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

Preface:

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

By ordinary S11 reflection methods where the DUT is measured at the TX reference plane after a SOL calibration.
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 selfresonance 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 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 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 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.

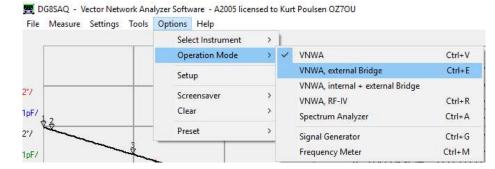
As an appendix 2 to this report is shown the complicated process if we should characterize the test adaptor when using the method 2, the S21 transmission method



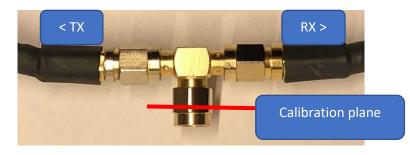
Shorting Bridge

The measurements using the T Adaptor Method

At first the VNWA must be switched to External Bridge mode

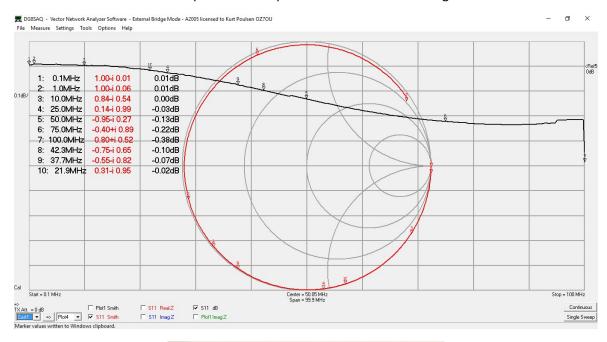


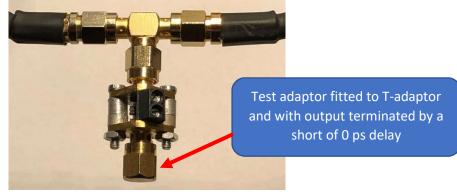
And a T adaptor fitted as shown below



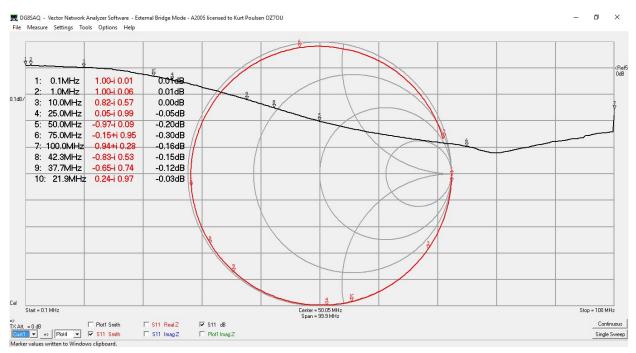
Perform a SOL calibration at the reference plane

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 form 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.

🚆 Enter Expression 2	for trace 6:			×
Expression:				
z2s(s2z(s_m)-z	_TA_s)			0
	ons (available in all express	ions, subexpressions ma	y use other subexpression	ns from above):
Name Alias	Expression			
Sub1 = z_TA_s	= s2z(Mem1)-i*w*1.	5e-9		
Sub2 = y_TA_0	= s2y(Mem2)			
Sub3 = s_m	= y2s(s2y(S11)-y_T/	4_0)		
Sub4 =	= 1			
Aliases:				Caption:
S21 =	S11 =	S12 =	S22 =	TTA
Mem1 =	Mem2 =	Mem3 =	Mem4 =	Mem5 =
	meniz =			
Mem6 =	Mem7 =	Mem8 =	Mem9 =	Mem10=
ok			Save	Load

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 **m**easured) 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.

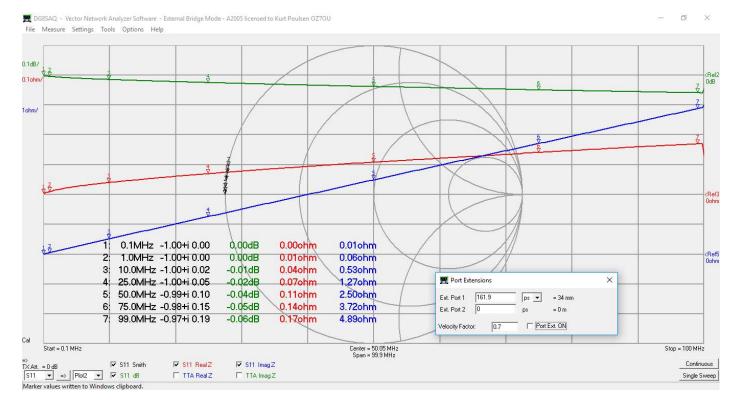
Finally in the main expression z2s(s2z(m_s)-z_TA_s) the S11 measurement is converted to Z parameter with the expression s2z(m_s) from which we subtract the test adaptor impedance from Sub1 z_TA_s and convert the difference back to S parameter by the expression z2s in front of the outer brackets.

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 500hm 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.

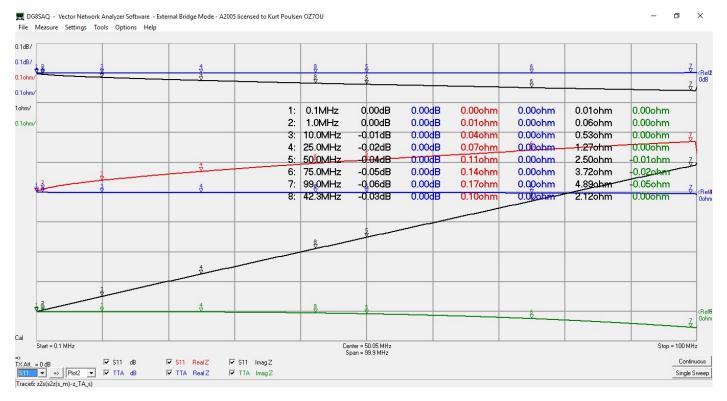
The return loos trace2 is 0dB, the RealZ Trace4 is 0 ohm and the ImagZ has a negative inductance introduced (ImagZ positive) due to the subtraction of the shorting bridge inductance in the custom trace. Adding an Ext. Port delay we can find what we must have enabled to offset the subtraction *if we subtract 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.

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	2: 1.0MHz 3: 10.0MHz 4: 25.0MHz	0.00dB -0.01dB -0.02dB	0.00dB 0.00dB 0.00dB	0.01ohm 0.04ohm 0.07ohm	0.00ohm 0.00ohm 0.00ohm	0.05ohm 0.43ohm 1.04ohm	0.00ohm 0.00ohm 0.00ohm	<u><u></u><u></u></u>			
D(y1=29.6 ps	2: 1.0MHz 3: 10.0MHz 4: 25.0MHz 5: 50.0MHz 6: 75.0MHz	0.00dB -0.01dB -0.02dB -0.04dB	0.00dB 0.00dB 0.00dB 0.00dB	0.01ohm 0.04ohm 0.07ohm 0.11ohm	0.00ohm 0.00ohm 0.00ohm 0.00ohm	0.05ohm 0.43ohm 1.04ohm 2.04ohm	0.00ohm 0.00ohm 0.00ohm 0.00ohm	<u><u></u><u></u><u></u><u></u><u></u></u>			~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
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When the custom trace does not subtract the shorting bridge inductanse (set to 0.0), the ImagZ traces is "straight" with the insignificant error at 99MHz of 0,050hm

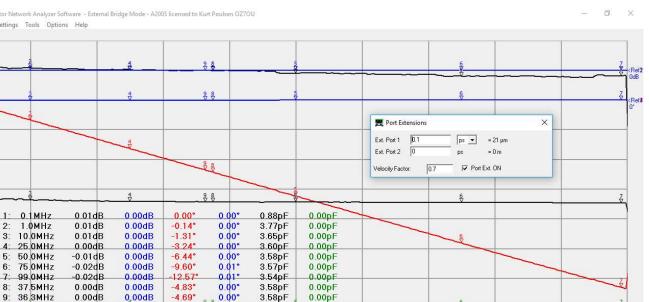


When importing the exported s1p file for the test adaptor named "S11 of TA open T method 0.1 to 100MHz 300 100ms points" and applying an extension port delay of 0.1ps all TTA traces turn to 0. That is another reason why the shorting bridge inductance as standard shall not be subtracted, as then shorted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

0.1dB 0.1dB

2.1 2.1

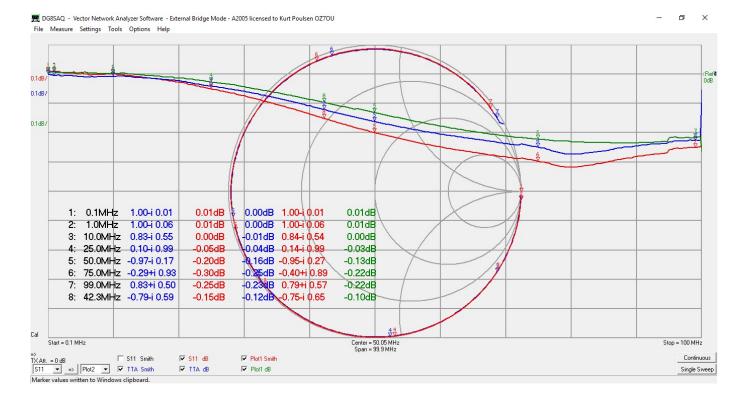
1pF/ 1pF/





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 (3), 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 500MHs 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 I 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 X
le Load Save Model Settings Optimize
ptimizer Splines
xpression to be globally fitted to S11 - Simulation stored to s_11 -
in restricted frequency range 0 MHz to 0.0013 MHz
:2s(i*w*l+r)
ame Alias Subexpression (available in main expression, subexpressions may use other subexpressions from below)
ub2 = = 1
/ariable_AliasReal ValueDeltaOptimize
x1 = = 1.00000000000000000000000000000000000
x2 = r = 1.0000000000E+000 1.0E-001 a descriptive text or picture!
x3 = = 1.0000000000E+000 0.0E+000
x4 = = 1.0000000000E+000 0.0E+000
x5 = = 1.0000000000E+000 0.0E+000
x6 = = 1.0000000000E+000 0.0E+000
ïgure of Merit = 1150 (should be as small as possible)
26:21 : Model loaded from VNCommon.ini

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 Splin	ave Model Settings Optimize	
Expression to be	·	
	frequency range 0 MHz to 0.0013 MHz	
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z2s(i*w*l+r)		
Name Alias	Subexpression (available in main expression, subexpressions may use other subexpressions from belo	<u>(wc</u>
Sub1 =	= 1	_
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Variable Alias	Real Value Delta Optimize	
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21:26:21 : Model - Vector Network Analyzer Softw re Settings Tools Options 1: 0.1MHz -1.00- 2: 1.0MHz -1.00- 3: 10.0MHz -1.00- 4: 25.0MHz -0.99- 6: 75.0MHz -0.98- 7: 99.0MHz -0.97-	ware - External Bridge Mode - A2005 licensed to Kurt Poulsen 0270U : Help 0+i 0.00 -1.00+i 0.00 0.00ohm 0.10ohm 0.01ohm 0.00ohm 0+i 0.00 -1.00+i 0.00 0.01ohm 0.10ohm 0.06ohm 0.05ohm 0+i 0.02 -1.00+i 0.02 0.04ohm 0.10ohm 0.50ohm 0.50ohm 0+i 0.05 -0.99+i 0.05 0.07ohm 0.10ohm 1.27ohm 1.24ohm 0+i 0.05 -0.99+i 0.05 0.11ohm 0.10ohm 2.50ohm 2.48ohm 0+i 0.15 0.14ohm 0.10ohm 3.72ohm 3.73ohm 0+i 0.05 0.99+i 0.15 0.14ohm 0.10ohm 2.50ohm 0+i 0.15 0.14ohm 0.10ohm 3.72ohm 3.73ohm 0+i 0.19 0.38+i 0.19 0.17ohm 0.10ohm 4.89ohm 4.92ohm 0+i 0.08 -0.99+i 0.08 0.10ohm 2.12ohm 2.10ohm §	-
21:26:21 : Model - Vector Network Analyzer Softw re Settings Tools Options 1: 0.1MHz -1.00- 2: 1.0MHz -1.00- 3: 10.0MHz -1.00- 4: 25.0MHz -0.99- 6: 75.0MHz -0.98- 7: 99.0MHz -0.97-	ware - External Bridge Mode - A2005 licensed to Kurt Poulsen 0270U : Help 0+i 0.00 -1.00+i 0.00 0.00ohm 0.10ohm 0.01ohm 0.00ohm 0+i 0.00 -1.00+i 0.00 0.01ohm 0.10ohm 0.06ohm 0.05ohm 0+i 0.02 -1.00+i 0.02 0.04ohm 0.10ohm 0.50ohm 0.50ohm 0+i 0.05 -0.99+i 0.05 0.07ohm 0.10ohm 1.27ohm 1.24ohm 0+i 0.05 -0.99+i 0.05 0.11ohm 0.10ohm 2.50ohm 2.48ohm 0+i 0.15 0.14ohm 0.10ohm 3.72ohm 3.73ohm 0+i 0.05 0.99+i 0.15 0.14ohm 0.10ohm 2.50ohm 0+i 0.15 0.14ohm 0.10ohm 3.72ohm 3.73ohm 0+i 0.19 0.38+i 0.19 0.17ohm 0.10ohm 4.89ohm 4.92ohm 0+i 0.08 -0.99+i 0.08 0.10ohm 2.12ohm 2.10ohm §	-
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21:26:21 : Model - Vector Network Analyzer Softw re Settings Tools Options 1: 0.1MHz -1.00- 2: 1.0MHz -1.00- 3: 10.0MHz -1.00- 4: 25.0MHz -0.99- 6: 75.0MHz -0.98- 7: 99.0MHz -0.97-	ware - External Bridge Mode - A2005 licensed to Kurt Poulsen 0270U : Help 0+i 0.00 -1.00+i 0.00 0.00ohm 0.10ohm 0.01ohm 0.00ohm 0+i 0.00 -1.00+i 0.00 0.01ohm 0.10ohm 0.06ohm 0.05ohm 0+i 0.02 -1.00+i 0.02 0.04ohm 0.10ohm 0.50ohm 0.50ohm 0+i 0.05 -0.99+i 0.05 0.07ohm 0.10ohm 1.27ohm 1.24ohm 0+i 0.05 -0.99+i 0.05 0.11ohm 0.10ohm 2.50ohm 2.48ohm 0+i 0.15 0.14ohm 0.10ohm 3.72ohm 3.73ohm 0+i 0.05 0.99+i 0.15 0.14ohm 0.10ohm 2.50ohm 0+i 0.15 0.14ohm 0.10ohm 3.72ohm 3.73ohm 0+i 0.19 0.38+i 0.19 0.17ohm 0.10ohm 4.89ohm 4.92ohm 0+i 0.08 -0.99+i 0.08 0.10ohm 2.12ohm 2.10ohm §	
21:26:21 : Model - Vector Network Analyzer Softw re Settings Tools Options 1: 0.1MHz -1.00- 2: 1.0MHz -1.00- 3: 10.0MHz -1.00- 4: 25.0MHz -0.99- 6: 75.0MHz -0.98- 7: 99.0MHz -0.97-	ware - External Bridge Mode - A2005 licensed to Kurt Poulsen 0270U : Help 0+i 0.00 -1.00+i 0.00 0.00ohm 0.10ohm 0.01ohm 0.00ohm 0+i 0.00 -1.00+i 0.00 0.01ohm 0.10ohm 0.06ohm 0.05ohm 0+i 0.02 -1.00+i 0.02 0.04ohm 0.10ohm 0.50ohm 0.50ohm 0+i 0.05 -0.99+i 0.05 0.07ohm 0.10ohm 1.27ohm 1.24ohm 0+i 0.05 -0.99+i 0.05 0.11ohm 0.10ohm 2.50ohm 2.48ohm 0+i 0.15 0.14ohm 0.10ohm 3.72ohm 3.73ohm 0+i 0.05 0.99+i 0.15 0.14ohm 0.10ohm 2.50ohm 0+i 0.15 0.14ohm 0.10ohm 3.72ohm 3.73ohm 0+i 0.19 0.38+i 0.19 0.17ohm 0.10ohm 4.89ohm 4.92ohm 0+i 0.08 -0.99+i 0.08 0.10ohm 2.12ohm 2.10ohm §	

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)

	Splines Splines on to be globally fitte		Simulation stored to	s_11 •		
	stricted frequency ra	nge 0 MF	lz to	0.0013 MHz		
1	L_TA+R_TA)					
Name Sub1 =		expression (available in m grt(f)+dR*f^2	iain expression, sube	xpressions may use other	subexpressions from below)	
Sub2 =						
Sub3 =	= 1					
Sub4 =	= 1					
Sub5 =	= 1					
Variable	Alias Real	Value	Delta Optimize			
×1 =	L = 8.1	12847773185E-009	1.0E-011	Right-click		
x2 =	R = 1.3	97042578775E-005	1.0E-007	a descriptiv	ve text	
×3 =	dR = 3.4	07549357774E-018	1.0E-020	or picture!		
×4 =	dL = -2.7	36948117015E-018	1.0E-020			
x5 =	= 1.0	00000000000E+000	0.0E+000			
		iould be as small as poss				
	Thom - 4.015 o fer	iodia be as sinali as poss	ibic)			
2004 BD	on calls = 68					
# functi		m VNCommon.ini				
# functi	Model loaded fro	m VNCommon.ini				
# functi 21:26:21 : Q - Vector Network Analyzer Soft	Model loaded fro	m VNCommon.ini	U			
# functi 21:26:21 Q - Vector Network Analyzer Soft sure Settings Tools Options	Model loaded fro ware - External Bridge Mode - Help	A2005 licensed to Kurt Poulsen OZ7O		9.99°		
# functi 21:26:21 : 2 - Vector Network Analyzer Soft sure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00	Model loaded fro ware - External Bridge Mode - Help H+i 0.00 -1.00+i 0.00 H+i 0.00 -1.00+i 0.00	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o	hm 179.98° 17 hm 179.86° 17	9.99° 9.88° 9.88°		
# functi 21:26:21 : sure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00 3: 10.0MHz -1.00	Model loaded fro ware - External Bridge Mode - Help I+i 0.00 -1.00+i 0.00	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o 0.04ohyy 0.04o	hm 179.98° 17 hm 179.86° 17 hm 178.80° 17 hm 178.80° 17 hm 177.08° 17	9.88° 8.84° 7.10°		- 0
# functi 21:26:21 : sure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00 3: 10.0MHz -1.00 4: 25.0MHz -1.00 5: 50.0MHz -0.95	Model loaded fro ware - External Bridge Mode - Help H+i 0.00 -1.00+i 0.00 H+i 0.02 -1.00+i 0.02 H+i 0.05 -1.00+i 0.02 H+i 0.05 -1.00+i 0.05 H+i 0.10 -0.99+i 0.10	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o 0.04ohm 0.04o 0.07ohm 0.07o 0.11ohm 0.11o	hm 179.98° 17 hm 179.86° 17 hm 178.80° 17 hm 178.80° 17 hm 177.08° 17 hm 174.27° 17	9.88° 8.84° 7.10° 4.26°		- 0
# functi 21:26:21 sure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00 3: 10.0MHz -1.00 4: 25.0MHz -1.00 5: 50.0MHz -0.98 6: 75.0MHz -0.98	Model loaded fro ware - External Bridge Mode - Help H+i 0.00 -1.00+i 0.00 H+i 0.02 -1.00+i 0.02 H+i 0.05 -1.00+i 0.02 H+i 0.05 -1.00+i 0.05	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o 0.04ohm 0.04o 0.07ohm 0.07o 0.11ohm 0.11o 0.14ohm 0.14o	hm 179.98° 17 hm 179.86° 17 hm 178.80° 17 hm 177.08° 17 hm 174.27° 17 hm 174.27° 17	9.88° 8.84° 7.10°		- (
# functi 21:26:21 = 2 - Vector Network Analyzer Soft isure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00 3: 10.0MHz -1.00 4: 25.0MHz -1.00 5: 50.0MHz -0.98 6: 75.0MHz -0.98 7: 99:0MHz -0.97	Model loaded fro ware - External Bridge Mode - Help H+i 0.00 -1.00+i 0.00 H+i 0.02 -1.00+i 0.02 H+i 0.05 -1.00+i 0.05 H+i 0.10 -0.99+i 0.10 H+i 0.15 -0.98+i 0.15	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o 0.04ohm 0.04o 0.07ohm 0.07o 0.11ohm 0.11o 0.14ohm 0.14o 0.17ohm 0.17o	hm 179.98° 17 hm 179.86° 17 hm 178.80° 17 hm 177.08° 17 hm 174.27° 17 hm 171.49° 17 hm 168.83° 19	9.88° 8.84° 7.10° 4.26° 1.48°		
# functi 21:26:21 = 2 - Vector Network Analyzer Soft sure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00 3: 10.0MHz -1.00 4: 25.0MHz -1.00 5: 50.0MHz -0.98 6: 75.0MHz -0.98 7: 99:0MHz -0.97	Model loaded fro ware - External Bridge Mode - Help Hi 0.00 -1.00+i 0.00 Hi 0.02 -1.00+i 0.02 Hi 0.05 -1.00+i 0.05 Hi 0.10 -0.99+i 0.10 Hi 0.15 -0.98+i 0.15 '+i 0.19 -0.97+i 0.19	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o 0.04ohm 0.04o 0.07ohm 0.07o 0.11ohm 0.11o 0.14ohm 0.14o 0.17ohm 0.17o	hm 179.98° 17 hm 179.86° 17 hm 178.80° 17 hm 177.08° 17 hm 174.27° 17 hm 171.49° 17 hm 168.83° 19	9.88° 8.84° 7.10° 4.26° 1.48° 8.86°		
# functi 21:26:21 = 2 - Vector Network Analyzer Soft sure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00 3: 10.0MHz -1.00 4: 25.0MHz -1.00 5: 50.0MHz -0.98 6: 75.0MHz -0.98 7: 99:0MHz -0.97	Model loaded fro ware - External Bridge Mode - Help Hi 0.00 -1.00+i 0.00 Hi 0.02 -1.00+i 0.02 Hi 0.05 -1.00+i 0.05 Hi 0.10 -0.99+i 0.10 Hi 0.15 -0.98+i 0.15 '+i 0.19 -0.97+i 0.19	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o 0.04ohm 0.04o 0.07ohm 0.07o 0.11ohm 0.11o 0.14ohm 0.14o 0.17ohm 0.17o 0.10ohm 0.10o	hm 179.98° 17 hm 179.86° 17 hm 178.80° 17 hm 177.08° 17 hm 174.27° 17 hm 171.49° 17 hm 168.83° 19	9.88° 8.84° 7.10° 4.26° 1.48° 8.86°		
# functi 21:26:21 = 2 - Vector Network Analyzer Soft sure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00 3: 10.0MHz -1.00 4: 25.0MHz -1.00 5: 50.0MHz -0.98 6: 75.0MHz -0.98 7: 99:0MHz -0.97	Model loaded fro ware - External Bridge Mode - Help Hi 0.00 -1.00+i 0.00 Hi 0.02 -1.00+i 0.02 Hi 0.05 -1.00+i 0.05 Hi 0.10 -0.99+i 0.10 Hi 0.15 -0.98+i 0.15 '+i 0.19 -0.97+i 0.19	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o 0.04ohm 0.04o 0.07ohm 0.07o 0.11ohm 0.11o 0.14ohm 0.14o 0.17ohm 0.17o 0.10ohm 0.10o	hm 179.98° 17 hm 179.86° 17 hm 178.80° 17 hm 177.08° 17 hm 174.27° 17 hm 171.49° 17 hm 168.83° 19	9.88° 8.84° 7.10° 4.26° 1.48° 8.86°		
# functi 21:26:21 = 2 - Vector Network Analyzer Soft sure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00 3: 10.0MHz -1.00 4: 25.0MHz -1.00 5: 50.0MHz -0.98 6: 75.0MHz -0.98 7: 99:0MHz -0.97	Model loaded fro ware - External Bridge Mode - Help Hi 0.00 -1.00+i 0.00 Hi 0.02 -1.00+i 0.02 Hi 0.05 -1.00+i 0.05 Hi 0.10 -0.99+i 0.10 Hi 0.15 -0.98+i 0.15 '+i 0.19 -0.97+i 0.19	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o 0.04ohm 0.04o 0.07ohm 0.07o 0.11ohm 0.11o 0.14ohm 0.14o 0.17ohm 0.17o 0.10ohm 0.10o	hm 179.98° 17 hm 179.86° 17 hm 178.80° 17 hm 177.08° 17 hm 174.27° 17 hm 171.49° 17 hm 168.83° 19	9.88° 8.84° 7.10° 4.26° 1.48° 8.86°		
# functi 21:26:21 = 2 - Vector Network Analyzer Soft sure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00 3: 10.0MHz -1.00 4: 25.0MHz -1.00 5: 50.0MHz -0.98 6: 75.0MHz -0.98 7: 99:0MHz -0.97	Model loaded fro ware - External Bridge Mode - Help Hi 0.00 -1.00+i 0.00 Hi 0.02 -1.00+i 0.02 Hi 0.05 -1.00+i 0.05 Hi 0.10 -0.99+i 0.10 Hi 0.15 -0.98+i 0.15 '+i 0.19 -0.97+i 0.19	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o 0.04ohm 0.04o 0.07ohm 0.07o 0.11ohm 0.11o 0.14ohm 0.14o 0.17ohm 0.17o 0.10ohm 0.10o	hm 179.98° 17 hm 179.86° 17 hm 178.80° 17 hm 177.08° 17 hm 174.27° 17 hm 171.49° 17 hm 168.83° 19	9.88° 8.84° 7.10° 4.26° 1.48° 8.86°		
# functi 21:26:21 = 2 - Vector Network Analyzer Soft sure Settings Tools Options 1: 0.1MHz -1.00 2: 1.0MHz -1.00 3: 10.0MHz -1.00 4: 25.0MHz -1.00 5: 50.0MHz -0.98 6: 75.0MHz -0.98 7: 99:0MHz -0.97	Model loaded fro ware - External Bridge Mode - Help Hi 0.00 -1.00+i 0.00 Hi 0.02 -1.00+i 0.02 Hi 0.05 -1.00+i 0.05 Hi 0.10 -0.99+i 0.10 Hi 0.15 -0.98+i 0.15 '+i 0.19 -0.97+i 0.19	A2005 licensed to Kurt Poulsen 0270 0.00ohm 0.00o 0.01ohm 0.01o 0.04ohm 0.04o 0.07ohm 0.07o 0.11ohm 0.11o 0.14ohm 0.14o 0.17ohm 0.17o 0.10ohm 0.10o	hm 179.98° 17 hm 179.86° 17 hm 178.80° 17 hm 177.08° 17 hm 174.27° 17 hm 171.49° 17 hm 168.83° 19	9.88° 8.84° 7.10° 4.26° 1.48° 8.86°		

Center = 50.05 MHz Span = 99.9 MHz

Stop = 100 MHz

Continuous

Single Sweep

 TX Att. = 0 dB
IX Att. = 0 dB
IX Att. = 0 d
IX A S11 RealZ 🔽 S11 c.Phase ₩ Opt RealZ ✓ Opt c.Phase

Cal

Start = 0.1 MHz

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)

Optimiz	zer Splines	1							
Expres	sion to be glo	obally fitted to	S11 💌	Simulation st	ored to s	_11 👻			
🗖 in	restricted free	quency range	0	MHz to	0	.0013	MHz		
y2s(i*v	w*C_TA+Y_T	'A)							
Name	-	and the second s	ssion (available i	n main expressi	on, subexpr	essions may	use other sub	expressions fro	om below)
Sub1 =	<u></u>	= Y+dY*f							
Sub2 =		= C+dC*f							
Sub3 =		= 1							
Sub4 =		= 1							
Sub5 =	=	= 1							
Variab	ile Alias	Real Value	e	Delta ()ptimize				
× dilab x1 =	C	_	- 1277402E-012	1.0E-014		Dight-	alick +	load	
	Y		7608428E-005	1.0E-007	- I		click to riptive		
x2 =				-		or pic			
x3 =	d۲		5699850E-013	1.0E-015					
×4 =	dC	= -8.784032	2669077E-022	1.0E-024					
# func	of Merit = 0.1 ation calls = 8 1 : Model Io	12	VCommon.ini	possiblej					
# func 21:26:2	ction calls = 8 1 : Model Io /zer Software - Extern	aded from VN							
# func 21:26:2	ction calls = 8 1 : Model Io /zer Software - Extern	aded from VN	VCommon.ini						
# func 21:26:2	ction calls = 8 1 : Model Io vzer Software - Extern Options Help 1: ϕ :	aded from VN nal Bridge Mode - A2003 1MHz 1.00-i 0	VCommon.ini 5 licensed to Kurt Poulsen	ozrou		~	01°		
# func 21:26:2	tion calls = 8 1 : Model Io rer Software - Extern Options Help 1: 0. 2: 1. 3: 10.	12 aded from VN nal Bridge Mode - A2003 1MHz 1.00-i 0 0MHz 1.00-i 0 .0MHz 1.00-i 0	Common.ini 5 licensed to Kurt Poulsen 1.00 1.00-i 0.00 1.00 1.00-i 0.00 1.02 1.00-i 0.02	-13.91µS -1 -15.42µS -1 -11.42µS -	3.79µS 9.77µS	-0.14° -0. -1.31° -1.	13° 30°		
# func 21:26:2	tion calls = 8 1 : Model Io rzer Software - Exten Options Help 1: 0. 2: 10. 3: 10. 4: 25.	12 aded from VN nal Bridge Mode - A2003 1MHz 1.00-i 0 .0MHz 1.00-i 0 .0MHz 1.00-i 0	VCommon.ini 5 licensed to Kurt Poulsen 1.00 1.00-i 0.00 1.00-i 0.00 1.00-i 0.00 1.00-i 0.02 1.00-i 0.02	-15.91µS - -15.42µS - -11.42µS - -3.02µS -	3.79µS 9.77µS 3.05µS	-0.14° -0. -1.31° -1. -3.24° -3.	13° 30° 24°		
# func 21:26:2	tion calls = 8 1 : Model lo zer Software - Exter Options Help 1: 0, 2: 1, 3: 10, 4: 25, 5: 50, 6: 75.	aded from VN nal Bridge Mode - A2003 1MHz 1.00-10 0MHz 1.00-10 .0MHz 1.00-10 .0MHz 1.00-30 .0MHz 0.99-10 .0MHz 0.99-10 .0MHz 0.99-10	VCommon.ini ilcensed to Kurt Poulsen 100 1.00-i 0.00 100 1.00-i 0.00 100 1.00-i 0.02 100-i 0.02 100-i 0.02 11 0.99-i 0.11 17 0.98-i 0.11	-13.91µS -1 -15.42µS -1 -11.42µS - -10.57µS -1 0.57µS -1 22.43µS 1	3.79µS 9.77µS 3.05µS 3.14µS 9.32µS	-0.14° -0. -1.31° -1. -3.24° -3. -6.45° -6. -9.61° -9.	13° 30° 24° 44°		
# func 21:26:2	tion calls = 8 1 : Model lo zer Software - Extern Options Help 1: 0. 2: 1. 3: 10. 4: 25. 5: 50. 6: 75. 7: 99	aded from VN nal Bridge Mode - A2003 1MHz 1.00-10 .0MHz 1.00-10 .0MHz 1.00-10 .0MHz 0.93-10 .0MHz 0.93-10 .0MHz 0.93-10	ICommon.ini 5 licensed to Kurt Poulsen 1.00 1.00-i 0.00 1.00 1.00-i 0.00 1.02 1.00-i 0.02 1.00-i 0.02 1.00-i 0.02 1.00-i 0.02 1.00-i 0.02	02700 -13.91µS -15.42µS -11.42µS -3.02µS -3.02µS -3.02µS -22.43µS 1 22.43µS 1 22.43µS 1	3.79µS 9.77µS 3.05µS 3.14µS 9.32µS 0.07µS -	-0.14° -0. -1.31° -1. -3.24° -3. -6.45° -6. -9.61° -9. 12.58° -12	13° 30° 24° 44°		
# func 21:26:2	tion calls = 8 1 : Model lo zer Software - Extern Options Help 1: 0. 2: 1. 3: 10. 4: 25. 5: 50. 6: 75. 7: 99	aded from VN nal Bridge Mode - A2003 1MHz 1.00-10 .0MHz 1.00-10 .0MHz 1.00-10 .0MHz 0.93-10 .0MHz 0.93-10 .0MHz 0.93-10	VCommon.ini 5 licensed to Kurt Poulsen 100 1.00-i 0.00 1.00-i 0.02 1.00-i 0.02 1.00-i 0.06 1.11 0.93-i 0.11 17 0.93-i 0.11 17 0.93-i 0.12	02700 -13.91µS -15.42µS -11.42µS -3.02µS -3.02µS -3.02µS -22.43µS 1 22.43µS 1 22.43µS 1	3.79µS 9.77µS 3.05µS 3.14µS 9.32µS 0.07µS -	-0.14° -0. -1.31° -1. -3.24° -3. -6.45° -6. -9.61° -9. 12.58° -12	13° 30° 24° 44° 59°		
# func 21:26:2	tion calls = 8 1 : Model lo zer Software - Extern Options Help 1: 0. 2: 1. 3: 10. 4: 25. 5: 50. 6: 75. 7: 99	aded from VN nal Bridge Mode - A2003 1MHz 1.00-10 .0MHz 1.00-10 .0MHz 1.00-10 .0MHz 0.93-10 .0MHz 0.93-10 .0MHz 0.93-10	VCommon.ini 5 licensed to Kurt Poulsen 100 1.00-i 0.00 1.00-i 0.02 1.00-i 0.02 1.00-i 0.06 1.11 0.93-i 0.11 17 0.93-i 0.11 17 0.93-i 0.12	02700 -13.91µS -15.42µS -11.42µS -3.02µS -3.02µS -3.02µS -22.43µS 1 22.43µS 1 22.43µS 1	3.79µS 9.77µS 3.05µS 3.14µS 9.32µS 0.07µS -	-0.14° -0. -1.31° -1. -3.24° -3. -6.45° -6. -9.61° -9. 12.58° -12	13° 30° 24° 44° 59°		-
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# func 21:26:2	tion calls = 8 1 : Model lo zer Software - Extern Options Help 1: 0. 2: 1. 3: 10. 4: 25. 5: 50. 6: 75. 7: 99	aded from VN nal Bridge Mode - A2003 1MHz 1.00-10 .0MHz 1.00-10 .0MHz 1.00-10 .0MHz 0.93-10 .0MHz 0.93-10 .0MHz 0.93-10	VCommon.ini 5 licensed to Kurt Poulsen 100 1.00-i 0.00 1.00-i 0.02 1.00-i 0.02 1.00-i 0.06 1.11 0.93-i 0.11 17 0.93-i 0.11 17 0.93-i 0.12	02700 -13.91µS -15.42µS -11.42µS -3.02µS -3.02µS -3.02µS -22.43µS 1 22.43µS 1 22.43µS 1	3.79µS 9.77µS 3.05µS 3.14µS 9.32µS 0.07µS -	-0.14° -0. -1.31° -1. -3.24° -3. -6.45° -6. -9.61° -9. 12.58° -12	13° 30° 24° 44° 59°		
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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 <u>https://chemandy.com/calculators/round-wire-inductance-calculator.htm</u>

or

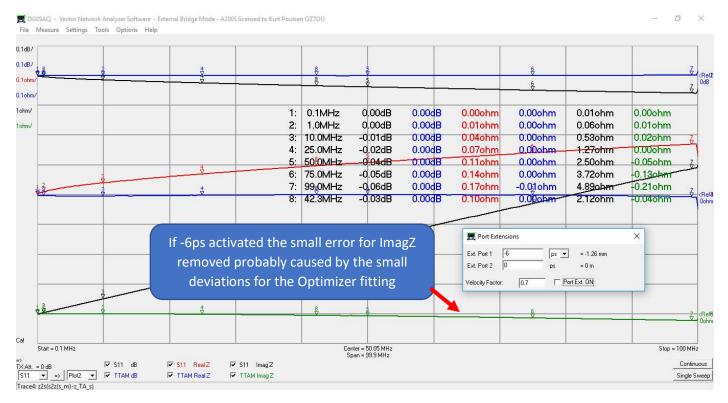
http://www.consultrsr.net/resources/eis/induct5.htm

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:				>
Express	ion:					
z2s(s:	2z(s_m)-z	_TA_s)				
Global S	Subexpressio	ons (available in all ex	pressions, subexpression	ns may use other subexpre	essions from above):	
Name	Alias	Expression				
Sub1 =	z_TA_s	= s2z(z2s(i*w*8	.1128E-009-2.7369	E-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	I.4757E-013*f))+i*w*Cx	
Sub3 =	s_m	= y2s(s2y(S11)	-y_TA_0)			
Sub4 =	Lx	= 0.0e-9				
Sub5 =	Cx	= 0.0e-12				
Aliases:					Caption:	
S21 =		S11 =	\$12 =	\$22 =	TTAM	
Mem1 =		Mem2 =	Mem3 =	Mem4 =	Mem5 =	
Mem6 =		Mem7 =	Mem8 =	Mem9 =	Mem10=	
no Errors						
0	k			Sa	ve Load	

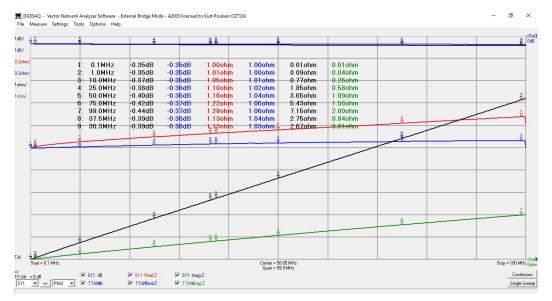
The custom trace still works as before here for the s1p file for the test adaptor with shorting bridge imported to S11



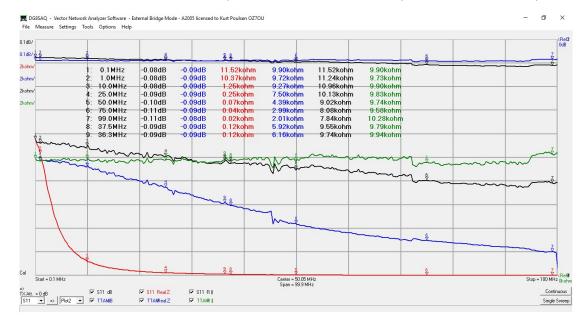
The custom trace also works as before for the s1p file for test adaptor with shorting bridge removed imported to S11



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 10hm and 10Kohm. The ImagZ are due to the pin pin lead length of 2x10mm, to which the SMD resistor are soldered. 1 0hm at 1.060hm at 100MHz.



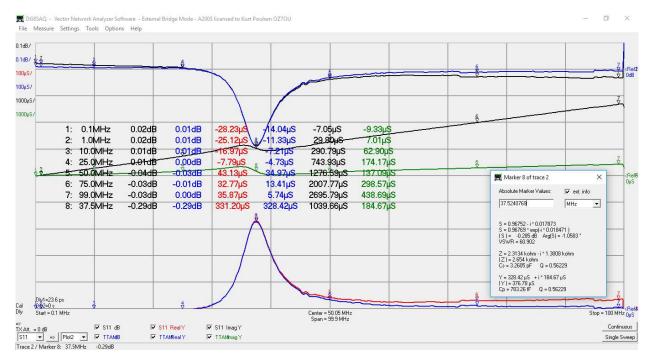
The only reliable measurement is TTAM RII and is within 3% to 99MHz, so the measurements at 10Kohm are excellent even the Shunt measurement technique as earlier noted does not promises such accuracy.



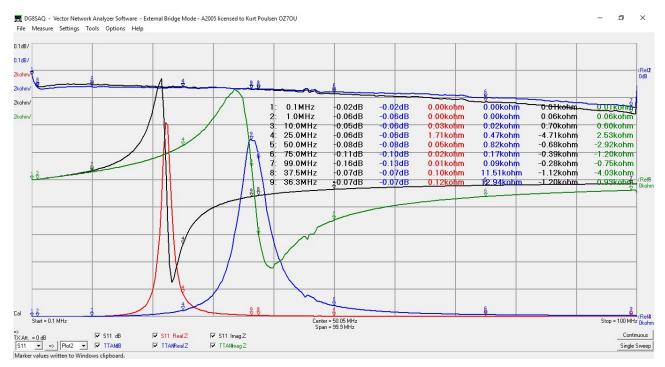
Finding the self-resonance of a 22-winding toroid



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

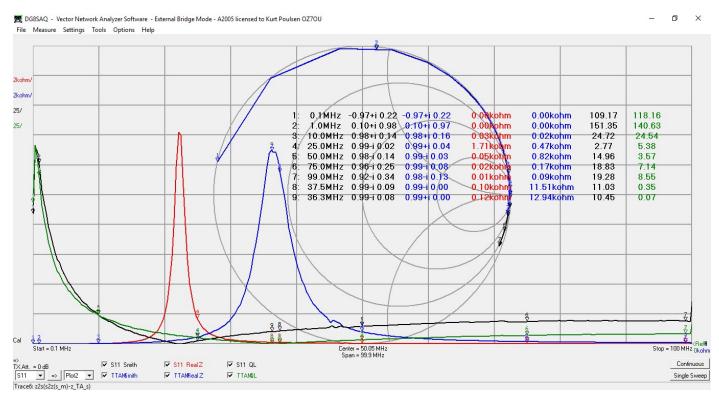


Measurement of the toroid mounted as DUT in the 2wide terminal block show a resonance frequency 36.3MHz. The shift to a lower frequency is caused by a capacitance increase of 0.13pF, which can be explained by an increase in the capacitance between the two wires of the toroid, now closer to each other 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

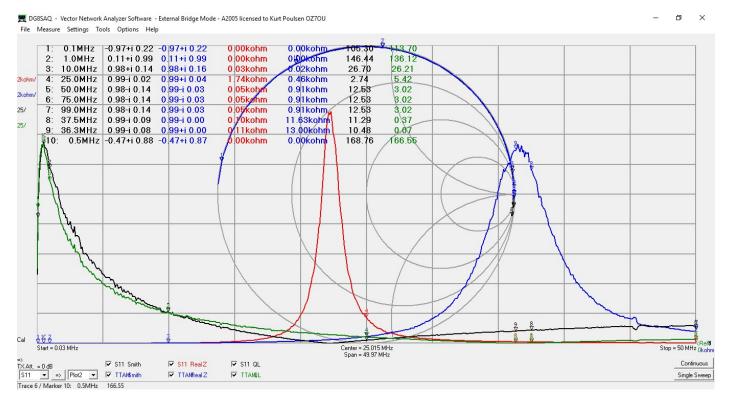


Q traces

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

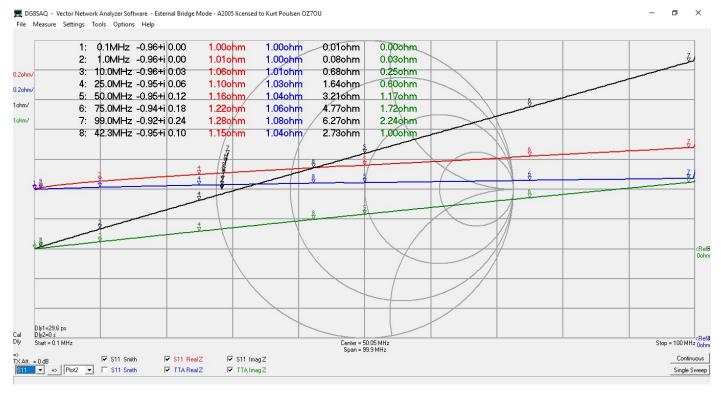
Appendix 1

Measurement accuracy test

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

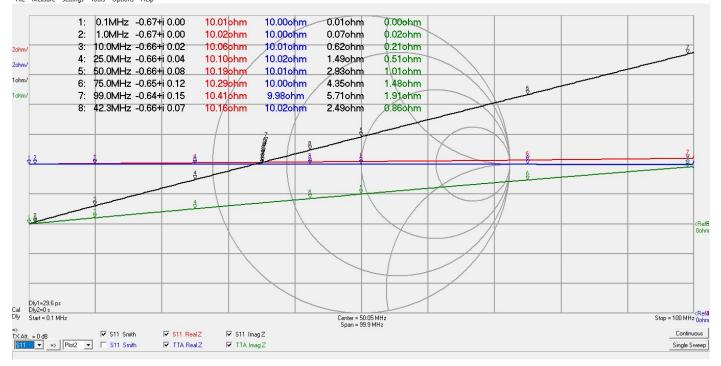
The Shunt measurement method is having the highest accuracy at low ohmic measurements so up to 10K ohm will be excellent if measured correctly.

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



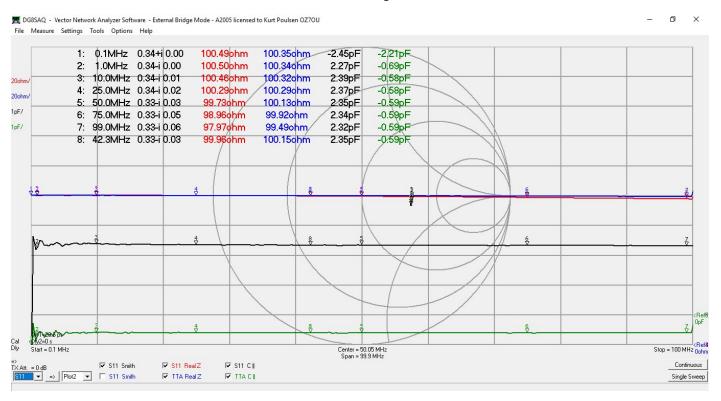
10 ohm fitted

E DG8SAQ - Vector Network Analyzer Software - External Bridge Mode - A2005 licensed to Kurt Poulsen OZ7OU File Measure Settings Tools Options Help



o ×

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



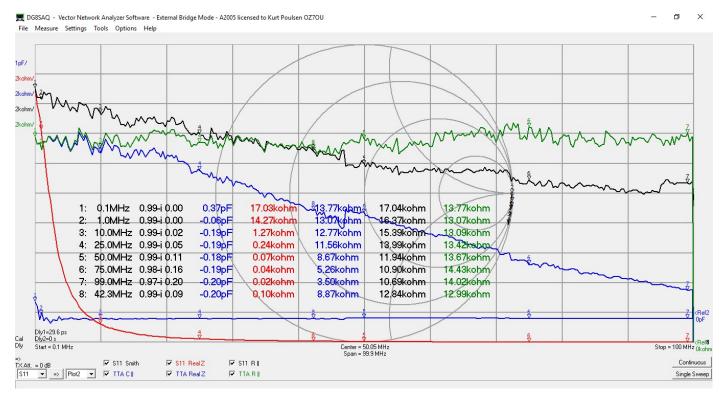
1Kohm fitted

翼 DG8SAQ - Vector Network Analyzer Software - External Bridge Mode - A2005 licensed to Kurt Poulsen OZ7OU File Measure Settings Tools Options Help

1: 0.1MHz 0.91-i 0.00 -0.01pF 1046.29ohm 1031.280hm 1046.290hm 2: 1.0MHz 0.91-i 0.00 1041.46ohm 1025.570hm 1042.060hm -0.14pF 3: 10.0MHz 0.91-i 0.02 986.80ohm 1025.36ohm 1037.67ohm -0.16pF 200ohr 786.15ohm 4: 25.0MHz 0.91-i 0.05 1024.30ohm 1028.28ohm -0.16pF 200ohm/ 1022.38ohm 1014.66ohm 5: 50.0MHz 0.90-i 0.10 464.89ohm -0.17pF 200ohm/ 6: 75.0MHz 0.89-i 0.14 280.65ohm 1022.79ohm 1007.18ohm -0.17pF 1pF/ 7: 99.0MHz 0.89-i 0.19 185.96ohm 1009.97ohm 1000.77ohm -0.18pF 1023.52ohm 8: 42.3MHz 0.90-i 0.08 551.70ohm 1022.00ohm -0.17pF (Ref6 0pF Dly1=29.6 ps Dly2=0 s Start = 0.1 MHz Cal Dly Stop = 100 MHz Oohm Center = 50.05 MHz Span = 99.9 MHz S11 RealZ ▼ S11 B I Continuous TTA CI ▼ TTA RealZ Single Sweep

ø ×

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 bee 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 S21 to S11 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 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 form 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 S11, S21, S12 and S22 and which improves accuracy of the S11 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 cased the F2 measurement saved as a s2p file for later retrieval of the test adaptor impedances in shorted and open condition.

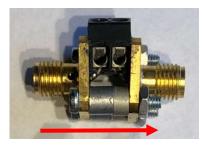
How to do step by step:

At first perform a full SOLT calibration of the VNWA with a female calibration kit with two male male test cables connected to the VNWA. Mount the female 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.

Multiport S-Parameter Measurement X	Multiport S-Parameter Measurement X
Terminal 1 => Terminal 2	Terminal 2 => Terminal 1
OK Annuller	OK Annuller

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

kit aveScreen rint	> Ctrl+P												
oport Data	>	Trace	>	4 <u>1</u> €			8	5			6		
nport Data	>	S2P	>	Real-Imag		1:	0.1MHz	1 00+1 0 00	0.00-i 0.00	50.00ohr	n 0.00ohm	0.00dB	0.00°
ave	>	S3P	>	Mag-Phase		2		1.00-i 0.00				0.00dB	-0.08°
etrieve	> [dB-Phase	Shift+Ctrl+2	3		1.00-i 0.01	0.00-i 0.00	N 1		0.00dB	-0.76°
oftware Updates	>			binary		1.000	25.0MHz	1.00-i 0.03	1 1 2 2 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	N N		-0.01dB	-1.87°
•				- /		5	/		0.00-i 0.02			-0.01dB	-3.70°
				/		6		0.99-i 0.10	C. S. M. M. M. Martin, Phys. Rev. Lett. 16, 121 (1998).	A A A A A A A A A A A A A A A A A A A	and the second se	-0.01dB	-5.52°
2				/				0.99-i 0.13	0.00-i 0.02		and the second se		-5.52 -7.53°
Summer and the second s	1		1			16	100.0MHz		0.00-1 0.03			-0.03dB	
				. 1		8		1.00-i 0.05				-0.01dB	-3.13°
2	-			2 4		9:		1.00-i 0.05	0.004 0.01			-0.01dB	-2.80°
				the the	2	1	0; 27.3MHz	1.00-1 0.04	0.00-i 0.01	49.96obr	n -0.86ohm	-0.01dB	-2.03°
2					- e	L	8	51	\times	1			
Survey and the second s	3		1	1		T			-A-				
				4 1C		N		-			8		
	_			and the			8		m				
							× · · · ·	7		2 A	6		
					\mathbf{X}					//~	e l		
			1		1		\sim	/		the second second	-		
			-						- /				
						\checkmark							and a second
tart = 0.1 MHz							Center =	50.05 MHz					Stop = 100

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

Exit	1						
SaveScreen	>						
Print	Ctrl+P					1	
Export Data	>	Trace	>	S11	>	Real-Imag	
Import Data	>	S2P	>	S21	>	Magnitude-cont.Phase	
Save	>	S3P	>	S12	>	dB-cont. Phase	
Retrieve	> [S22	>	binary	
Software Updates	>			Memory	, Г	4: /25.0	OMH
			+	Plot1	· -	5: 50.	OMHz
				Plot2	>		0MHz
12				Plot3	>	1	
			1. 11	Plot4		/ 7: 100	UMH

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

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

SL				
Global Subexpre Name Alias Sub1 =	ssions (available in all ex Expression = 1	pressions, subexpression	ns may use other subexpre	essions from above):
	- [1			
Aliases:				Caption:
521 =	S11 =	S12 =	\$22 =	SL
viem1 =	Mem2 =	Mem3 =	Mem4 =	Mem5 =
vlem6 =	Mem7 =	Mem8 =	Mem9 =	Mem10=

By a right mouse click om 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

m/		1: 0.1MHz 1.00+i 0.00 0.00-i 0.00 50.00ohm 0.00ohm 0.01ohm 49.57ohm 2: 1.0MHz 1.00-i 0.00 0.00-i 0.00 49.99ohm -0.03ohm 0.03ohm 49.60ohm
m/		3: 10.0MHz 1.00-i 0.01 0.00-i 0.00 49.99ohm -0.32ohm 0.01ohm 49.69ohm 4: 25.0MHz 1.00-i 0.03 0.00-i 0.01 49.96ohm -0.79ohm -0.10ohm 49.74ohm
		5: 50.01/Hz 1.00-10.06 0.00-10.02 49.870hm 1.560hm -0.330hm 49.880hm 6: 75.01/Hz 0.99-10.10 0.00-10.02 49.730hm -2.310hm -0.480hm 49.490hm 7: 100.01/Hz 0.99-10.13 0.00-10.03 49.540hm -3.010hm -0.490hm 49.240hm
6 6	4 1	8: 42,9MHz 1.00-i 0.05 0.00-i 0.01 49,910hm -1,320hm -0.260hm 49,720hm 9: 37,7MHz 1.00-i 0.05 0.00-i 0.01 49,920hm -1,180hm -0.220hm 49,730hm
		10: 27.3MHz 1.00-10.04 0.00-10.01 49.96ohm -0.86ohm -0.13ohm 49.74ohm 511 \$
		Memory > Plot > Other >
		Export Trace to slp
		Clear Trace

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

🚆 Enter Comment	
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

🚆 Enter Comment		×
SMA TA open F2 swap 0.1 to 100MHz 300 1	00ms points	~
		~
No Comment OK	Abort	

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

Exit	1			4 19	8	₿	5			6			
SaveScreen	>												
Print	Ctrl+P						1: 0.1MHz		1.00-i 0.00	-0.02°	4.70pF	179.17°	-3.99pF
xport Data	>	Trace	> H				2: 1.0MHz	0.00+i 0.00	1.00-i 0.00	-0.14°	-3.88pF	175.67°	-1.97pF
mport Data	>	S2P	>	Real-Imag		n I	3: 10.0MH:	z 0.00+i 0.01	1.00-i 0.02	-1.35°	3.75pF	177.54°	-0.09pF
Save	>	S3P	>	Mag-Phase			4: 25.0MH	z \0.00+i 0.02	1.00-i 0.06	-3.32°	3.69pF	202.11°	0.27pF
Retrieve	>			dB-Phase	Shift+Ctrl+2		5: 50.0MH	z 0.01+i 0.04	0.99-i 0.11	-6.56°	3.65pF	226.12°	0.42pF
Software Updates	>			binary		11/	6: 75.0MH:	z 0.01+i 0.05	0.98-1 0.17	-9.77°	3.63pF	223.63°	0.41pF
			-	A			7: 100.0MH	z 0.02+i 0.07	0.97-i 0.22	-12.69°	3.54pF	213.12°	0.32pF
				4		V	8: 42.3MH		0.99-i 0.10	-5.57°	3.66pF	223.14°	0.40pF
				-x-el		1	9: 37.7MH		0.99-10.09	-4.97°	3.67pF	219.51°	0.38pF
	C				2	1		Iz 0.00+i 0.02		-3.61°	3.69pF	206.18°	0.30pF
					- R	1 8	- A						
										- ž			
							-			1			
2	-			4 15	2	1 g				6			
					V	1	Ť		7	4-0			
				X				X	-/1	r			
									- //				
					$\overline{\}$				/				
				4 16	8	× v			/	6			
				V V									-
2 art = 0.1 MHz	-		+			2017	Center = 50.05 Span = 99.9 M						Stop = 100

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

🧱 Enter Comment	×
S11 SMA TA open 0.1 to 100MHz 300 100ms points	^
	~
No Comment OK Abort	

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.consultrsr.net/resources/eis/induct5.htm

or

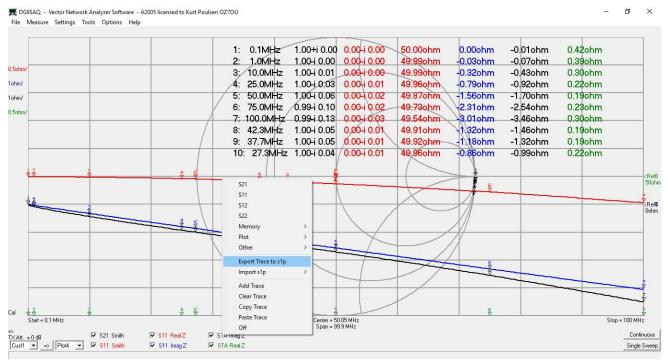
http://www.finetune.co.jp/~lyuka/technote/inductor/inductor-straight-flat.html

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

The 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.

2s(s2z(S11)-s2z(SL)-i*w*1.5e-9)		
		pressions, subexpression	ns may use other subexpr	essions from above):
ame Alias ub1 =	Expression = 1			
1				
liases:				Caption
21 =	S11 =	S12 =	S22 =	STA
em1 =	Mem2 =	Mem3 =	Mem4 =	Mem5 =
lem6 =	Mem7 =	Mem8 =	Mem9 =	Mem10=

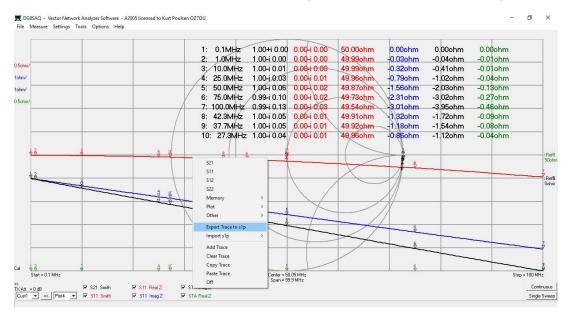
The screen image shows the result which by right click on label SL is Exported to s1p with a file name of "S11 of TA shorted subtracted SL and shorting bridge SL 0.1 to 100MHz 300 100ms points"



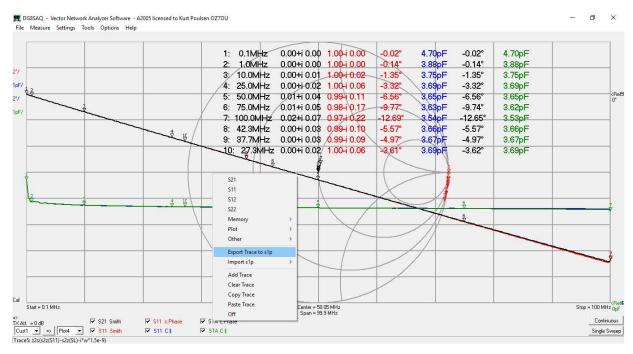
By a DC measurement of the resistance of the shorted Test Adaptor's RealZ of 0.42ohm seems a bit high, as it is more 0 ohm or few milli ohm, so we create a new custom trace where we subtract 50 ohm in stead of s2z(SL) and Export SL to a s1p file with the name "S11 of TA shorted subtracted 50ohm and shorting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

z2s(s2z(S11)-50-i*w*1.5e-9)			
i lobal Subexpr o Iame Alias	essions (available in all e Expression	xpressions, subexpression	ns may use other subexp	ressions from above):
ub1 =	= 1			
diases:				Caption:
21 =	S11 =	S12 =	S22 =	STA
1em1 =	Mem2 =	Mem3 =	Mem4 =	Mem5 =
1em6 =	Mem7 =	Mem8 =	Mem9 =	Mem10=

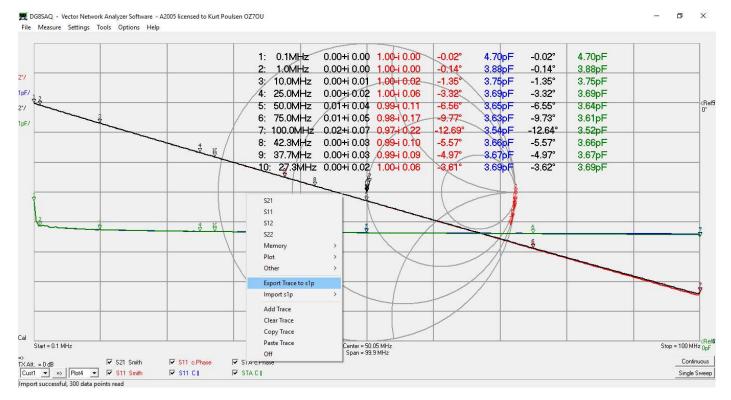
Now at least at low frequencies up to 25MHz the real part is from 0 to 0.04 ohm. Which to use depends very must of the frequency range of interest and negative resistance values might be real as the Test Adaptor is not a 50 ohm transmission line. The F2 12 terms measurement of the shorted Test Adaptor 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