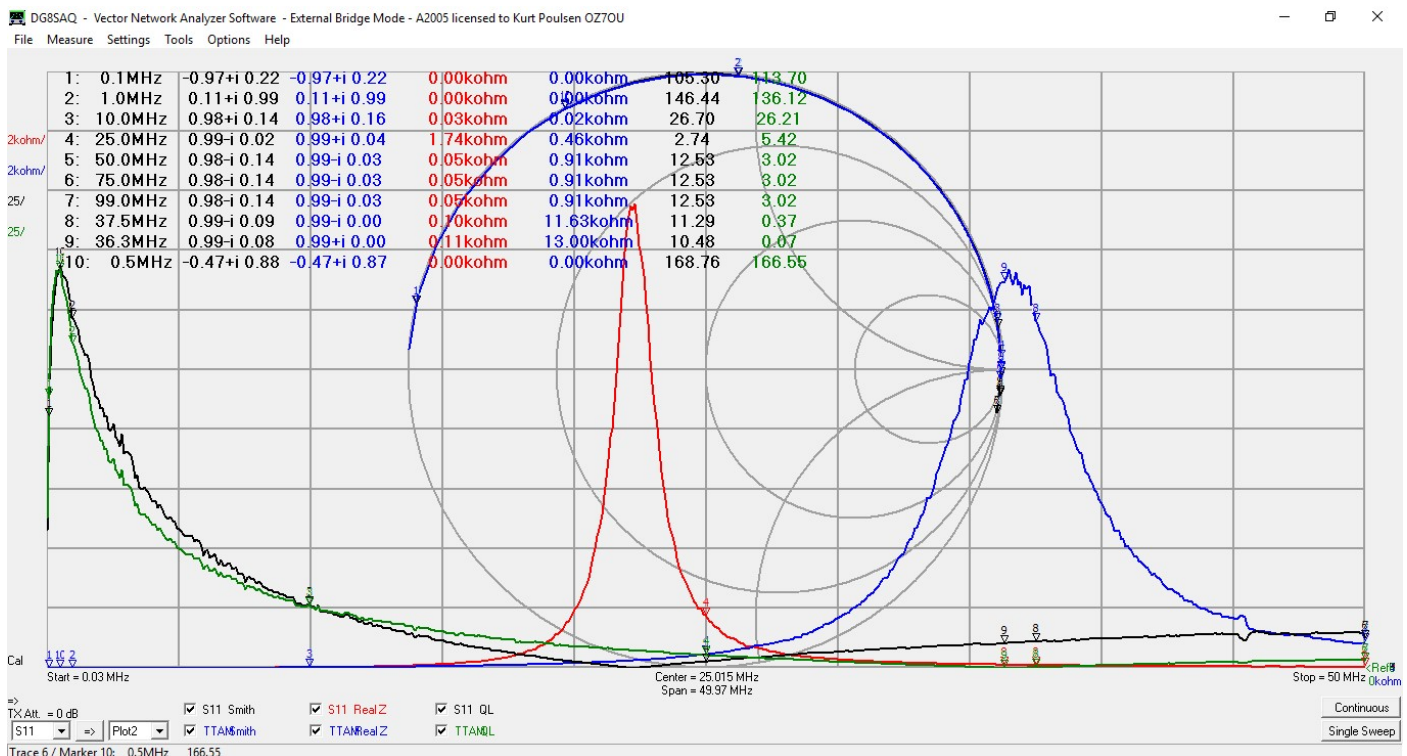


## Q traces

It is obvious that the number of point (300) are too few for Q measurements, in particular seen from the Smith Chart traces. So, we will now benefit from the Custom trace with mathematical models and change number of points to 600 with 50ms per point and change frequency span to 0.03 to 50MHz. It requires only a new SOL calibration at the calibration reference point.



A maximum Q of 167 at 0.5MHz and maximum is not dependent of the Custom Trace only frequency dependence as both RealZ and ImagZ measured correctly by the custom trace TTAM.



## Final Comments:

Mission completed and the possibility to measure using short test leads with crocodile clips fitted to the 2way terminal block, will be dealt with in a separate document

12-3-2019 Kurt Poulsen



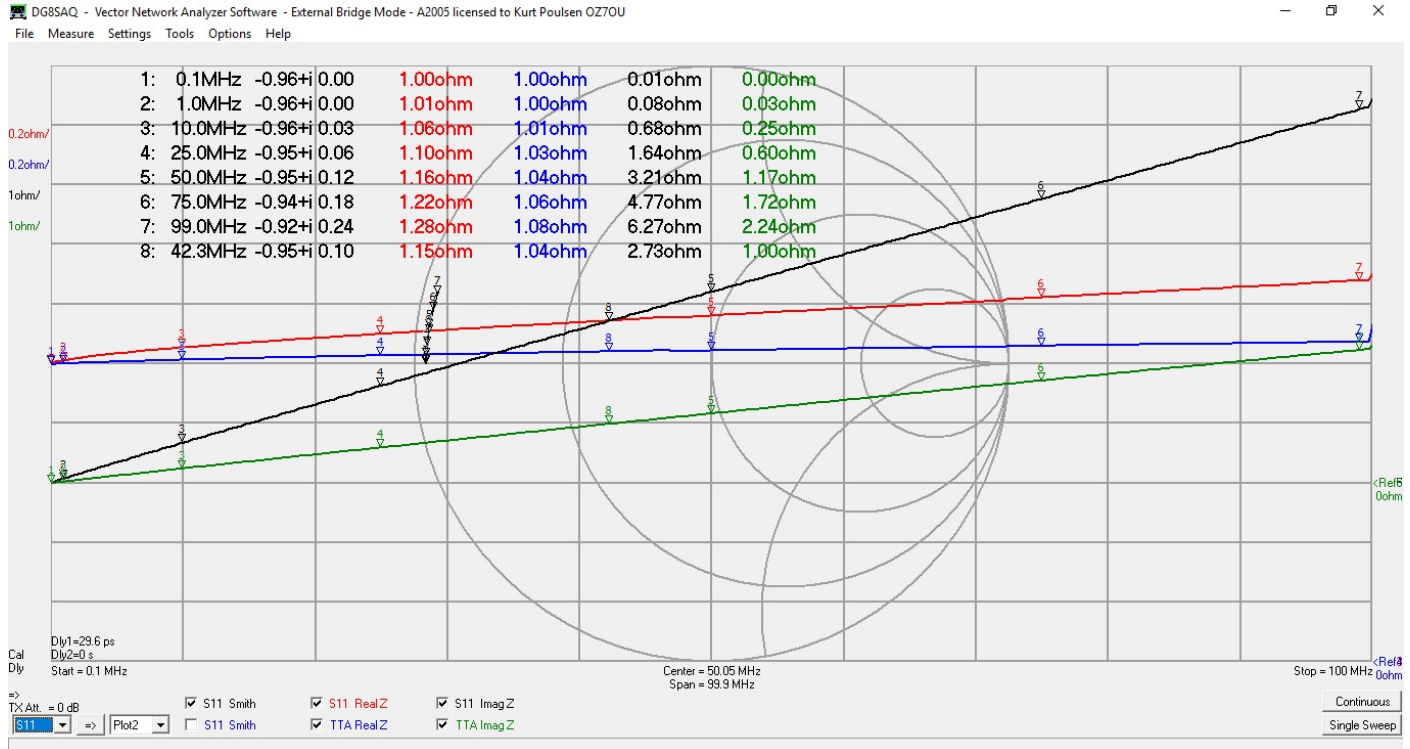
## Appendix 1

### Measurement accuracy test

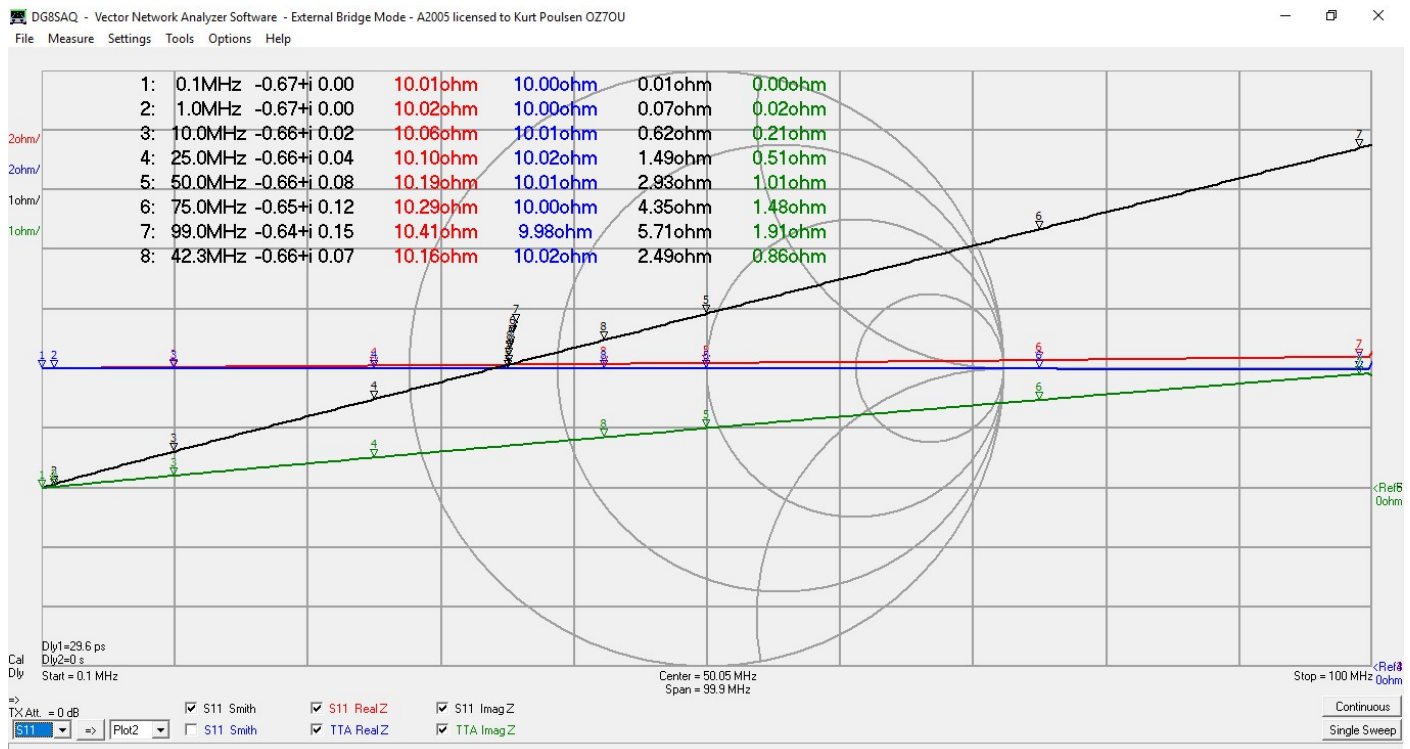
To Proof the concept, we will measure some SMD 1% resistor of 1, 10, 100, 1K, and 10K ohm.

The Shunt measurement method is having the highest accuracy at low ohmic measurements so up to 10K ohm will be excellent if measured correctly.

1 ohm fitted the high ImagZ content due to the pin pin adaptor used with 2x10mm pin length with no compensation

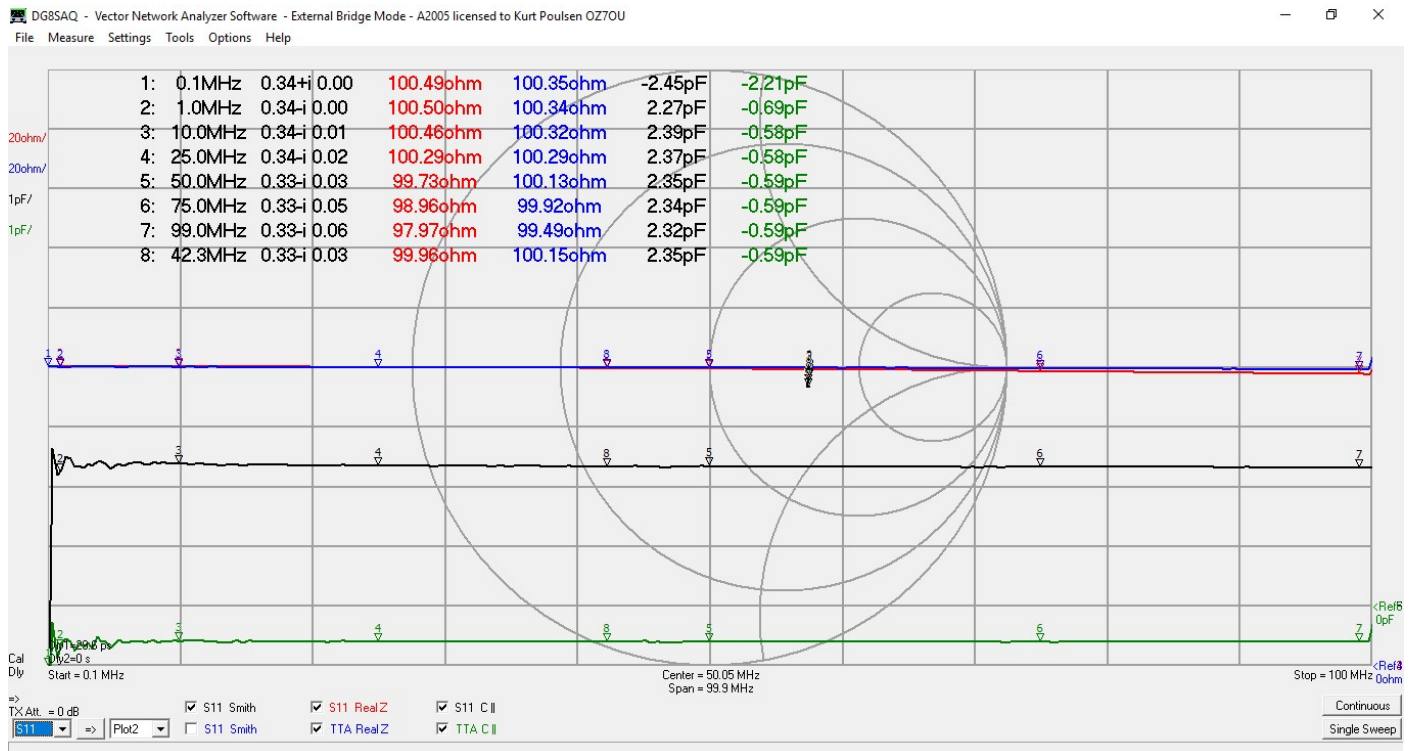


### 10 ohm fitted

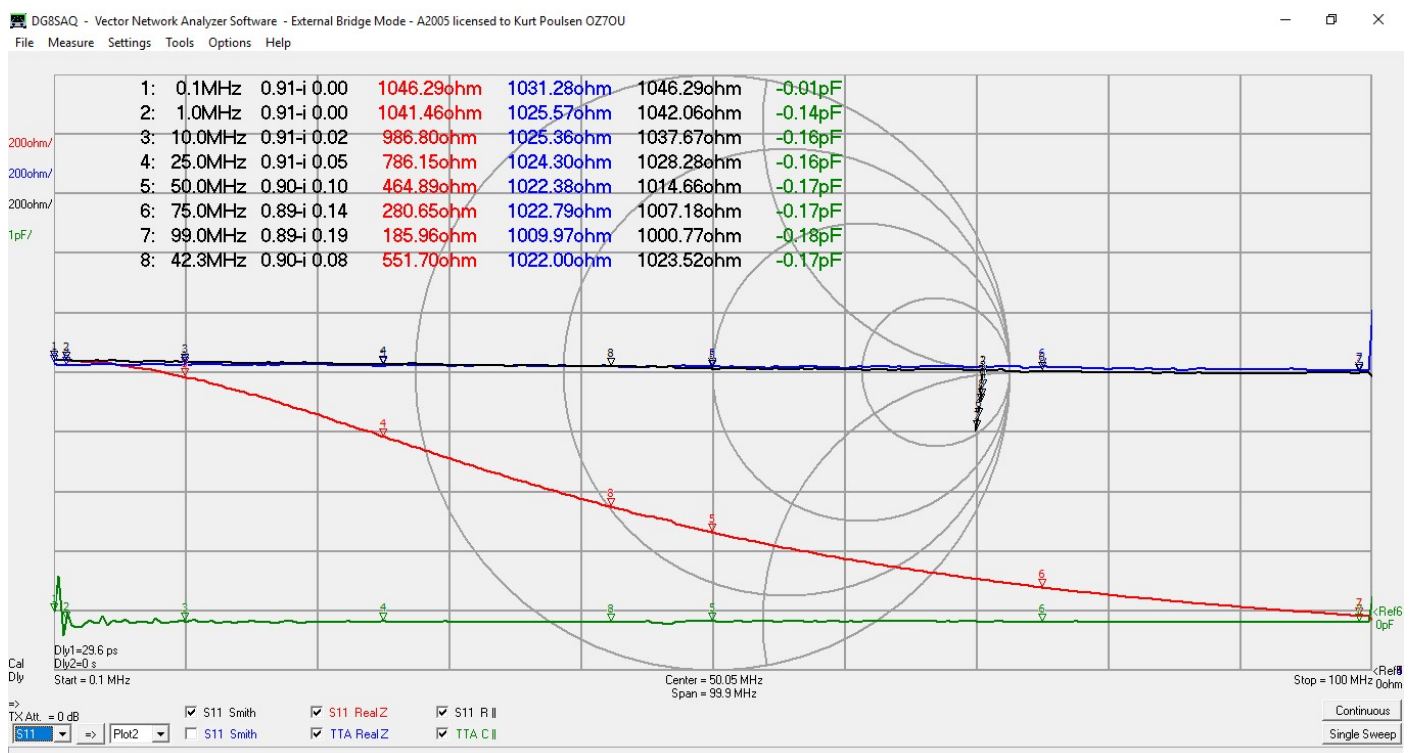




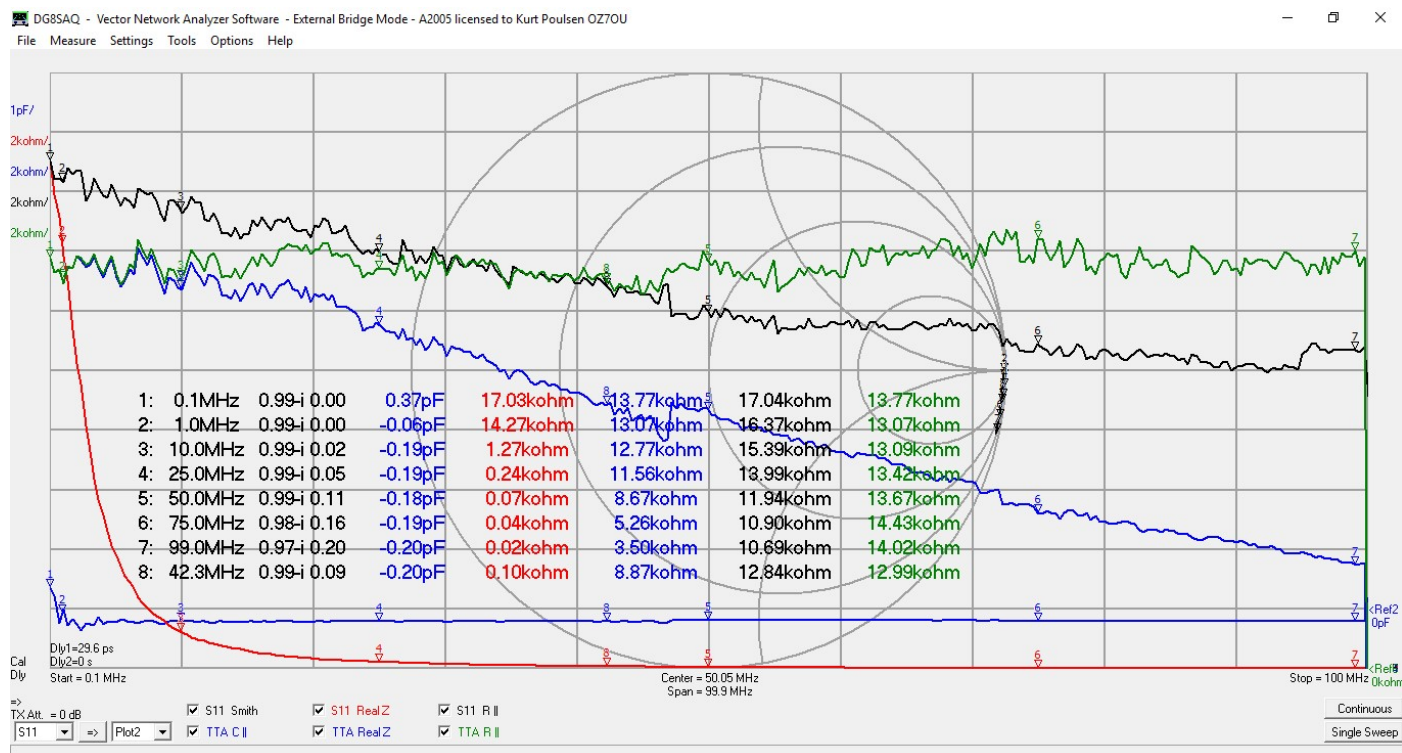
## 100 ohm fitted above 50 ohm CII is a better indicator than ImagZ



## 1Kohm fitted



10Kohm Fitted TTA RII – green trace - is the best indicator and although 13-14Kohm surprisingly constant across 0.1 to 100MHz. The noise due to the shunt measurement principle clearly visible. The calibration was many hours old else better result. Afresh calibration yields within 3% shown above for the custom trace with mathematical model

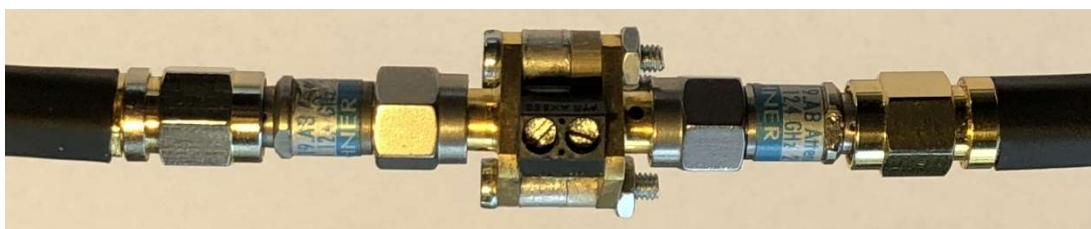


Appendix 2 to follow

## Appendix 2 characterizing the test adaptors S parameters for us with the transmission method by using the smart features embedded in the VNWA software

It might seem tempting to use the transmission method to measure DUT's as only a Thru calibration is required (thru match shall be omitted) and then convert from transmission to reflection in a custom trace by the expression  $t2s$ . The shunt C in the test adaptor then can be removed by a Crosstalk calibration. There are however a number of considerations to take, as firstly the Thru calibration done with the calibration kit file defining the delay of the thru adaptor used during thru calibration ensure that the two test cables are exactly 0 phase and amplitude matched at their calibration planes and secondly when the test adaptor mounted between the two test cables it is included in the transmission measurement and when converting from  $S_{21}$  to  $S_{11}$  by the expression  $t2s$  in a custom trace, we have just measured the test adaptors S parameter (with some degree of accuracy) and when a DUT fitted to the 2way terminal block we need to subtract the test adaptor S parameter in the custom trace. The "smart guy" then suggest why not do the Thru calibration with the test adaptor fitted in between the two test cables then it is not included when doing the  $t2s$  conversion and any shunt capacitance calibrated away with the Crosstalk calibration?? That method is seen described but are all wrong because the shunt C in the test adaptor is having a delay shift relative the shorting bridge in the test adaptor, now included as part of the test cables causing wrong calculation of the self-resonance if the DUT. If this method used then at least the calibration kit file must be modified to have no Thru delay.

In all cases the  $t2s$  transformation assumes the source and load impedance seen from the test cables reference plane towards both the TX and RX port are strictly 50 ohm and that is far from being the case for the VNWA so at least 10dB inline attenuators should terminate the TX and RX test cables at their calibration plane.



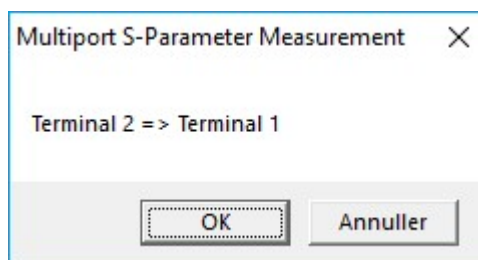
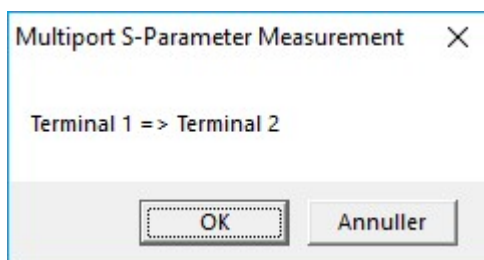
So to do it right we need to characterize the test adaptor the hard way and we will benefit from the smart feature in the VNWA software to characterize the test adaptor as after a standard SOLT calibration, where the calibration planes of the male adaptors on the two test cables are in 0 phase and amplitude sync, insert the test adaptor with the shorting bridge mounted, between the two male test cables and press the F2 key on the computer keyboard and follow the on-screen instructions.

By this procedure the Test Adaptor measured with full 12 Term error correction  $S_{11}$ ,  $S_{21}$ ,  $S_{12}$  and  $S_{22}$  and which improves accuracy of the  $S_{11}$  measurement, from which we are going to derive the impedance of the Test Adaptor in both the shorted and open condition.

This procedure repeated with the shorting bridge removed and I both cases the F2 measurement saved as a s2p file for later retrieval of the test adaptor impedances in shorted and open condition.

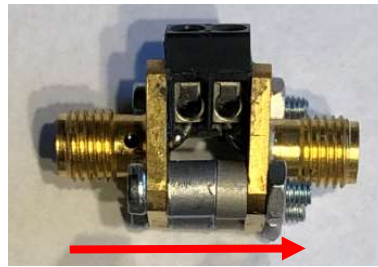
### How to do step by step:

At first perform a full SOLT calibration of the VNWA with a female calibration kit with two male test cables connected to the VNWA. Mount the female Test Adaptor (with shorting bridge mounted) to the two test cables ending with male adaptors and press the F2 key on the PC keyboard.

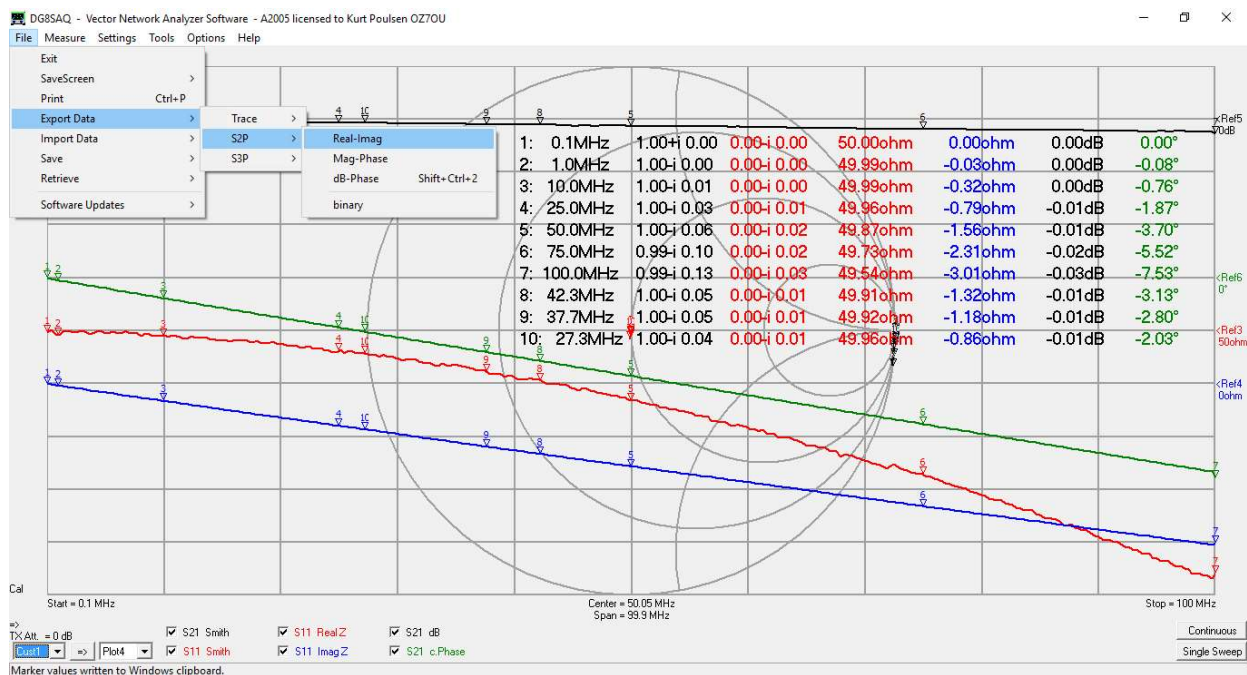


Click OK and Forward direction measured **Reverse the female female** test adaptor Click OK for reverse direction

NB !! keep track of what is the TX and RX side of the test adaptor. During the F2 procedure all 4 S parameters are measured and a full 12 Term error correction performed independent of the trace configurations of what S parameter is presently selected. My test adaptor used in this report is fitted with SMA female adaptor and a 2 wide screw terminal as shown below



Now save the Measurement to a s2p file



Provide a descriptive file name for the s2p file in the Comment field. By mark and copy the txt you are ready to save with given name to the paste the s2p file named “SMA TA F2 swap 0.1 to 100MHz 300 100ms points” into a selected folder.

Enter Comment

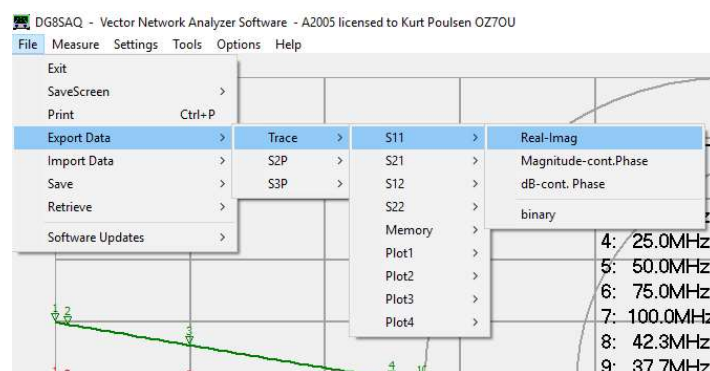
SMA TA shorted F2 swap 0.1 to 100MHz 300 100ms points

No Comment

OK

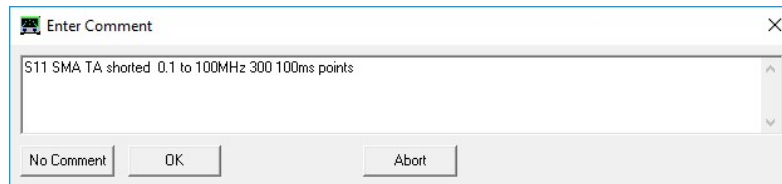
Abort

As we are only interested in the S11 data we right away save the S11 to a s1p file with a descriptive name

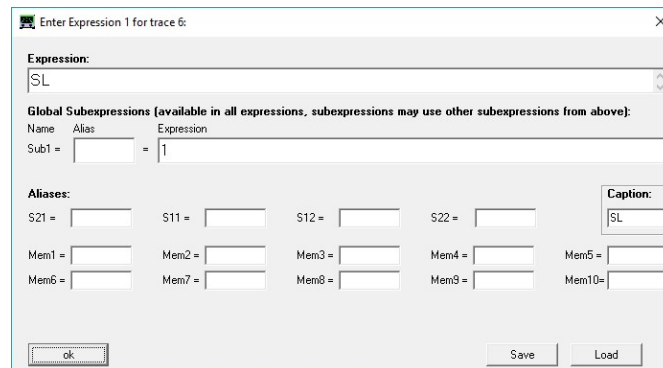




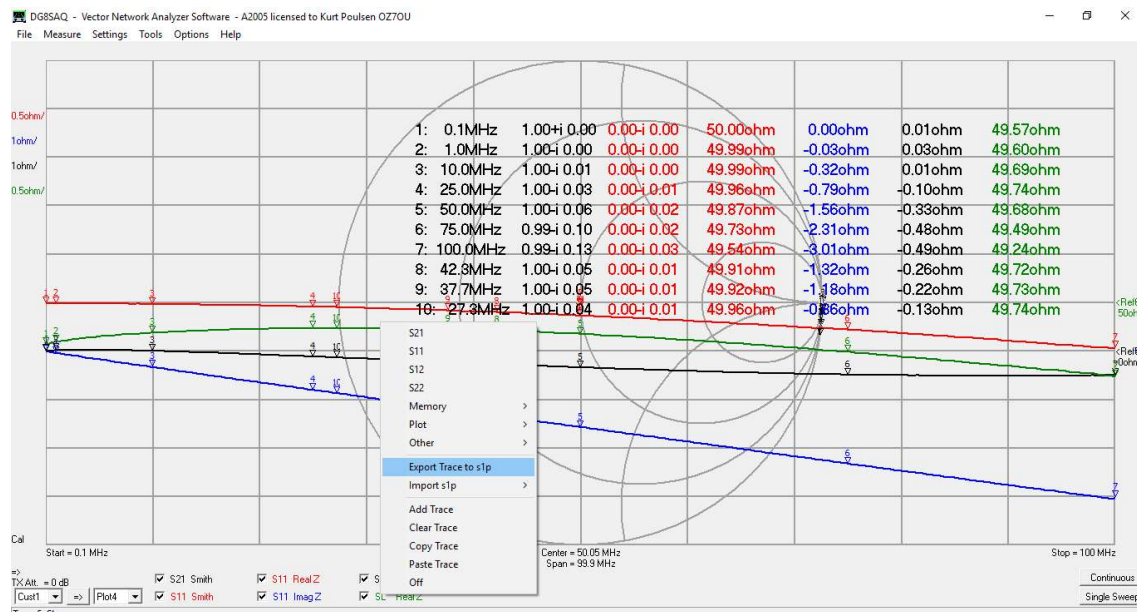
Here the S11 data exported to a s1p file named “S11 SMA TA shorted 0.1 to 100MHz 300 100ms points”



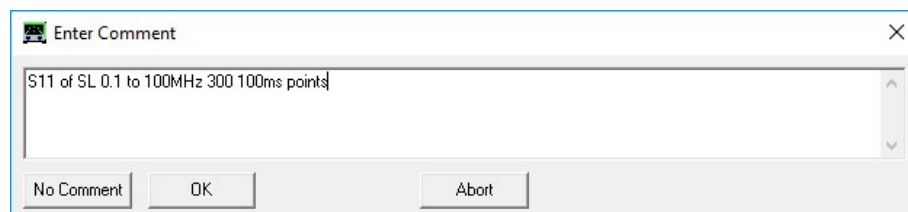
The S11 data is showing that the real part is about 50 ohm because the Test Adaptor is terminated with the input impedance of the RX port measured at the reference plane for the RX test cable which the VNWA software knows as the S parameter expression SL, which we need to save to find the accurate S11 parameter of the Test Adaptor by subtraction. This is done by a custom trace with the expression SL. All custom traces can be saved for later retrieval



By a right mouse click on the label SL for the Custom Trace the S parameter SL can be Exported to s1p as shown below and we see the real part difference will be positive and the imaginary part difference negative and inductive

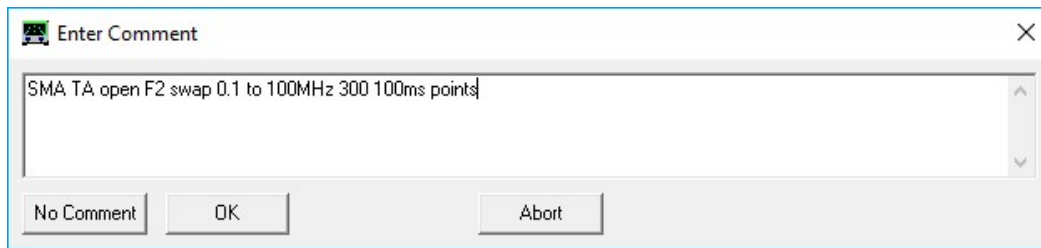


The S parameter SL Exported to a s1p file of name “S11 of SL 0.1 to 100MHz 300 100ms points”

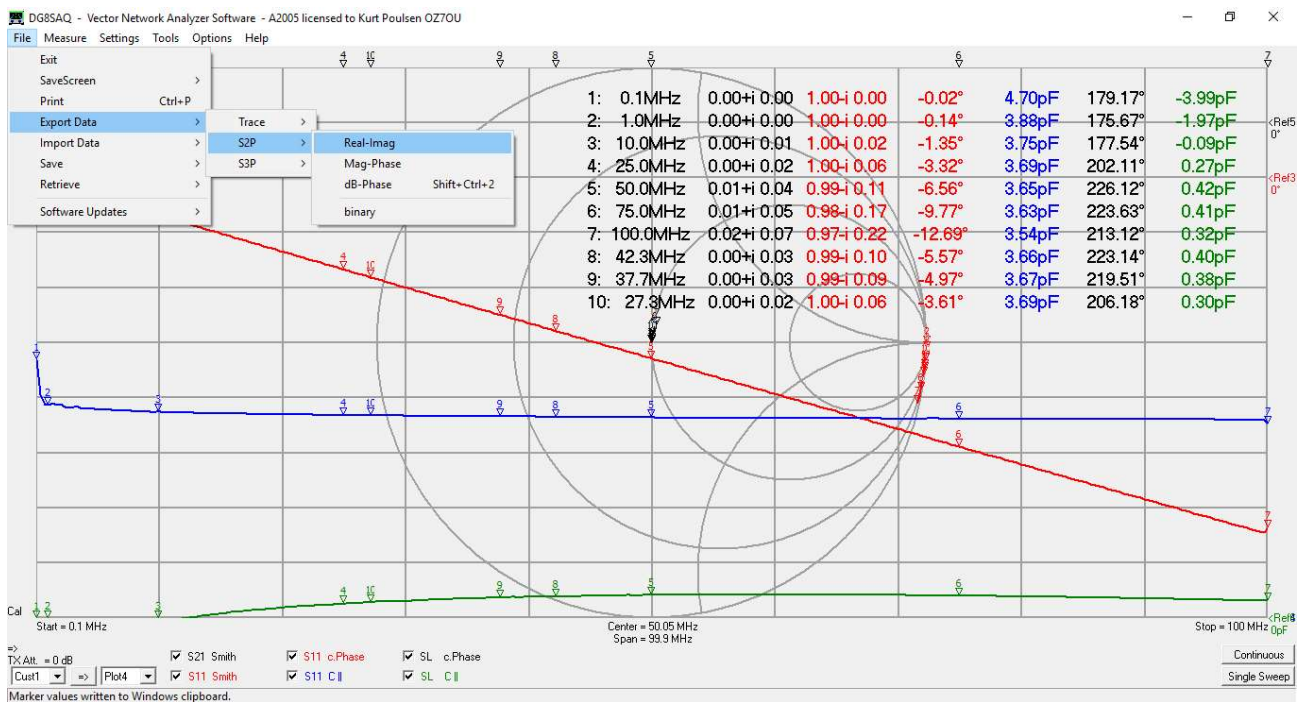


### The Test Adaptor with the shorting bridge removed

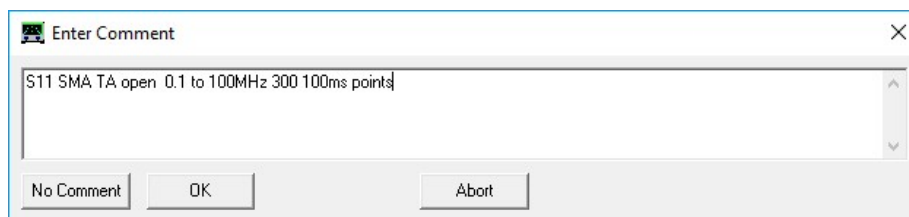
In the same way after the F2 procedure with the shorting bridge removed save the Measurement to a s2p file as SMA TA open F2 swap 0.1 to 100MHz 300 100ms Points.s2p



We see the shunt C in the Test Adaptor is 3.65pF . The S11 data Exported right away as before and we see the SL trace CII is mainly capacitive by about 0.4pF



We save the S11 data with a descriptive name as S11 SMA TA open 0.1 to 100MHz 300 100ms Points.s1p



These initial steps to characterize the Test Adaptor is just done once and to calculate the S parameter of the Test Adaptor we must subtract the two sets of S11 expressions from each other by a custom trace, the measured Test Adaptor with and without shorting bridge subtracted the S parameter of SL.

A final preparation is to figure out the serial inductance for the shorting bridge, and in my case 1.5nH so it can be offset in the Custom Trace we are going to create if of any importance. In this case the 4 mm wide shorting bridge can be considered as 2 mm lead length for the DUT inserted **so do not as standard subtract the inductance of the shorting bridge in the custom trace** and only done her to demonstrate the possibility if later on it is required.

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.consultsr.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 custom traces for the final determination of the Test Adaptor S parameter in shorted and open condition is as follows. The Expression  $s2z(S11)$  transforms the S11 measurements to impedance (z) likewise does  $s2z(SL)$  and  $i*w*1.5e-9$  is the shorting bridge impedance of 1.5nH and as standard set it to 0.0e-9. The expression  $z2s$  in front of the brackets convert the difference of the impedances back to S parameters.

Enter Expression 1 for trace 5:

Expression:  
 $z2s(s2z(S11)-s2z(SL)-i*w*1.5e-9)$

Global Subexpressions (available in all expressions, subexpressions may use other subexpressions from above):

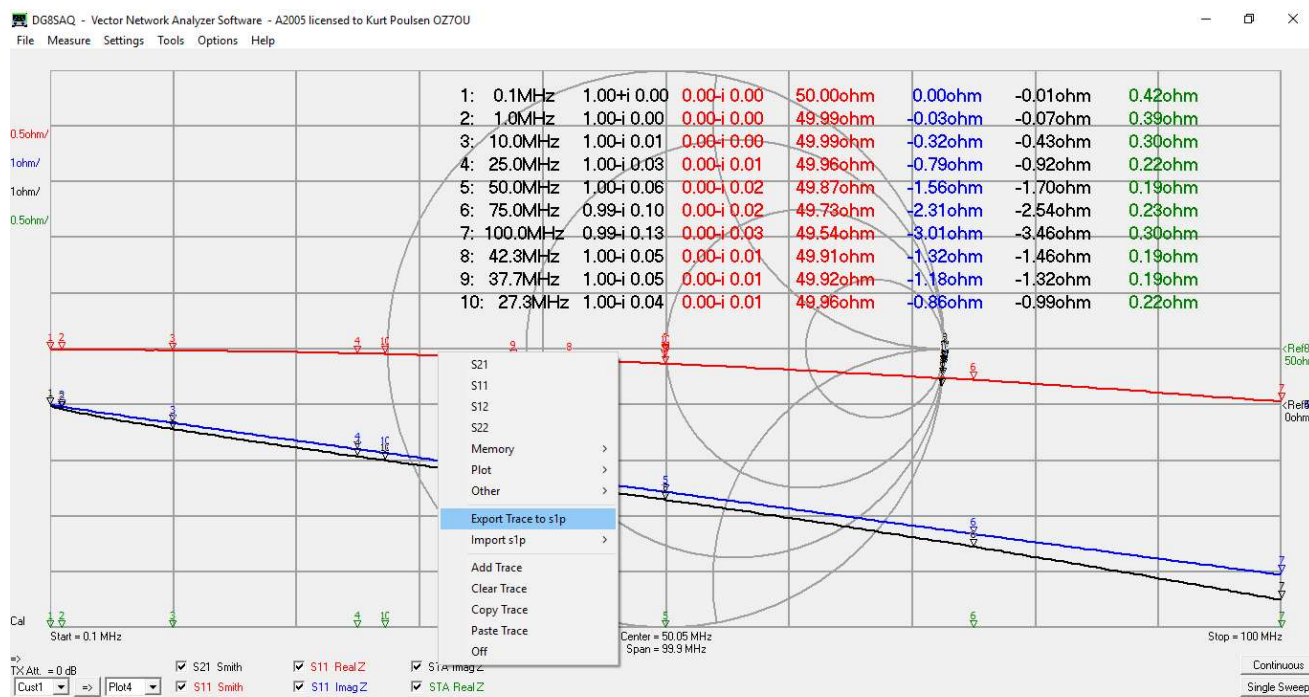
Name	Alias	Expression
Sub1 =		1

Aliases:

S21 =	S11 =	S12 =	S22 =	Caption: STA
Mem1 =	Mem2 =	Mem3 =	Mem4 =	Mem5 =
Mem6 =	Mem7 =	Mem8 =	Mem9 =	Mem10 =

ok Save Load

The screen image shows the result which by right click on label SL is Exported to s1p with a file name of “S11 of TA shorted subtracted SL and shorting bridge SL 0.1 to 100MHz 300 100ms points”



By a DC measurement of the resistance of the shorted Test Adaptor's RealZ of 0.42ohm seems a bit high, as it is more 0 ohm or few milli ohm, so we create a new custom trace where we subtract 50 ohm in stead of  $s2z(SL)$  and Export SL to a s1p file with the name “S11 of TA shorted subtracted 50ohm and shorting bridge SL 0.1 to 100MHz 300 100ms points”

Enter Expression 1 for trace 5:

Expression:  
 $z2s(s2z(S11)-50-i*w*1.5e-9)$

Global Subexpressions (available in all expressions, subexpressions may use other subexpressions from above):

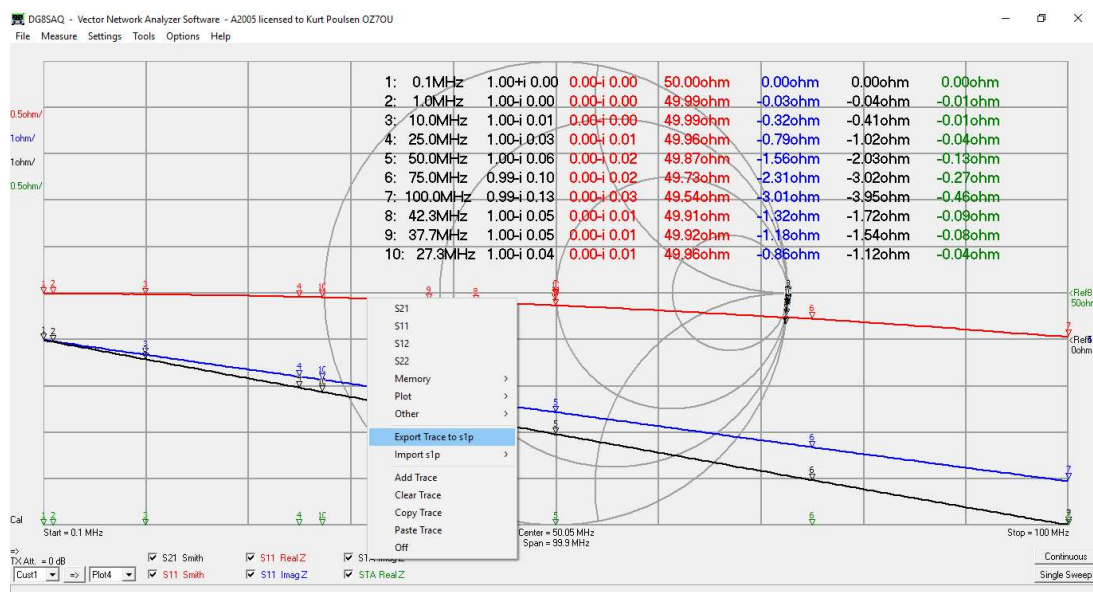
Name	Alias	Expression
Sub1		1

Aliases:

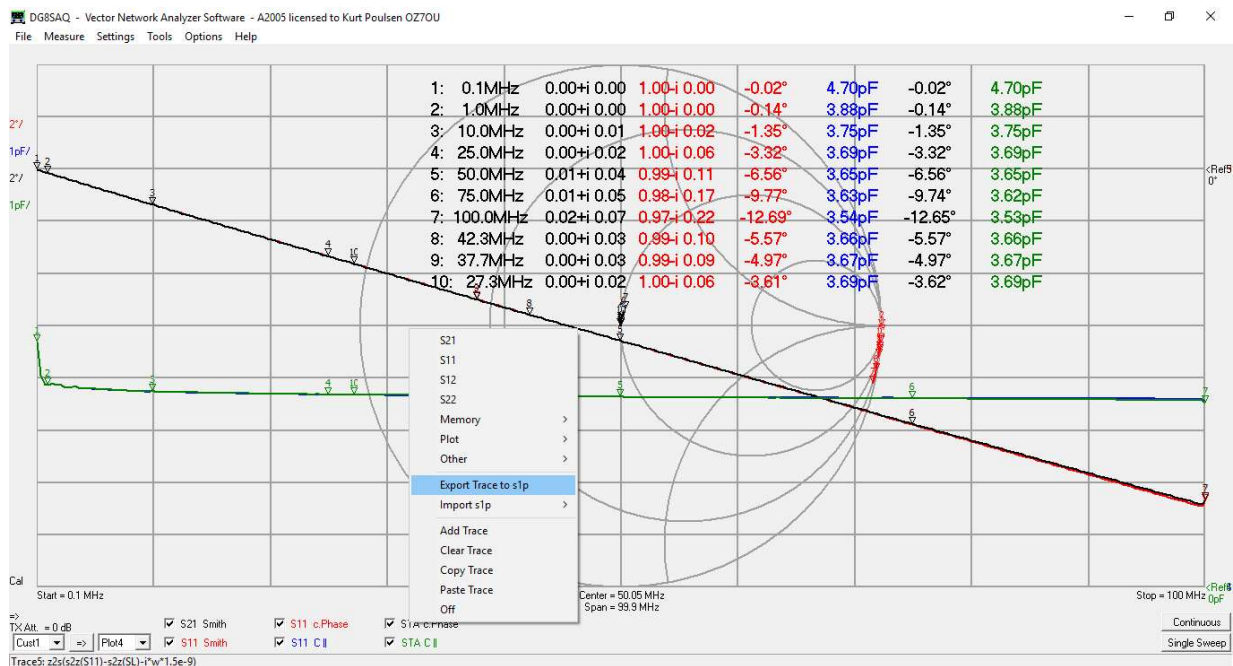
S21 =	S11 =	S12 =	S22 =	Caption: STA
Mem1 =	Mem2 =	Mem3 =	Mem4 =	Mem5 =
Mem6 =	Mem7 =	Mem8 =	Mem9 =	Mem10 =

ok Save Load

Now at least at low frequencies up to 25MHz the real part is from 0 to 0.04 ohm. Which to use depends very much of the frequency range of interest and negative resistance values might be real as the Test Adaptor is not a 50 ohm transmission line. The F2 12 terms measurement of the shorted Test Adaptor assumes a perfect 50ohm termination which at 0.1MHz is 50 ohm and at 100MHz 49.54ohm. It all depends of the calibration accuracy for the VNWA.

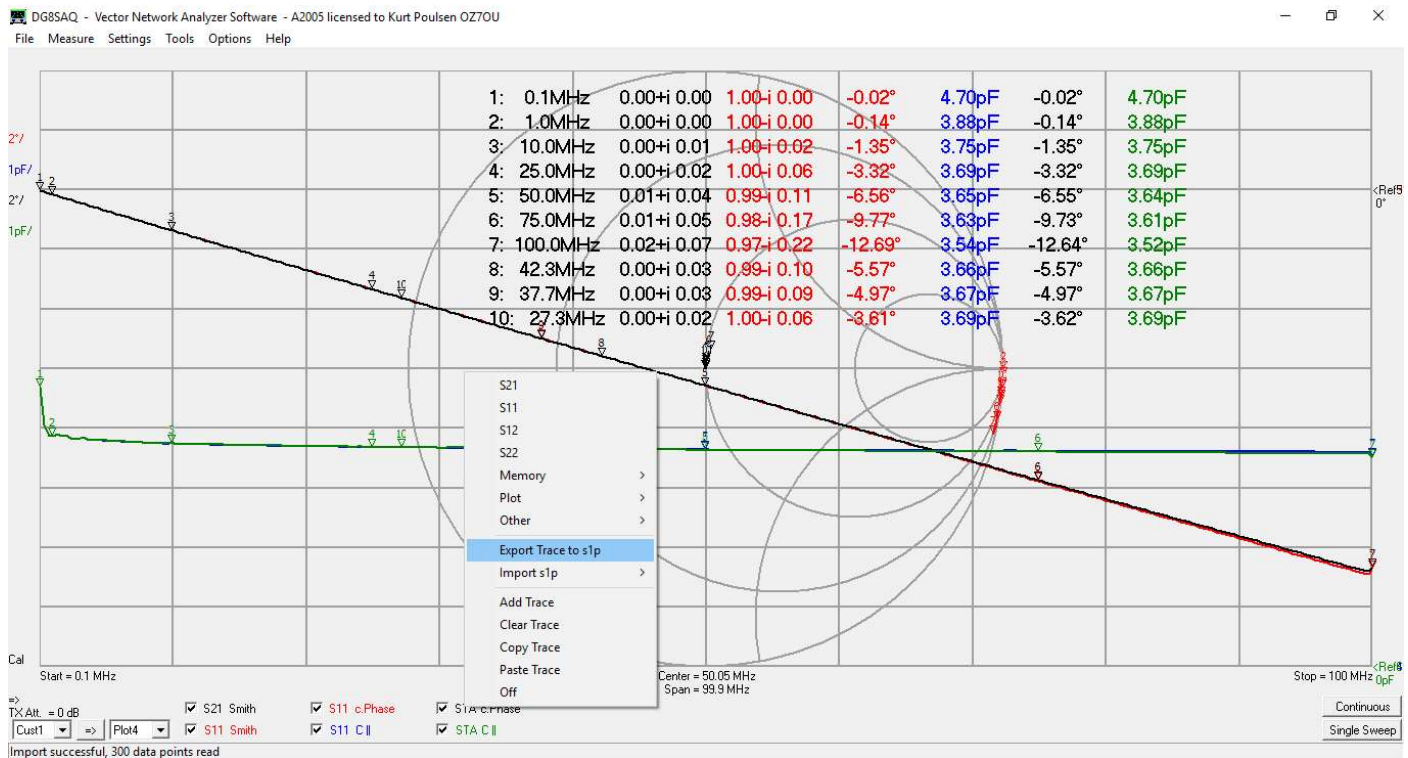


For the open Test Adaptor with subtraction of s2z(SL) we get following result exported as a s1p file named “S11 of TA open subtracted SL and shorting bridge SL 0.1 to 100MHz 300 100ms points”





For the open Test Adaptor with subtraction of 50 ohm instead of s2z(SL) we get following result exported as a s1p file named "S11 of TA open subtracted 50ohm and shorting bridge SL 0.1 to 100MHz 300 100ms points"  
The results are identical whatever subtracted only a phase change of 0.01degree at 100MHz



So that concludes the characterization of the Test Adaptor and as seen there are quite some uncertainties in what is the correct values for the test adaptor impedances. How the actual measurements are shown of result for e.g. the test toroid demonstrated for the Shunt T method in this report is not dealt with but the result when doing test with the S21 to S11 method shows the doing the Crosstalk calibration causes negative RealZ values in some part of the lower frequency range and also above the self-resonance frequency. Also, measurement of the true self-resonance frequency fails and the apparent tempting way to use the transmission S21 to S11 method is not that smart when studied in details.

So as conclusion, the T adaptor shunt method is the favorite method and accurate if RealZ at resonance of the DUT is below 10Kohm and whatever method used the characterization of the test adaptor is unavoidable.

Appendix 2 from 25.2.2019 Kurt Poulsen de OZ7OU

Revised 12-3-2019