How to fabricate a N male and female calibration kit
With arbitrary calibration data for VNWA 2 and VNWA3

Preface:

I managed to borrow two N male HP calibration kit type 85032E, where the Agilent homepage provides the calibration data for both the male and female short, open and load calibration standards. These calibration data consist of the delays and the needed L and C coeffcients to create the arbitrary calibration string for VNWA2 and VNWA3.

The data to be found on following link. http://na.tm.agilent.com/pna/caldefs/PNA/85032BE.htm

Below table is an extract from the link andd brought here to explain how the arbitrary calbibration setup for the VNWA is done. Any frequency dependant data for the load is not included, as not relevant, because the only information needed is the resistance defined as 50 ohm and the Loss being 0.7Gohm/Sec and not at all important for the VNWA calibration, due to the frequency range limited to 1.3GHz. Below is explained how the delays, L and C coefficient has to be understood.

Std No.	Label	Description	Connector	Sex	C0 F(e-15)	C1 F(e-27)/Hz	C2 F(e- 36)/Hz^2	C3 F(e-45)/Hz^3	Fmin (MHz)	Fmax (MHz	Delay (Sec)	Loss (Gohm/Sec	Z0 (Ohm)
2	OPEN -M-	Type N (50) male open	Type N (50)	MALE	62.14	-143.07	82.92	0.76	0	999000	1.74E-11	0.7	50
5	OPEN -F-	Type N (50) female open	Type N (50)	FEMALE	119.09	-36.955	26.258	5.5136	0	999000	0.00E+00	0.7	50
Std. No.	Label	Description	Connector	Sex	L0 H(e-12)	L1 H(e-24)/Hz	L2 H(e-33)/Hz^2	L3 H(e-42)/Hz^3	Fmin (MHz)	Fmax (MHz)	Delay (Sec)	Loss (Gohm/Sec)	Z0 (Ohm)
3	SHORT -M-	Type N (50) male short	Type N (50)	MALE	0	0	0	0	0	999000	1.78E-11	2.1002	50.209
6	SHORT -F-	Type N (50) female short	Type N (50)	FEMALE	0	0	0	0	0	999000	9.30E-14	0.7	49.992

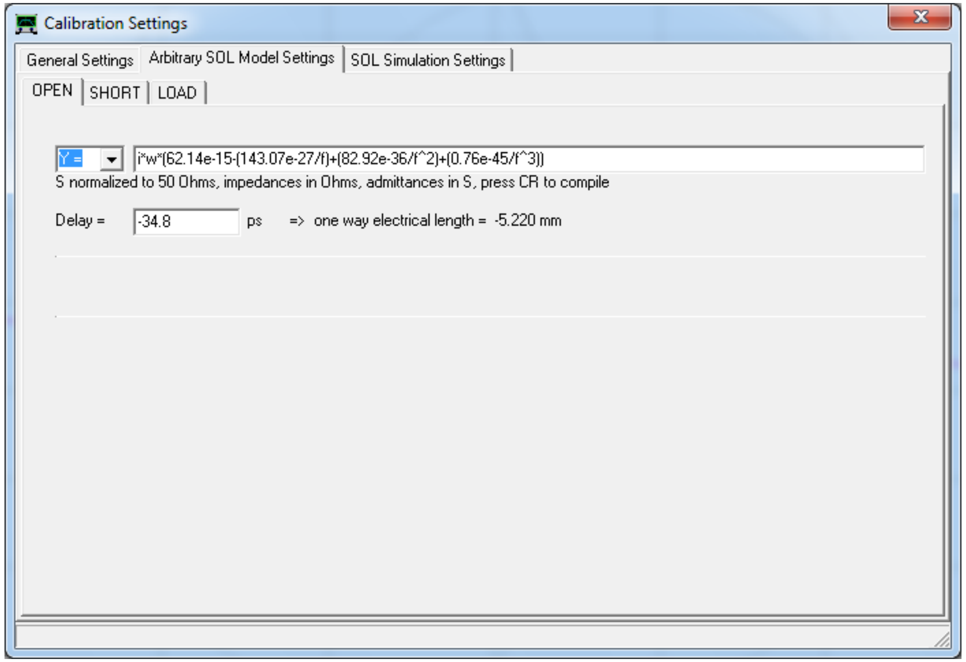
These above data is defined for calibration plane identical to the N connectors reference plane. Below is given explanation for the open male standard being the example used.

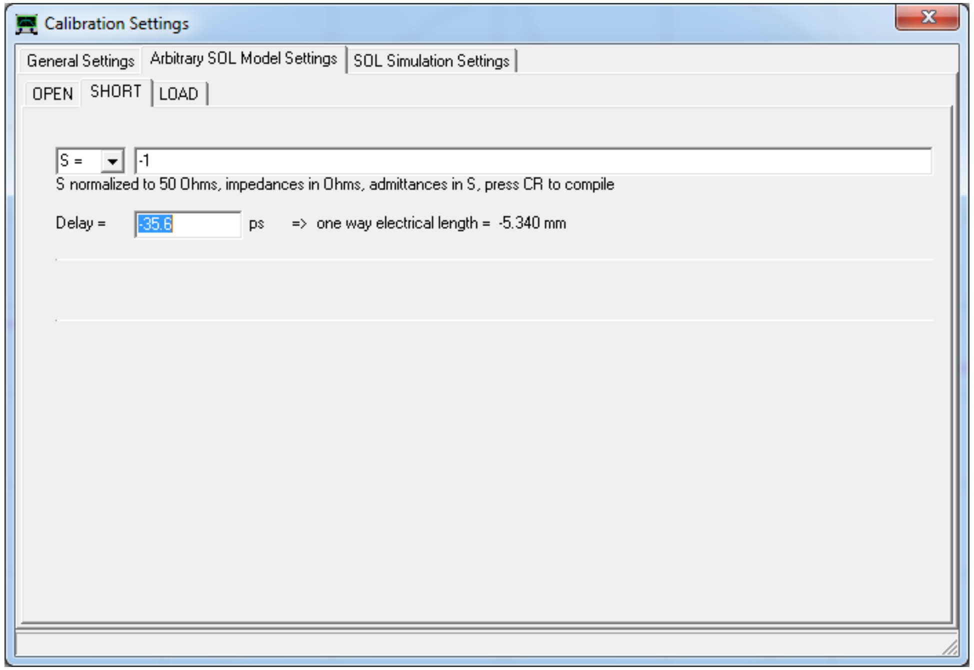
For the open male standard notice the delay 1.74E-11 seconds, which correspond to 17.4ps and it is the one way delay. For the VNWA calibration setting you must be entered twice that value, as a negative delay, equal to -34.8p. The C values is the relevant data to simulate the frequency dependance (end point radiation) from the open center conductor. C0 is the frequency indepedant fringe capacitance of 0.06214pF (equvivalent to a one way delay of 3.107ps calculated by dividing the C0 value in fF by 20) , and the C1, C2 and C3 is frequency dependant capacitive elements in Farad, divided with the frequency in Hz for C1, frequency in Hz squared (^2) for C2 and frequency in Hz triplicated (^3) for C3.

Thus the formula in VNWA Arbitrary calibrated settings is quite simple to express as admittances (Y), because these capacitive elements is summed together due to be in parrallel. Rember that for admittance the sign for C is positive (like for S parameters) but negative if expressed as impedance (Z).

I have been there ☺.

For the expression i*w, the **i** equal to imaginary data indication (same as j) and w is equal to 2*phi*freq so the complete expression is:
i*w*(62.14e-15-(143.07e-27/f)+(82.92e-36/f^2)+(0.76e-45/f^3)) (just copy and paste into the VNWA arbitrary calibration setting) and below is seen the complete entry for the VNWA calibration settings





Above the settings for N male open

Above the setting for N male short as only a delay 2x17.8ps = -35.6ps is defined (no L0, 1, L2 and L3). Remark the delay is negative.

Note.! If you do not want to use arbitrary calibration but ordinary simple model the the C0 value must be added to the fixed delay being 2x (17.8+3.107)ps = -41.814ps

A notice of warning !!!

The data for Std. No 5 - the open female calibration standard - contains a C0 value of 119.09fF = 5.9545ps which as well for the C1, C1 and C3 values is pending the use of a center condutor extender. Such a device is not normally avaible/supplied if you purchase a HP 85032B/E clone kit on e.g. e-bay (as I did) and that problem is dealt with later in this report, how to handle, and still be able to used the arbitrary calibration data for the female calibration standard. It is only really relevant if you want to create ultimate calibration and is going beyond the 1GHz range. You will be shown how to calibrate without use of the center conductor extender. However I have made a center conductor extender based on some simulation (as being shown) and when using the arbitrary calibration the string for copy and paste is:

i*w*(119.09e-15-(-36.955e-27/f)+(26.258e-36/f^2)+(5.5136e-45/f^3))

Using simple model the delay is 2x (0.00+5.9545)ps = 11.909ps

How did it all start

I purchased long ago, from Ebay, a complete N male and female open and short calibration kit, which to my pleasant surprise, I later discovered were clones of the HP85032BE kit. Below I show some pictures of these open and short calibration standards.

Rear view male and female short and open

front view male and female short

front view male and female open

As seen the open calibration standard just consist of a 7mm drilled hole. The female short calibration standard is just a shorting center bushing standing out from the reference plane, which when mated with a N male adator ensures connection to the inner conductor and engagement to the reference plane of the N male adaptors outer conductor, of internal diameter 7mm, and thus provide a delay of 0 ps (actaully 0.09ps if an exact clone the HP85032/BE).

The male short calibration standard is connecting to the mating female adaptor center conductor and its outer conductor, of internal diameter 7mm is engaging to the N female adaptors reference plane, thus will the delay be determined by how deep into the outer conductor the shorting disk is positioned on of the male short calibration standard. It depth measured to be 5.34mm which divided by 0.3 (speed in air 0.3ps/mm) results in a delay of 17.8ps, exactly like the Std. no 3 of the HP 85032/BE. The mated center condcutor has a diameter of 3.04mm which combined with the hole of 7mm provides a Z0 of 50 ohm. A direct copy and home made set of male and female standards is is not an easy task, without having fine machinery, but there is **a simpler way** to do it, **still producing a well defined male and female open and short calibration standards, for VNWA3 and VNWA2 use, and which is reproduceable.**

The basic simplicity of the design as shown on the pictures indicates it must be able to fabricate homemade N calibration standards, and as having access to 2 pc. male HP85032E calibration kits, I can calibrate my VNWA3 + VNWA2 and measure both the Ebay clone kit, as well as my own homemade ”clones of the clones and clones of HP85032/BE”, and from saved Touchstone S11 files mathematically derive a set of coefficients, (if needed at all) fully useable for arbitrary calibration of the VNWA2 and VNWA3. I have done such coefficient deriviations earlier for both Rosenberger and Amphenol Connex SMA male/female calibration standards, so I have proven it works as expected.

25.2 mm End to End

31.7 mm end to end when mated
30.6mm for the outer conductor
of inner diameter of 7 mm

The Essential information for this Sideview picture is the lenght for the open male and female calibration standards and as shown. It will be proven that the lenght is not ctritical, but for those which plan to use/test at frequencies beyond the VNWA range of 1.3GHz they are copied as exact as possible.

Side view for the male and female open and Short

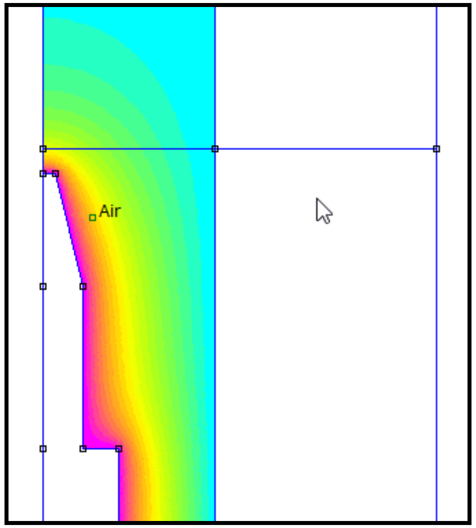
Regarding the load standard I strongly recommend to purchase a cemmercial Load. I have purchased a couple and in particular the Radial N male load (Radial part nr. R404240000 from Farnell (part nr. 4196624) is very close in characterstic to the HP85032E Load standard. I have also designed a homemade load which is tested to be OK as well for the VNWA frequency range. More on that later.
The numerious other N male loads are from R&S, Huber Suhner and a very accurate HP inline attenuator which, when loaded on the output with 50 ohm also act as a good load. I will provide more data in the last section of this report.

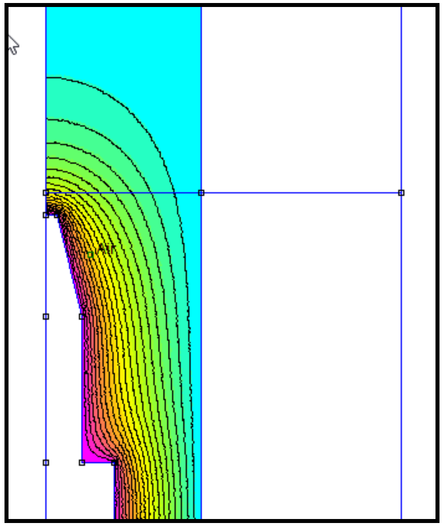
For comparison I show below picture of the HP 85032E male calibration kit

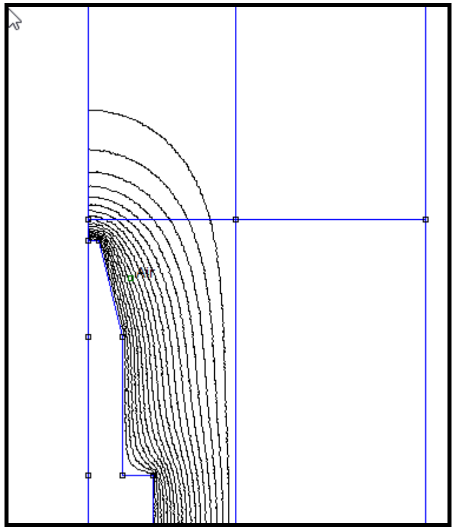
The only relevant info is the depth of the open champer with inside diameter of 7mm which is 32.5mm. for the short the shorting disk is recessed 5.25mm. When trying to calculate the delay we get 5.30/0.3 ps/mm = 17.67ps. The Agilent data say 17.8ps so the caliper I used it not accurate ☺ the distance is 17.8*0.3=5.34mm. When the open male is mated with a female N connector it is the mating center conductor which is creating the delay pushed into the depth of the 32.5mm deep “hole” of diameter 7mm. The “hole” or outer conductor of diameter 7 mm is just controlling the the matings center conductors environment from the mating connectors reference plane (also the open male’s reference plane) to the end of the center conductor incl. the fringe capacitance C0 (and its frequency dependant capacitances) and made to strict mechanical tolerances. We will below further examine this situation and as shall be seen **the quality of the calibration** it **not dependant** to any great extend **of the male open calibration standard but more of the mechanical tolerances** of **the female mating connector** onto which the N female calibration standard is fitted. This connector is e.g. sitting at the end of the testcable and thus part of the calibration… **surprise surprise**…

How to understanding a calibration standard from a physical point of view.

Before we start looking on how to create a homemade N male and female calibration kit, let us first understand what happens from a physical perspetive point of view.
As an example lets examine the N male calibration standard which is just a cylindric out conductor (a hole) of diameter 7mm when fitted to the female mating connector at the end of a testcable or fitted to a N female on the front of the VNA/VNWA, by using a free and very excellent Finite Element Method program called Femm.

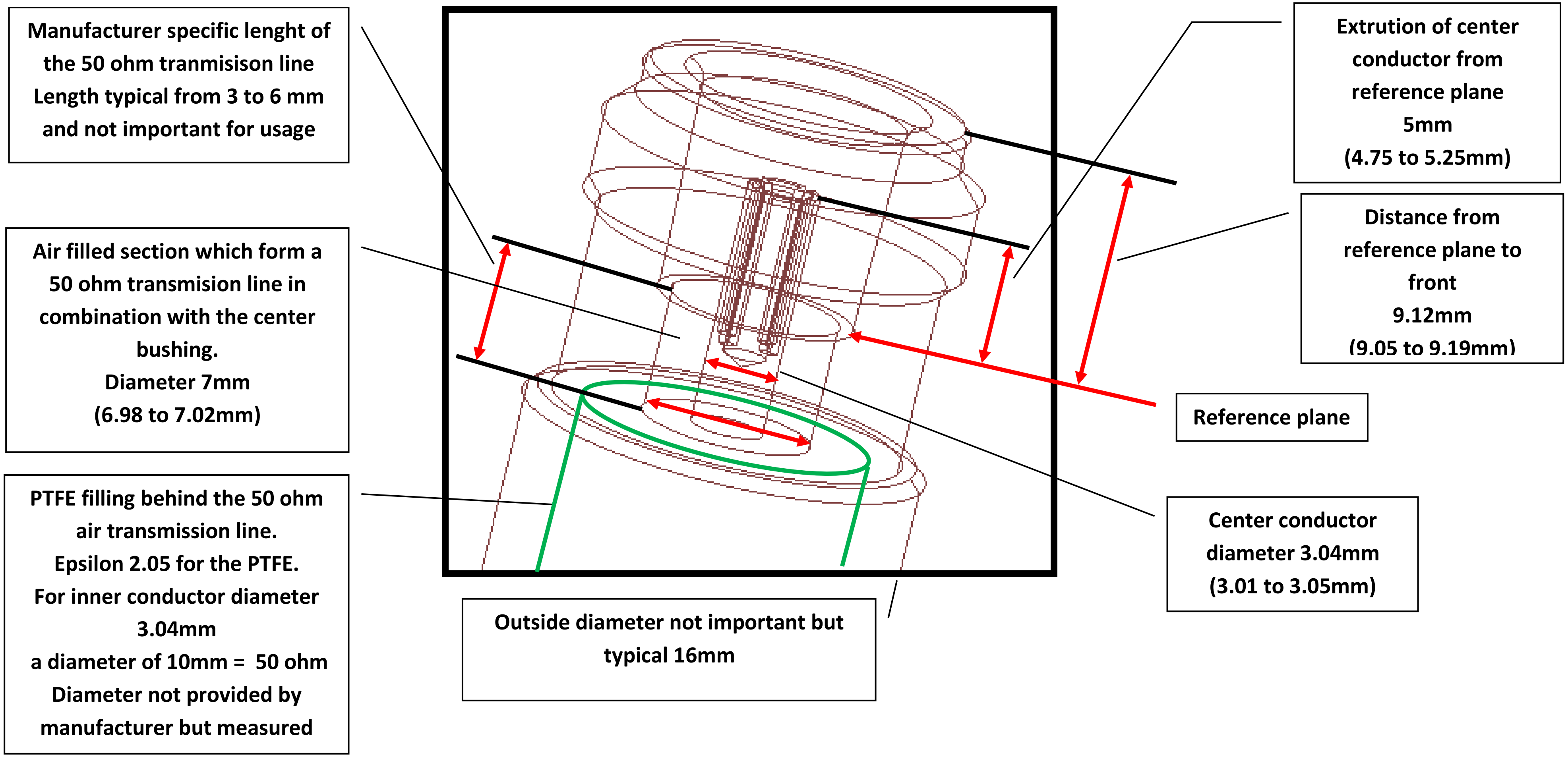




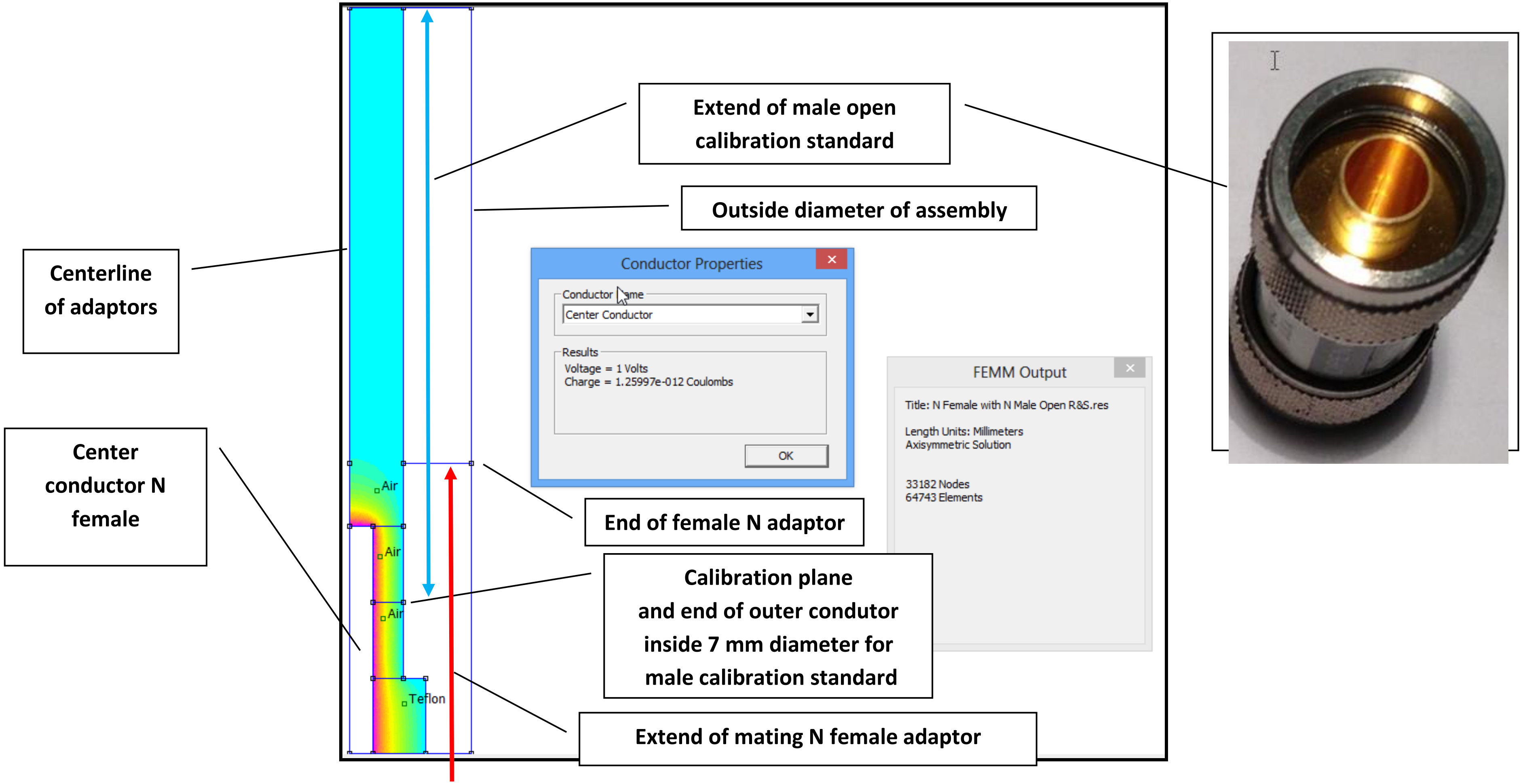


Varoius representations of the simulations is possible, but including the equipotential lines, which is very ilustrative in full screen mode, is however not practical to apply when images scaled down, as the lines melt together and as well hiding the material indicators, such as air shown in the examples. Conclusion …lines avoided in this report.
Next step:
For simulating the assembly of N male calibration standard and the mating female N adaptor we need to find and define the mechanical dimensions.

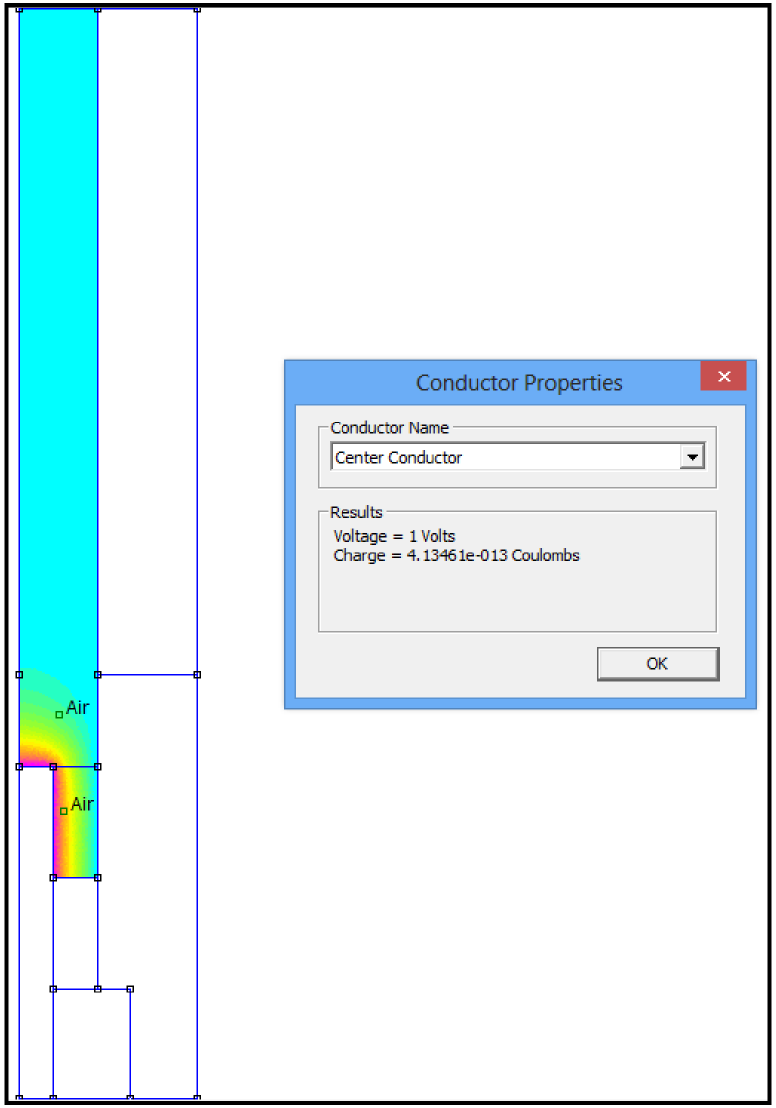
For that purpose a study of the Huber Suhner, Rosenberger, Radial and Amphenol connex homepage for connectors showed they all were very identical as follows.

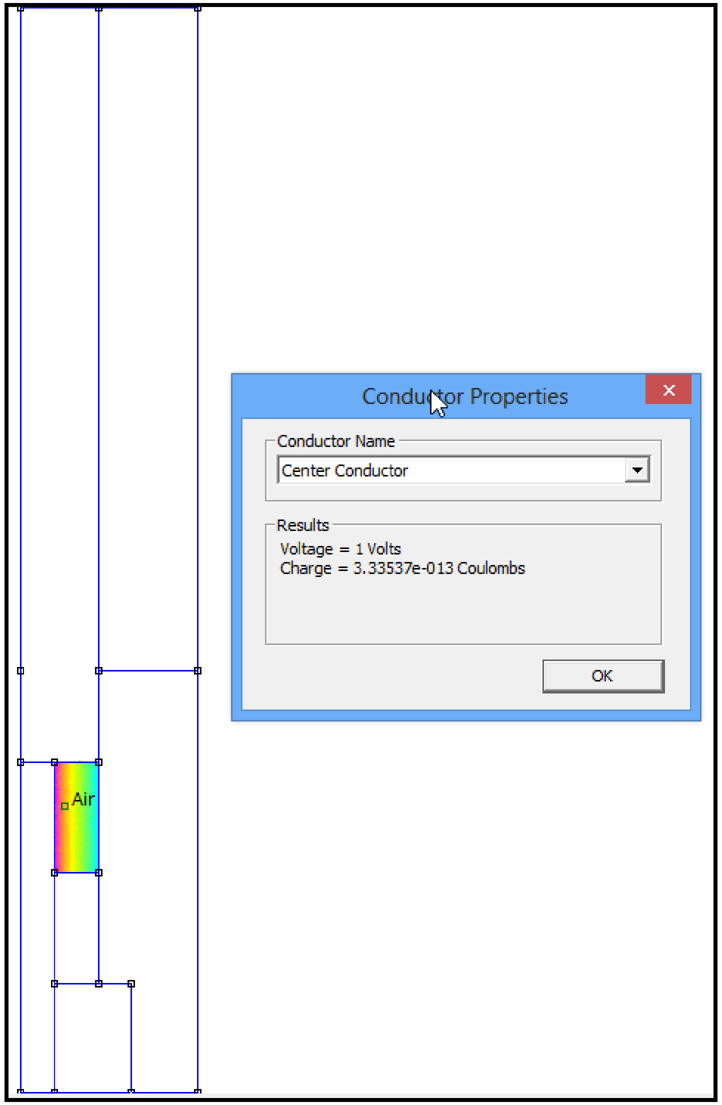


These dimensions used for the simulation in Femm, and to understand below pictures, the assembly is shown in vertical position with only half of the adaptor shown with centerline to the left side. The mating connector (N female) shown below and the male open calibration standard above. If you do not understand right away the carry on reading.



In the picture is shown the measured Charge at 1 Volt which is identical to the capacity 1.25997 pF or 1259.97fF, which equals to a delay of 1259.97/20 ps = 62.9985 ps. This is not the entire delay of the N female adaptor as in the simulation is only taken an arbirary length with teflon. The section of interst is the delay above the reference plane which is the delay for the 5 mm long center conductor, and the fringe capacitance at the end of the center conductor, which you can see is intruding into the male open calibration standard some 5 mm from the tip of the center adaptor. We will now determine the delay of the center adaptor from reference plane incl. fringe capacitance and the center adaptor from reference plane on its own. The difference wil be the fringe capacitance contribution.





The delay for center adaptor incl. fringe is 413.461fF/20 = 20.673ps and for the center conductor alone 333.537fF/20 = 16.667ps . Thus the fringe capacitance alone is 4.006ps or or by subtracting the charges we get 413.461-333.537 = 79.924fF.

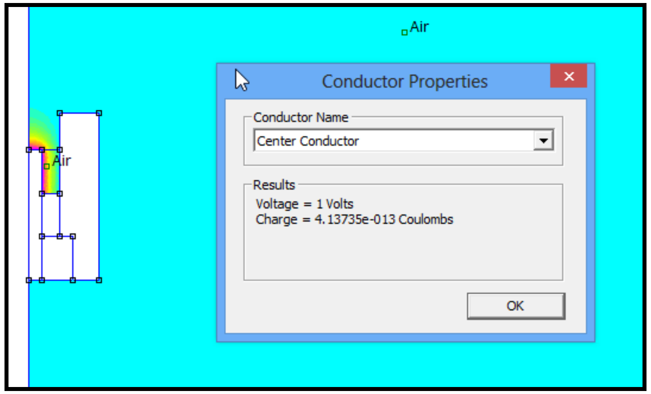
We will now compare these calculation with the data provided for the HP 85032BE kit which in below schematic is the Std. No. 2

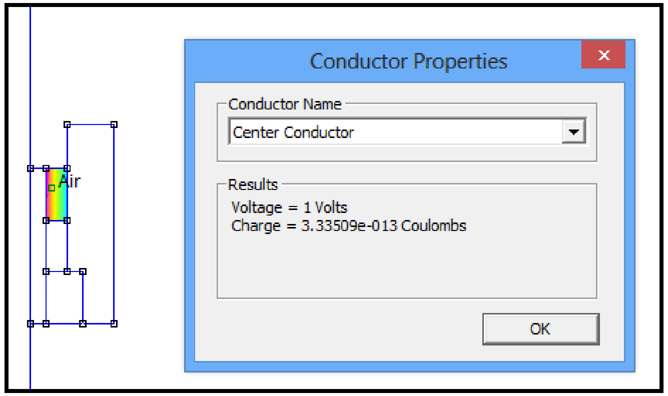
Std No.	Label	Description	Connector	Sex	C0 F(e-15)	C1 F(e-27)/Hz	C2 F(e- 36)/Hz^2	C3 F(e-45)/Hz^3	Fmin (MHz)	Fmax (MHz	Delay (Sec)	Loss (Gohm/Sec	Z0 (Ohm)
2	OPEN -M-	Type N (50) male open	Type N (50)	MALE	62.14	-143.07	82.92	0.76	0	999000	1.74E-11	0.7	50
5	OPEN -F-	Type N (50) female open	Type N (50)	FEMALE	119.09	-36.955	26.258	5.5136	0	999000	0.00E+00	0.7	50
Std. No.	Label	Description	Connector	Sex	L0 H(e-12)	L1 H(e-24)/Hz	L2 H(e-33)/Hz^2	L3 H(e-42)/Hz^3	Fmin (MHz)	Fmax (MHz)	Delay (Sec)	Loss (Gohm/Sec)	Z0 (Ohm)
3	SHORT -M-	Type N (50) male short	Type N (50)	MALE	0	0	0	0	0	999000	1.78E-11	2.1002	50.209
6	SHORT -F-	Type N (50) female short	Type N (50)	FEMALE	0	0	0	0	0	999000	9.30E-14	0.7	49.992

The delay for the center conductor is 17.4ps (simulation was 16.667ps) and the static fringe capacitance C0 is 62.14fF = 3.107ps (simulation was 79.924fF = 3.9962ps) and the HP delay is then 17.4 + 3.107ps = 20.507ps . The simulated delay is 20.673ps and the delay difference of 0.166ps correspond to - 0.05mm displacement relative HP 83032E open. Just a small adjustment of the center conductor length will impact the delay e.g. extending within the tolerances 4.75 to 5.25mm with increase the delay from 16.667ps to 17.5ps = 0.25mm far more than the difference of 0.05mm. The Femm accuray is supposed to be within + - 0.2% and thus proven to be superb for the job. The fact is the mating connector is the major contributor to the delay so tolerances is to be expected. **Anyway the issue was not to prove the accuracy but to facilitate the physical understanding and demonstrate that if we produce a homemade N male open calibration standard, the only requirement is to provide a tubular diameter of 7 mm of adequate length and we can fully justify to use the HP arbitrary calibration data incl. the C0, C1, C2 and C3 data and trust the result.** What else ☺ …….

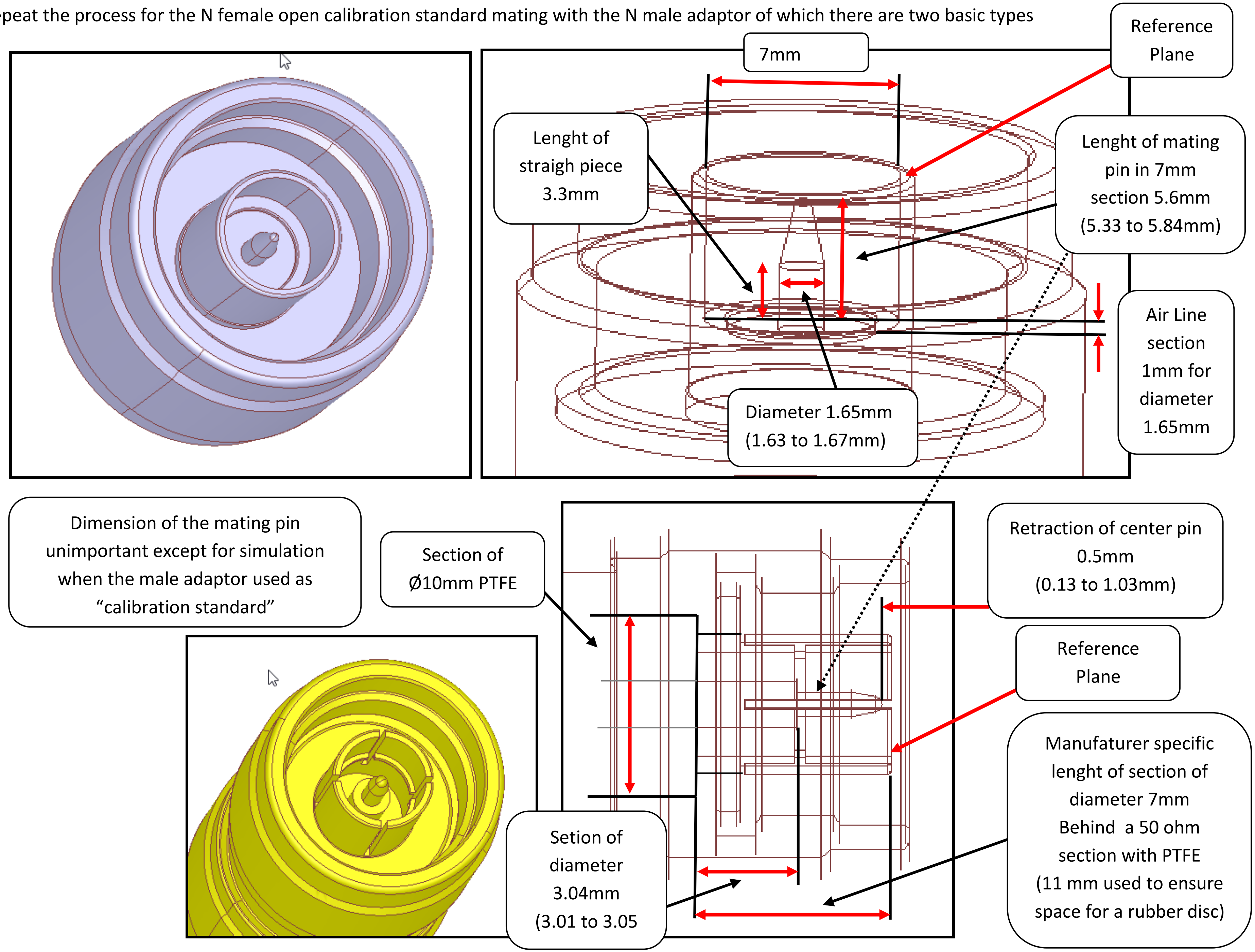
But what about using the female N adaptor without extension of the Outer conductor for the N male open calibration standard for calibration ?
As it is not the N male calibration standard adaptor which determine the delay but almost only the mating N female adaptor we might use that on its own. Below is shown the simulation and the result is a difference of (20.673 – 20.69)ps = -0.017ps so nothing. However remember

The total charge is 413.735fF and without Fringe capacitance it is 333.509fF (as seen before although a bit smaller due to a finer mesh in the simulation) Then the total delay is 413.735/20 = 20.69ps where the fringe capacitance accounts for 4.01ps(413.735-333.509)/20.
We shall later on see how that works when comparing to the “official calibration method” for the VNWA up to 1.3GHz

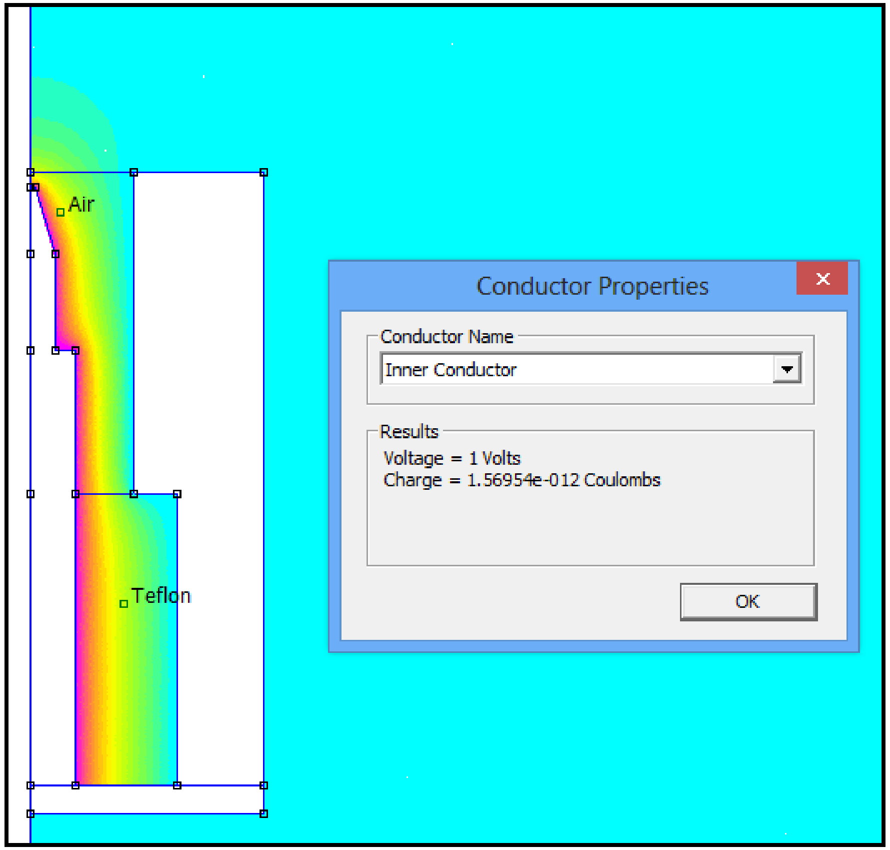


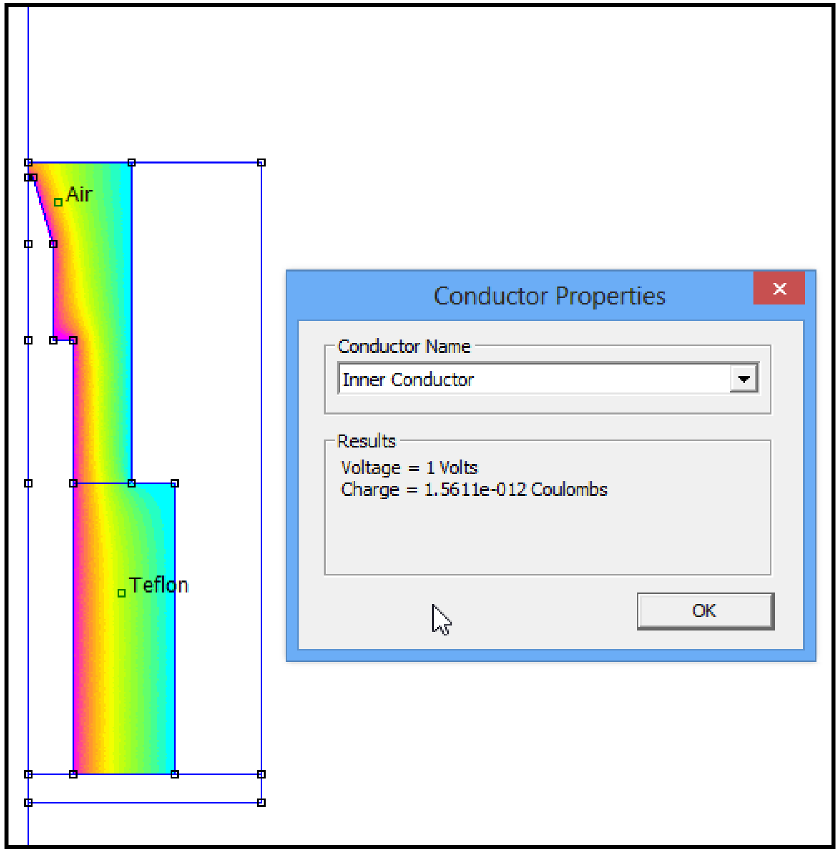


Now we shall repeat the process for the N female open calibration standard mating with the N male adaptor of which there are two basic types



Simulation of the N male adaptor without the N female calibration adaptor.

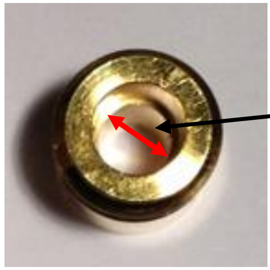




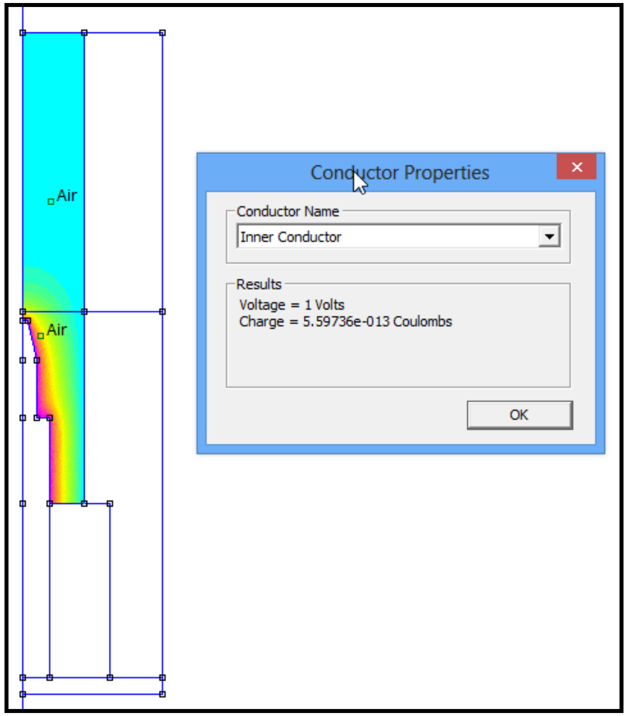
The entire charge is 1569.54fF (left image) and below the alibration plane (right image) the charge is 1561.1fF. Then the difference is the fringe capacitance of **8.44fF** and by division of 20 is correspond to a delay of **0.422ps**. Remember that by definition there is no fixed delay as the electrical calibration plane is identical to the mechanical reference plane for a male N adaptor.

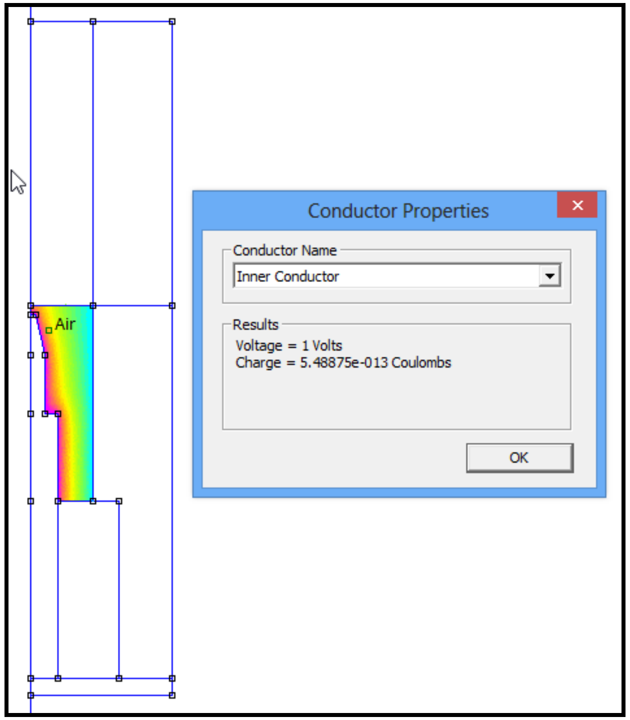
Next follows the simualtion when the N female calibration adaptor fitted to the mating N male adaptor:

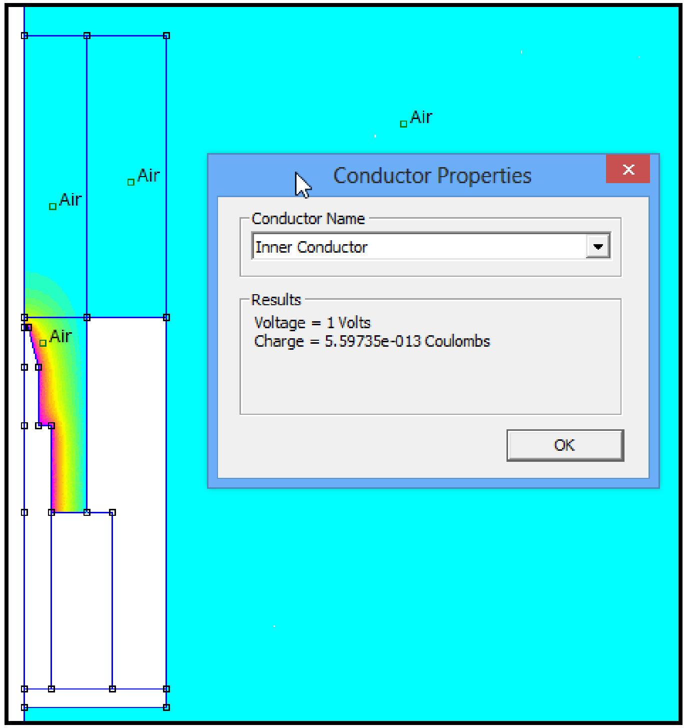
25.2 mm End to End



The outer conductor starting at the reference plane with diameter 7mm is recessed 9.12mm and the top inside diameter is more than 8.1mm (8.3mm) so the outer conductor of the N male (with inside diameter 7mm) can mate against the reference plane 9.12mm down .







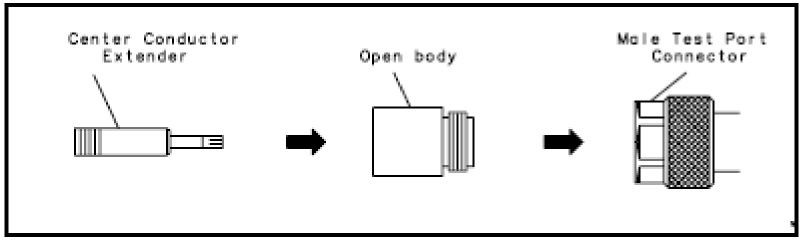
The entire charge is 559.736fF (left image) and below the calibration plane (right image) the charge is 548.875fF. Then the difference is the fringe capacitance of **10.861fF** and by division of 20 is correspond to a delay of **0.543ps**. Remember again that by defenition there is no fixed delay as the electrical calibration plane is identical to the mechanical reference plane for a male N adaptor. The impact on the fringe capacitance when mounting the N female calibration adaptor is next to nothing only 0.001fF = 0.00005ps (559.735-559.736)fF corresponding to a displacement of the calibration by 0.0000015mm. So no need for the N female open calibration adaptor aparently or what ??

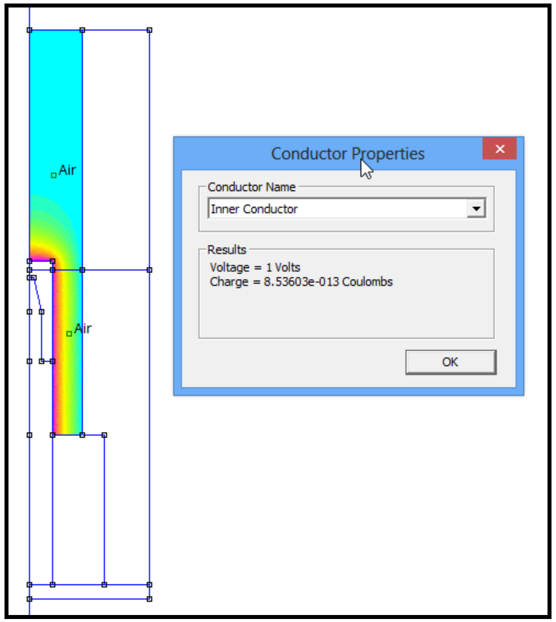
We have to go back to the HP 85032/BE kit table to see how the conditions are when calibrating with the female open standard which is Std. No 5

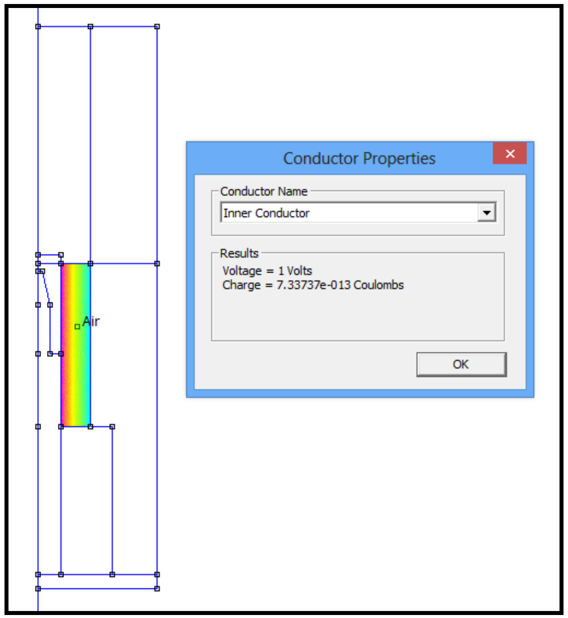
Std No.	Label	Description	Connector	Sex	C0 F(e-15)	C1 F(e-27)/Hz	C2 F(e- 36)/Hz^2	C3 F(e-45)/Hz^3	Fmin (MHz)	Fmax (MHz	Delay (Sec)	Loss (Gohm/Sec	Z0 (Ohm)
5	OPEN -F-	Type N (50) female open	Type N (50)	FEMALE	119.09	-36.955	26.258	5.5136	0	999000	0.00E+00	0.7	50

The delay as expect 0.00E+00 but the Fringe Capacitance C0 is 119.09fF ?? What is the explanation to that. See below why…

The Explantion is quite simple (when you first find it ☺) as the user manual for the HP 85032BE has a picture showing a center conductor extender, which is part of the N female calibration kit. There is no information how long this center conductor extender is, but simulations to follow is resulting in 6.7mm. This center conductor extender is sitting at the of an isolated shaft, ensures the diameter is 3.04mm all along and this to ensure proper operation for the entire frequency span up to some 6 GHz so the C1, C2 and C3 coefficient is valid to use. The idea is probably to extend it to the calibration reference plane but I do not know if that is true, but in that case it should be about 1 mm shorter. I made myself a center conductor extender as show on the picture to the right 6.7mm long. For VNWA frequencies up to 1.3GHz it is hardly nessesary to do anything but just use the fringe capacitance delay of **<u>0.543ps</u>** as found above and use no extender. That will be tested and documented later in this report.





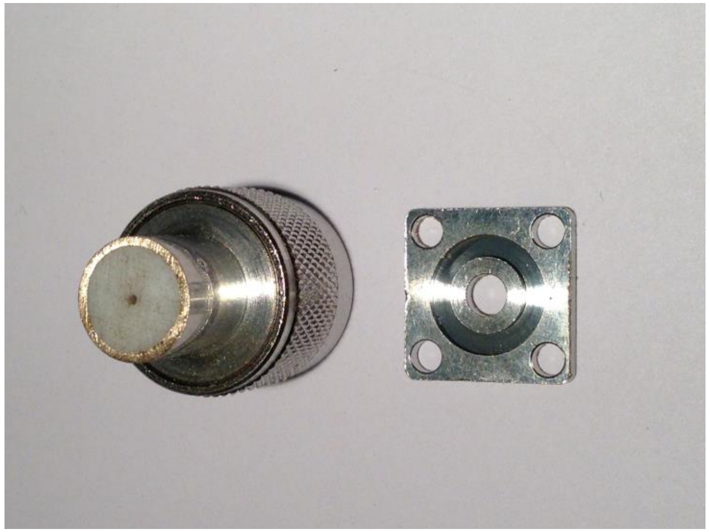


The entire capacity is 853.603fF and with the fringe capacitance above the calibration plane 733.737fF . Difference is 119.866fF equivalent to the HP figure for C0 of 119.09fF. Simulation of the fringe capcitance above the calibration plane is 119.163fF. So the fringe capacitance delay is 119.866/20 = 5.99ps to be used as - 6ps or –(2 x 6)ps in the calibration seeting for VNWA, when using the center conductor extender but without applying arbitrary calibration where C0 C1, C2 and C3 comes into force. That concludes all the simulation as there is no point in examine the other N male type and as the short calibration standards are straight forward and will be dealt with in the next section.

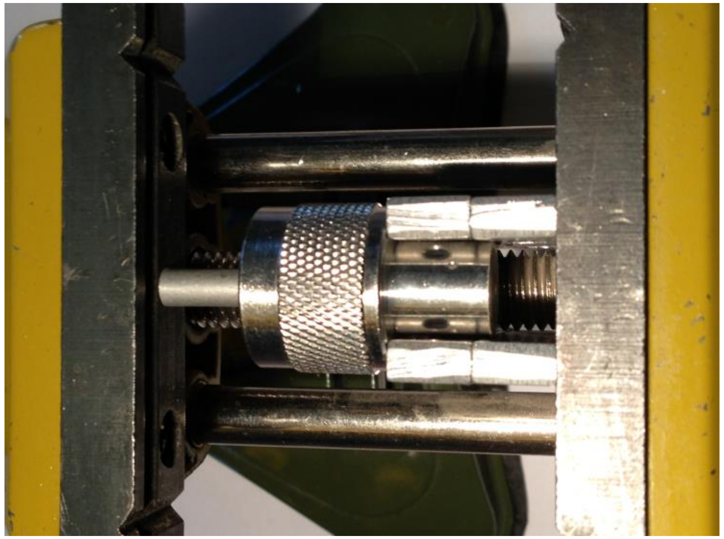
Let get started with the fabrication of the homemade N male short open and load calibration standard

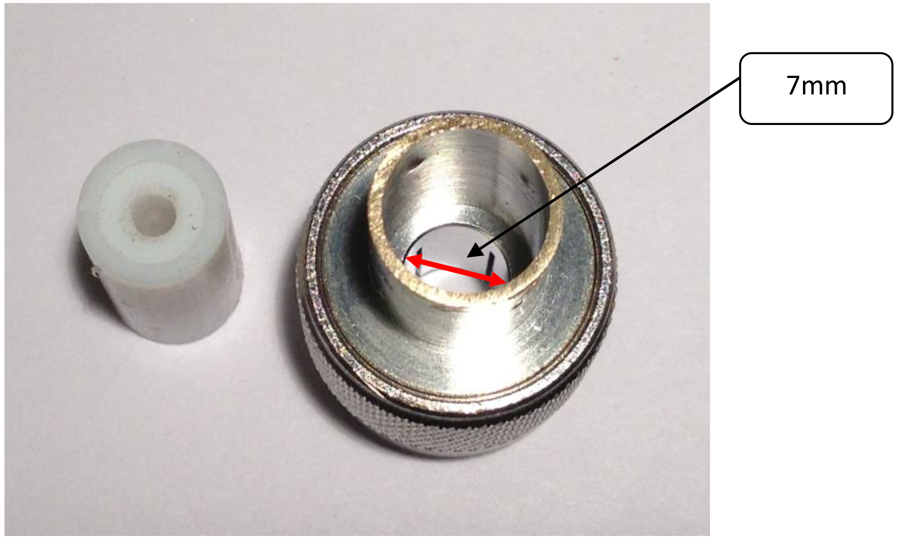
It all started with the following part from Aphenol Connex Part No. 172260-10 which I aquired cheaply from Ebay

These adaptors are well suited for the production of the male short and open calibration standards. I have permanently removed all rubber disk inside the adaptors used

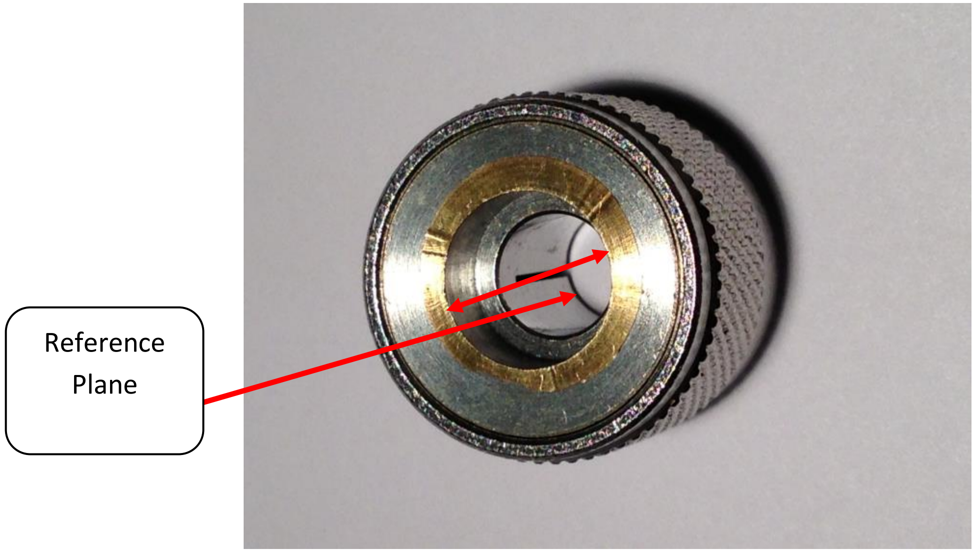


At first we need to remove the center conductor as shown on the left picture in a vice using a 1.5mm rod and a long 5mm aluminium/brass tube with an inside diameter of 3mm. Next jigsaw the endplate of the adaptor and grind it clean flat.

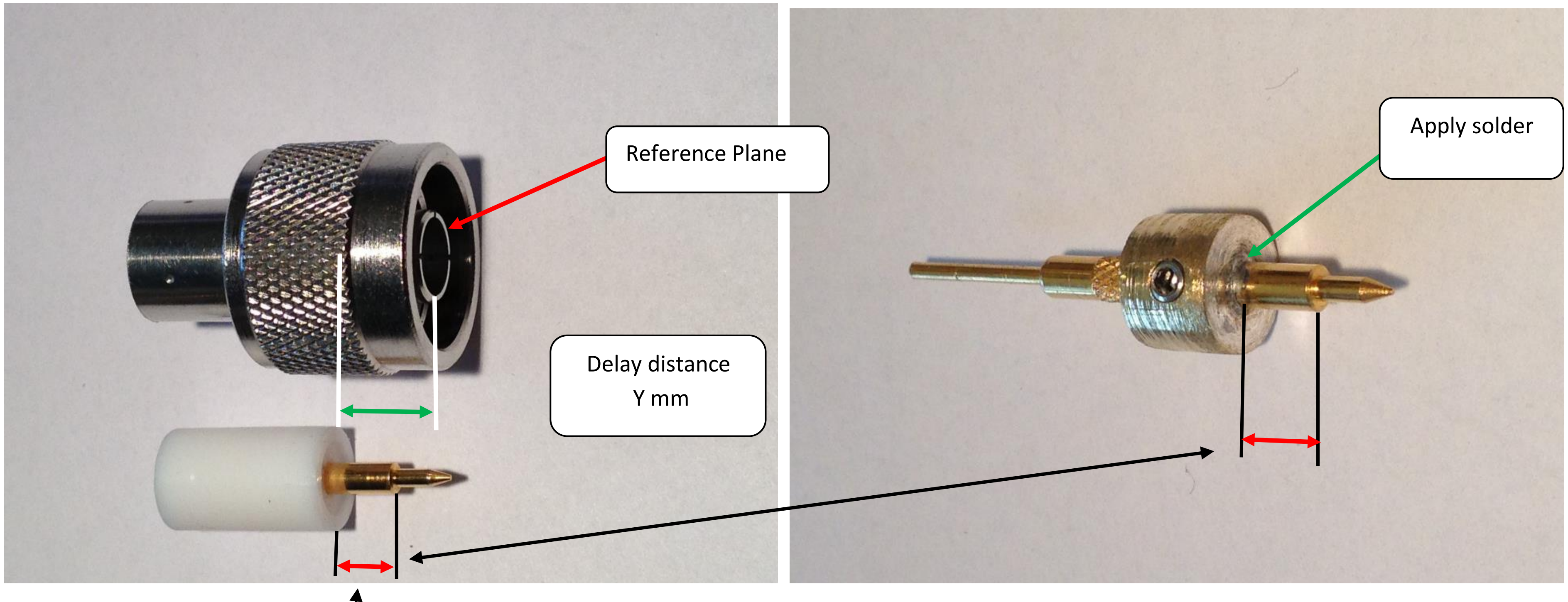




In a vice press out the PTFE bushing as shown, using a mm aluminium/brass tube with inside diameter 3mm. Now we have a clean adaptor with a view down to the 7mm diameter hole to form the open and short calibration adaptors controlled environment with inside diameter of 7mm.



You may grind/mill the adaptor down as shown on left picture (or leave as is but it is beneficial to grind it down to just above the ensuface) and then find a piece of 10mm Cu tubing used for household water plumbing with a wall thickness of 1.5mm and cut a thin longitudal slot to adjust the inside diameter to 7 mm when the edges of the slot is pressed together. Trim the outside diameter so it can be pressed into the adaptor against the rim where the indside 7 mm diameter starts and use the vice for a firm assembly.   The Length from the calibration plane to end of the Cu tube is 32mm. Solder a small disk at the end of the Cu tube and close the slot by a small amount of solder. The male open calibration standard is now finally made as a HP clone. **You may check the inside depth from the reference plane to the buttom to be 32mm**



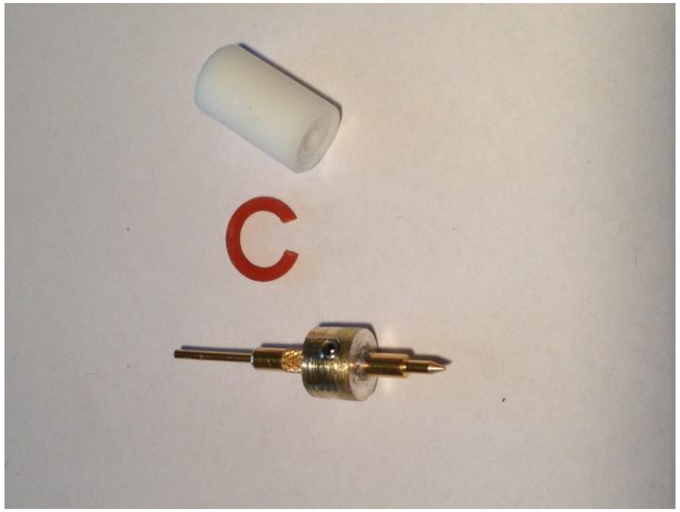
Produce a second adaptor where you also cut the center conductor when jigsaw'ing the endplate off and use a vise as shown above to remove the PTFE insert with the center conductor still fitted.

<u>Measure and note the distance shown accurately</u> as needed for ensuring the center conductor is brought back to its original position.

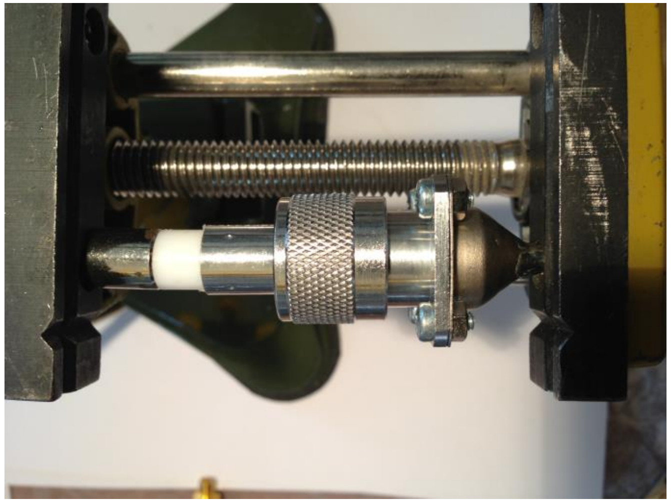
Also measure the delay distance inside the adaptor very accurate to Y mm. **<u>The delay in ps is Y mm divided by 0.3</u>**

The PTFE bushing from the production of the male open standard is used for the next steps.

Produce a shorting disk as shown on the right picture with outside diameter 9.9mm (or what diameter your adaptor might have) for being a press fit into the empty adaptor. I have drilled a 2mm hole for a 2.5mm thread and inserted a small hex screw to adjust and fix the distance to the same as measured on the PTFE unit on left picture. Use minimum of solder and cut away with a scalpel the excess solder.

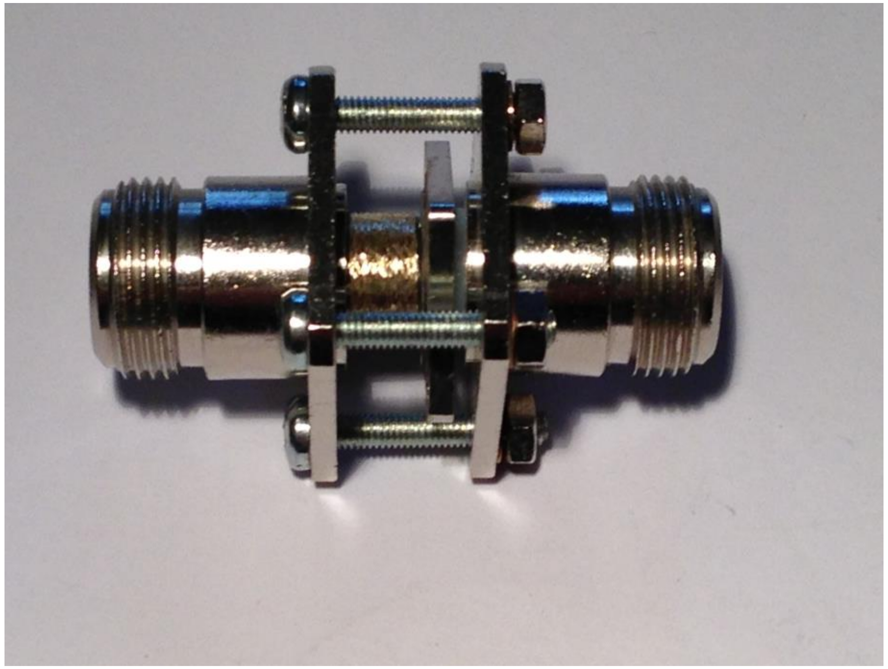
 

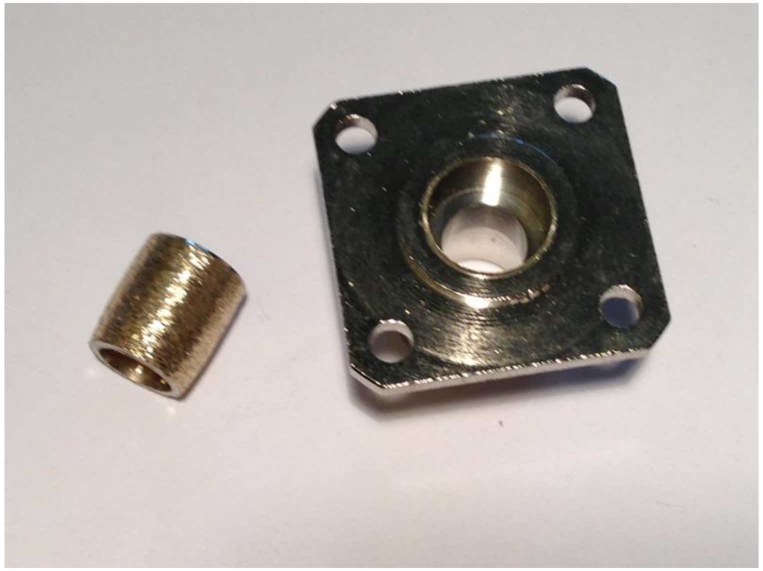
Cut a section of the surplus O-ring (to maintain pressur on the shorting disk) and the parts on the left picture now ready to be inserted into the empty adaptor

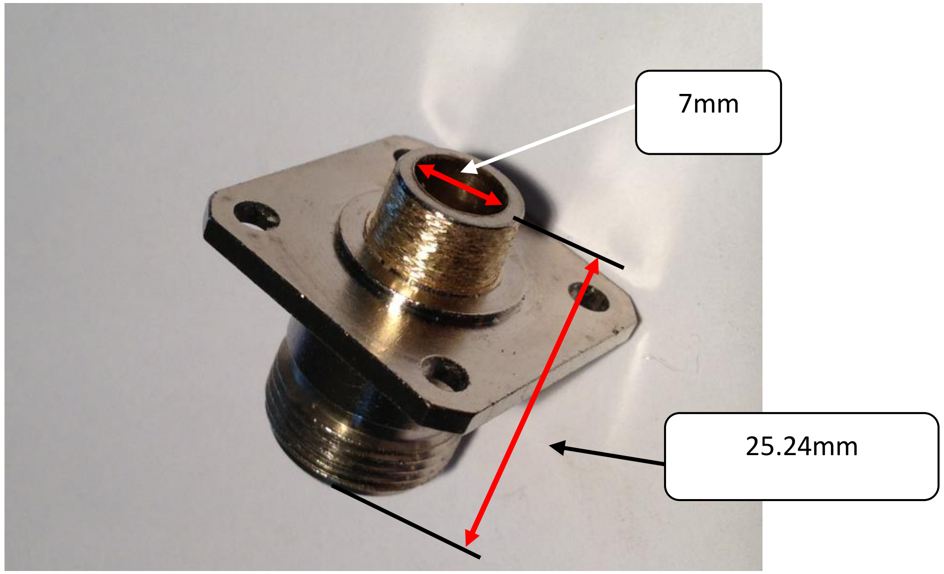
 

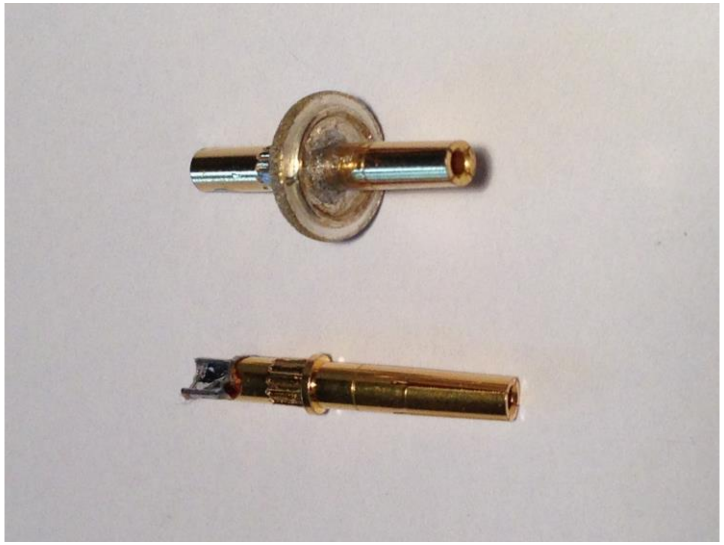
Mount the adaptor on a N female adaptor as shown above and use the vice to press the PTFE insert in place and while still under pressure drill a 2.5mm hole for each 90 degree and cut 3mm thread. Do not drill into the center conductor. Mount the 4 screw and take it apart for inspection and control measurements of the shorting disk depth from the reference plane. Mine measured to 11.7mm equal to a delay of 11.7/0.3 = **39.00ps**. That was the production of the male short calibration standard.

Much the same way is the femal open and short calibration standards made. The pictures are quite illustative. Again for the open standard a tube of inside 7 mm diameter is prepared for a pressfit into the empty adaptor. The total lenght of the tube and the distance to the reference plane is 16.12mm (23.24mm from front to end). Clone of Clone !!!!
Please note the combined short and open shown on the left picture is exerimental, as the open is shorted with a disk for finding out if the caracteristics is influenced at all. Basicly it should be a advantage for very high frequencies. More on that later.
Also very important is to measure and note the distance from end of PTFE to end of center conductor when the PTFE insert is pressed out in a vice with the center conductor still fitted. This distance needed for mounting and soldering the center conductor to a shorting disk so it is exactly in the same position inside the adaptor when assembled.

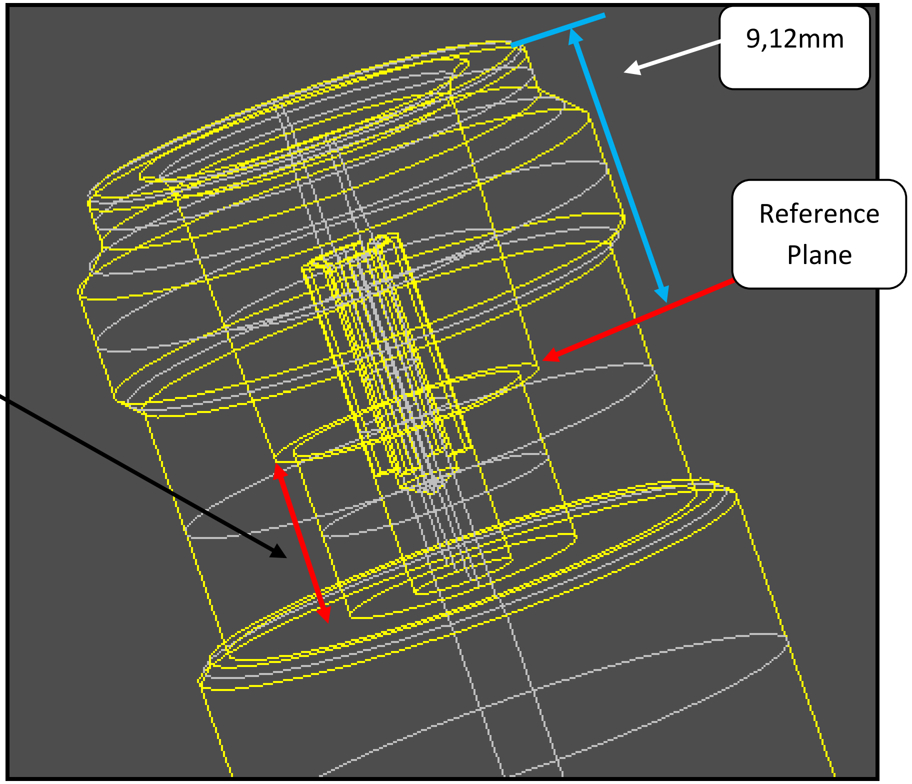






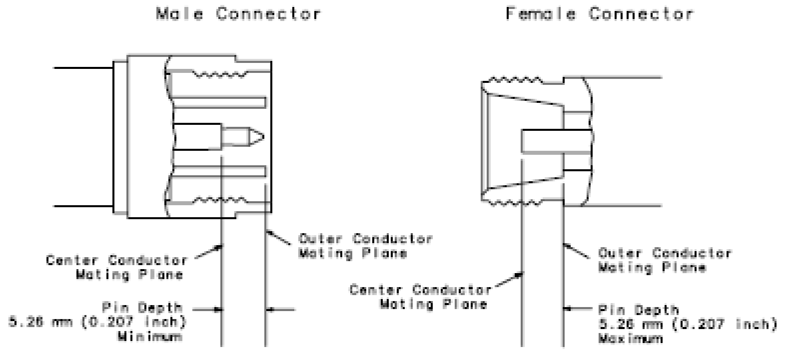


Pending the female adaptor you are going to use following dimensions are inportant to measure and note.
The refereence plane **is 9.12mm** from the front. You have to control and design the distance from the shorting disk to the reference plane. If the shorting disk is positioned where the PTFE went flush with the plane where the diameter of 7mm begins then the distance X is as on the drawing to the right. The negative delay in the calibration setting for the VNWA will **be a one way delay of X mm** divided by 0.3 in ps, and when entered in calibration settings it must be entered with double value as it is a reflection.
If you can manage to design a shorting disk flush with the refrence plane then the delay will be 0 ps.
In my case the distance is 14.6mm from the front and then the one way delay being (14.55-9.12)/0.3 = **-18.1ps. Yours will be different… The importance is to measure accurate and if you can measure the distance from reference plane to the shorting disk in mm and divide by 0.3 then you cannot do it better. Then add 0.093ps to the result (the shorting disk contribution) and in my case is now the result -18.2ps to use.**



A note about detail picked up from the user manual of the HP 85032B/E calibration Kit.

Figure 2-1 Connector Pin Depth



The center conductor for the male is indicated to be no further out than 5.26mm from the reference plane. As the dimension range for the mating male part is 5.33 to 5.88mm long, the tip will then be outside the reference plane by 0.07 to 0.42mm which is rarely seen. In most cases the tip is below the calibration plane by up to 0.5mm. I the simulations is used a recessed tip of 0.5 mm, specified by Radial as the only the only company specifying anything. The 3-dimensional drawing used in this document (from Huber Suhner) also indicate a recessed tip of 0.5mm.

Next section of this ducument will be a summary af all the calibration settings and followed by measurements with comparison to the two HP85032/E kit and the HP85032/BE clones using the center conductor extender.

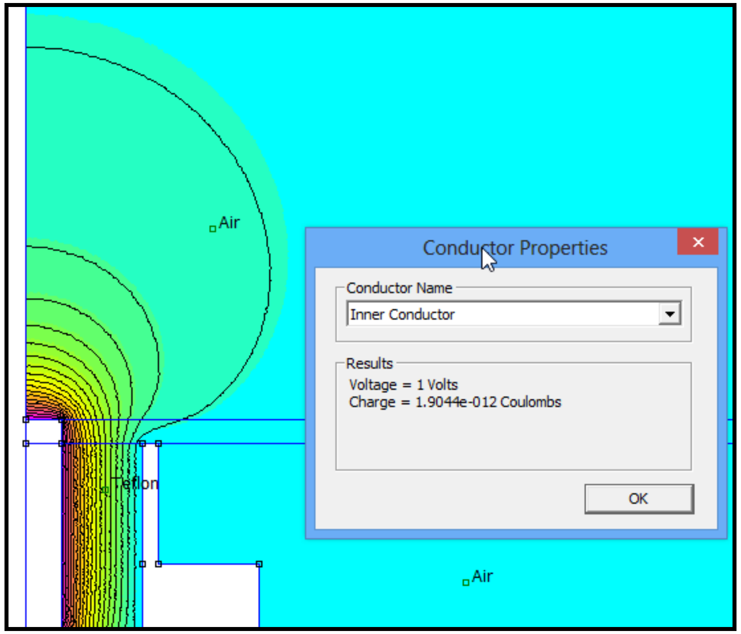
As several persons is waitinf for this document and I have other waiting activities for a couple of weeks I will relase **this draft document** and invites comments and suggesstion as well correction id you find errors.

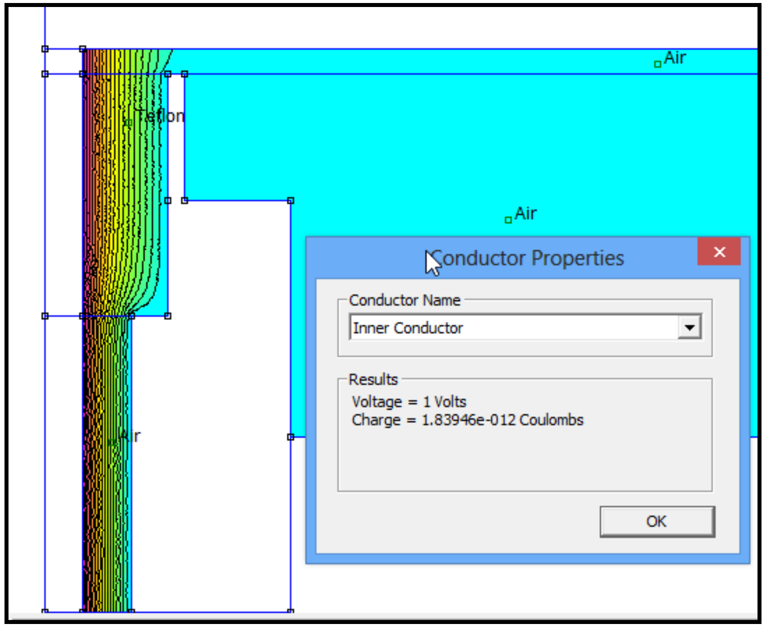
Kind regards

Kurt

Februar 22 2014

Designing a male load





The male load has mounted two SMD 1206 100 ohm 1% resistor onto the edge of the outer conductor of internal diameter 10mm. The centerpin is milled/grinded doen to 1mm above the PTFE flush with the outerconductor. The height of the outer conductor is 5.2mm. The PTFE section starts 12.18mm from the reference plane and the total length from refence plane to end of out condutor measured to 22.08mm which gives a PTFE lengt of 9.9mm. The total delay excl. the delay of the 1 mm centerconduor and fringe capacitance is airsection 12.18/0.3 ps and the PTFE 9.9/0.3/0.69 ps in total 88.426ps. Simulation showed 1790.06fF = 89.75ps again a close match.

The simulation including the 1mm conterconductor delay is having a charge of 1839.46fF = 91.973ps and increase of

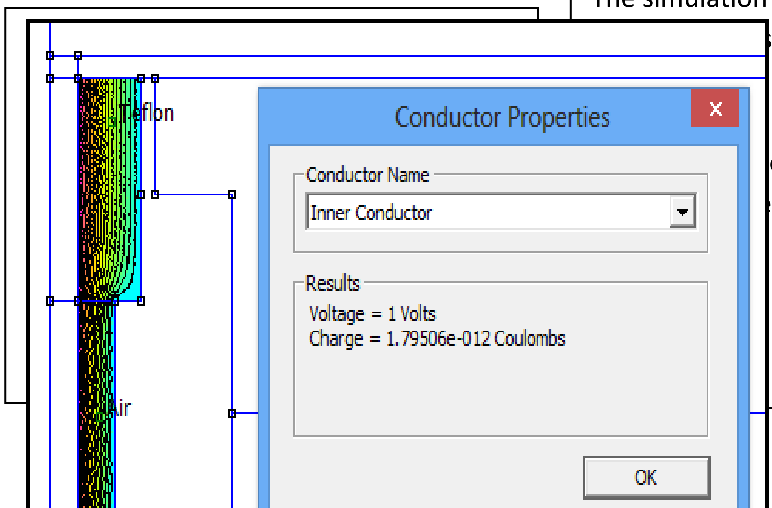
.

of the entire delay is 1904.4fF = 95.22ps and the increase is 64.94fF = 3.247ps

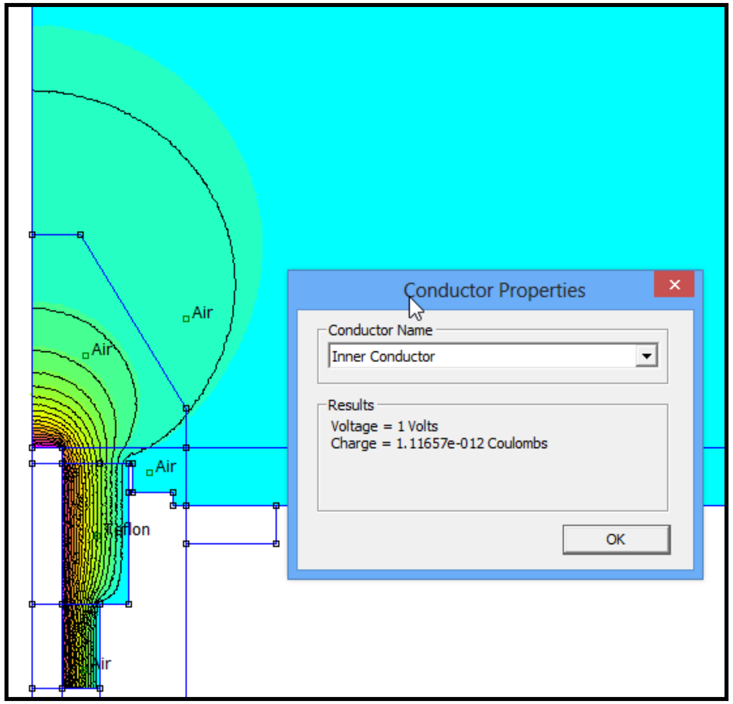
for this type of load is to use arbitrary calibration and the delay for the load is then 95.22ps. Alternatively

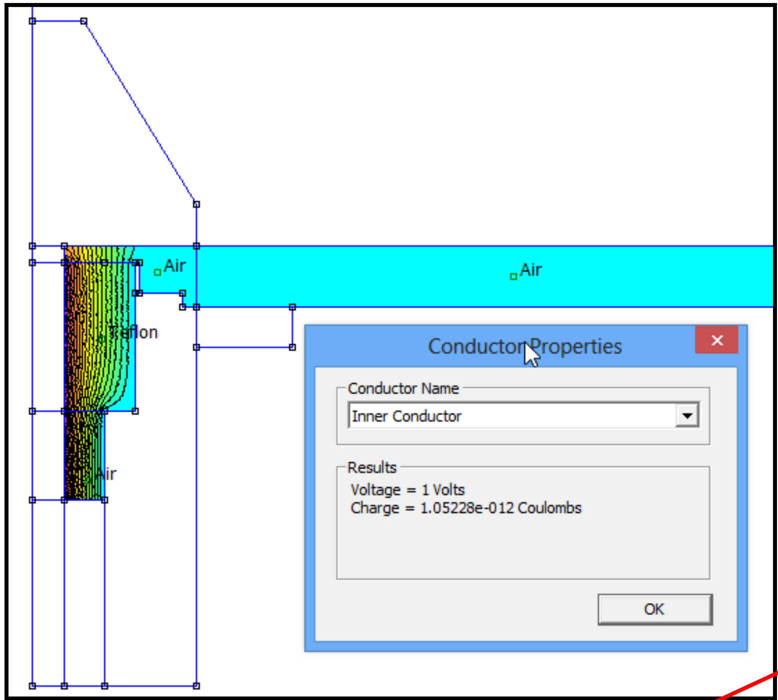
e the delay is 91.973ps and the resistors having a parallel capacitance of 64.94fF. we wil later se what is

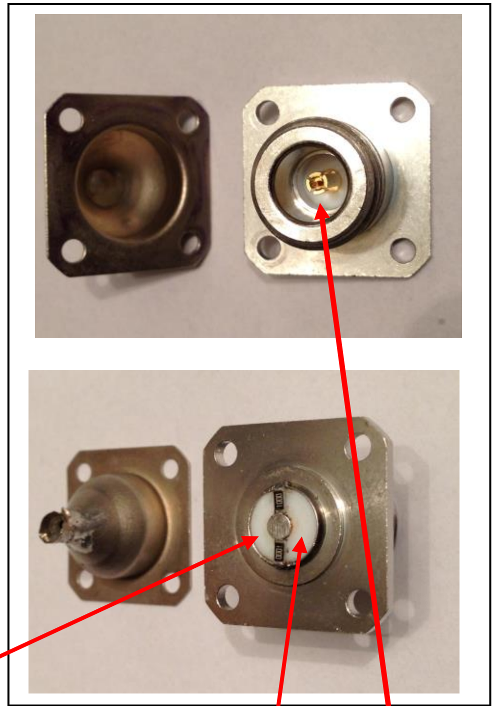
.

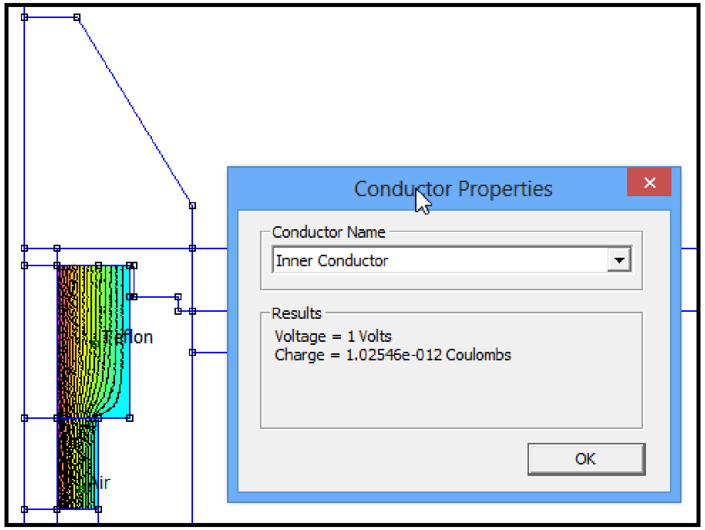


Designing a female load









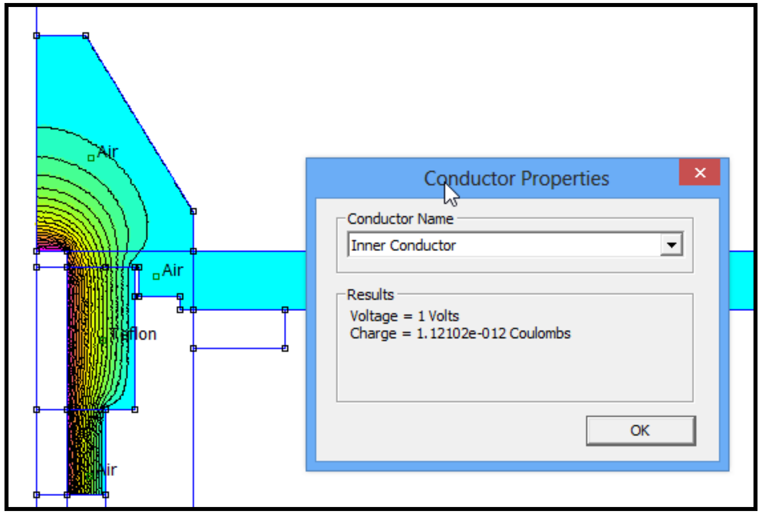
The female load has two SMD 1206 100 ohm 1% resistors soldered to the rearside. The centerpin milled/grinded down to height 0.8mm above PTFE. The airline section from the reference plane is 4.38mm deep (4.38/0.3 ps) and the FTFE section is 7.5mm long inside diameter 10mm (7.5/0.3/0.69 ps). Total delay calculated 50.83ps excl. Fringe capacitance and delay of the 0.8mm center conductor. To the left the simulation shows 1025.46fF = 51.273ps a close match.

The delay of the 0.8mm center conductor included shows 1052.28fF = 52.614ps an addition of 1.341ps

Simulating the total charge incl. Fringe capacitance but with out the screen yelds 1116.57fF = 55.8285ps and the fringe capacitance is then 3.215ps. Total delay beyond 51.273ps is then 4.555ps

Adding the Shield in the simulation as seen on below picture the charge increases to 1121.02fF being the total delay to use and equal to **56.051ps**. the addition in the fringe capacitane is then 4.45fF = 0.2225ps so very small addition. My resistor measured to 50.01 ohm when mounted.

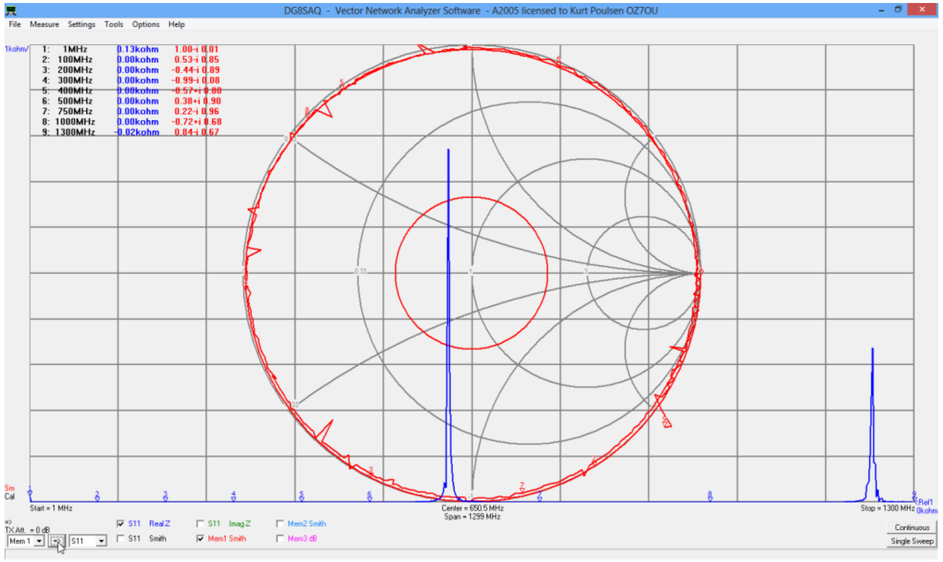
Total delay beyond 51.273ps is then (1.341 + 3.215 + 0.2225)ps = 4.779ps or 95.57fF. The two SMD resistor has each 50fF shunt C so in total 195.57fF or 9.779ps

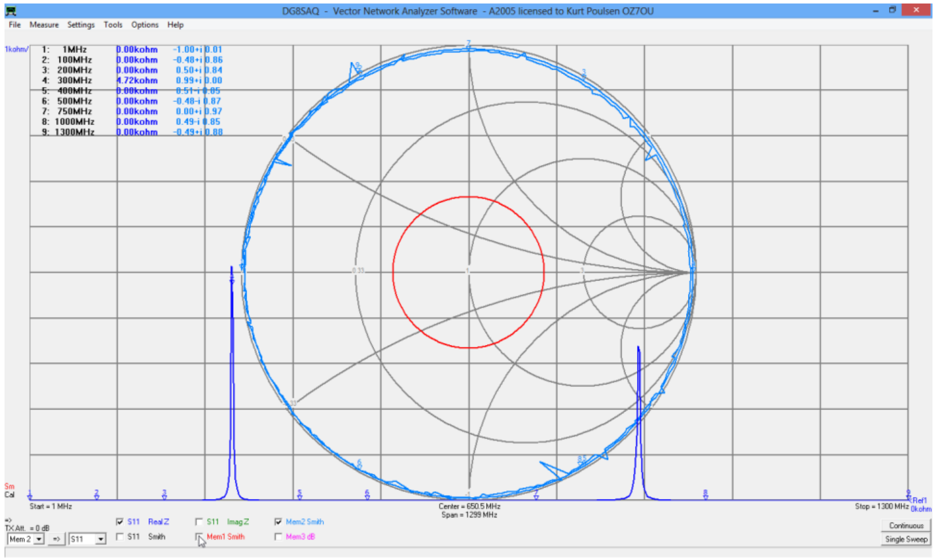


Testing of the performance

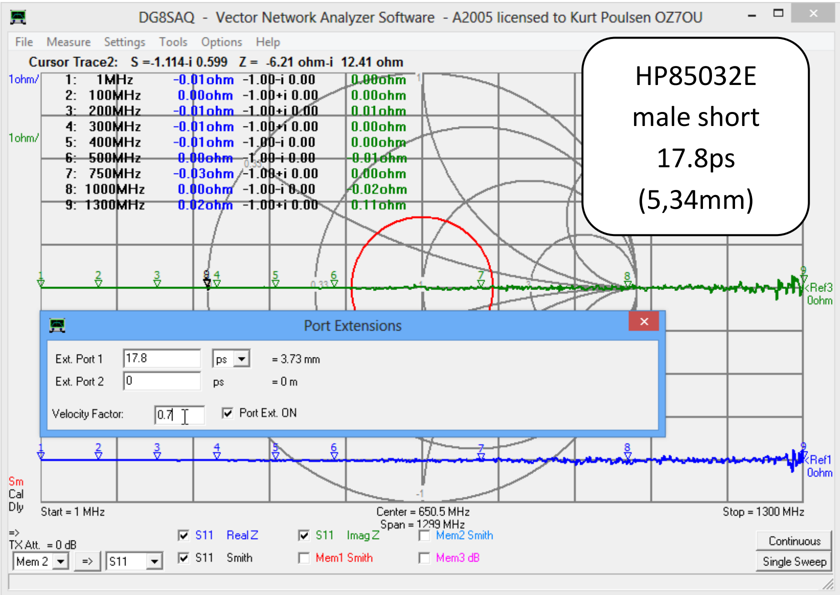
After been designing all the part for a complete N male and female calibration kit it is time for testing the performance.

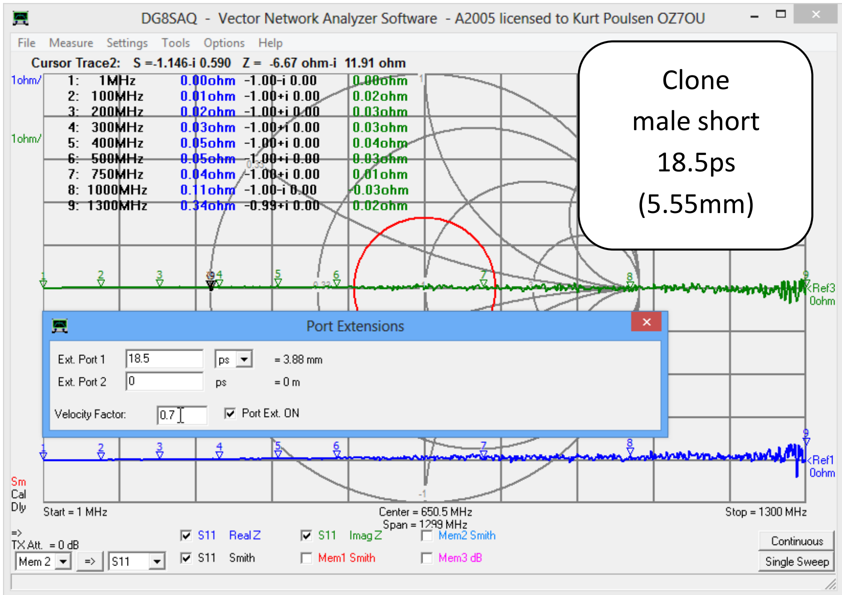
For that purpose we at first use the HP 85032E Male calibration kit and performa a complete SOL(T) calibration using arbitratrary calibration. Next we shall see how a Smith chart plot of a shorted and open semirigid stub of lenght 170mm looks like when the VNWA for sure is perfect calibrated uing the HP85032E kit. These two plots to be saved as Touchstone files for later reference as „proof“ that the homemade N male short, open and load performs in a identical wayl. These two stub are also a perfect tool for finetuning the delays as shall be seen later. Left image is the open stub and right image the shorted stub. In both cases a perfect trace, open is covering the outer limit.

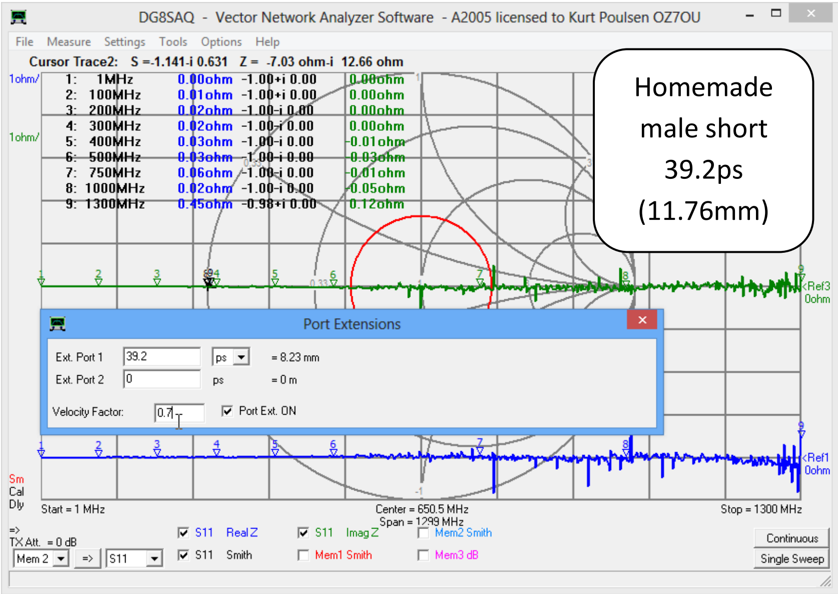


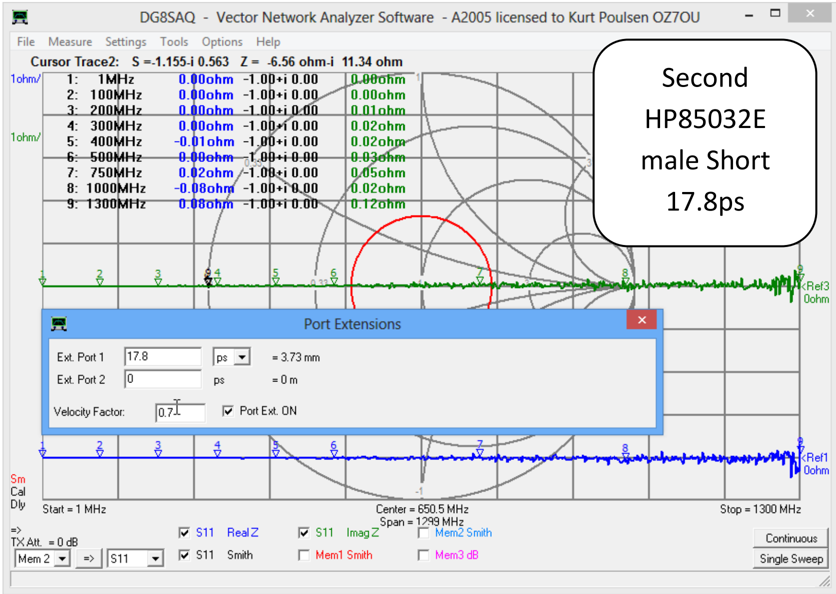


Next we will test the N male clone and homemade short against the HP85032E short.



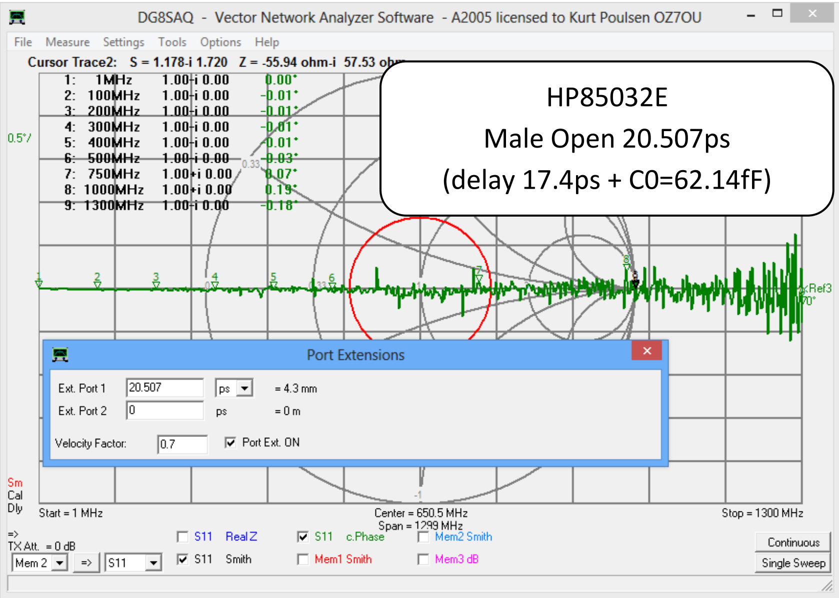


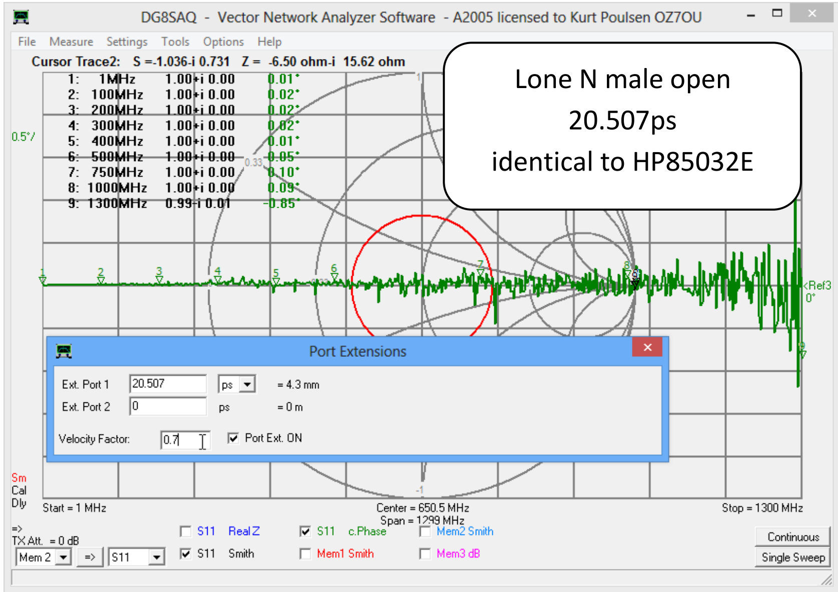


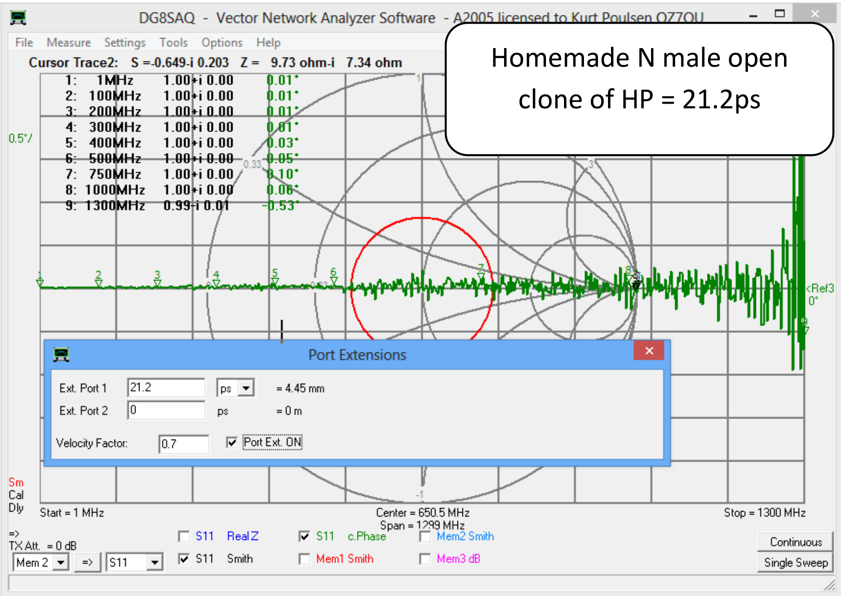


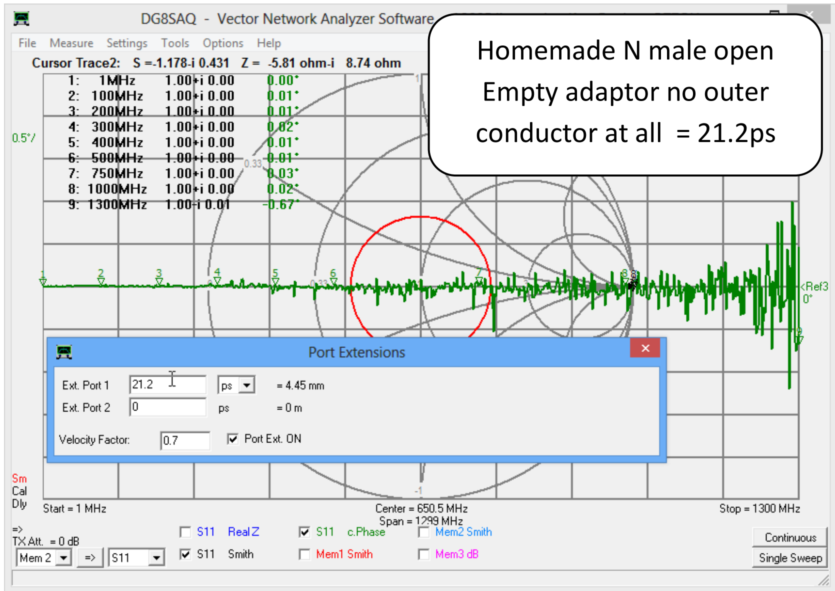
The two HP85032E short are identical. The clone male short has an 0.7ps additional delay (0.21mm and meachanical measurement confirm the difference) and the homemade was measure mechanically and calculated to 39.0ps so only 0.2ps = 0.06mm error relative the reference plane and quite OK.

Then follows the test of the male open standards



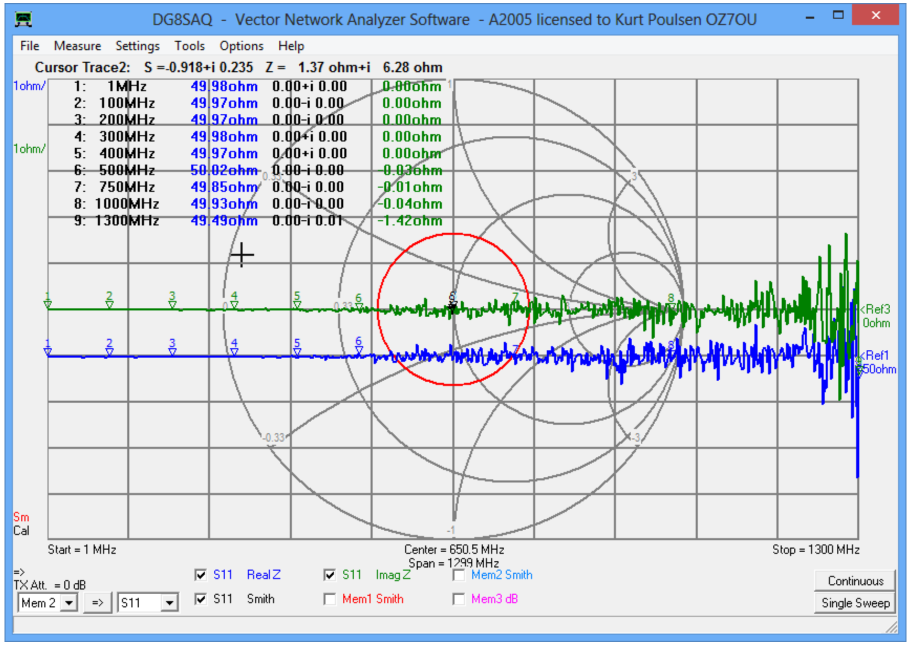


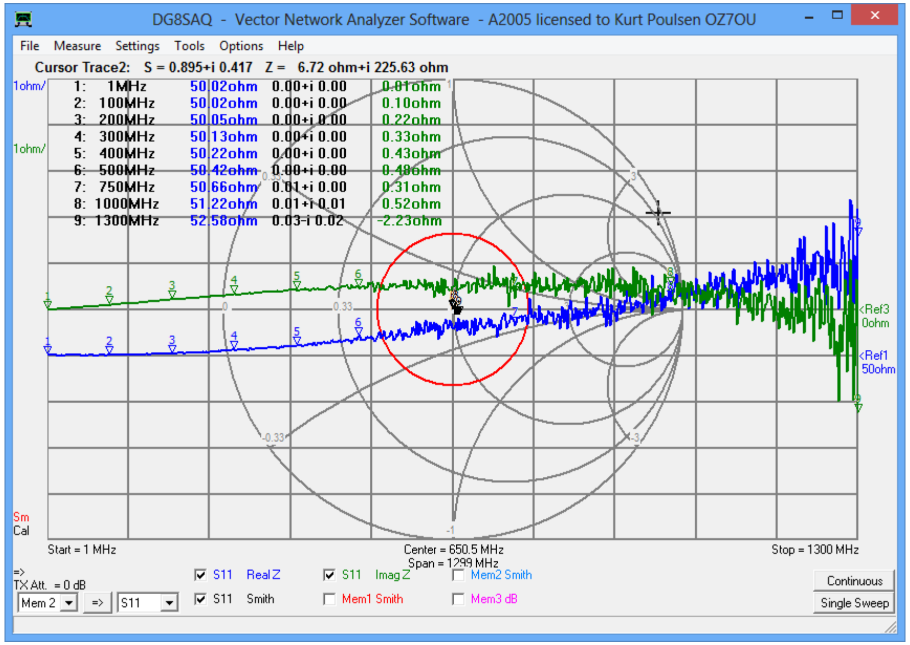


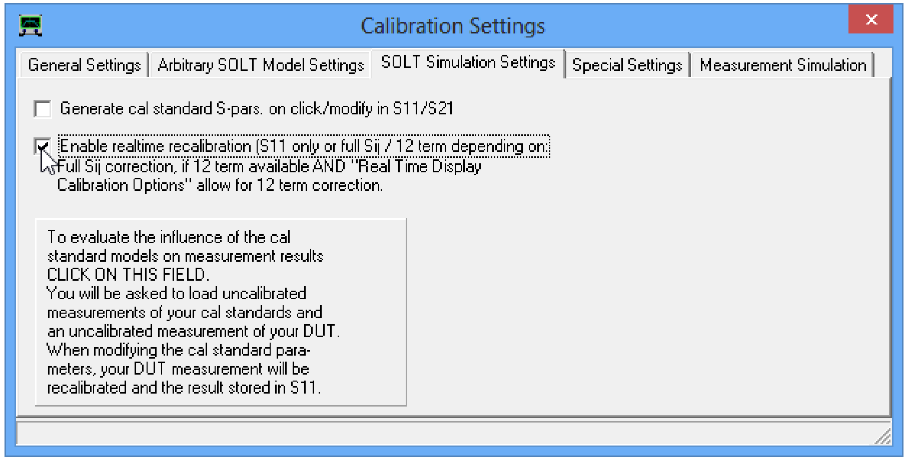


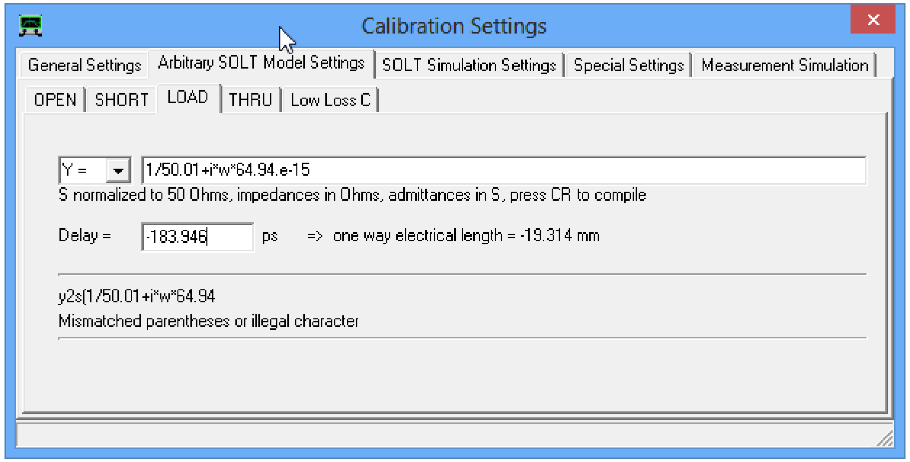
Above result demonstrates that the N male open does no need any extension of the outer conductor with 7 mm inside diameter. (see picture collection later)
However the delay is 21.2 -20.507=0.993ps larger (0.208mm). The only reason is the internal diameter of outer conductor is not to specification and measured to 6.9mm.

Next is test of the homemade load

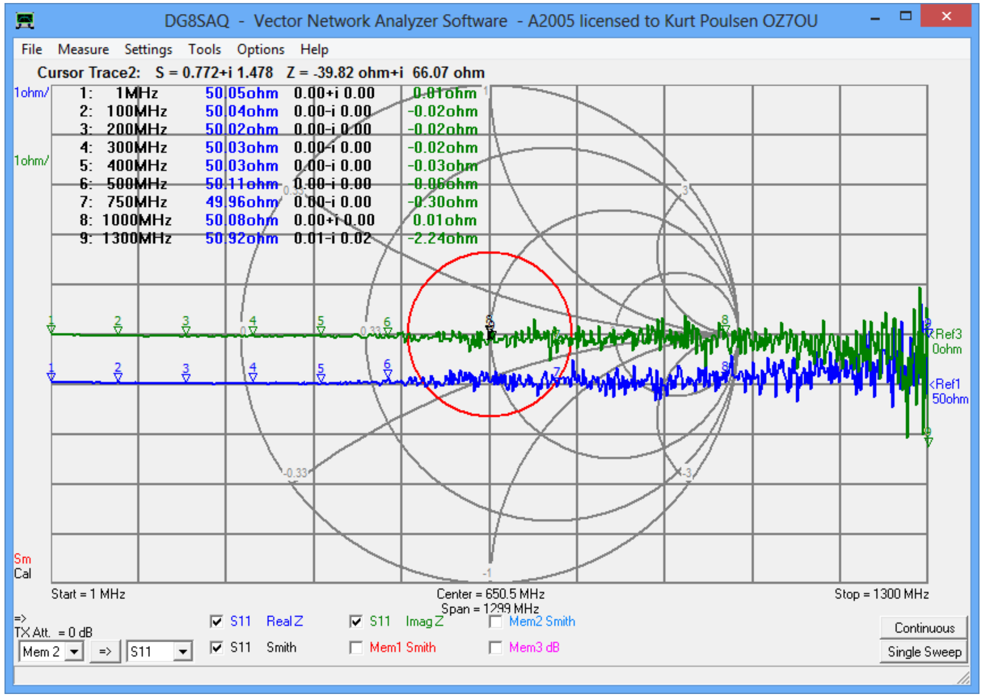








The simulation gave the result that fringe capacitance C0 was 64.94fF and the delay was 91.973ps to be entered as 2x91.973 = -183.946ps as seen above the admittance Y for the DC resistance 50.01ohm and the C0 is the expression 1/50.01+i*w*64.94e-15. Below is seen that the real Z and Imag Z is very excelelnt flat to more than 500MHz and vey small deviation towards 1.3GHz.



To the left is seen the result where the realtime recalibraiton has changed the trace and recalibrated the calibration setting to match the homemade N male load. The tickmark can now be removed and the calibration setting saved under a new name after the sign for the fringe capacitance has been changed from + to - .

LOAD: Y=1/50.01+i*w*64.94e-15 changed to 1/50.01-i*w*64.94e-15

Delay: -183.946ps

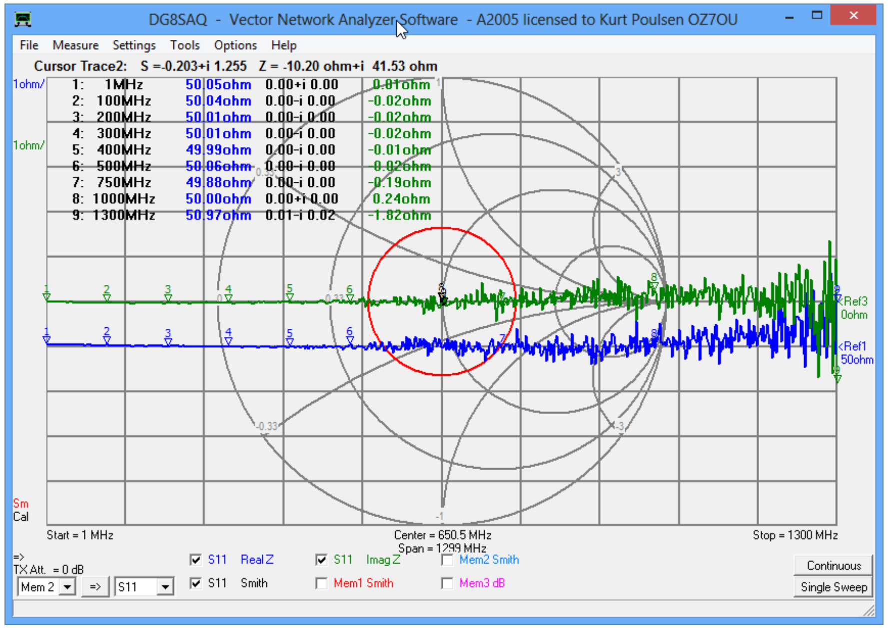
Below is a modified setting which seems to a better fit where the expression is.

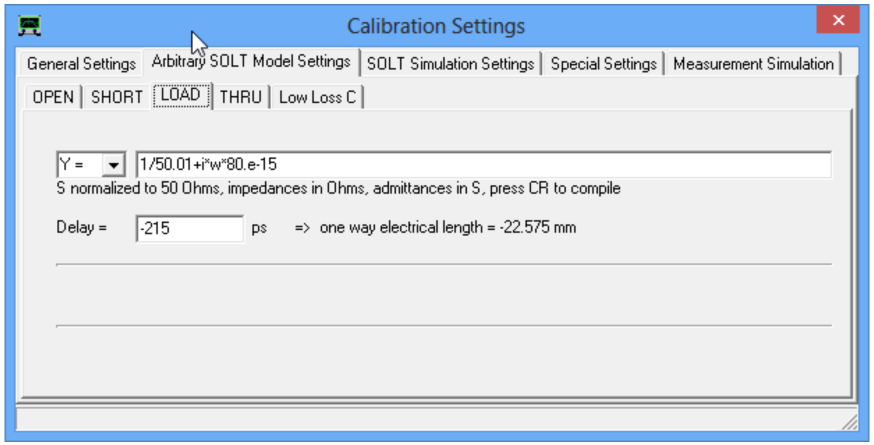
LOAD: Y=1/50.01+i*w*80e-15 changed to 1/50.01-i*w*80e-15

Delay: -215ps

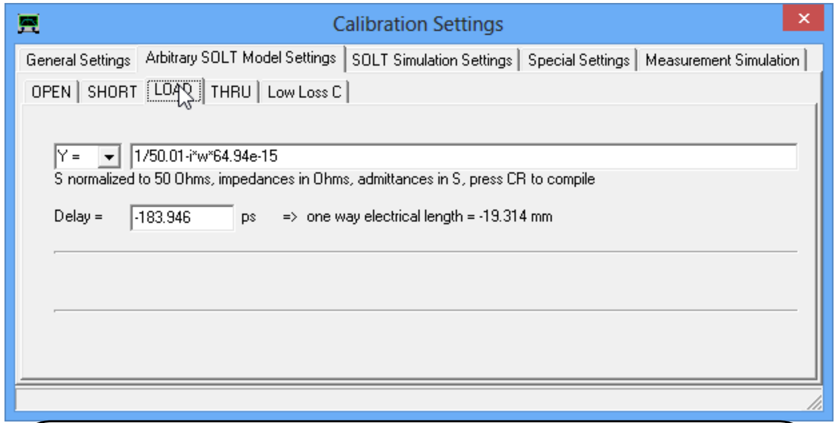
Why this fit is better can be explained by the fact fringe capacitance for the two SMD resistors has not been added and the delay through the PTFE is based on Vf=0.69 where is might be Vf=0.7 and the simualtion is based on internal diameter of 7mm but is actually 6.9mm for the outer conductor and the out for PTFE is not 10 mm but 9.9mm. New calulation gives delay 2x94.375ps = - 188.75ps

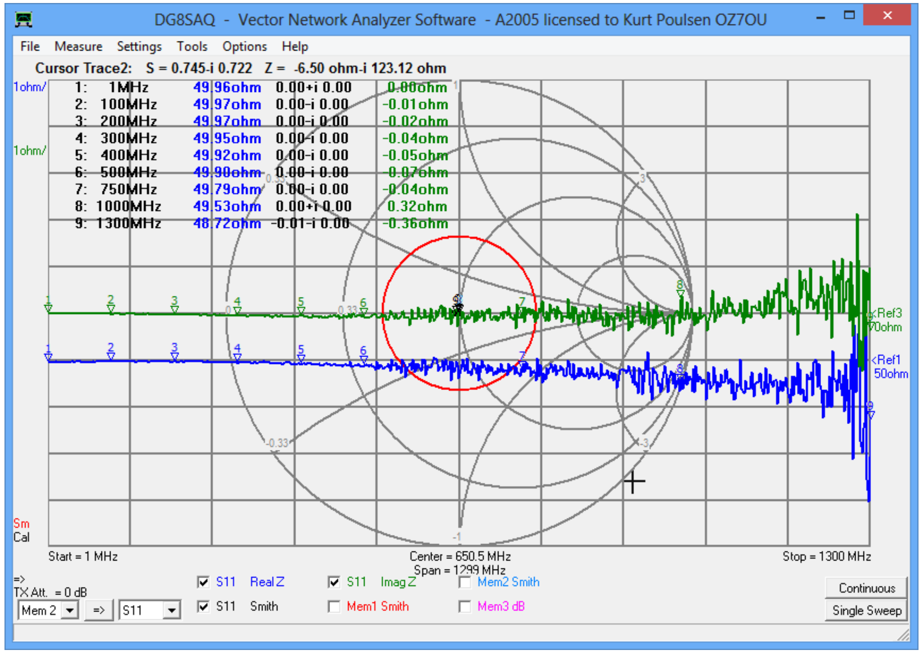
By the way.. the HH85032E loas is 49.98 ohm



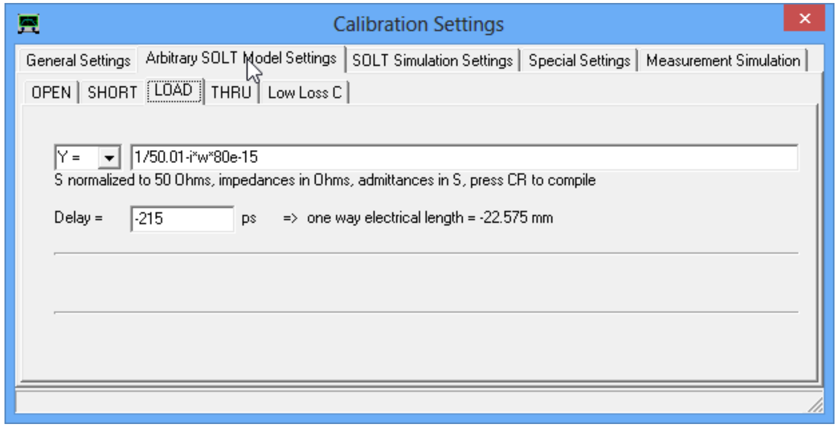


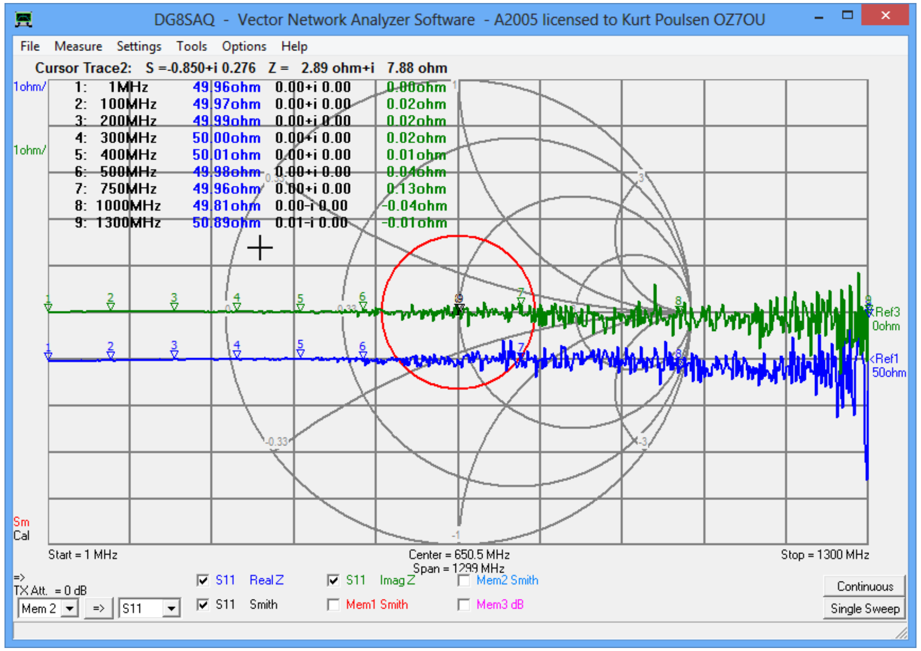
Below is the measurement of the HP85032E load based on calibration with the homemade N male load an the calibration settings as shown below (with the + sign changed to -) . The used male short an open isHP85032E The result are excellent up to 500MHz else pretty good



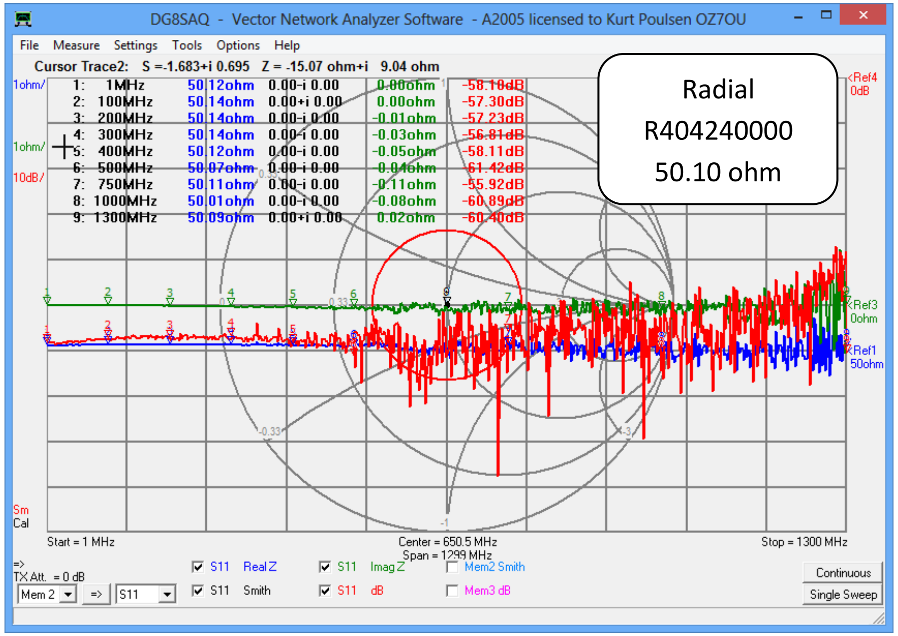


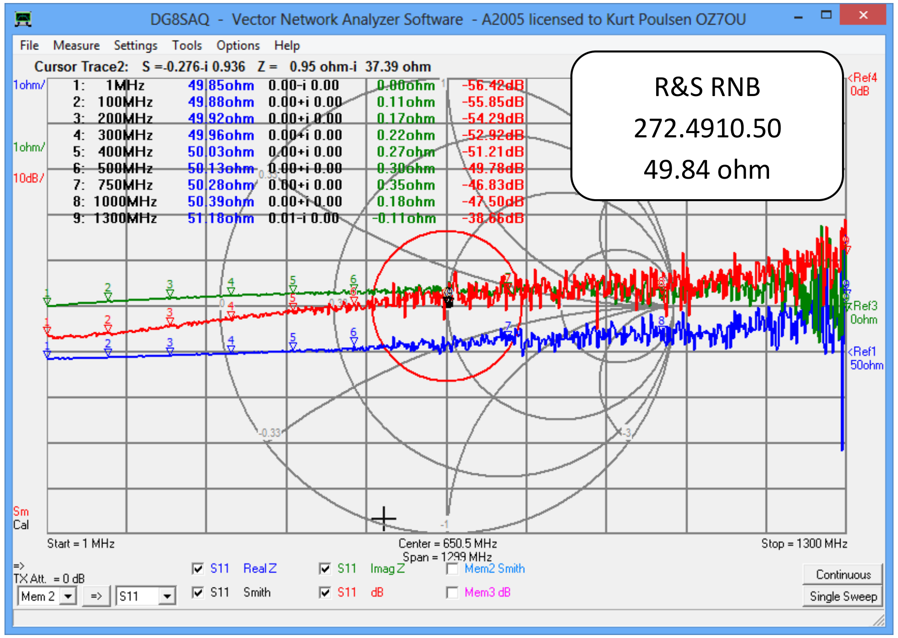
Based on the modified settings the result is superb up to 1.3MHz and surprisingly good in general.
Below will be shown an number of measurement of commercial loads and **none as good as the homemade N Load except the Radial and of course the HP85032E male load**

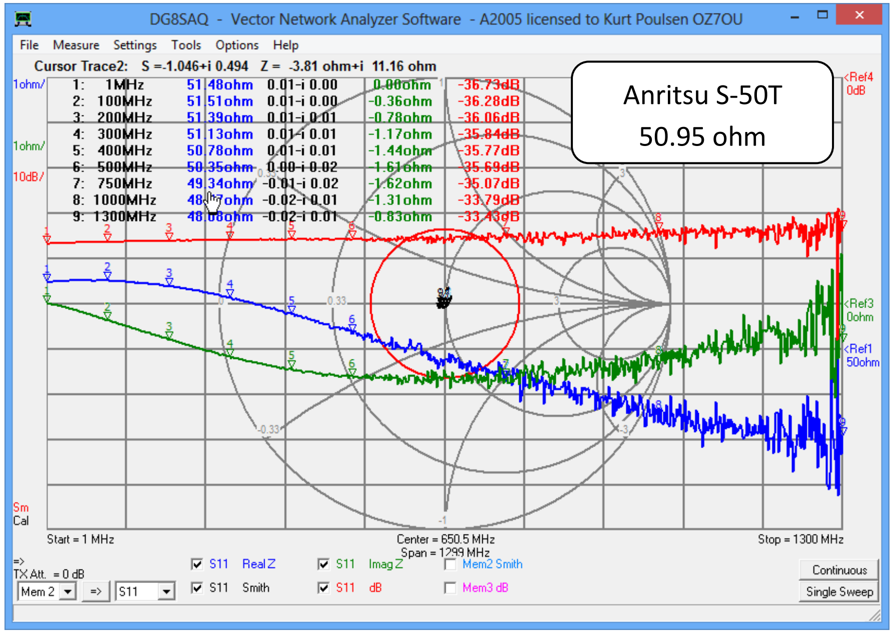


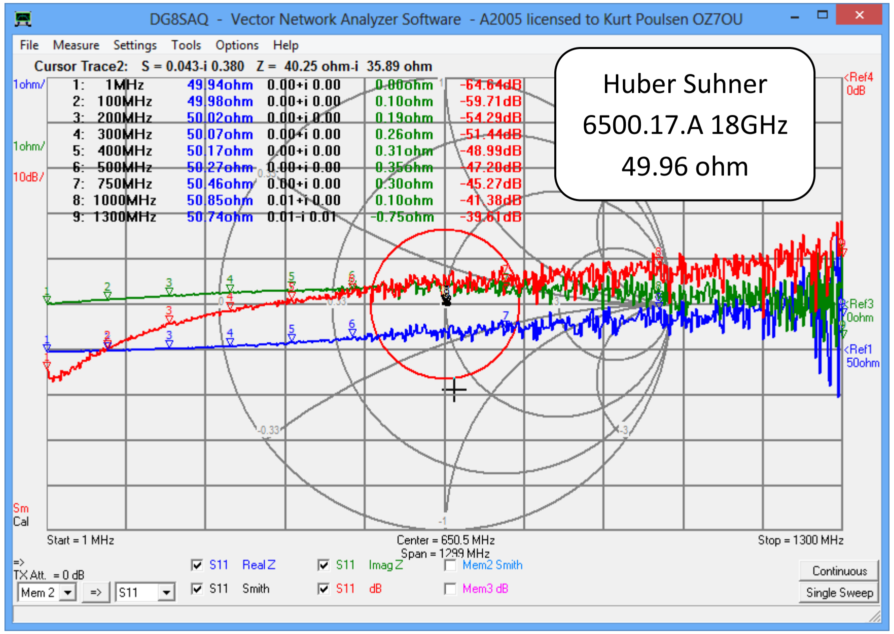


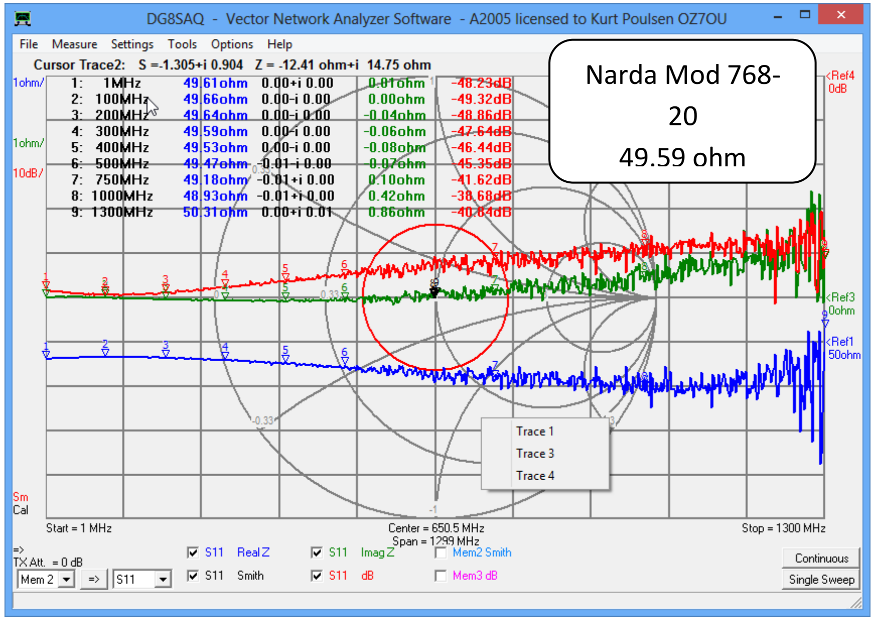
Plots of numerious commercial loads.

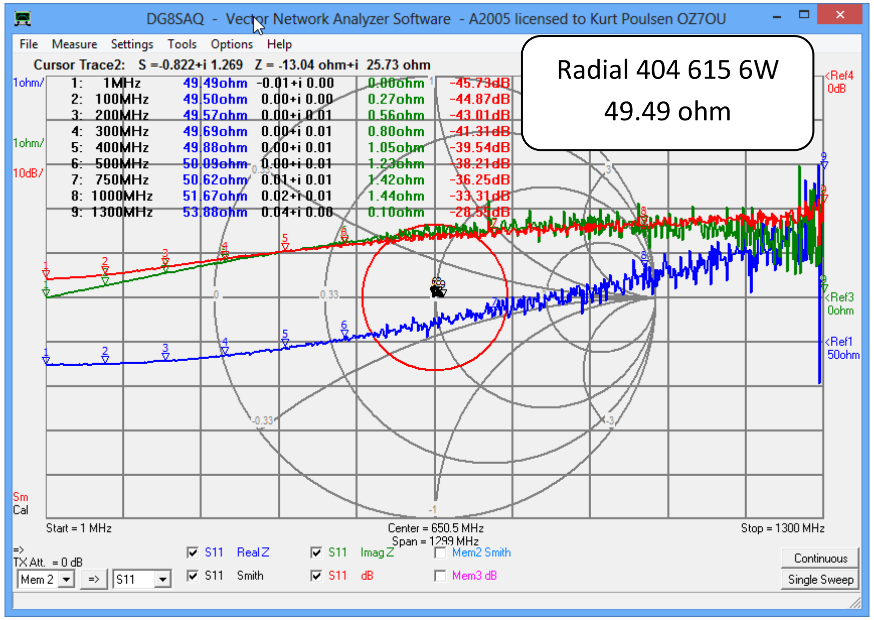


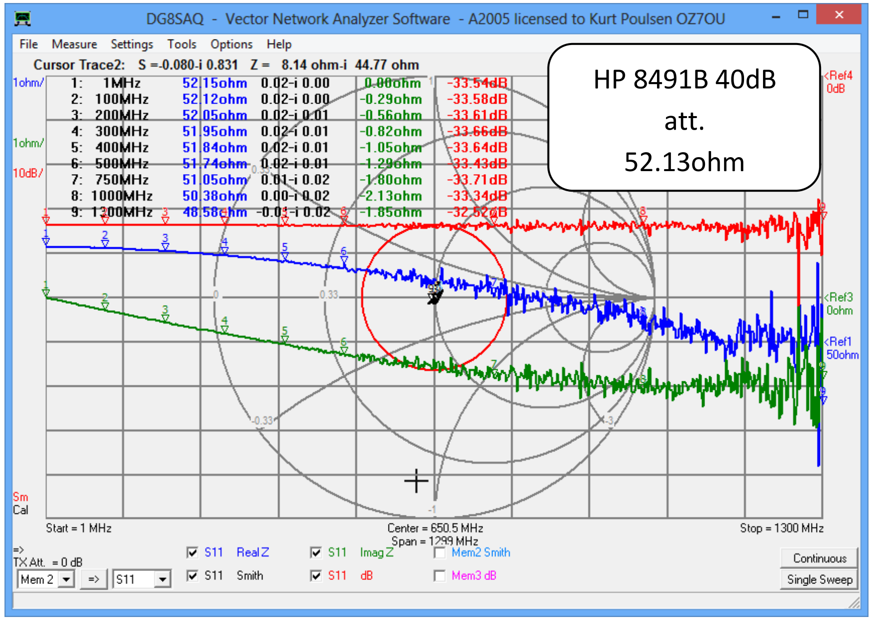


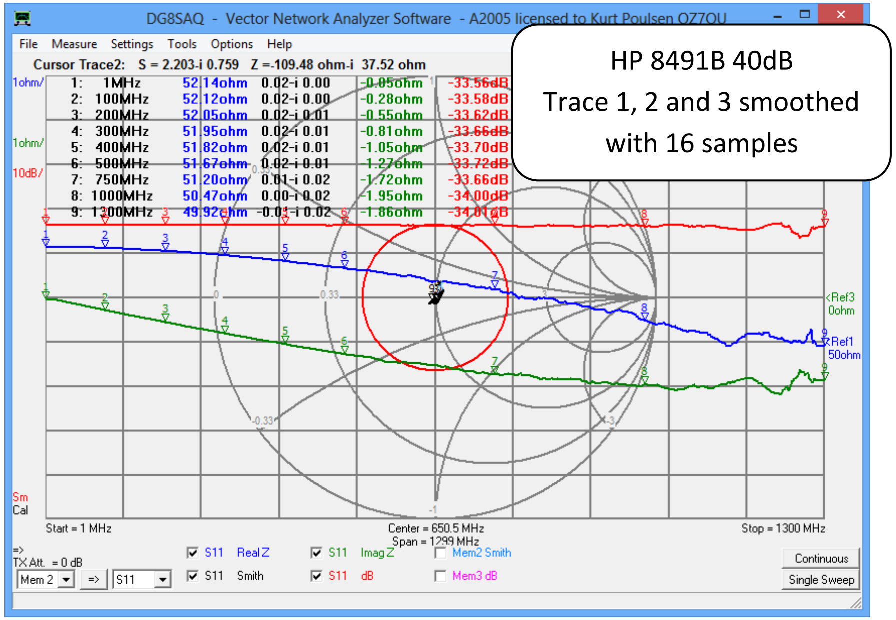












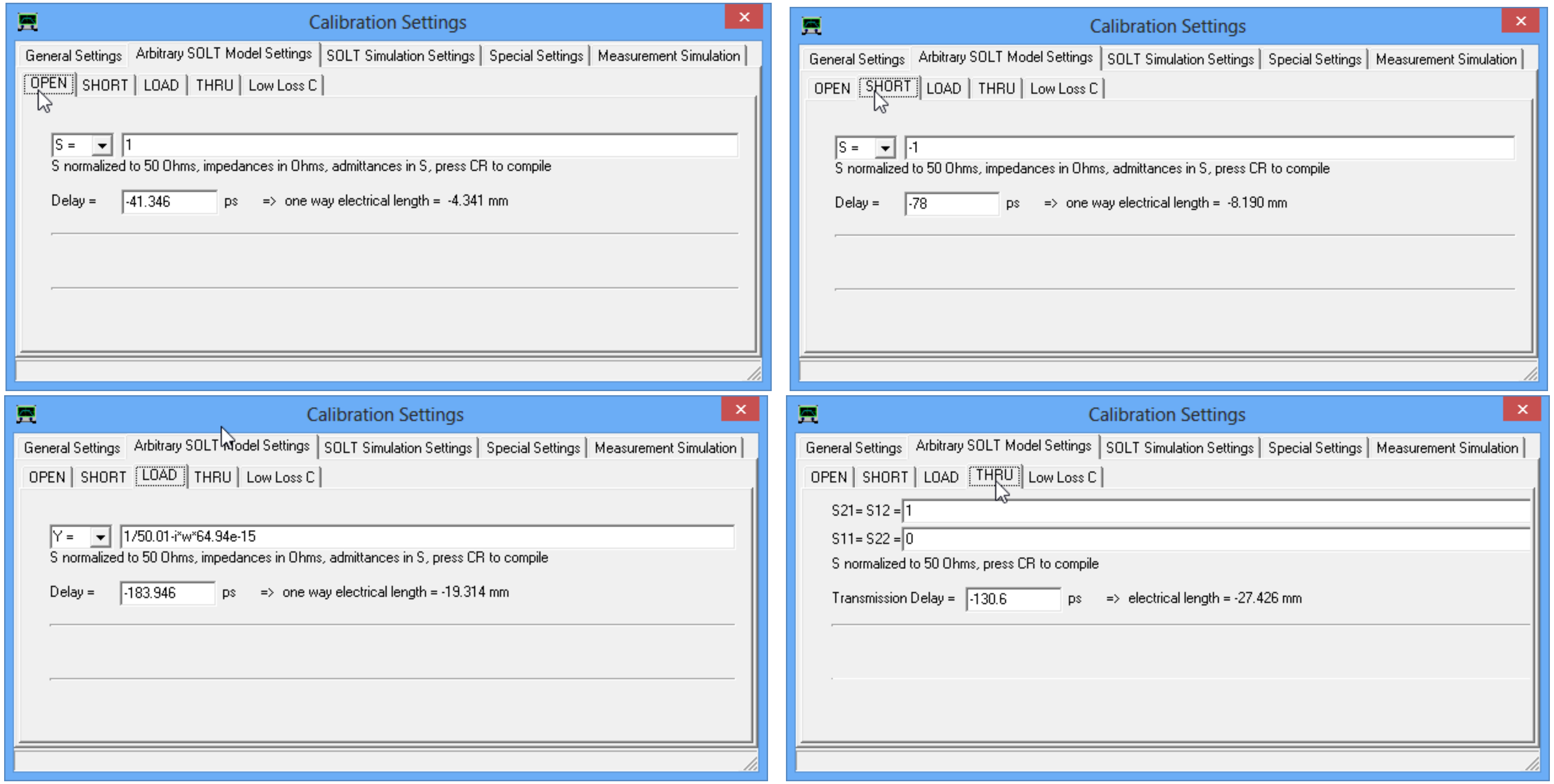
Above 7+1 images clearly demonstrates that we are able to produce an excellent load by a proper study how to do. The right picture just demonstrates the smoothing function, not used before in this document, and how efficient it is. When saving a smoothred trace as touchstone the smoothing is included.

Next Topic is (finally) to demonstrate the calibration quality of a calibration with the HP85032E male kit and compare to a calibration with our homemade N male calibration kit .

We have two situation:

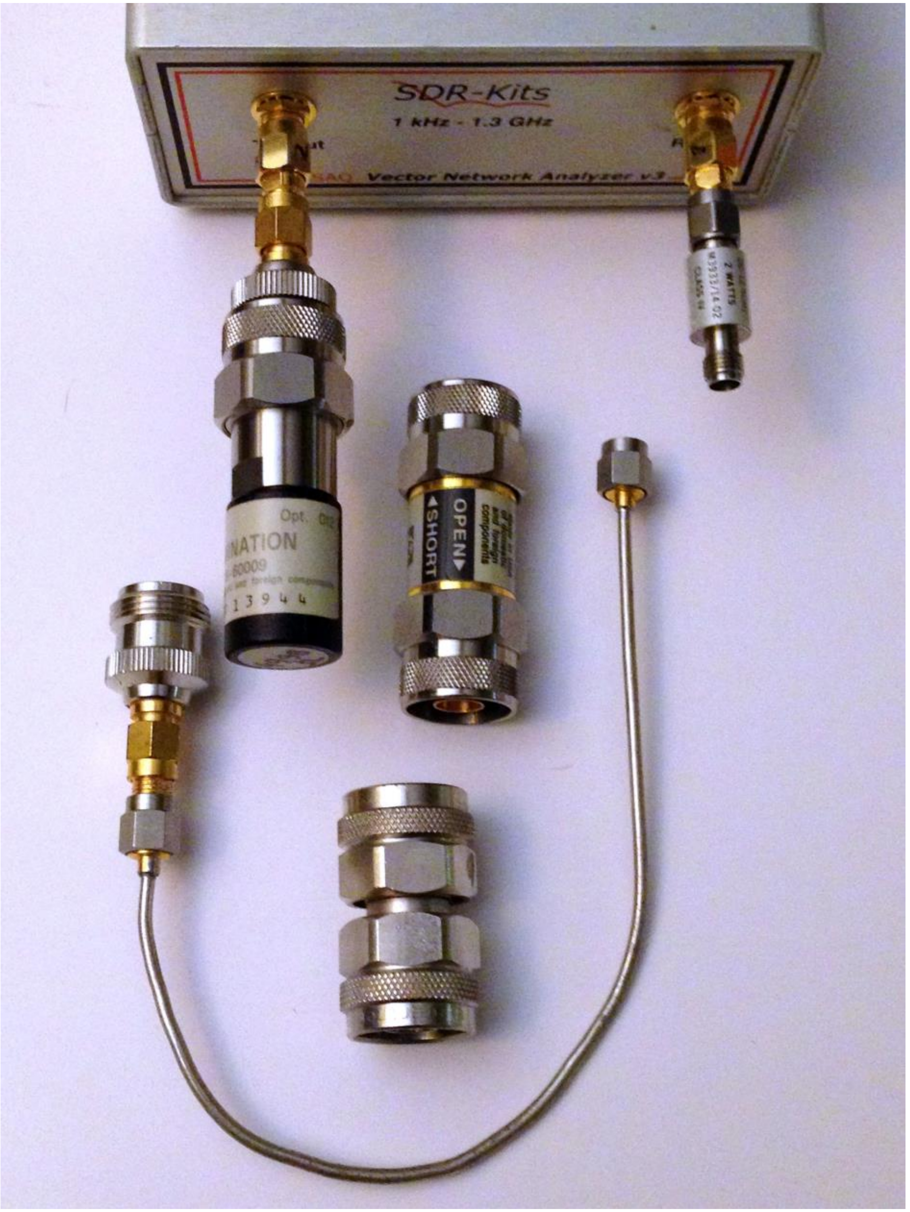
1. Using the calibration parameter only derived by measurements of mechanical dimension and the ascociated calculations of delays and the additionale simulation done with Femm of fringe capacitances and delays.
2. Measured calibration parameters by comparison with the HP85032B N male calibration kit in with comments regarding the Femm simulation.

By examining these two conditions we get a picture how close we can get without having access to a professional calibration kit and in general how excelent the VNWA performs in general. First we use the condition 1



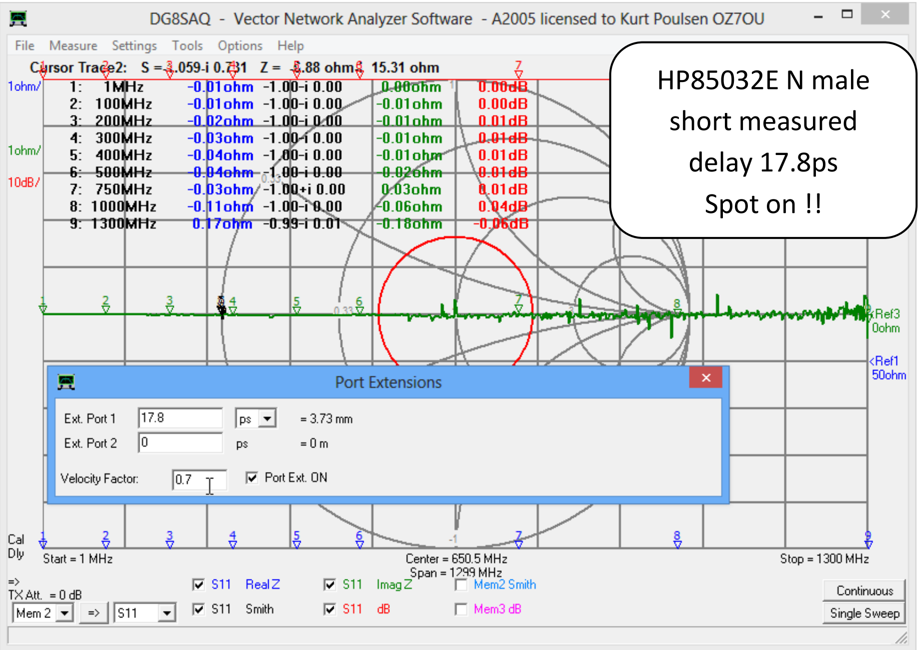
These are the setting from simulation where open is 2x -20.673ps incl. fringe capacitance short based on mechanical measurements 2x -39ps and the load 50.01 ohm based on a 4 point measurement in my earlier described 4 point measurment test jig and the Femm simulated delay and fringe capacitances but without the fringe capacitances of the 2x100 ohm 1206 SMD resistors. The Tru delay only shown for completeness but not used yet and commented later how to determine.

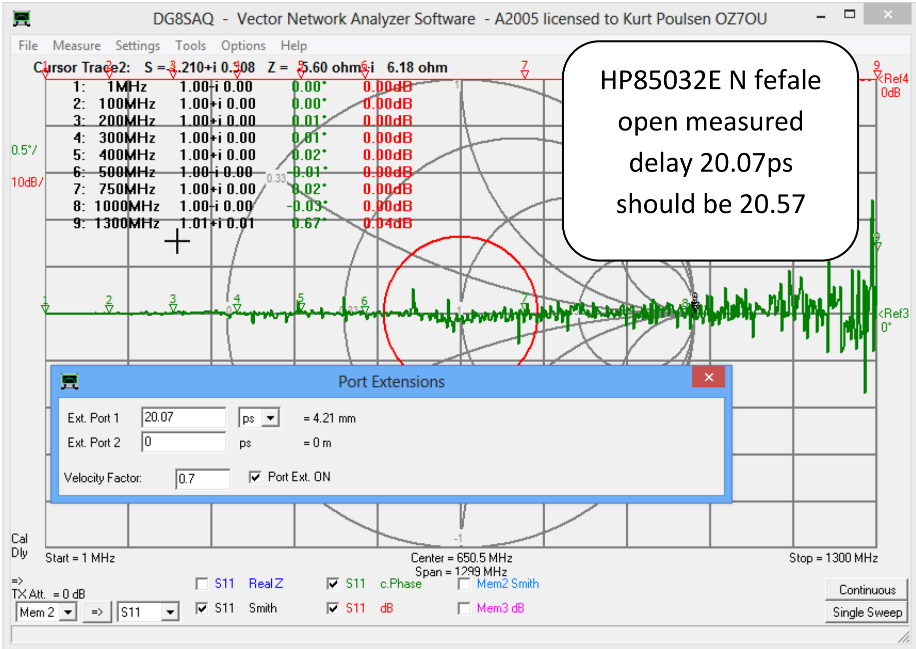
The test setup

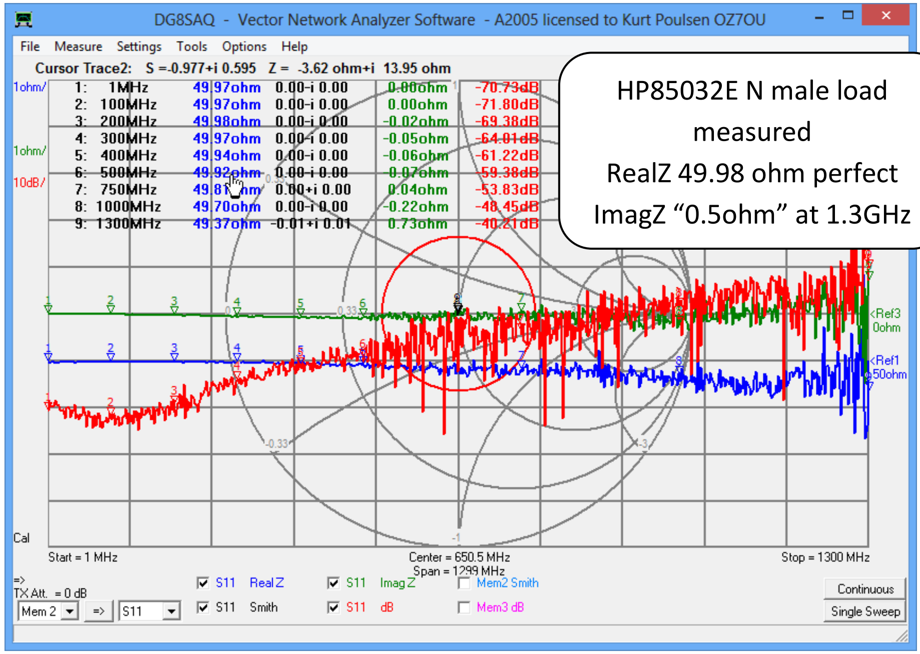


The VNWA is equipped with apropriate adaptors to allowcalibration using the HP85032E N male calibration kit. The RX port for the VNWA is fitted with an inline SMA 10dB attenuator as for the T-Check this adaptor required to liniarize the VNWA RX port toward a clean 50 ohm input. Basicly the 10 dB adaptor should be placed closer to the S11/S21 calibration plane but fro convinience omitted. The semirigid cable is of good quality and 50 ohm so the result is good enough. The N male male adaptor used for S21 calibration. Unfrotunately I have not a N male T-Adaptor so I can not perform T-Check fro N male calibrations. Above picture showws the open and shorted N male and female stubs used for checking and fine tuning the calibration settings. For the female calibration kits I have good quality N type T adaptors of type F-F-F and F-M-F so T-Check possible.

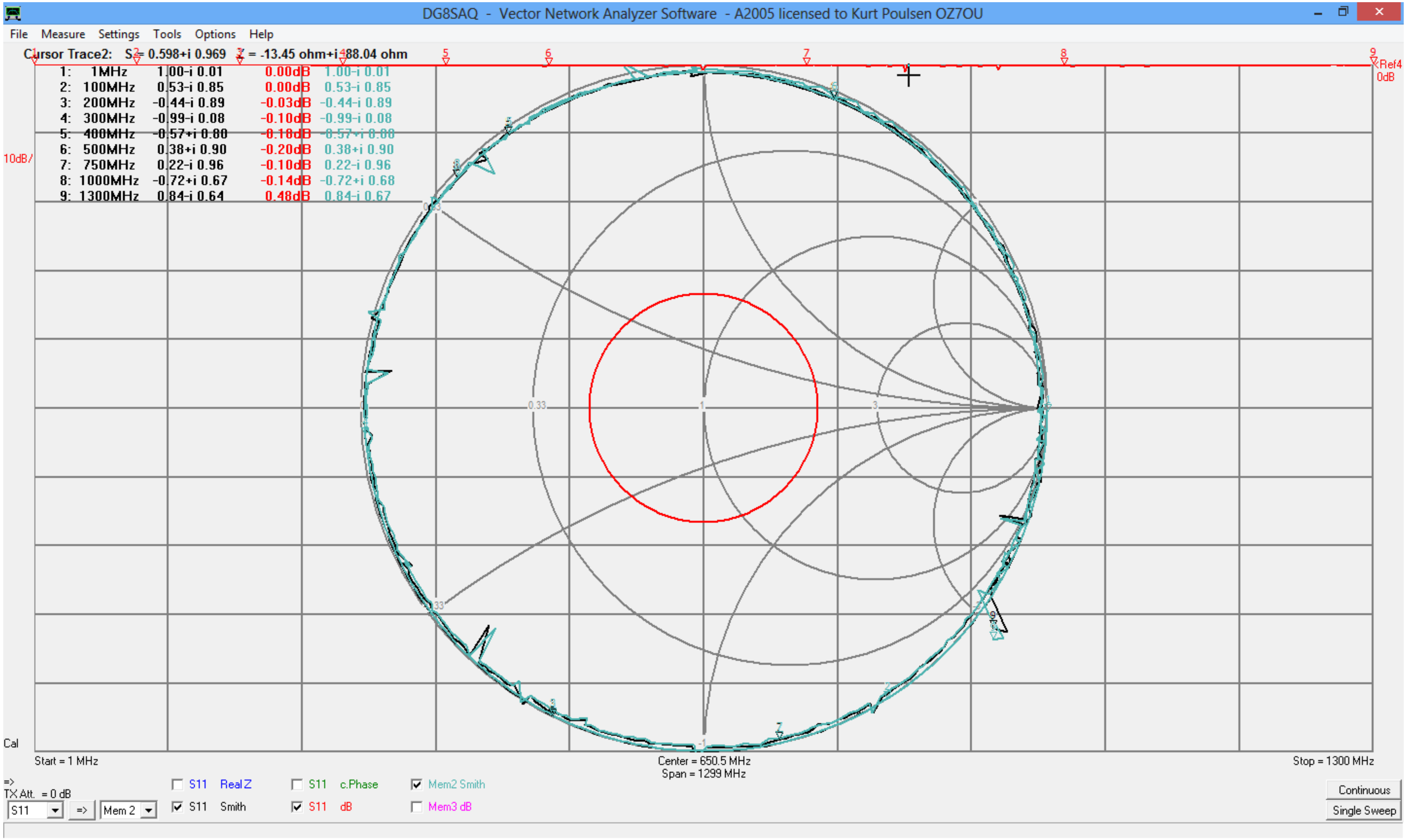
For learning to t-Check study http://hamcom.dk/VNWA/How to perform a T-Check for a VNWA Calibration.pdf



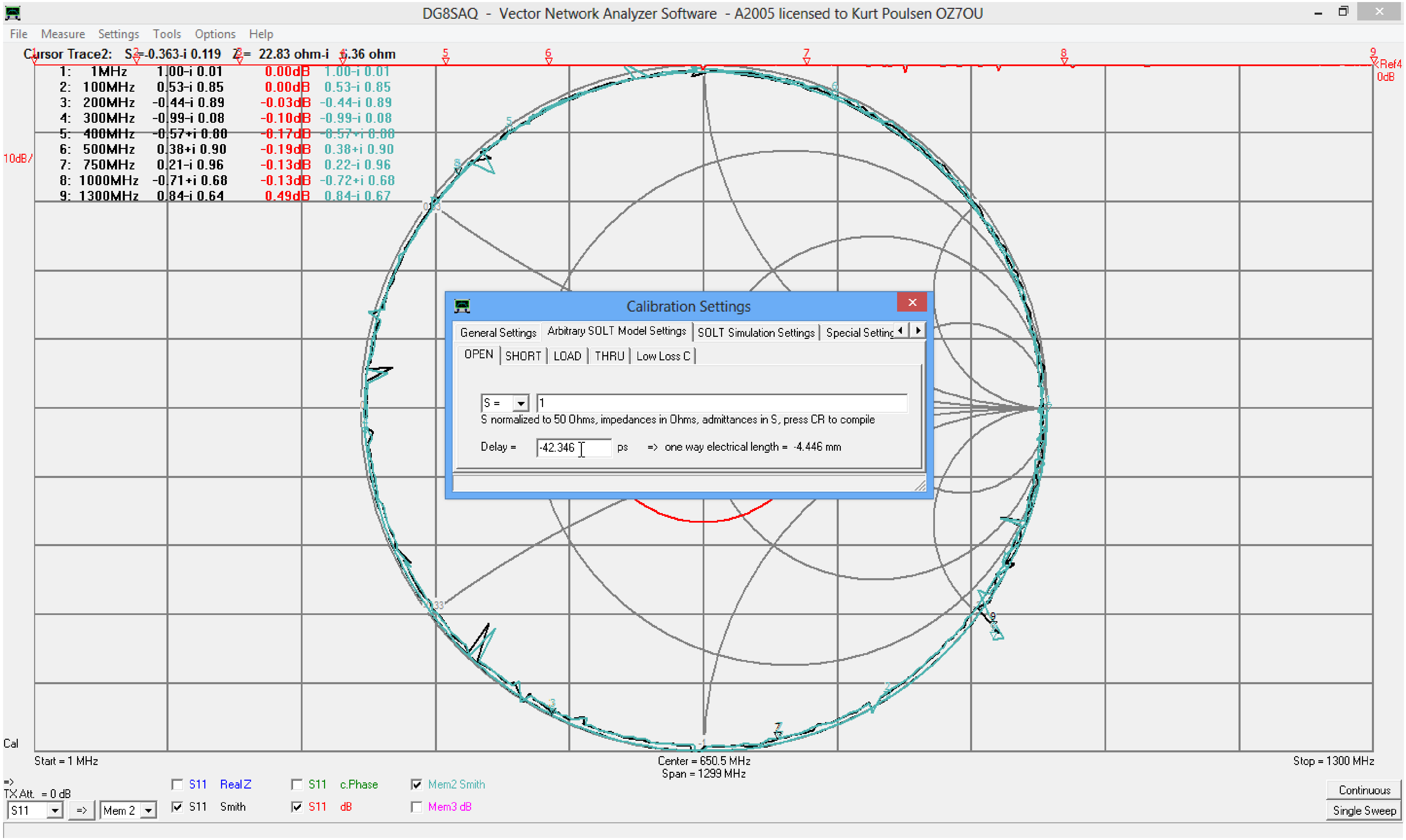




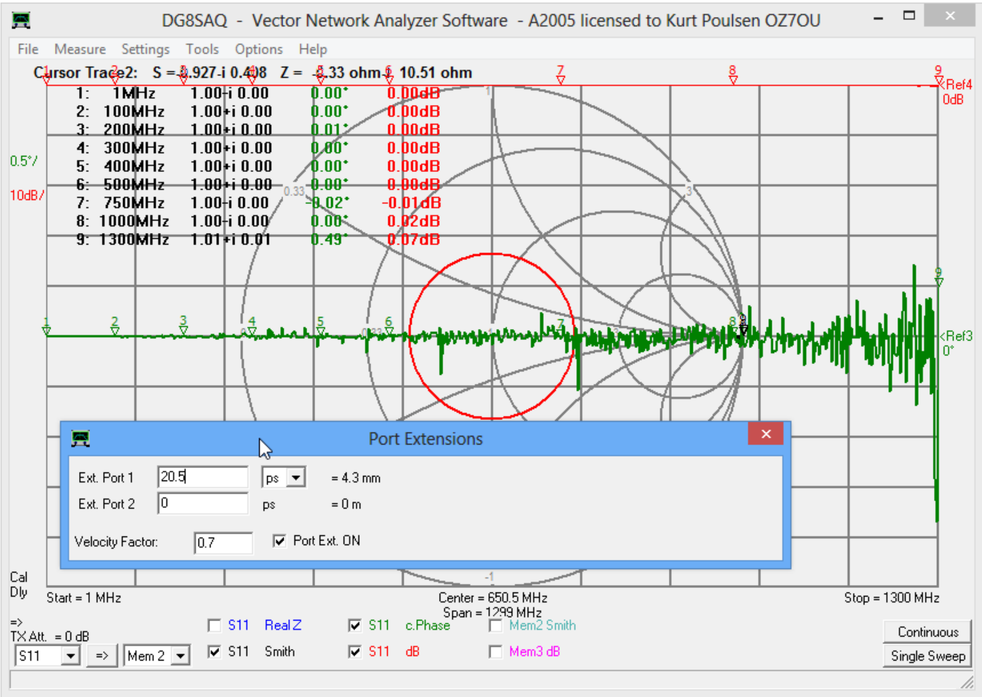
This test demonstrates that without any other means than mechanical measurements and calulations of the short delay combined with pure Femm simulation the result is absolutely fine for a N male calibration kit. As the open dealy is only 0.5ps wrong and the load is a bit reactive we might fine tune the calibration by using the open and shorted stub by comparing the stored sweep for the HP85032E calibration. This means that if I publish this Touchstone file (which I do) then anyone can fine tune their homemade N male calibration kit. Let us carry on and see how that works.

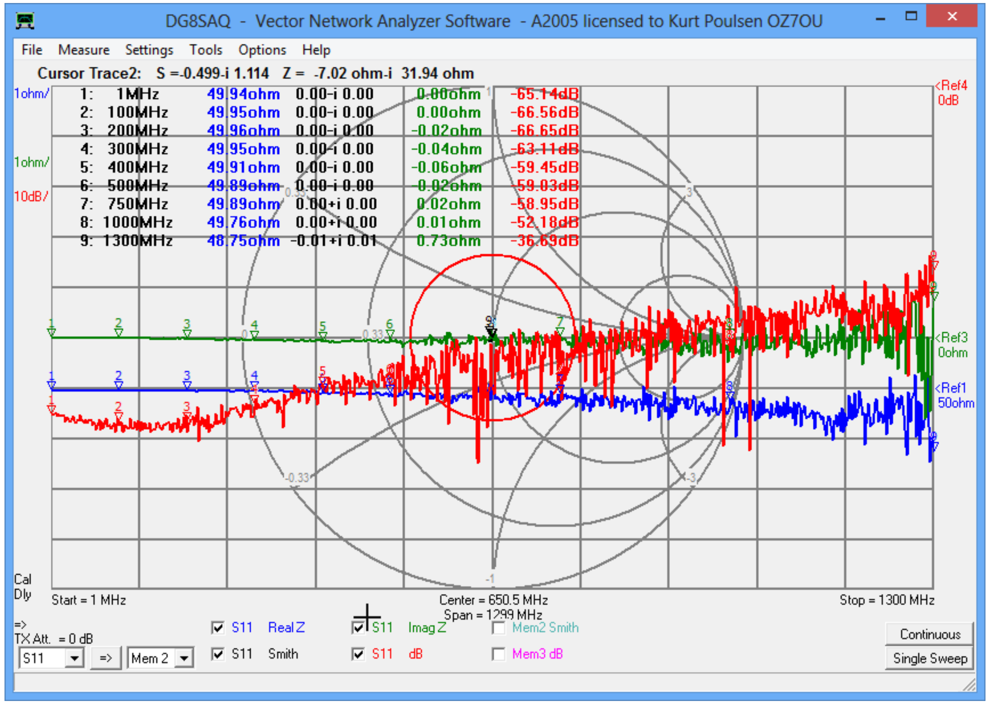


Above Smith Chart has the HP85032E trace of the Open Stub Saved in MEM2 (blue and the live measurement of the open stub in S11 (black) The fit is ammost perfect but if we anable realtime recalibration in the Calibration setting we can the adjust either the open delay or the fringe capacitance for the load (maybe also the load delay). In any case do nor change the short delay as it the accurate device provided you measure the mecha icla dimensions quite accurate.



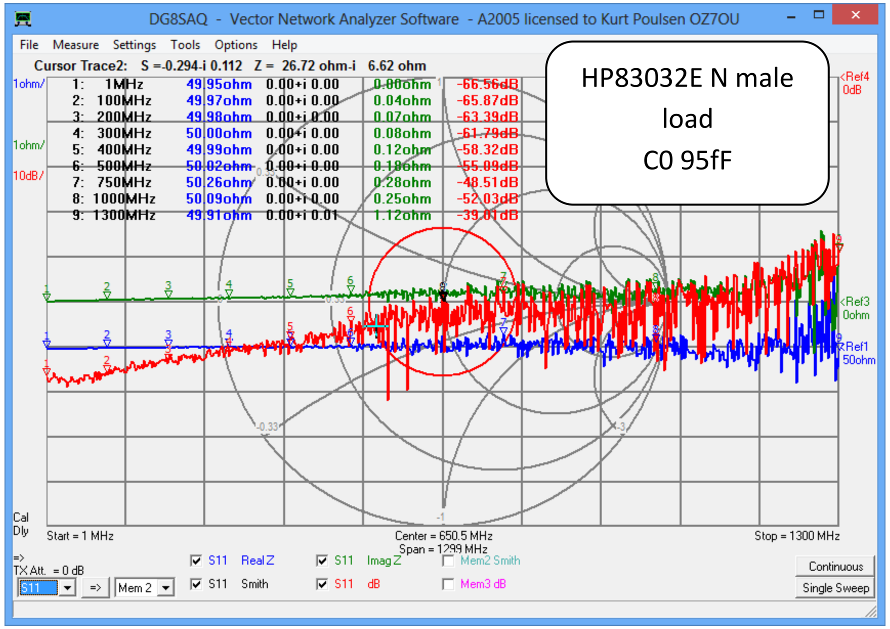
for this plot the open delay has been increased by 1 ps and the fit is far better so we will now remeasure the HP85032E open and load to se the changes based on the corrected calibration.

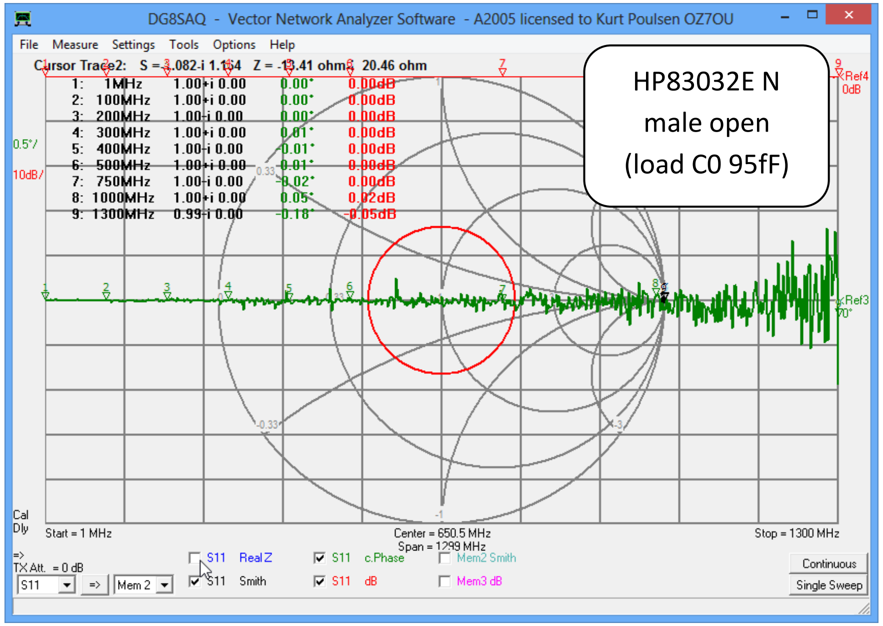




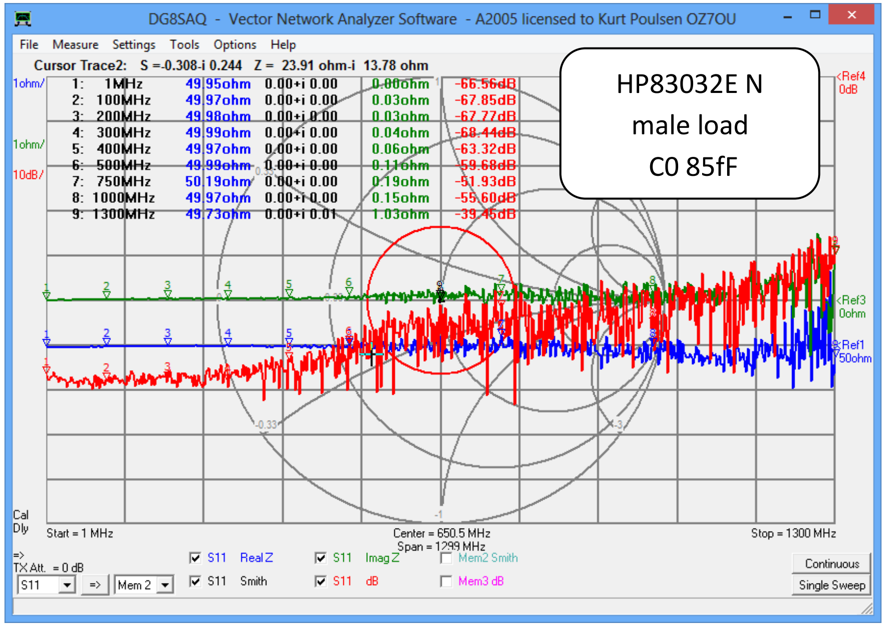
The delay for open is now spot on 20.5ps as the HP85032E N open has a delay incl. fringe capacitance of 20.507ps so the method with the open stub works !!! we have found the delay of the homemade open is 42.346/2= 21.173 ps and not 20.693ps as the simulation with Femm told us, which means 0.5ps larger as we stepped 1 ps in calibration settings. The many digits are realy nonsens but does not harm ☺

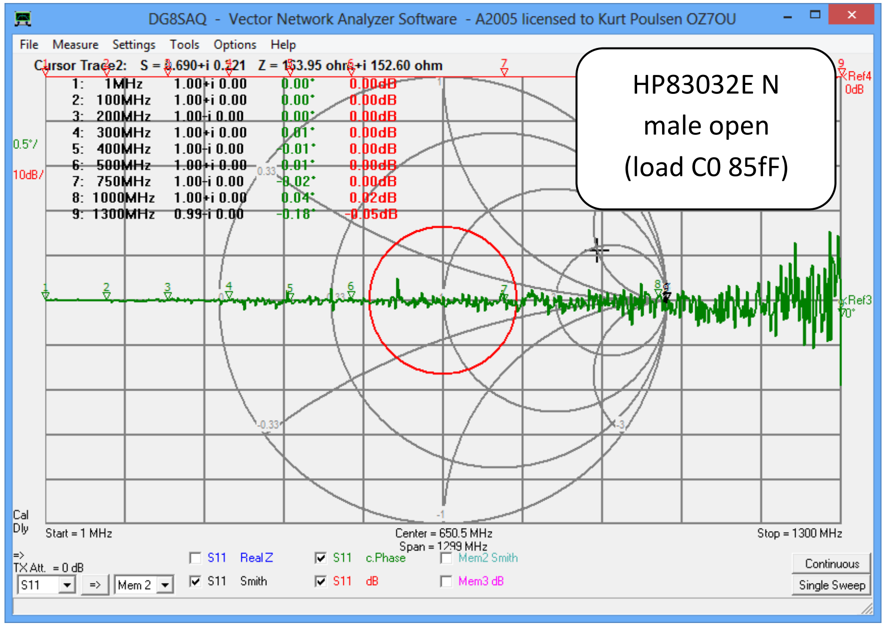
Renewed measurement of the HP Load seen on the right picture shows the imaginary part ImagZ trace 3 is perfect and the resistive part Real Z is dropping slighly of above 400MHz but still considered as a fine load as reflection coefficient better than 40dB to 1.3GHz. As earlier shown modifying the C0 to 80fF from 64.94fF (and delay to 215ps from 183.946ps) brings the performance in top class. To prove the better fit is is nesscary to have a reference load as that was not the assumptions for this test but earler studies has given the result that the pringe capacitance is about 30-50fF for two 100 ohm SMD resistors so it is justified to increase the C0 from 64.94fF to range 95-120fF and keep the delay as simulated . Let us try 95fF and repeat calibrationand test of the HP85032E calibration devices.





The result is very good as the RealZ is now perfect and ImagZ now slighly rising but below 0.1-0.2 ohm to 1GHz. The Open on right image is not affected.

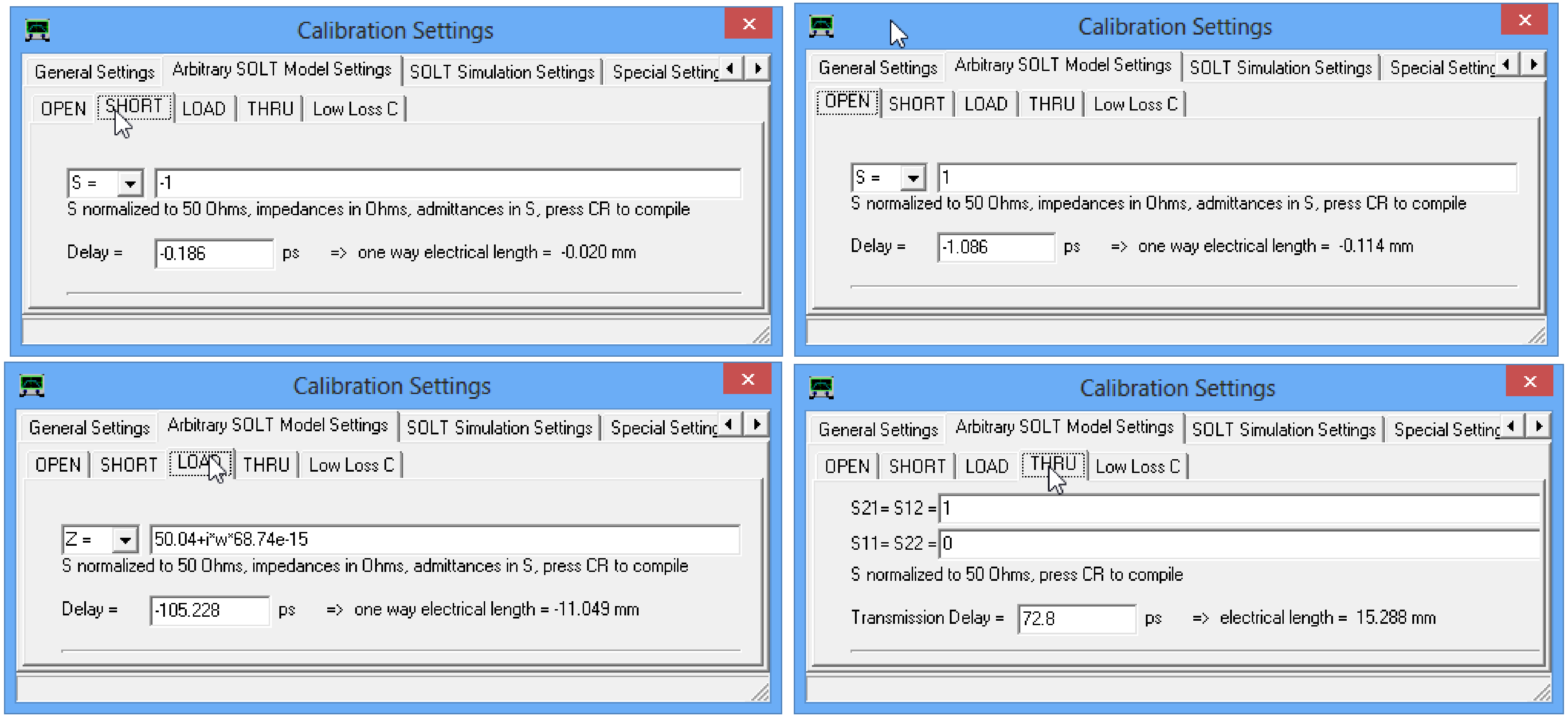




Changing the C0 (fringe capacitance) for the load from 95fF to 85fF bring the plot perfection. So without cheating any way the fringe capacitance for the homemade load shall be the simulated delay 64.94fF and the fringe capacitance for the two SMD 1206 resistors from 20 to 30fF. A far better result than expected Hurra…☺

Test of the homemade N female calibration kit

As I have no HP 83032E N female calibration kit to compare but only a HP85032 clone N female open and short, we must trust the homemade female load. Based on experiance gained during test of the homemade N male calibration kit and also by performing a T-Check of the final calibration settings. The final calibration setting is derived by test against the open and short stub measurements earlier saved as touchstone files and based on calibration with the HP85032E N male calibration kit. The trace in the smith chart will be the same irrespectly the gender male of female for the stubs. Thus both a T-Check ands the stub checks is used for verification and comparign to the clone short and open adaptors.



These calibration setting are for homemade female load and clone female open and short. Delays for the open derived from the mechanical dimensions for the clone female open mated with the Male N adaptor and calculations of fringe capacitances using Femm simulation.

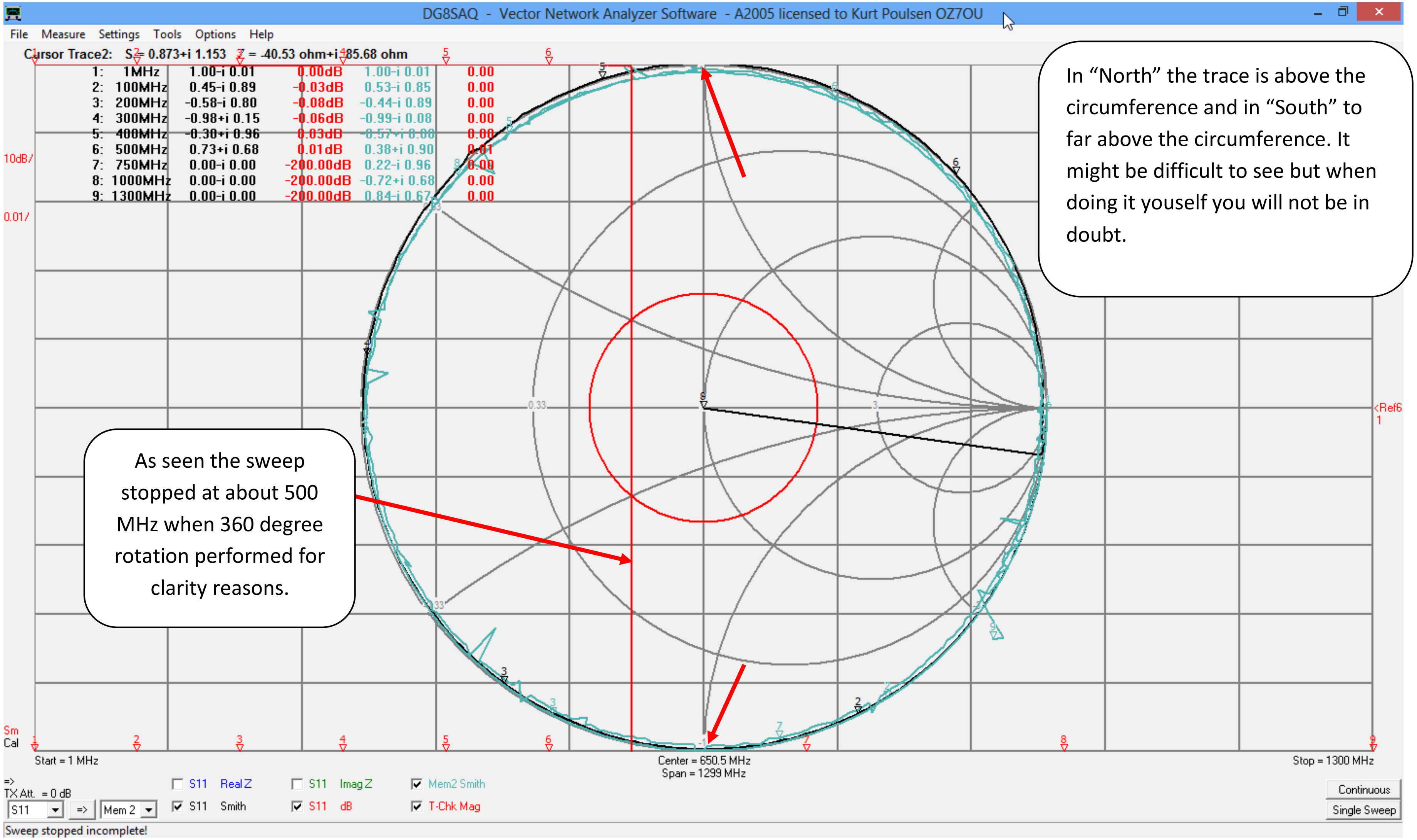
The open delay is <u>without use of center conductor extender</u> and thus the male adaptor in connection with the clone female open simulated to be 0.543ps beyond calibration plane entered as – 1.086ps.

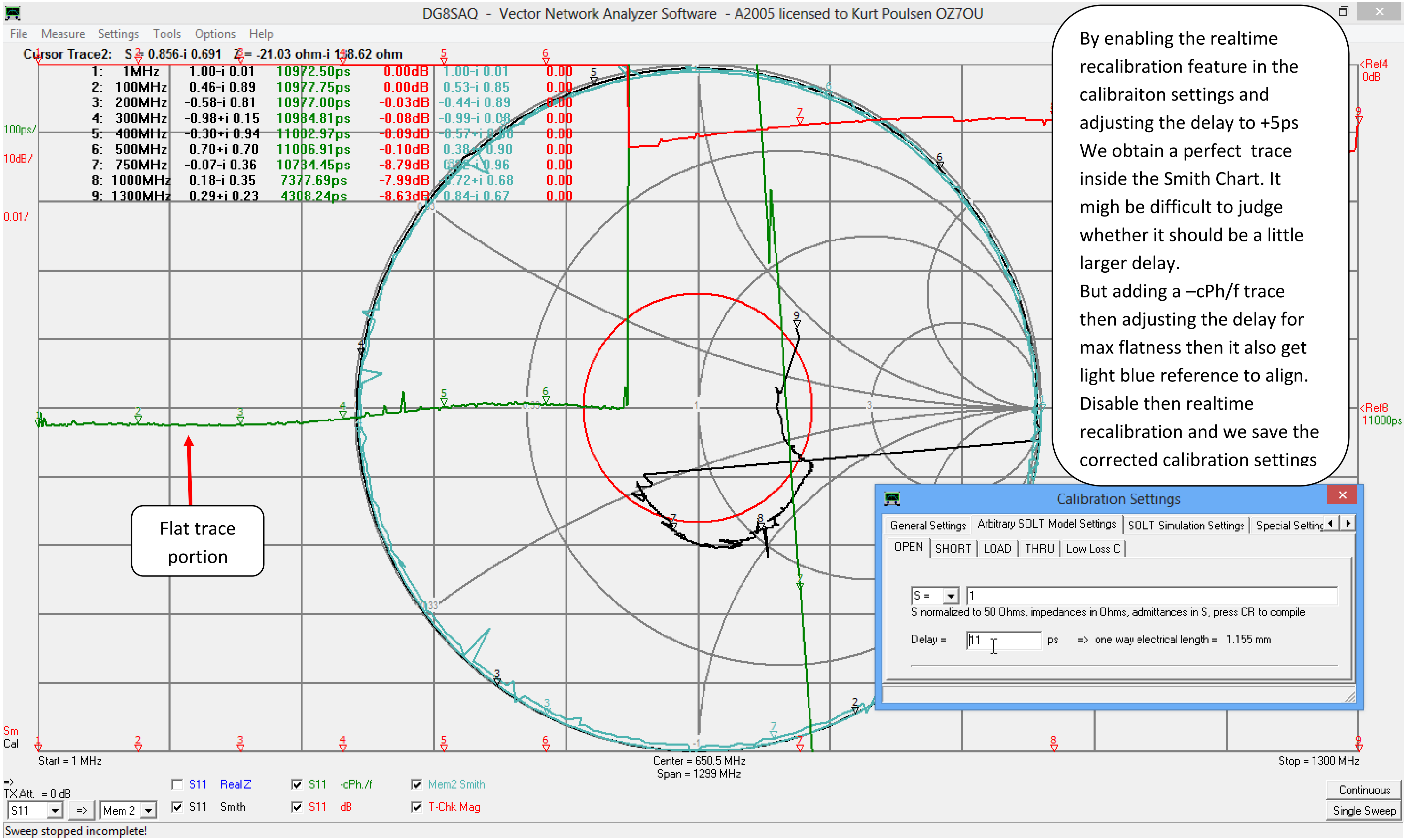
The short is basicly 0ps but from the HP data is picked a delay of 0.093ps entered as -0.186ps in calibration setting (contribution from the shorting disk I suppose).

For the load delay Femm simulated to be 52.614ps entered as -105.228ps in calibration settings. Fringe capacity C0 Femm simulated to be 68.75ps and the load resistance measured with the 4 point test box to be 50.04ohm. The transmisson delay for the thru adaptor being 72.8ps (later on described how to find)

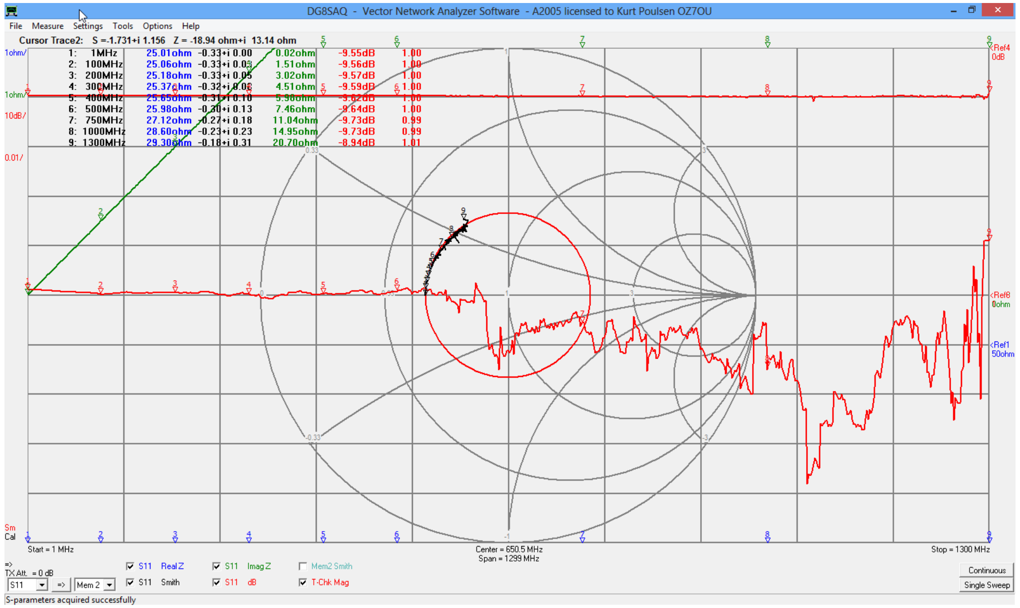
After calbration we have following conditions and uncertanties:

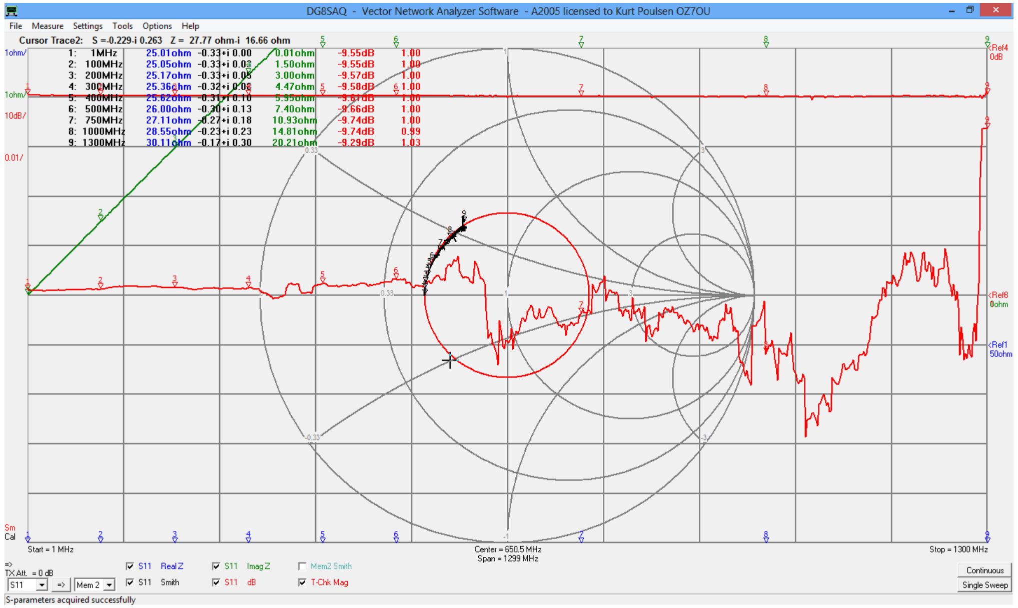
The short is not an uncertancy as well defined. The load is well defined apart from the fringe capacitance which is simulated and we has not added any fringe capacitance for the two 1206 100 ohm SMD resistors. The open dealy Is an uncertancy as simulated and the mating male adaptor center conductor may way in position by 0.25mm on either side of nominel positon. So if doing a open stub test by observing the trace on the Smith Chart, in particular where the impedance is pure resistive, and that is in the "North" and "South" positions, we might then adjust the open delay because if the trace is not following the circumference in an inward spiral with continous increasing distance to the circumference, the short and open "measurement/calibration plane" is not identical. Later on a T-Check facilitates adjustment of the total fringe capcitance.




DG8SAQ - Vector Network Analyzer Software - A2005 licensed to Kurt Poulsen OZ7OU
File Measure Settings Tools Options Help
Cursor Trace2: S = 0.856-i 0.691 Z = -21.03 ohm-i 158.62 ohm
1: 1MHz 1.00-i 0.01 10972.50ps 0.00dB 1.00-i 0.01 0.00
2: 100MHz 0.46-i 0.89 10977.75ps 0.00dB 0.53-i 0.85 0.00
3: 200MHz -0.58-i 0.81 10977.00ps -0.03dB -0.44-i 0.89 0.00
4: 300MHz -0.98+i 0.15 10984.81ps -0.08dB -0.99-i 0.08 0.00
5: 400MHz -0.30+i 0.94 11002.97ps -0.09dB -0.57+i 0.88 0.00
6: 500MHz 0.70+i 0.70 11006.91ps -0.10dB 0.38+i 0.90 0.00
7: 750MHz -0.07-i 0.36 10734.45ps -8.79dB 0.32-i 0.96 0.00
8: 1000MHz 0.18-i 0.35 7377.69ps -7.99dB 0.72+i 0.68 0.00
9: 1300MHz 0.29+i 0.23 4308.24ps -8.63dB 0.84-i 0.67 0.00
100ps/
10dB/
0.01/
Ref4 0dB
Ref8 11000ps
By enabling the realtime recalibration feature in the calibraiton settings and adjusting the delay to +5ps We obtain a perfect trace inside the Smith Chart. It migh be difficult to judge whether it should be a little larger delay.
But adding a –cPh/f trace then adjusting the delay for max flatness then it also get light blue reference to align.
Disable then realtime recalibration and we save the corrected calibration settings
Flat trace portion
Calibration Settings
General Settings Arbitrary SOLT Model Settings SOLT Simulation Settings Special Setting
OPEN SHORT LOAD THRU Low Loss C
S = 1
S normalized to 50 Ohms, impedances in Ohms, admittances in S, press CR to compile
Delay = 11 ps => one way electrical length = 1.155 mm
Sm Cal
Start = 1 MHz
Center = 650.5 MHz
Span = 1299 MHz
Stop = 1300 MHz
TX Att. = 0 dB
S11 => Mem 2
S11 Real Z
S11 Smith
S11 -cPh./f
S11 dB
Mem2 Smith
T-Chk Mag
Continuous
Single Sweep
Sweep stopped incomplete!

After calibration a T-Check excecuted and left image shows the result. As load on the T Adaptor is used the homemade female load.

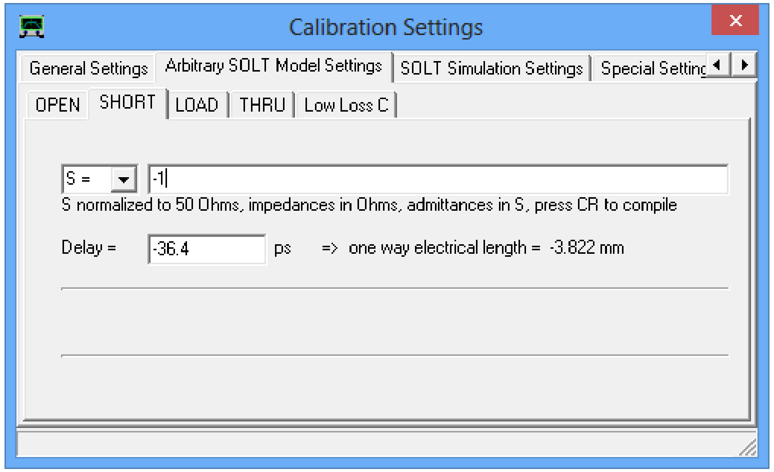


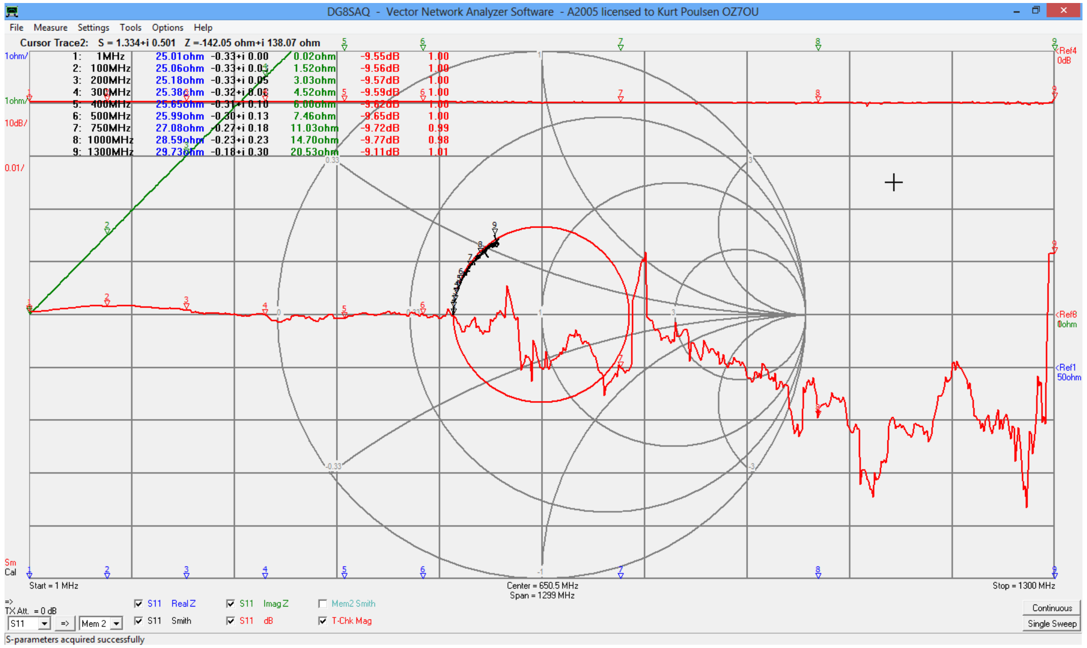


Left image shown the excellent result as the T-Check is superb up to 600MHz and less than 0.1% and better than about 3 % to 1.3GHz
A repeated calibration and T-Check is shown on the right image and still very good result as a less than 1% T-Check considered superb and the range above 600Mhz improved due to recalibration (drift over time).

The T-adaptor is a good quality (R&S brand) where the load must be female. The homemade load used (as a very fine load) as well the Rosenberger SMA female load via a good quality N female to SMA male adaptor which showed similar results.

Next step is to use the homemade open and short calibration standards. The only change should be the short delay which is 18.2ps entered in calibration settings as -36.4ps. We have previsus seen the home made open is perfect compared to the open clone and we have changed the delay to + 11pS.





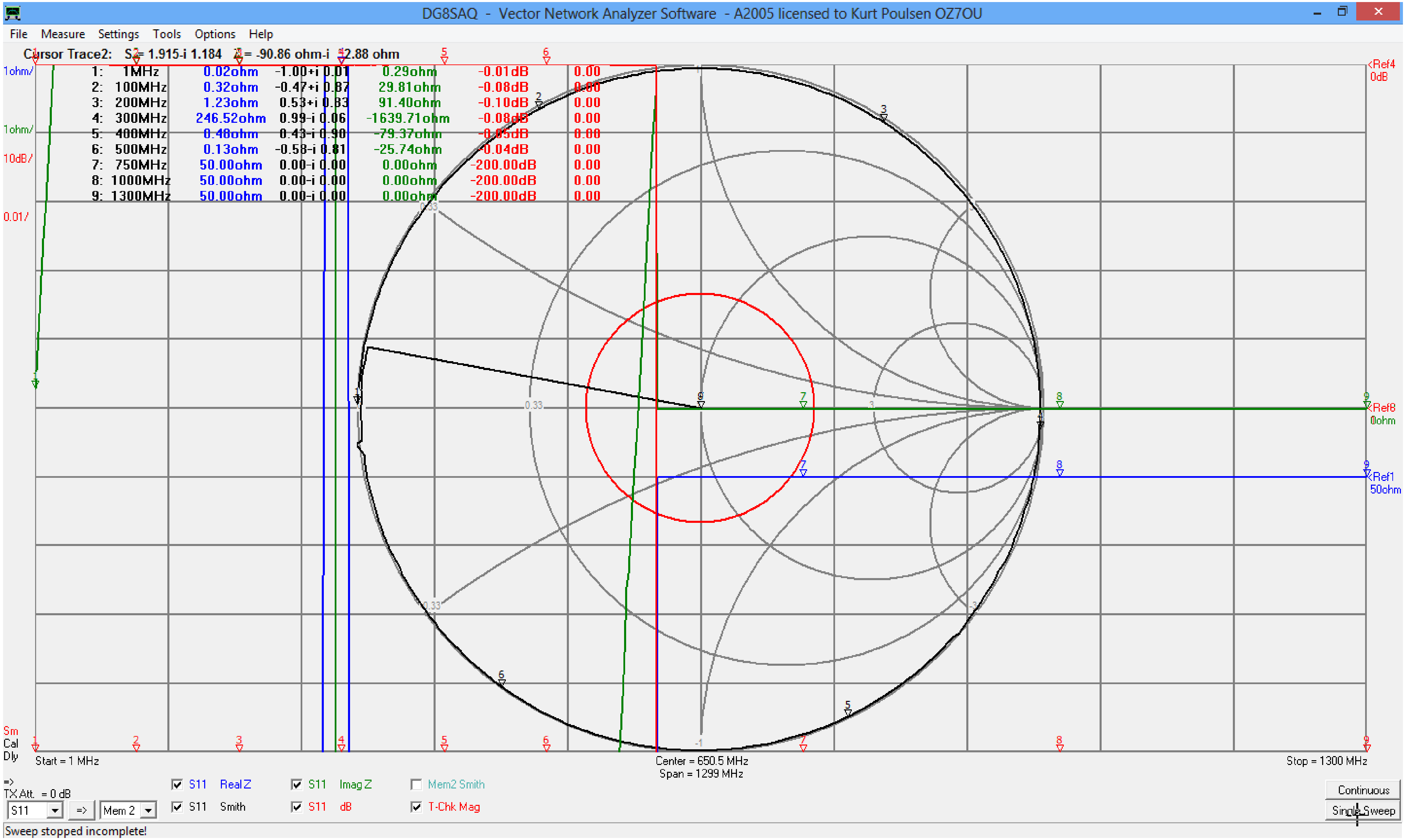
The T-Check result above shown identical result so job done.

Summary:

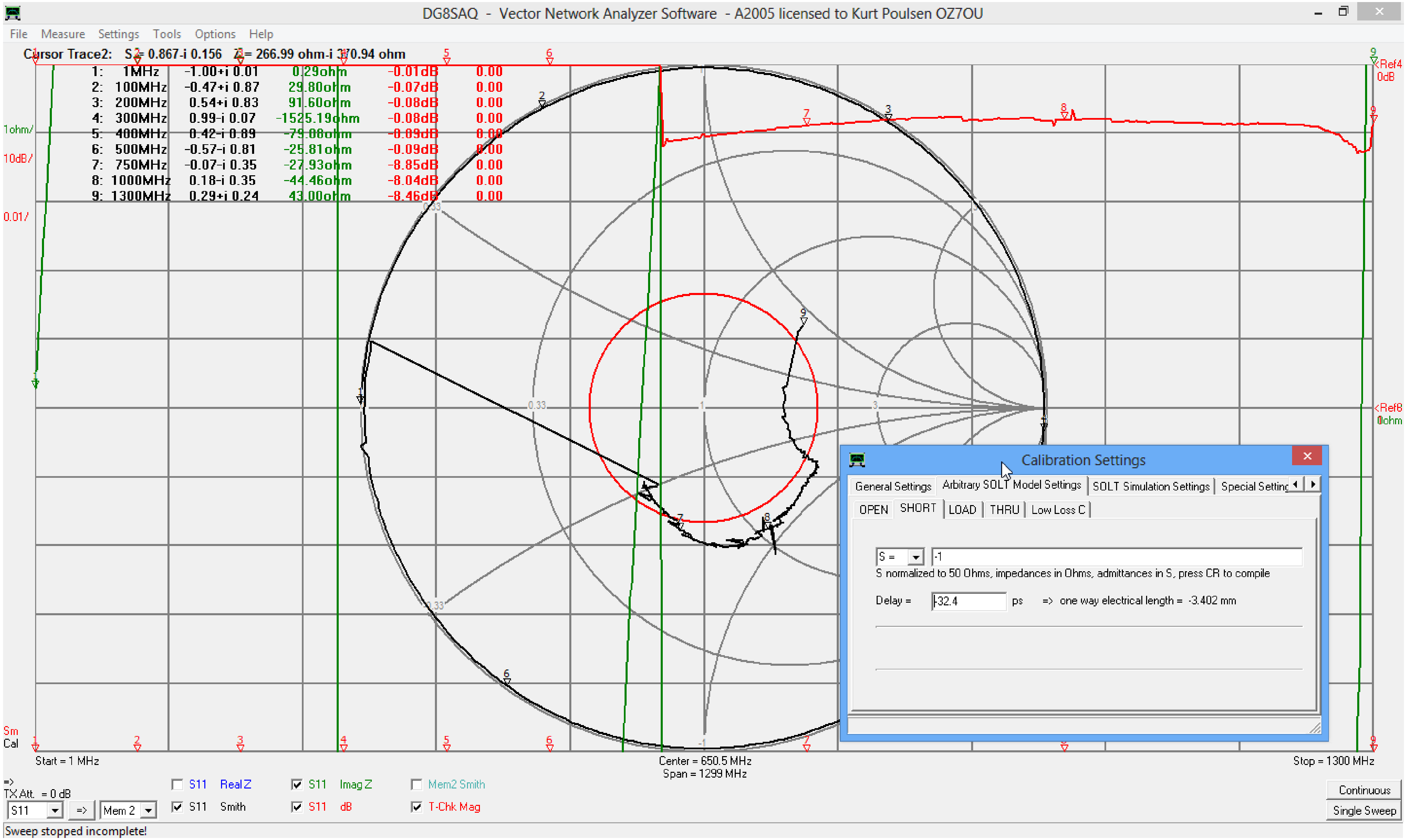
We have calibrated with the homemade female calibration kit with data derived solely from mechanical dimension of the of the female short and simple calculation of the delay based on x mm/0.3= short delay, where x is the distance from the reference plane to the shorting disk. The female open based on Femm simulation as the center conductor extender not used and the mating male adaptor used as the “counterpart”. A open female stub measurement used fro finetuning the delay for open. The load designed based on simulation in Femm and it has been seen that changing the total fringe capacitace no effect on the T Check so left as simulated.

Final check and eventual refinement:

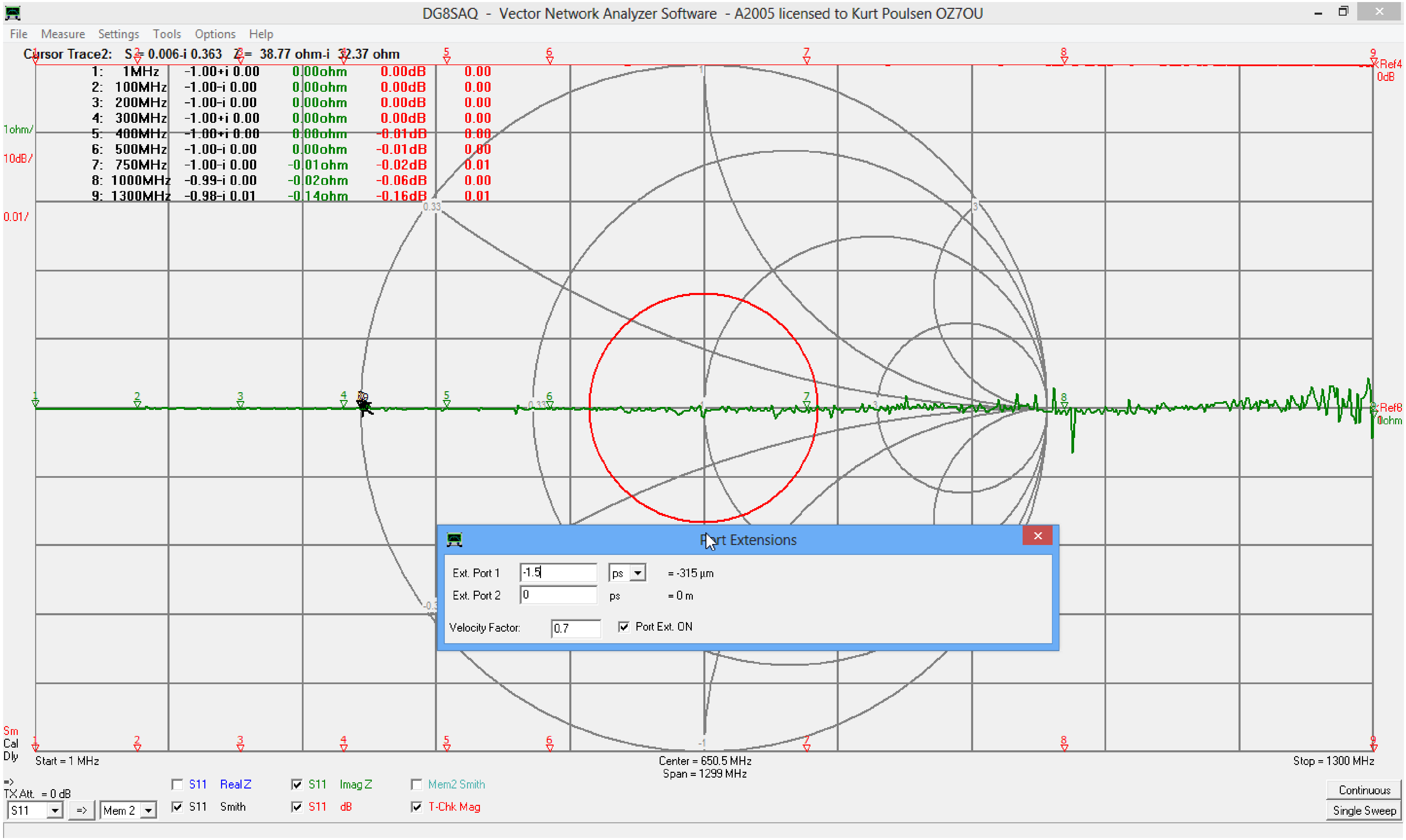
We have not yet on purpose measured the homemade short against the clone female short and before that we run a female shorted stub test.
We also stop the sweep at 600MHz as giving a more clear picture of what is going on.



Running a open short stub test indicated a small correction needed

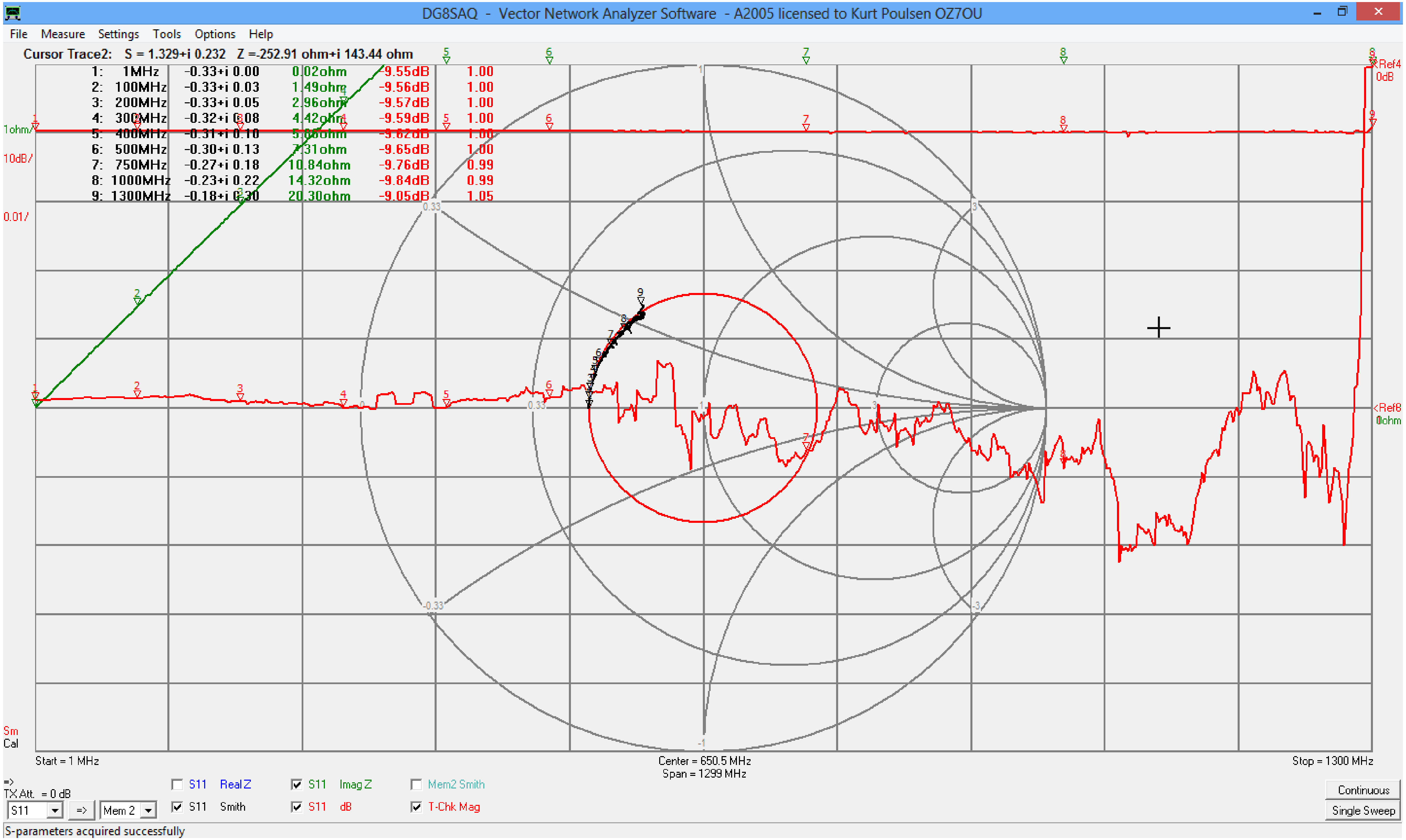


Redduction from -36.4 to -32.4ps seem providing a better trace equal to a delay for the open short of 16.2pS

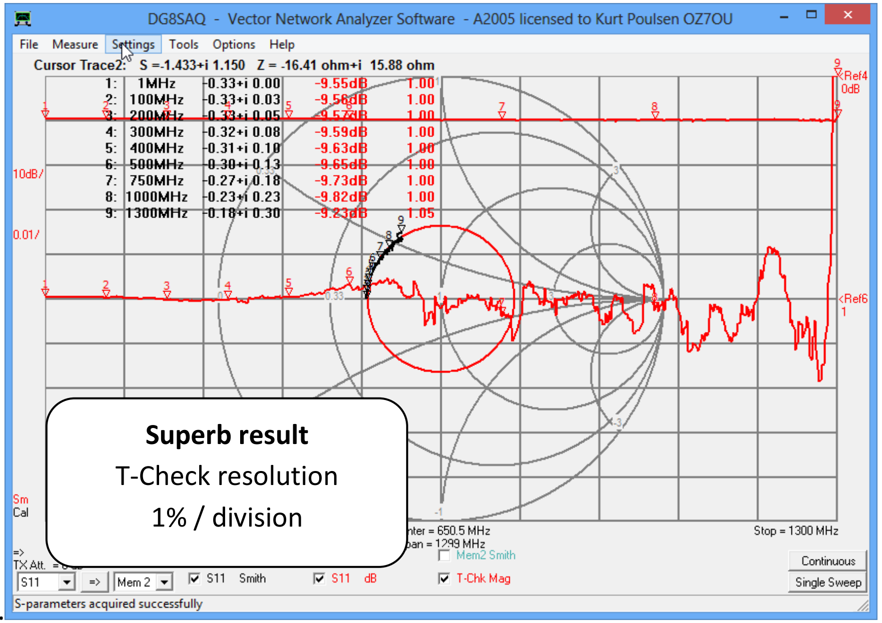


Actual measurement of the open clone short based on the new setting for homemade open short delay of -32.4ps a ext port delay of -1,5ps is needed so the true delay for the homemade short is 16.2 + 1.5ps = 17.7pS. The calculated delay was 18.2ps so we are able to determine the postion of the calibration plane around 1ps being around 0.3mm displacement with out having any other tools than the caliper and the FEM simulation software and the female open and short stubs.

A final recalibration and T-Check after the varios fine tuning where the calibration setting are open = +11pS and short -32.4ps with load unchanged



Another test and the stability over time



A very impressive result for the T-Check. Quite impossible to improve
The project can be claimed to be successfull.
Result as said within some 1 ps for the open and short standards. The load is also well behaving and easy to produce
Further proof and refinements requires a female set of calibration adaptor from a HP85032B calibration kit to evaluate, but the T-Check confirms the calibration plane for reflection and transmission is identical for frequencies up to 500MHz.
<u>How stable is the calibration over time ?</u>
I made a new T-Check after 15min standby (the VNWA running. After 200minutes of standby the calibration was still very fine and only above 500MHz the drift was noticeable. Next day more drift by 50% additional.