Measurements on the Amphenol Connex male and female calibration kit acquired from SDR-Kit3 thru 3 deliveries over a period of more than two years

Preface:

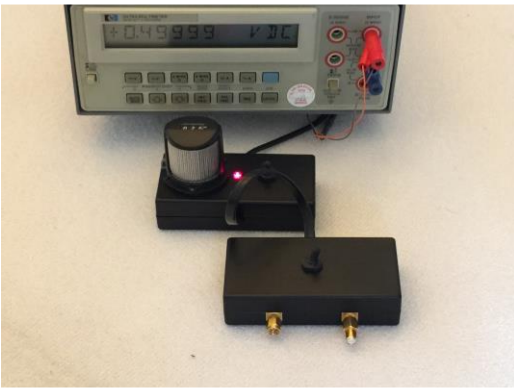
SDR-Kits has for a long time supplied male and female VNA calibration kits, based on Amphenol Connex short, open and load adaptors. In total 3 versions of calibration sheets have been issued over the years, and now is the time to update the latest version with the title:

SDR-Kits – Amphenol Connex CAL Standards for the DG8SAQ VNWA by Kurt Poulseen OZ7OU revision 3 May-2013

The background being I have acquired a HP85033C 3,5mm calibration kit and thus am better equipped to measure.

The task:

For the task I used the VNWA in combination with my recently acquired HP85033C 3.5mm calibration kit, which also includes twice of each phase matched, male and female APC-7 to 3.5mm adaptors. That allows for accurate measurements of S21 delays of any type of SMA thru adaptors such as male-male, female-female and male-female, just by exchanging the gender for one of the APC-7 to 3.5mm adaptors, after a full calibration of the VNWA. Off course, the 3.5mm calibrations standards can be used directly with the VNWA, but then direct delay measurements of symmetrical thru adaptors is not possible. Both the 3.5mm male and female short have identical delays of 16.695ps and likewise the 3.5 mm male and female open have identical delay of 14.491ps and C0=53x10(-15)F C1=150x(-27)F/Hz and C2=0 , C3=0. Male 3.5mm load DC resistance was measured to 49.932 ohm and female load was measured to 50.065 ohm with 0.01% accuracy.



Test equipment for 0.01% precision measurement of load DC resistance

A further detailed description of the HP85033C and how to use it and how to evaluate the measured response to be found at http://www.hamcom.dk/VNWA/How to use and verify HP35033C.pdf

Thus an APC-7 front end was made for the VNWA, to utilize all the features of my HP85033C calibration kit.

The APC-7 to 3.5mm female flange fitted to the VNWA with two SMA male-male adaptor

Measurements performed for the Amphenol Connex calibration kit

The APC-7 to 3.5mm female adaptors fitted to the VNWA APC-7 frontend
to demonstrate the test environment.

The VNWA settings are a span from 1 to 501MHz with step size 2MHz and thus 251point needed. 100mS per point selected.

After a complete calibration with the HP85033C **male** calibration standards, the first item to be measured is the delay of the Amphenol Connex male-female adaptor.

AMPHENOL CONNEX MALE-FEMALE Adaptor

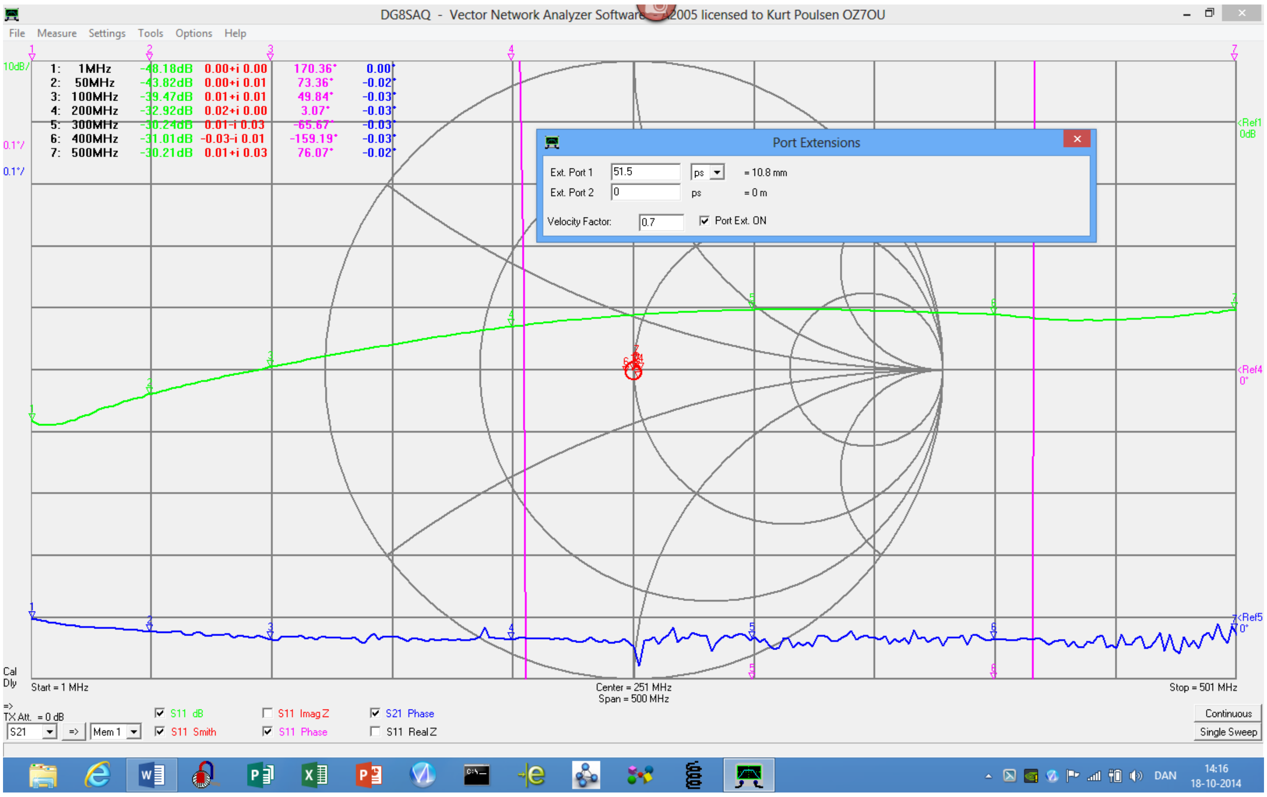
S21 delay	M-F extender1	M-F extender2	M-F extender3	M-F extender4
AVG=56.68ps	56.55ps	56.66ps	56.75ps	56.75ps

After a complete calibration with the HP85033C **male** calibration standards and swapping the female APC-7 to 3.5mm adaptor with the male APC-7 to 3.5mm adaptor, the next item to measure is the S21 delay of Amphenol Connex female-female adaptor.

AMPHENOL CONNEX FEMALE-FEMALE Adaptor

	S21 delay	F-F_ref	F-F1	F-F2	F-F dot1	F-F dot2	F-F dot3	F-F dot4	F-F dot5
At 1MHz	**AVG=51.43pS**	**51.5ps**	**51.2ps**	**51.5ps**	**51.25ps**	**51.25ps**	**51.5ps**	**51.55ps**	**51.65ps**
+delay	**AVG=0.039deg**	**0.03deg**	**0.04deg**	**0.04deg**	**0.04deg**	**0.04deg**	**0.04deg**	**0.04deg**	**0.04deg**
>50MHz	**AVG=51.54ps**	**51.58ps**	**51.3ps**	**51.6ps**	**51.35ps**	**51.35ps**	**51.6ps**	**51.65ps**	**51.75ps**

Below seen the image for F-F_ref.
All adaptors have the same appearance and the delay adjusted until it has its maximum flat response above 100MHz and the increased delay above 100MHz was recorded as a phase offset. As we have a span from 1 to 501MHz this correspond to a half wavelength length of 300mm at 500MHz and based upon velocity of light it leads to 1000ps for 360degree = 2.7777.. ps per degree. Hereby we can calculate the delay better suited for frequencies above about 50MHz. The difference is caused by the change of velocity in a transmission line across the frequency range, as being lower a low frequencies thus electrically shorter.

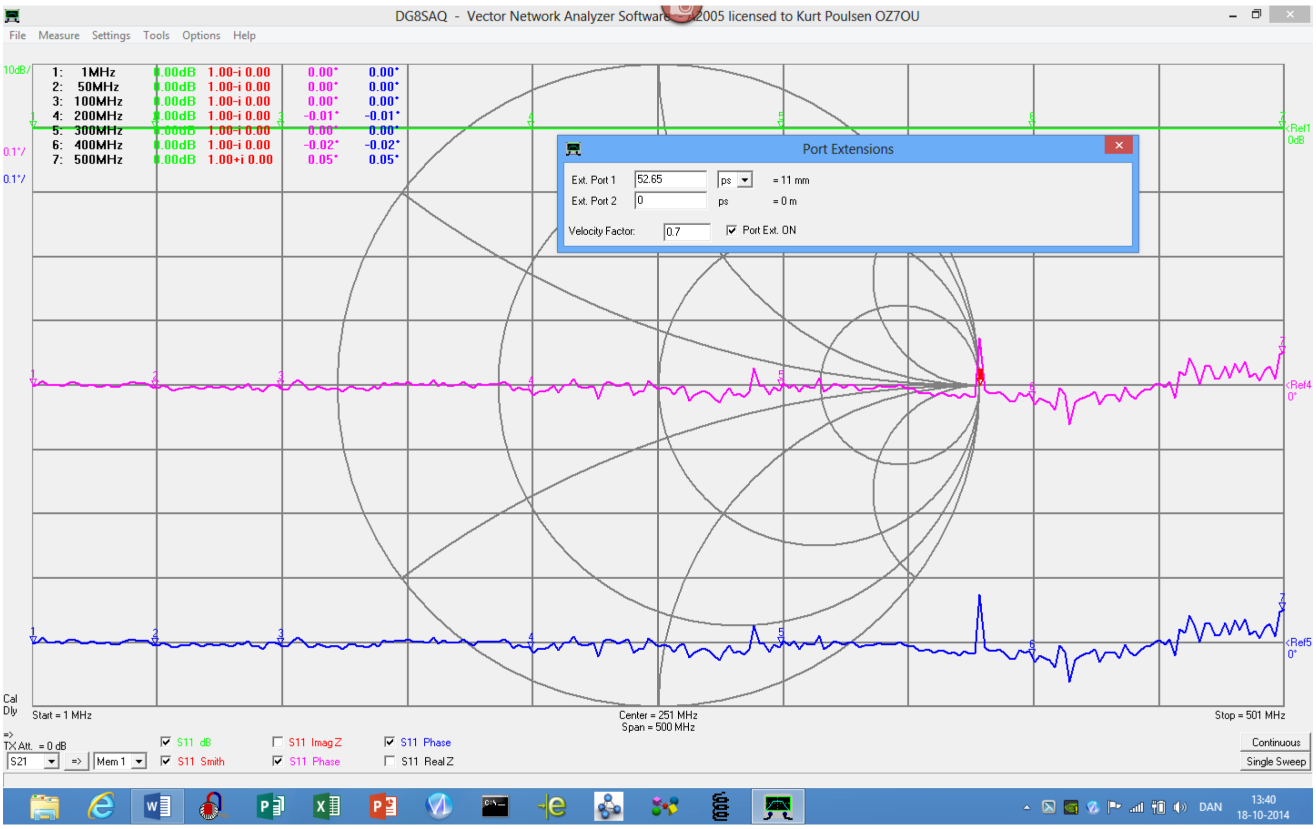


Without any change to the setup or calibration, measurements of the delay of a female-female open was done.

AMPHENOL CONNEX FEMALE-FEMALE Adaptor as Open

S11 Delay	F-F_ref	F-F1	F-F2	F-F dot1	F-F dot2	F-F dot3	F-F dot4	F-F dot5
AVG=51.62ps	52.4ps	50.9ps	51.80ps	50.85ps	50.85ps	51.95ps	51.8ps	52.4ps

Below image shows the measurements for F-F_ref but any other F-F has exactly the same appearance.

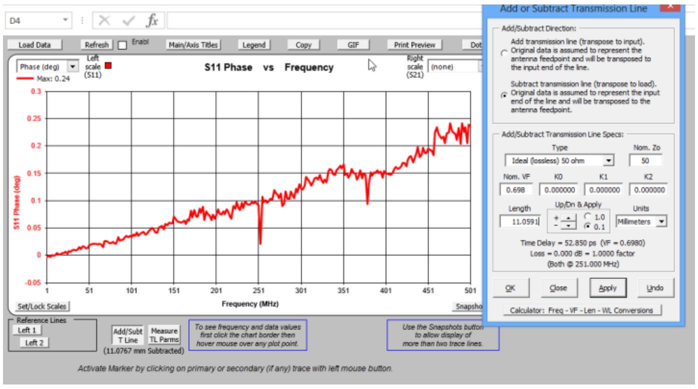


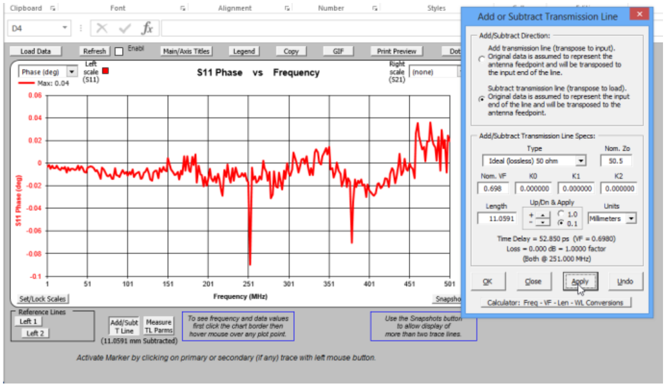
Delay measurement for FF_ref shown above

Repeated measurement of the F-F open were done (called New S11) after the APC-7 to 3.5mm male being used for calibration with the HP85033C female standards.
The differences calculated below demonstrate phase difference between the two APC-7 to 3.5mm adaptors when used for S11 measurements and the influence from the Amphenol Connex female-female adaptors not having a Z0 of exactly 50 ohms.

	AVG delay	F-F_ref	F-F1	F-F2	F-F dot1	F-F dot2	F-F dot3	F-F dot4	F-F dot5
New S11	**AVG=51.58ps**	**52.35ps**	**51.05ps**	**51.85ps**	**50.8ps**	**50.35ps**	**52.05ps**	**51.75ps**	**52.45ps**
Old S11	**AVG=51.62ps**	**52.40ps**	**50.9ps**	**51.80ps**	**50.85ps**	**50.85ps**	**51.95ps**	**51.8ps**	**52.40ps**
S21	**AVG=51.43ps**	**51.50ps**	**51.2ps**	**51.50ps**	**51.25ps**	**51.25ps**	**51.5ps**	**51.55ps**	**51.65ps**
NewS11-S21	**AVG=-0.01pps**	**+0.85ps**	**-0.15ps**	**+0.35ps**	**-0.45ps**	**-0.1ps**	**-0.45ps**	**+0.2ps**	**-0.2ps**
Old S11-S21	**AVG=+0.06ps**	**-0.10ps**	**-0.30ps**	**+0.30ps**	**-0.40ps**	**-0.40ps**	**+0.45ps**	**+0.25ps**	**-0.25ps**
NewS11-Old S11	**AVG=-0.04ps**	**-0.05ps**	**+0.15ps**	**+0.05ps**	**-0.05ps**	**-0.5ps**	**+0.1ps**	**-0.05ps**	**-0.05ps**

The simulated difference in earlier studies between S21 delay and S11 delay due to fringe capacitance, is 1.5ps and the measured value for the female APC-7 to 3.5mm adaptor as open is 1.35ps. In above table the only measurement done with the male APC-7 to 3.5mm adaptor properly calibrated is the "new S11". All other measurements are under the assumption the swapping the APC-7 to 3,5mm adaptor should not change anything. However interestingly to observe is that measuring the difference between the two sets of S11 measurements of the 8 female-female adaptors are pretty accurate within average -0.04ps varying between + 0.15ps/-0.05ps with only F-F dot2 being off with -0.5ps which very well could change by a repeated measurement. It indicates the delay differences between the two APC-7 to 3.5mm adaptors are indeed small which also S21 test by swapping adaptors demonstrate the difference is less than 0.1ps and by several repeated tests closer to 0ps. As the next demonstration, using ZPlots, will show the impact from Z0 differences of the APC-7 to 3.5mm adaptor very well can account for the any difference. Also it will explain why the S21 delay difference between S11 and S21 both is positive and negative and not exactly +1.5ps as simulated versus 1.35ps as measured. At least the "Old S11" measured under the same conditions as the S21 delay shows a positive average delay difference as it must do, but only 0.06ps average against the expected simulated 1.5ps. ***However using the male calibration kit and measure the unterminated APC-7 to 3.5mm female adaptor a delay was measured to 1.35ps which equally well can be the correct value.***





For the F-F_ref adaptor a sweep was made and loaded into ZPlots. The S21 delay of 51.5ps is added to the fringe capacitance 1.35ps in total 52.85ps and being simulated in ZPlots by subtracting a TL of length 11.0591mm and a Nom VF of 0.698 (PTFE) which provides the delay of 52.85ps. In the left image this scenarios seen and in the right picture the Nom. Z0 changed to 50.5ohm and BINGO the phase S11 phase is 0 degree within 0.02 degree merely being noise corresponding to 0.03ps. A female-female adaptor or any other adaptor will easily have such mechanical tolerances leading to the error. A center conductor of diameter 1.26mm will for a change of Z0 to 50.5ohm be 1.245mm, a change of 15micron, or if the VF of the PTFE changes from 0.698 by 2% gives the same result.
So hereby is proven that the Z0 of the adaptors has a great impact on the S11 delays for open measurements.

Summary for Amphenol Connex Female-Female adaptor
Average S21 delay=51.43ps + - 0.22ps at 1 MHz
Average compensated S21 delay=51.54ps + - 0.25ps above 50MHz
Open delay S11=51.60ps + - 0.8ps

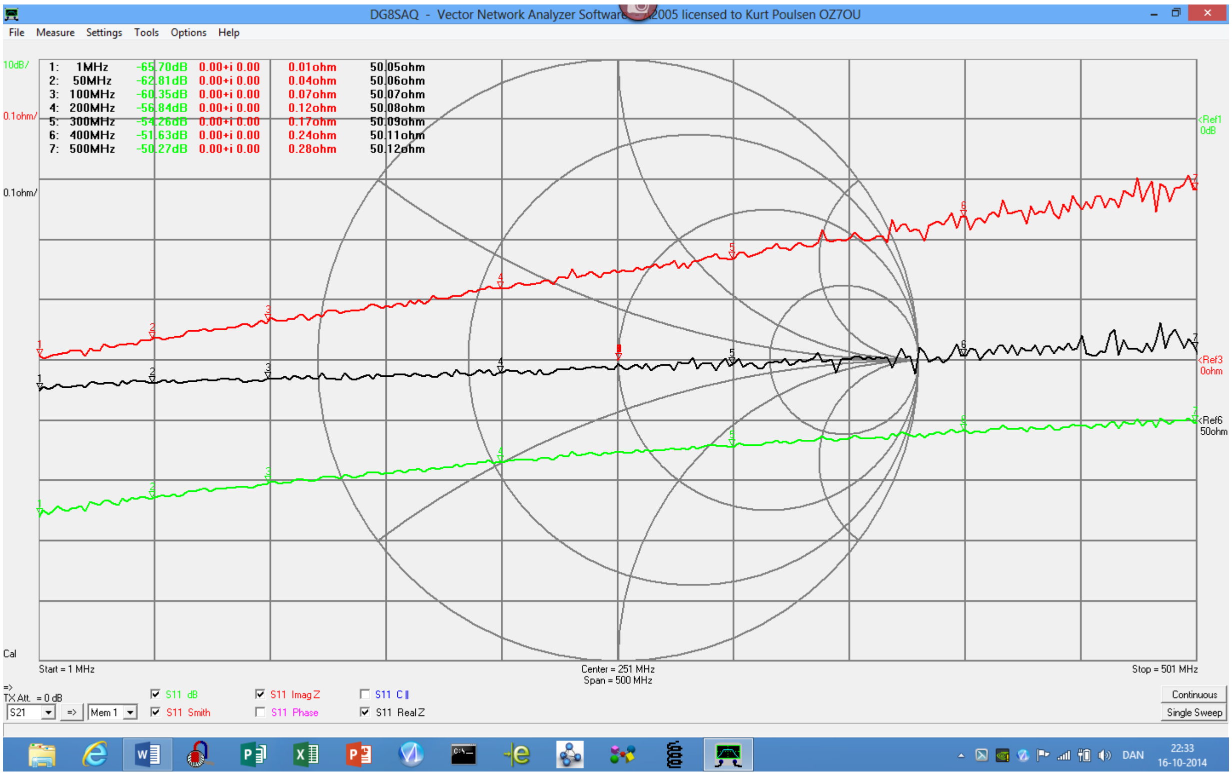
It is advisable not to use the S21 delay and add 1.35/1.5ps for the open female-female standard as the adaptors seem to be of fairly equally in design over the years. So the given measured values are more accurate due to the deviation of the Z0 from 50 ohm of the adaptors.

Measurements on the Amphenol Connex female Load

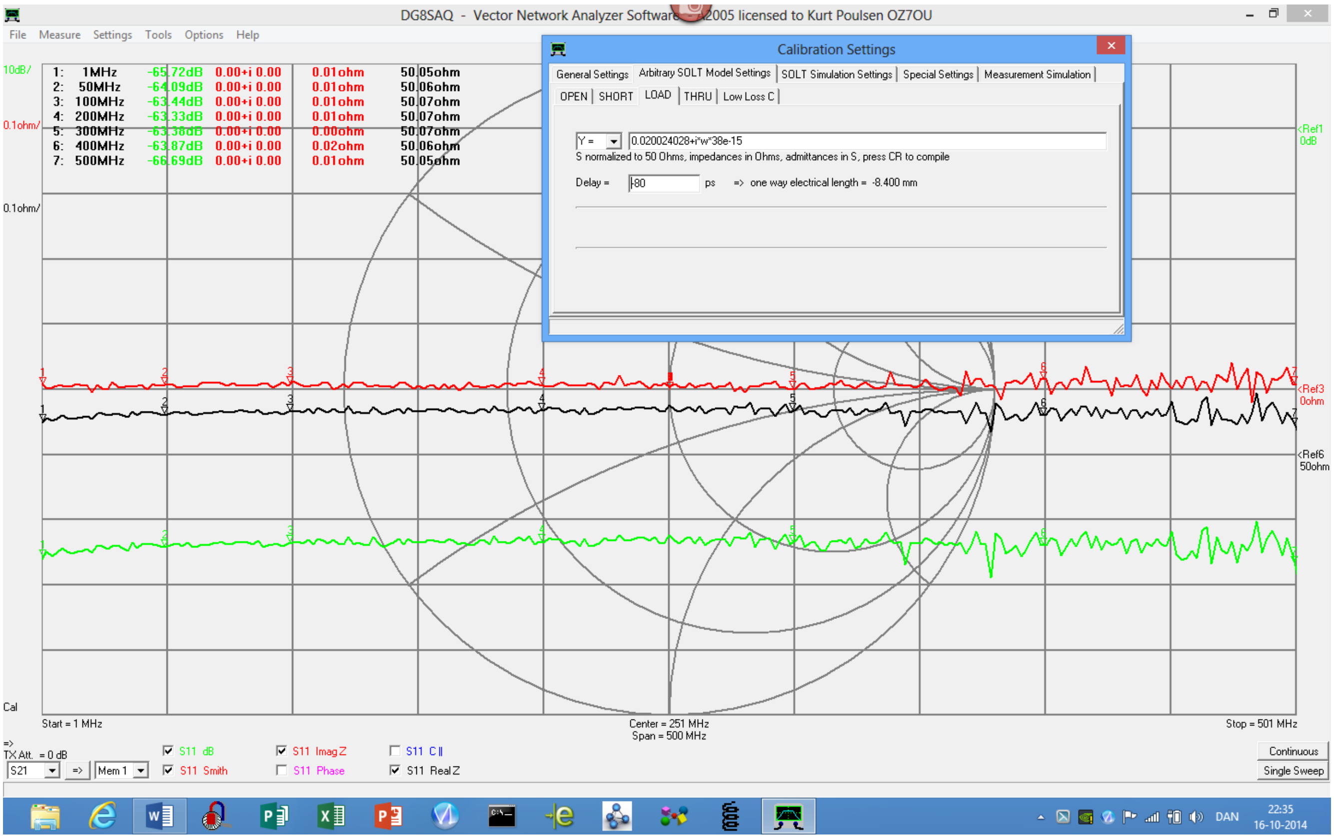
The procedure used is first to measure the DC resistance of the load and then examine it with a calibrated APC-7 to 3.5mm male adaptor using the HP85033C female calibration standard, and first determine what delay and C II needed to be added in the calibration setting, with realtime recalibration enabled, to obtain flat RealZ and ImagZ traces when measuring the HP85033C female load standard, and are recorded in the table below.
These averaged data are used for entries in the individual calibration settings for each of the tested Amphenol Connex female loads, where the measured DC resistance is also entered in the calibration setting as Y value (conductivity). As delay -50ps and as C II 50fF was selected. For each load the VNWA is recalibrated with respect to load only and the HP85033C female load standard was subsequently measured and the obtained traces seen below. It is characteristic for the Amphenol Connex female loads that they are all inductive, which is the reason for the negative delay value.
A disassembled load shows that the 2x100 ohm resistor are positioned 6.25mm behind the reference plane, which correspond to a delay of 30pS. Apparently the delay must be moved behind the reference plane (mirrored) causing the delay to be twice and thus negative due to the inductive character. Please remark the used delay for the calibration data is -50pS but could as well have been -60ps. However, experimental result shows that -50pS seem to be to preferred, as the 7 items tested demonstrated a more flat response for the RealZ, (the delay primary corrects the RealZ trace, and likewise the C II value primarily corrects the imagZ trace). Indeed the images below demonstrate a very good calibration when observing the return loss, as for the used HP85033C female load stand of DC value 50.065ohm leading to a return loss of -63.7dB. As seen for the 7 images below the ImagZ is both inductive as well as capacitive. It will always be a compromise with the spread from item to item as seen in the table

	FL_ref	FL1	FL2	FL-dot2	FL-dot3	FL-dot4	FL-dot5
	49.940	50.044	49.942	49.971	50.051	49.969	50.118
AVG=49.7fF	38fF	50fF	60fF	35fF	55fF	35fF	75fF
AVG=-54.2ps	-80ps	-30ps	-30ps	-50ps	-60ps	-60ps	-70ps

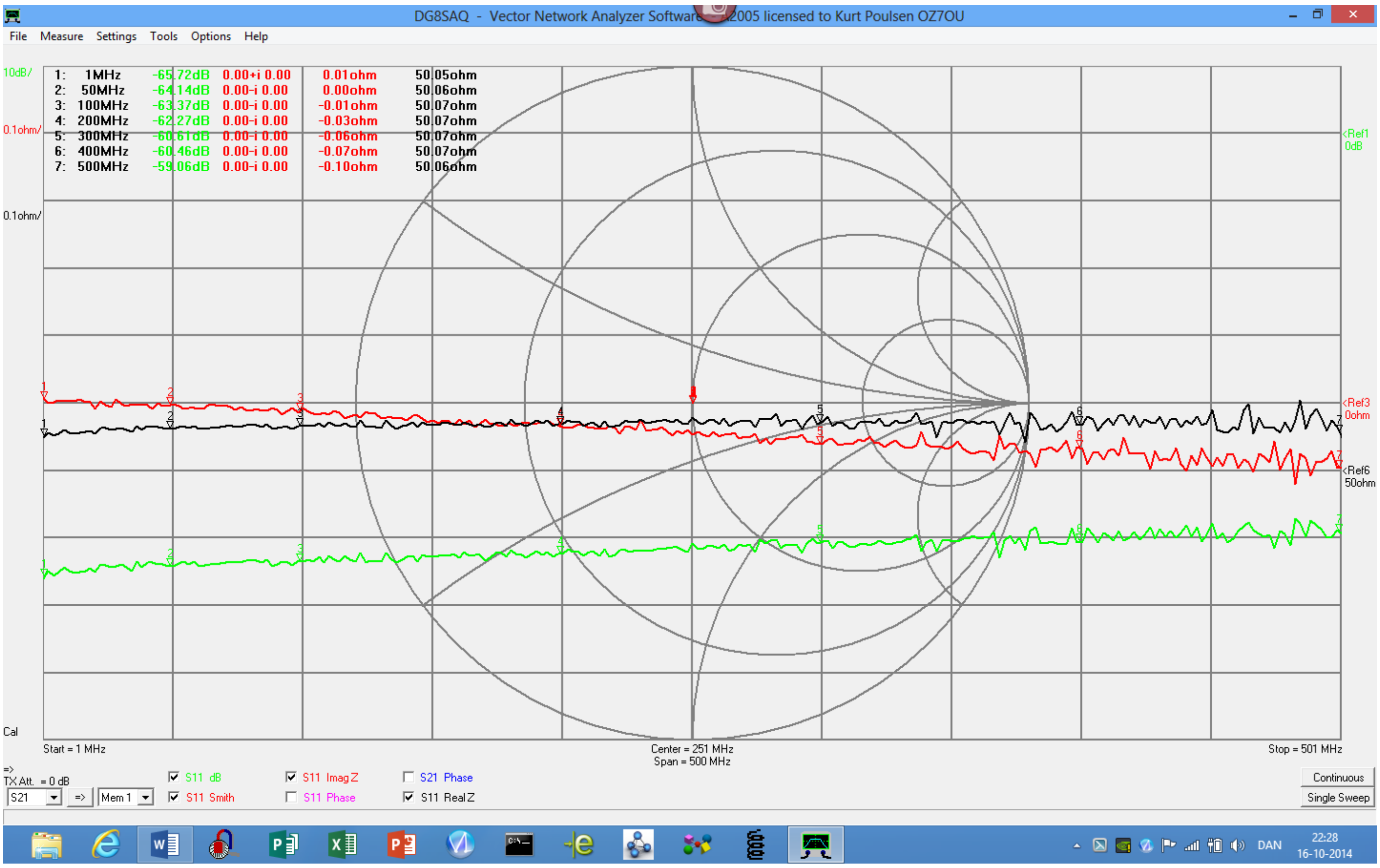
The 3 images below are for the F_Ref. female load acquired about 3 years ago. First without any correction in the calibration setting <u>except for the DC resistance</u>, followed by the delay and C II correction which perfects RealZ and ImagZ an **finally with -50pS delay and 50fF as proposed for standard values in the calibration settings**.



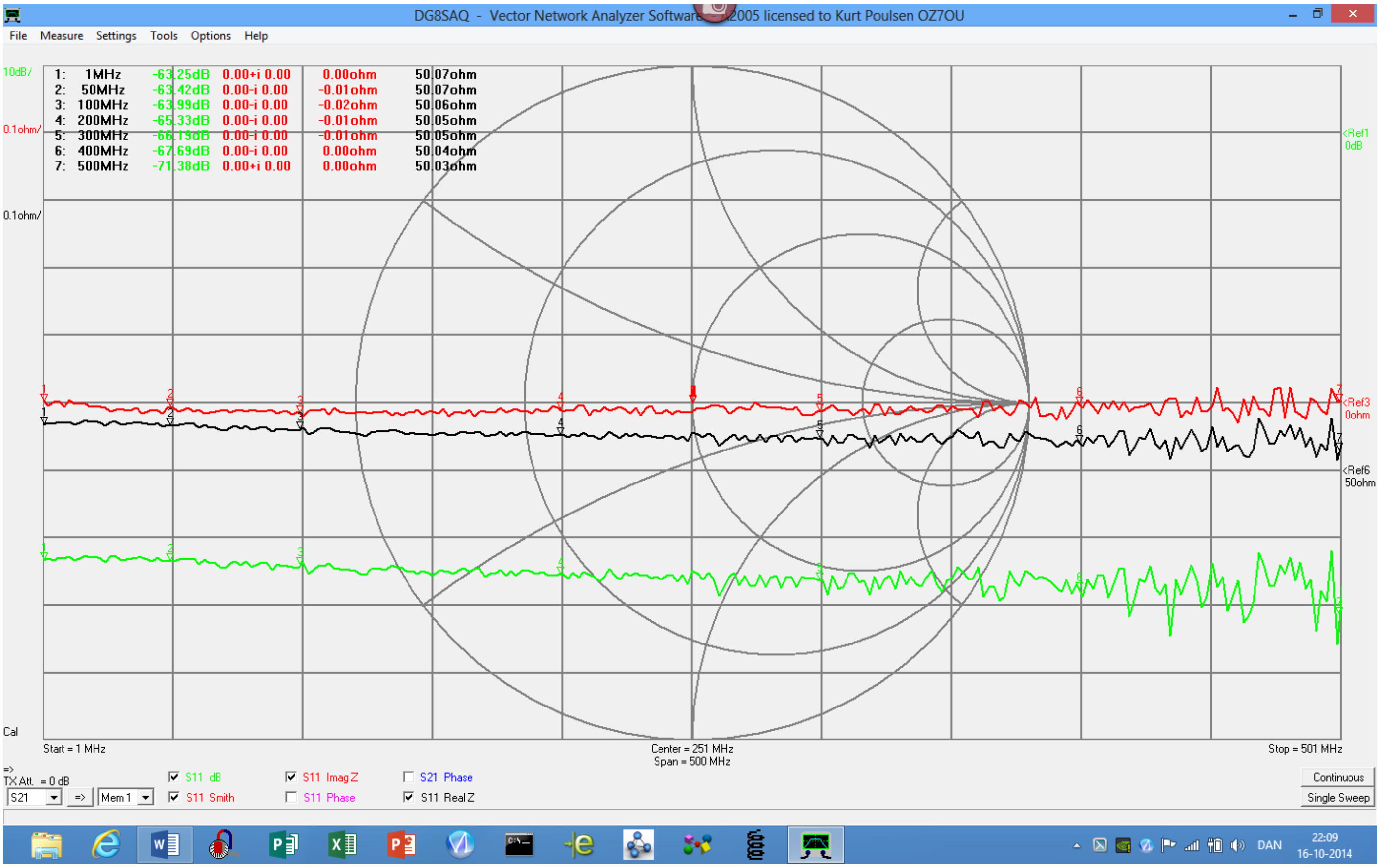
Above HP85033C female load standard of 50.065ohm measured with no CII and no delay in the calibration settings for the FL_ref. load used during calibration.



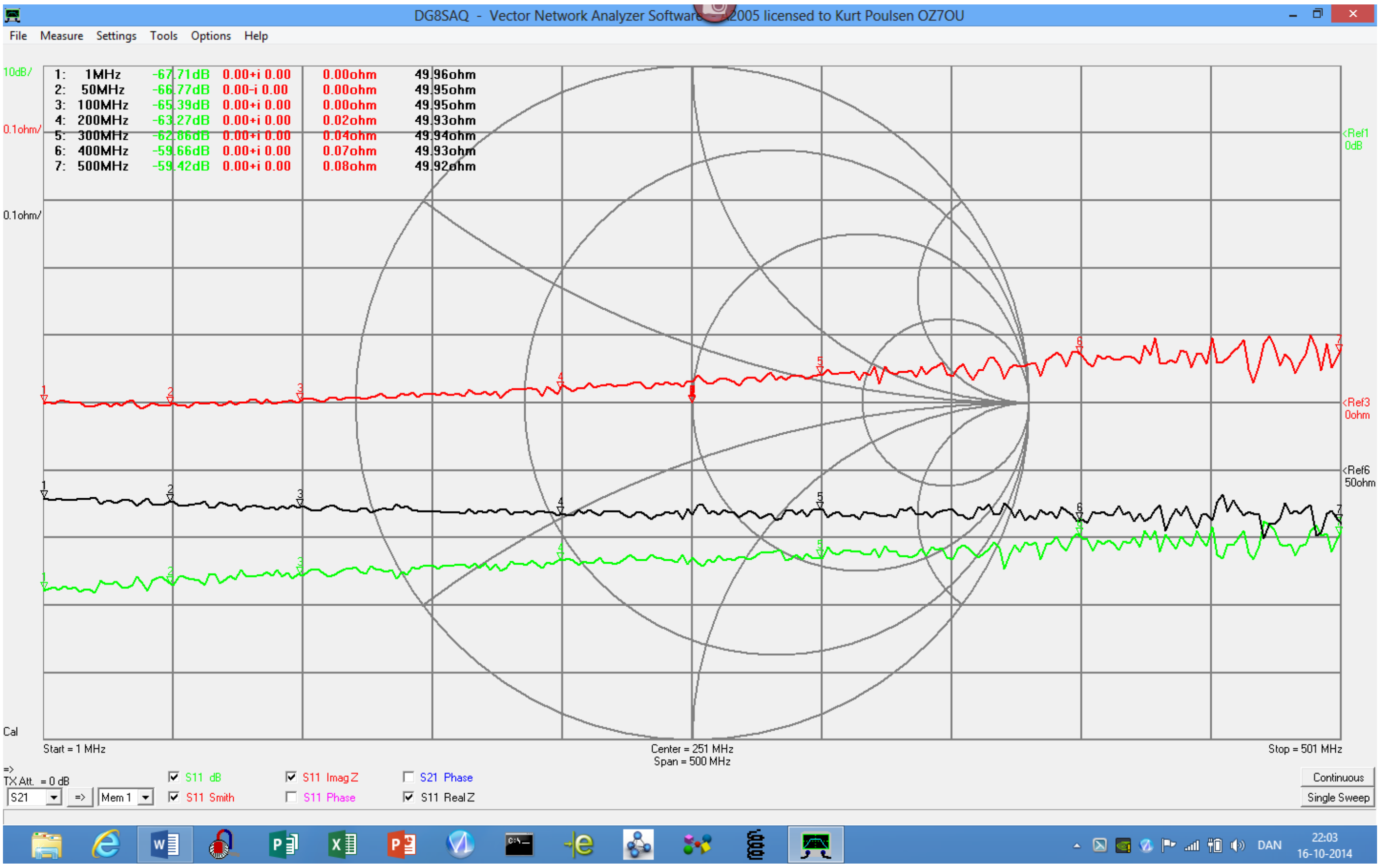
Above HP85033C female load standard measured of 50.065ohm with Cll=38fF and delay=-80ps in the calibration settings for the FL_ref. load used during calibration.



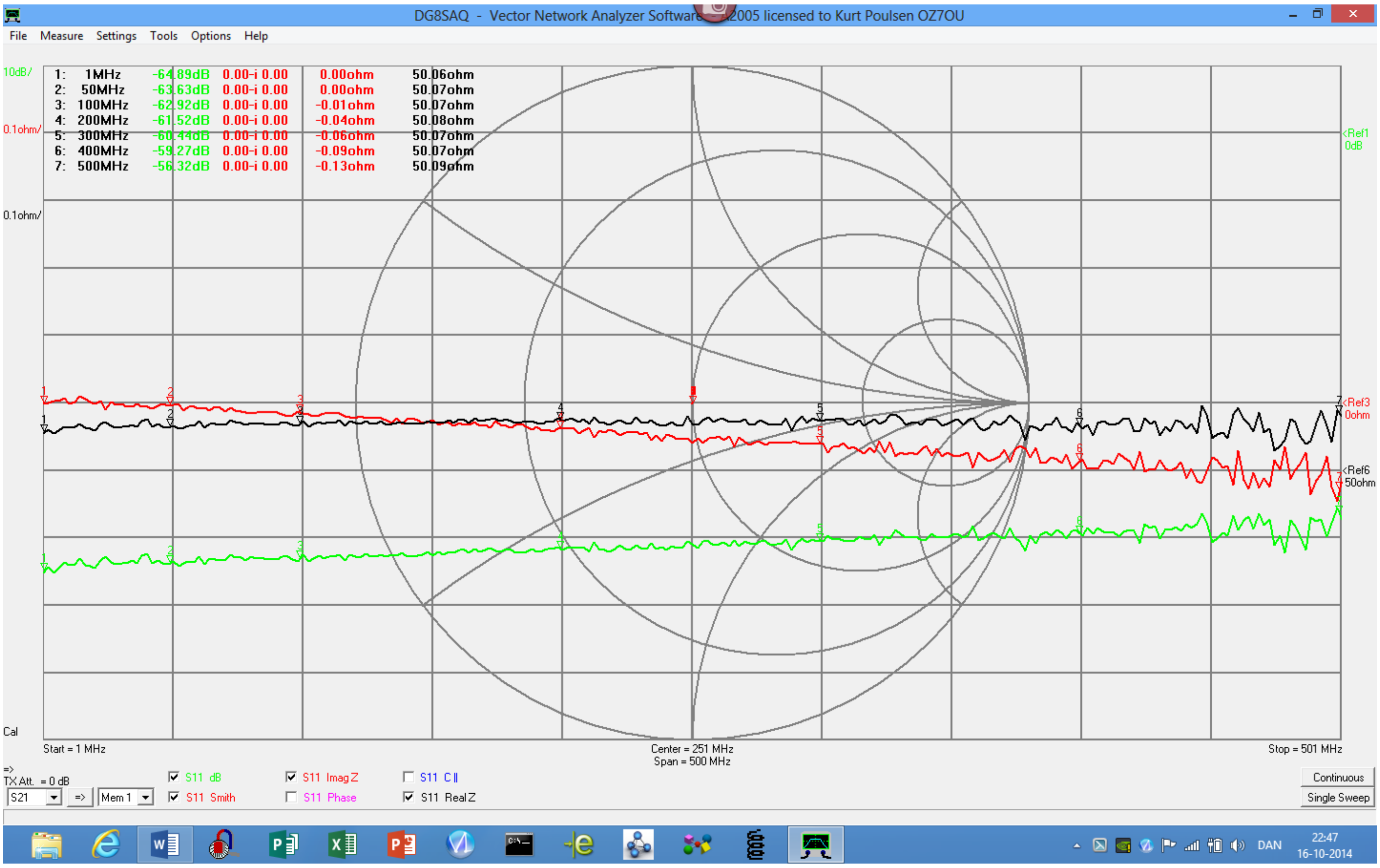
Above HP85033C female load standard measured of 50.065ohm with Cll=50fF and delay=-50ps in the calibration settings for the FL_ref. load used during calibration.



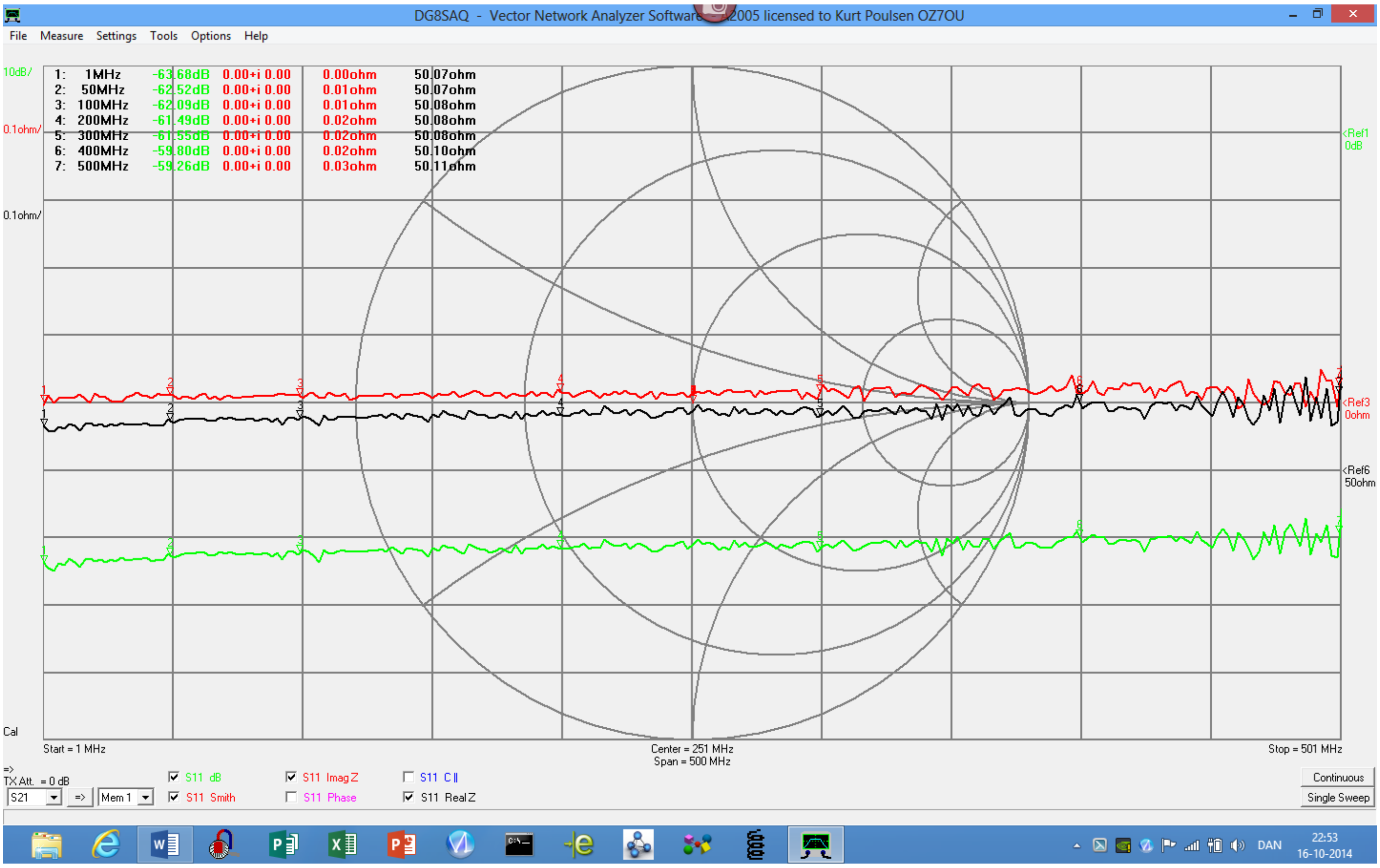
Above HP85033C female load standard measured of 50.065ohm with Cll=50fF and delay=-50ps in the calibration settings for the FL1 load used during calibration. The correct DC resistance also entered.



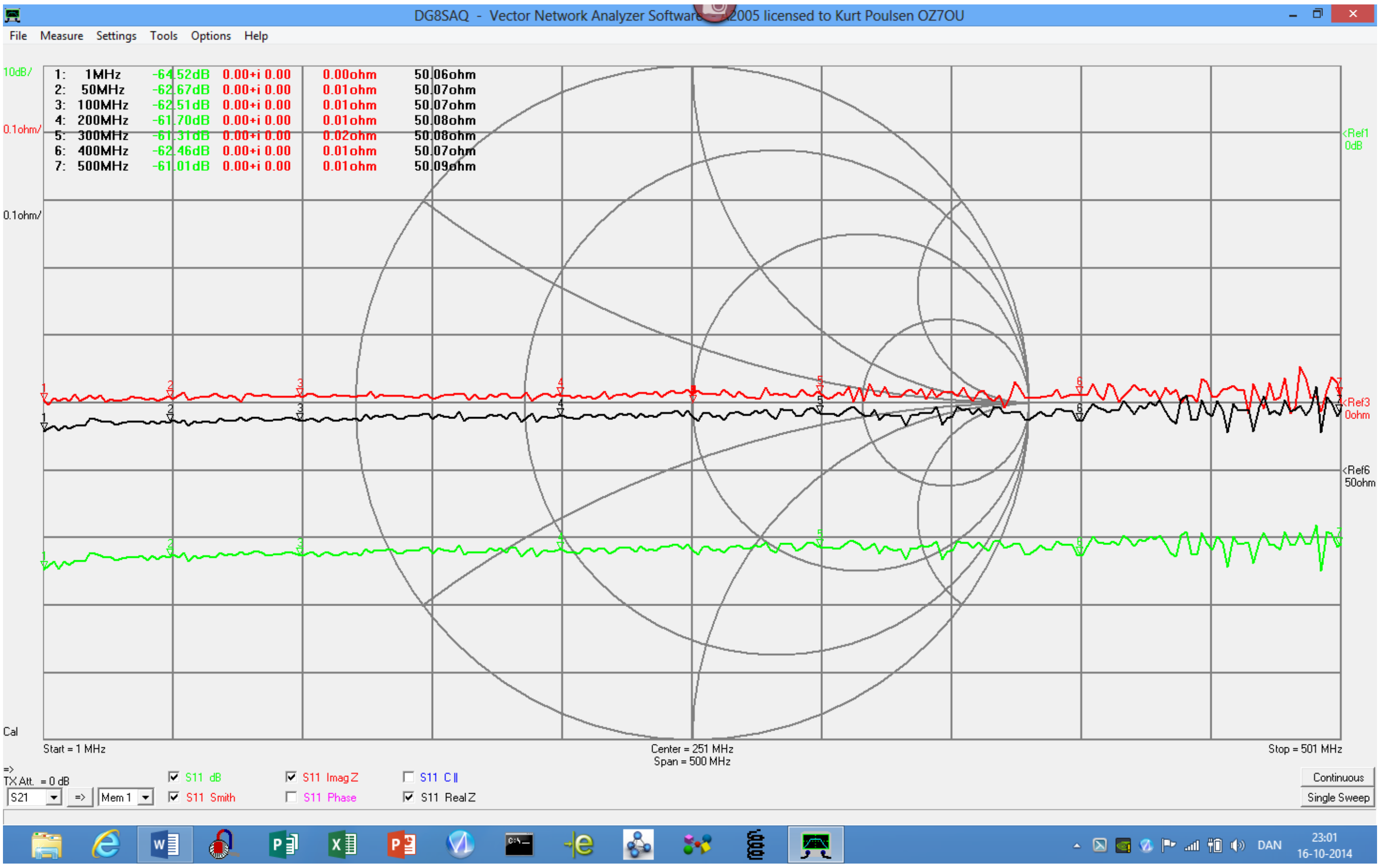
Above HP85033C female load standard measured of 50.065ohm with Cll=50fF and delay=-50ps in the calibration settings for the FL2 load used during calibration. The correct DC resistance also entered.



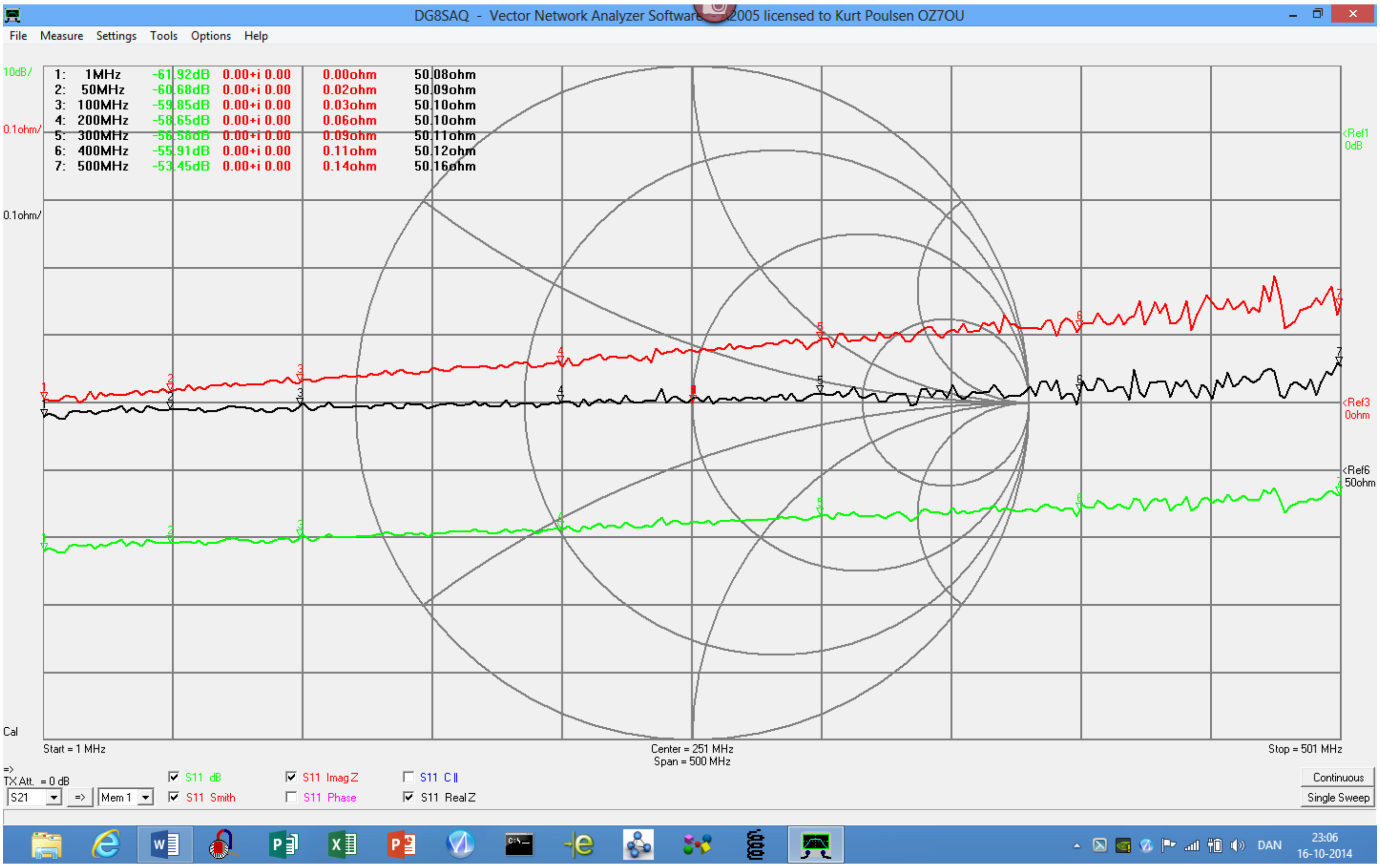
Above HP85033C female load standard measured of 50.065ohm with Cll=50fF and delay=-50ps in the calibration settings for the FL-dot2 load used during calibration. The correct DC resistance also entered.



Above HP85033C female load standard measured of 50.065ohm with Cll=50fF and delay=-50ps in the calibration settings for the FL-dot3 load used during calibration. The correct DC resistance also entered.



Above HP85033C female load standard measured of 50.065ohm with CII=50fF and delay=-50ps in the calibration settings for the FL-dot4 load used during calibration. The correct DC resistance also entered.



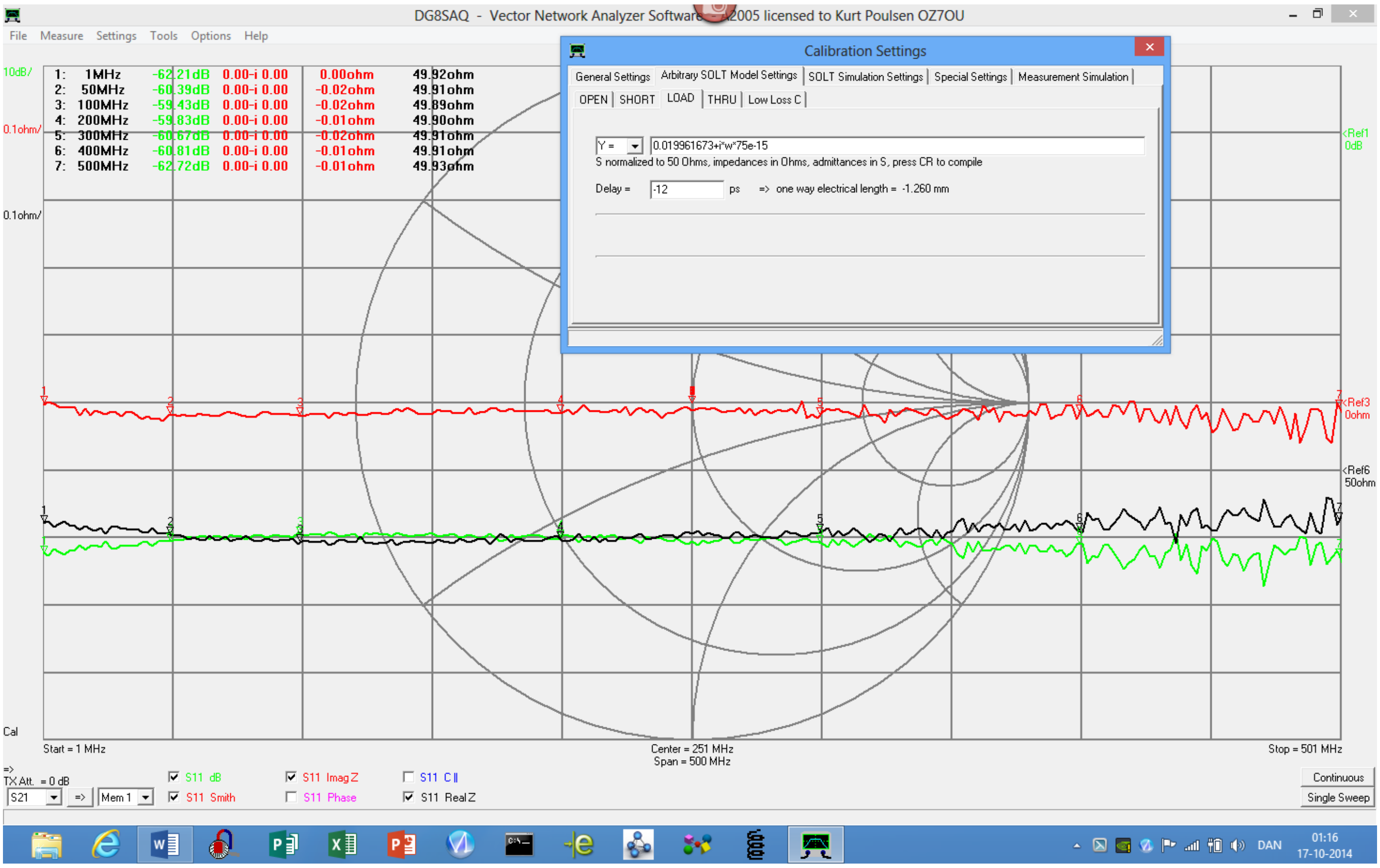
Above HP85033C female load standard measured of 50.065ohm with CII=50fF and delay=-50ps in the calibration settings for the FL-dot5 load used during calibration. The correct DC resistance also entered.

Summary for the female load: Use delay -50ps and CII 50fF in the arbitrary calibration setting

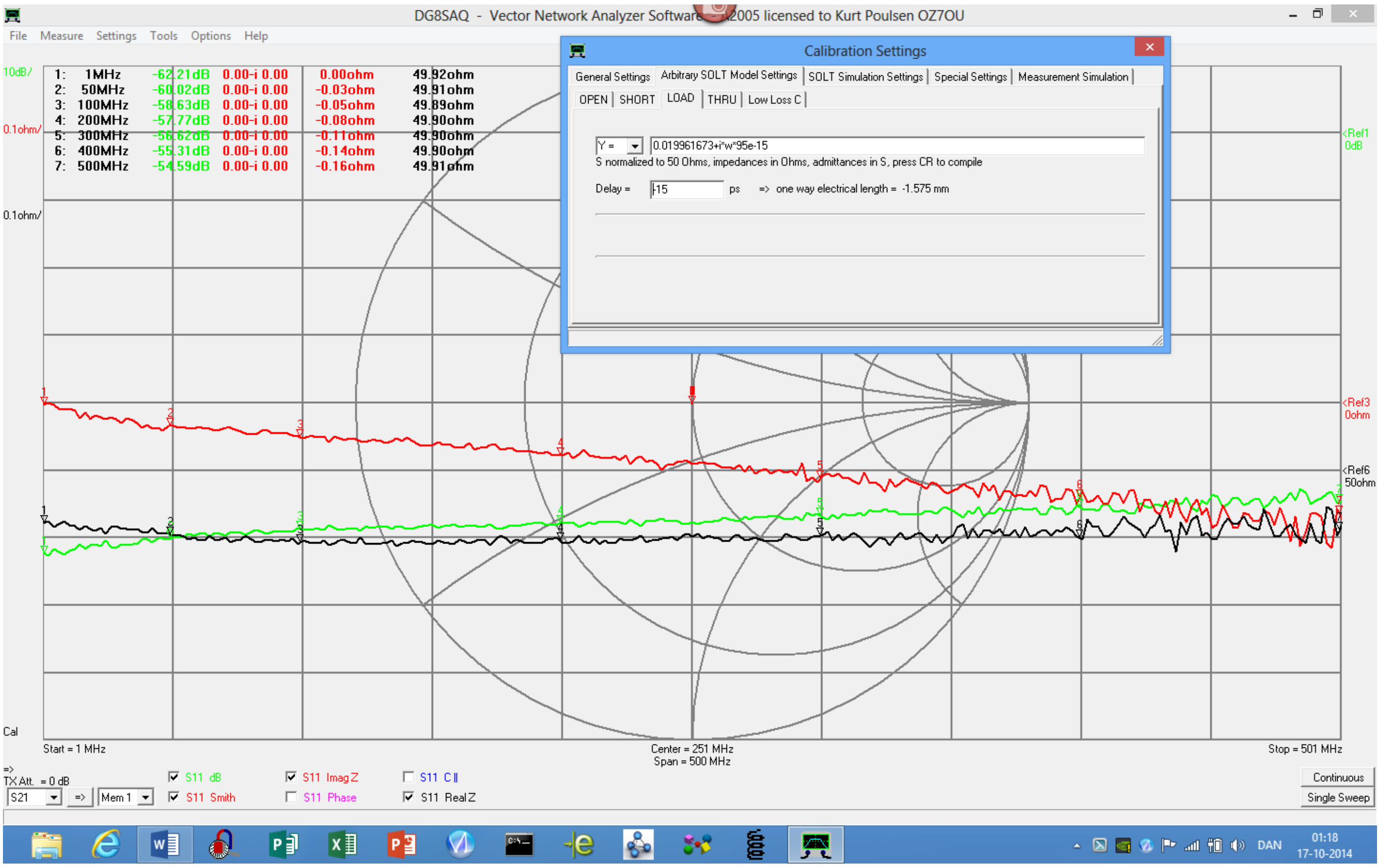
Measurements of the Amphenol Connex male load

	ML1	ML2	ML3	ML4	ML-dot1	ML-dot2	ML-dot3	ML-dot4	ML-dot5
	50.096	50.051	50.064	50.034	49.971	50.070	49.994	50.010	50.067
AVG=91.9fF	75fF	defective	85fF	80fF	95fF	95fF	90fF	115fF	100fF

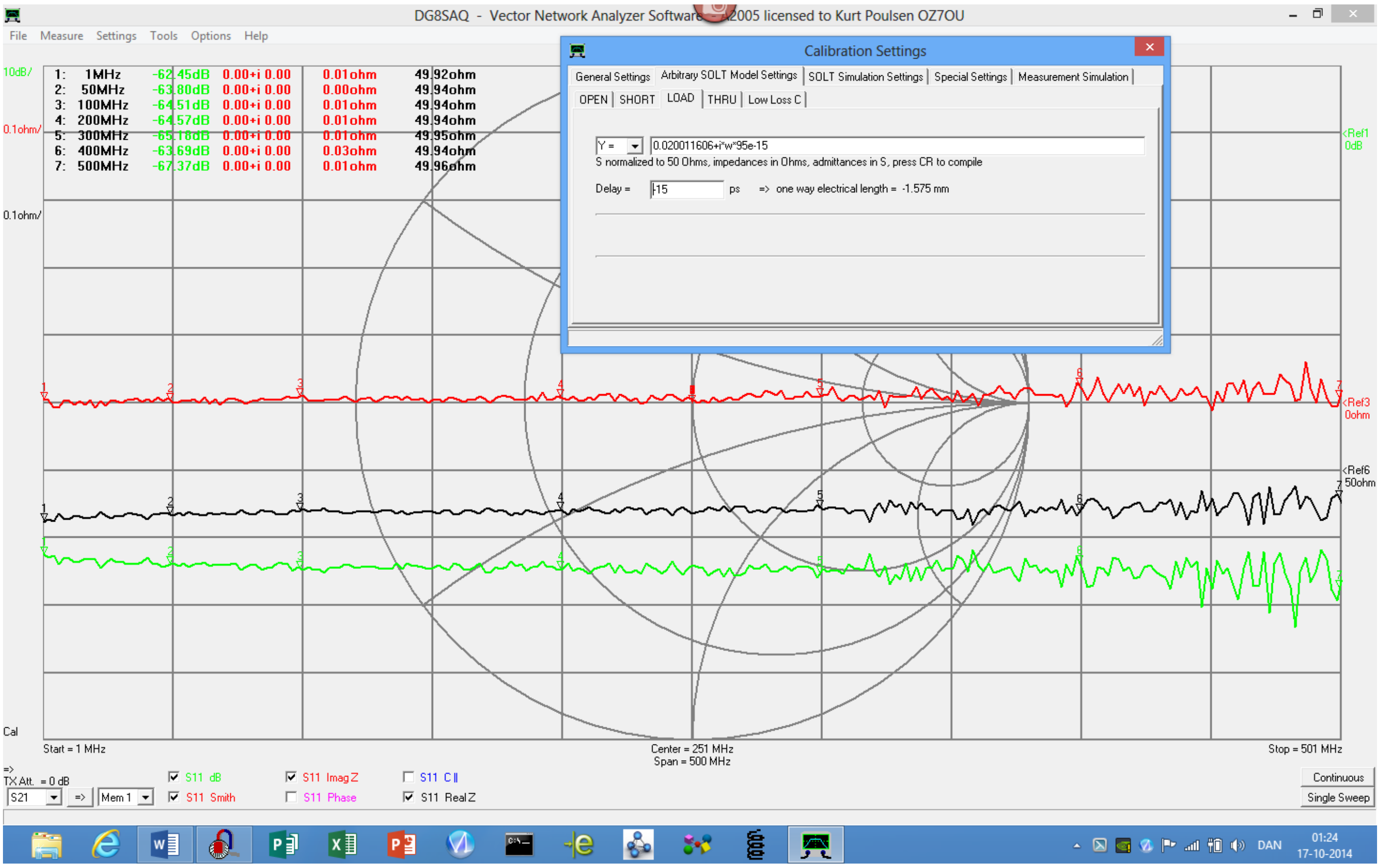
For the male load a delay of -15ps and a CII of 95fF was found to be the best average value
Please note images for ML-dot3 and ML-dot5 not shown but just measured and confirmed in the table above



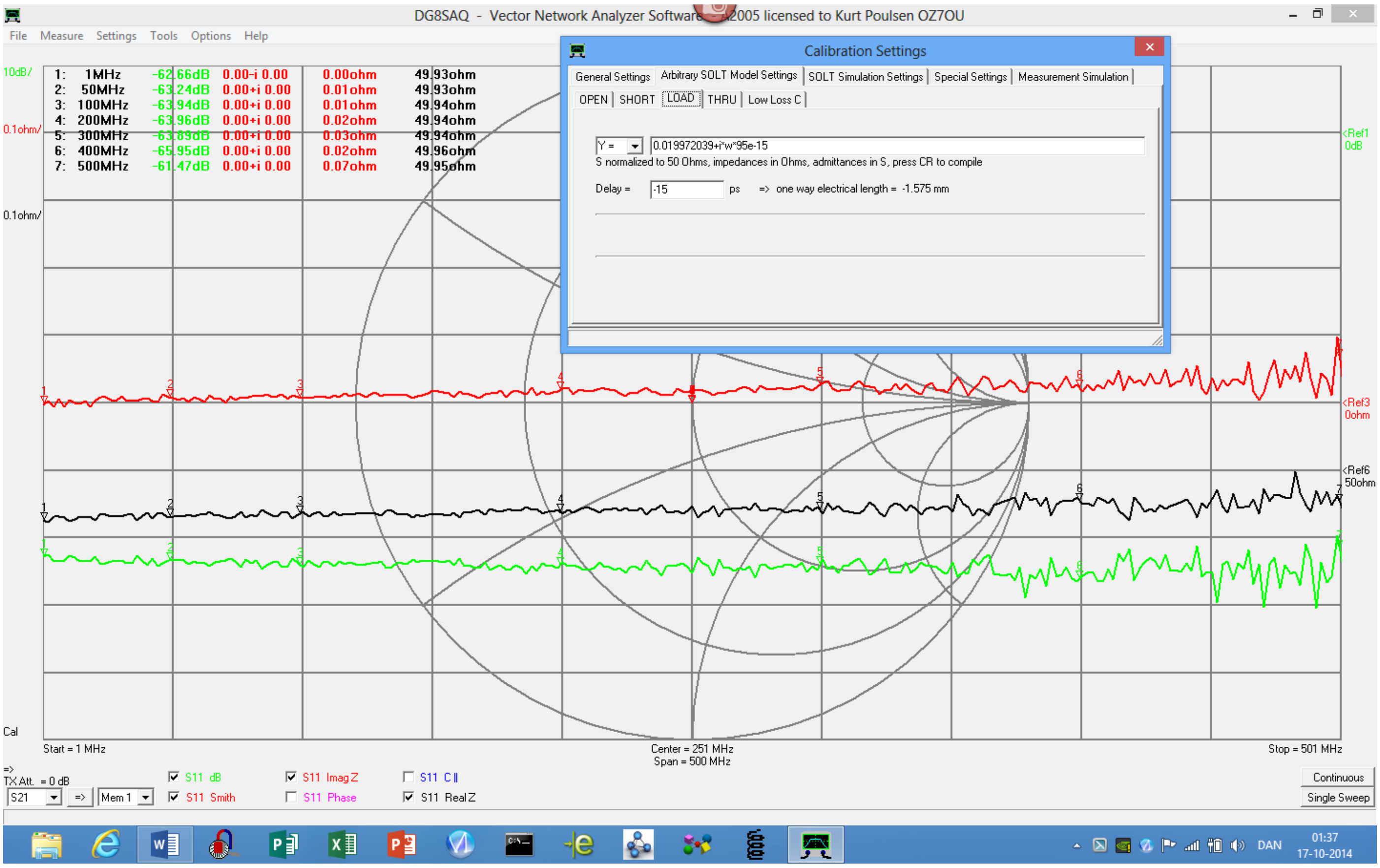
ML1 CII=75fF delay=-12ps



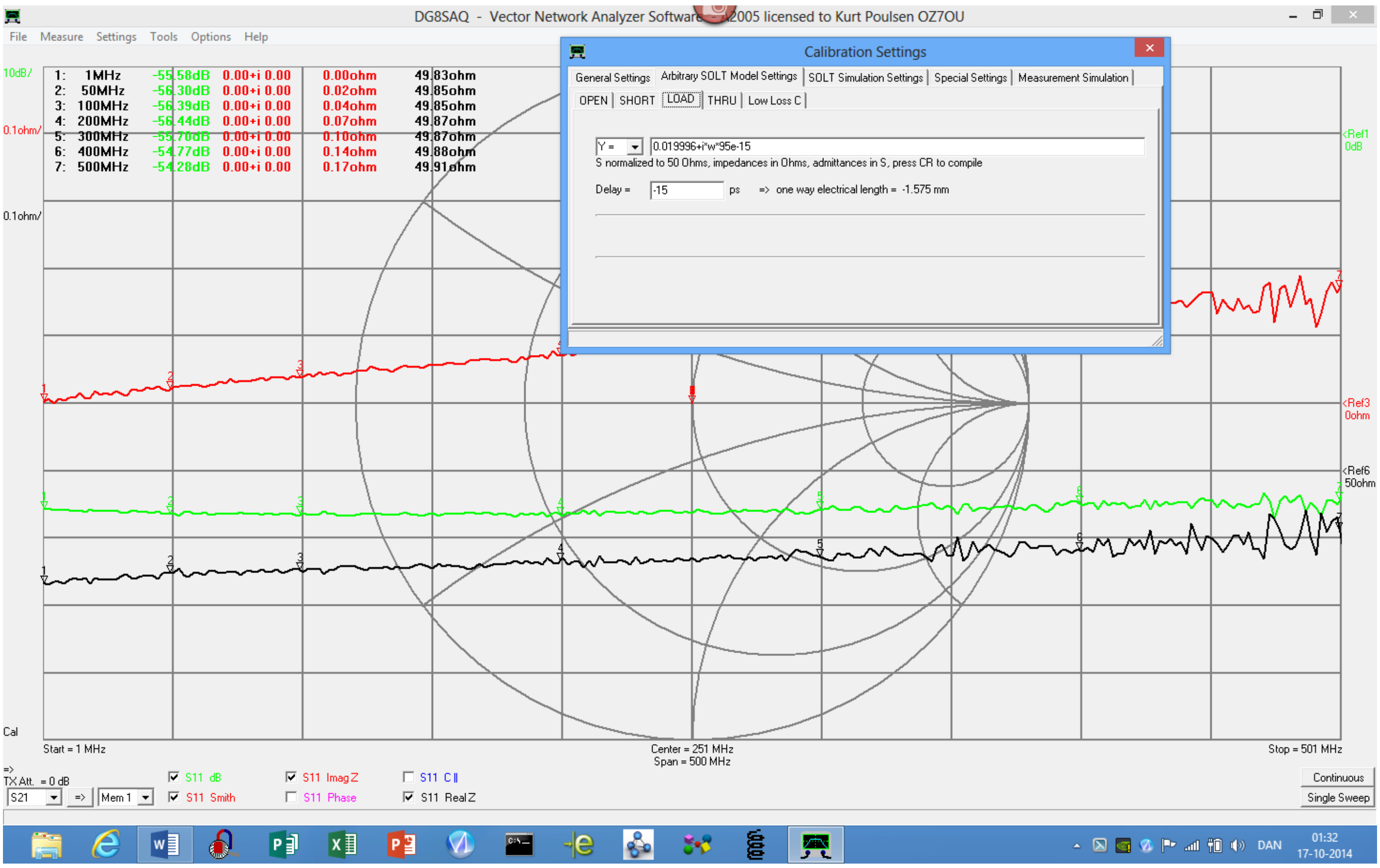
ML1 CII=95fF delay=-15ps



ML-dot1 CII=95fF delay=-15pF



ML-dot2 CII=95fF delay=-15pF



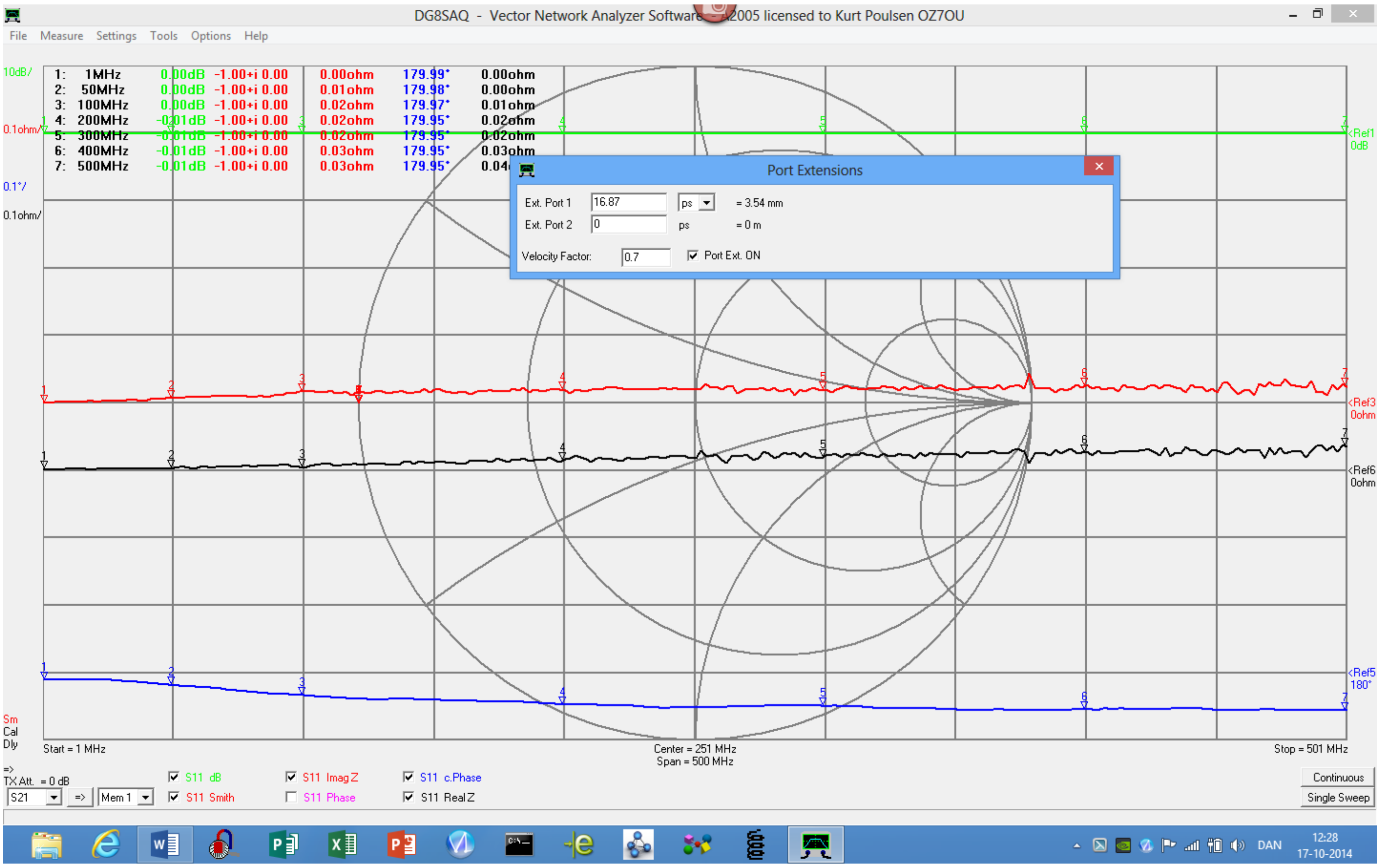
ML-dot4 CII=95fF delay=-15ps

Summary for the male load: use a delay of -15ps and a CII of 95fF in the arbitrary calibration settings

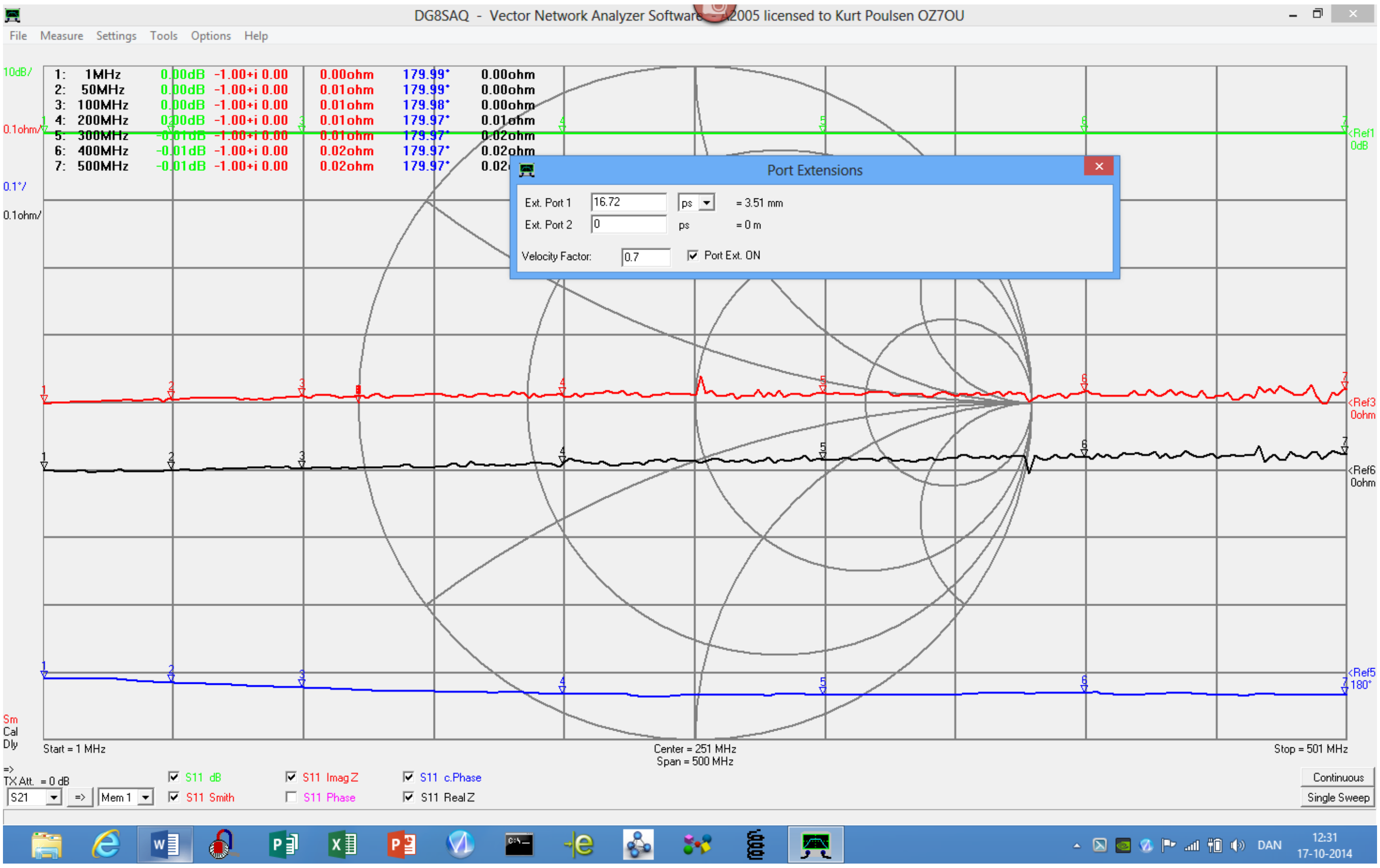
Measurement for the Amphenol Connex Male Short

		MS_ref	MS1	MS2	MS3	MS-dot1	MS-dot2	MSdot3	MS-dot4	MS-dot5
=1MHz	AVG=17.102	16.87ps	16.72ps	16.72ps	17.01ps	17.35ps	17.4ps	17.3ps	17.3ps	17.25ps
+ delay	AVG=0.05deg	0.05deg	0.03deg	0.05deg	0.06deg	0.05deg	0.05deg	0.05deg	0.06deg	0.05deg
>50MHz	AVG=17.24ps	17.00ps	16.80ps	16.86ps	17.18ps	17.49ps	17.54ps	17.44ps	17.47ps	17.39ps

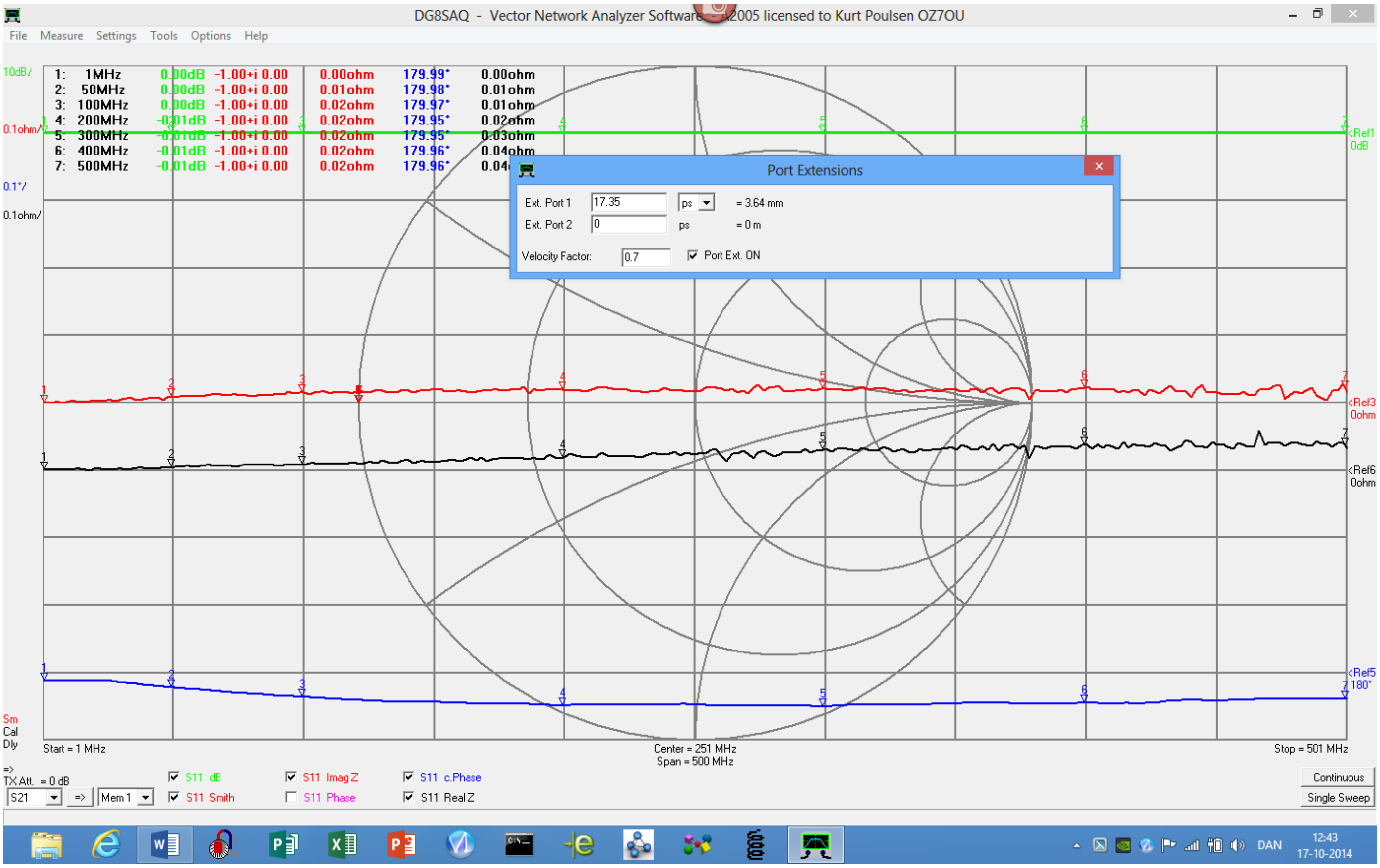
The above calculations for frequencies above 50MHz are due to the fact that we are dealing with reflection mode and a phase shift of 360 degree happens for an airline at half wavelength. We have a span from 1 to 501MHz this correspond to a length of 300mm at 500MHz and based upon velocity of light it leads to 1000ps for 360degree = 2.7777.. ps per degree. In below images the ext. port1 delay was adjusted so the c.phase (with smoothing), and thus the delay, approaches a constant value for high frequencies. This phenomenon (partly because the velocity factor) is lower in a transmission line at low frequencies and thereby having an electrically shorter length. However there might be a further influence based on the current distribution in the male shorting disk/body being different at low frequencies, probably due to the shorting disk and the general structure, does not contain adequate metallic volume behind the shorting pin, which is much higher for the HP 83033C shorting standards. I do not know a better explanation at present time. The resistive part of some 20 mohm at 400 MHz is also an element to consider.
All the shorts have the same, typical trace (only a few images documented below).



MS_ref



MS1



MS-dot1

Summary for the male short:

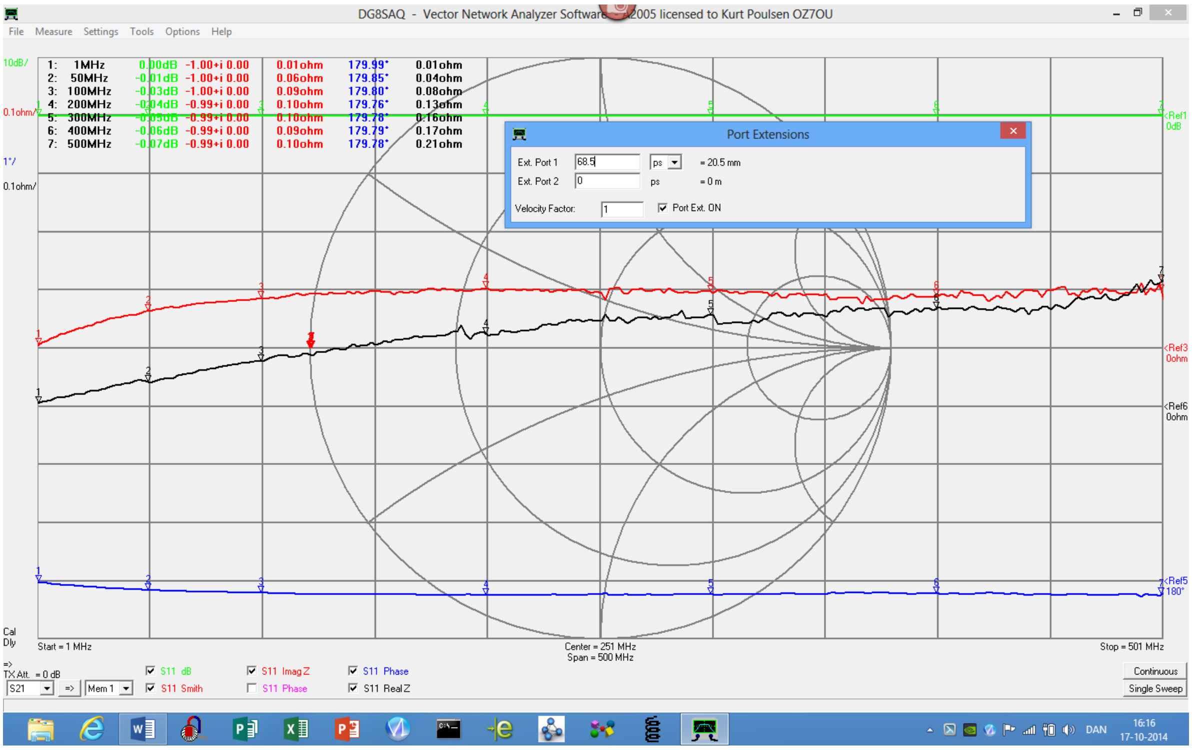
Delay to use at 1MHz: 17.10ps + - 0.3ps at 1MHz

Delay to use above 50MHz = 17.24ps + - 0.3pS

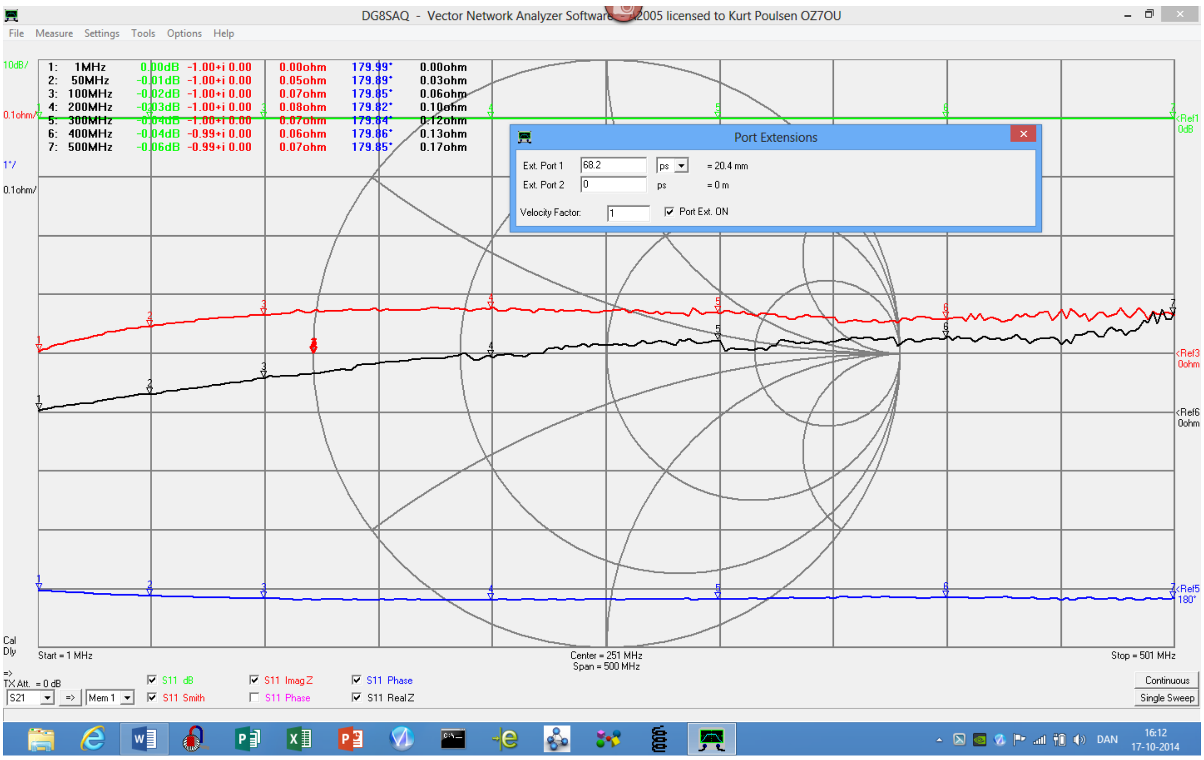
Measurements on the adaptor combination for an Amphenol Connex Female Short

Female shorts as such do not exist in the SDR-Kits calibration kit but are created by a male short in series with a female-female adaptor. Care was taken to match adaptors supplied at the same time for the three different periods over the years, to accommodate for the most likelihood for other deliveries.

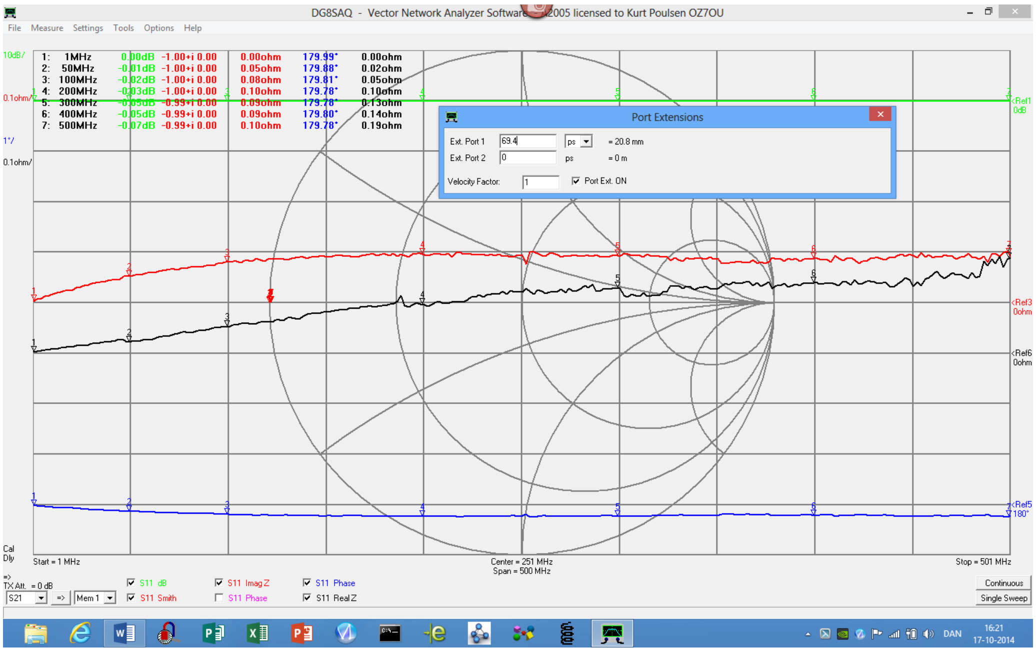
		FS_ref	FS1	FS2	FS-dot1	FS-dot2	FS-dot3	FS-dot4	FS-dot5
1MHz	AVG=68.67ps	68.2ps	68.5ps	68.15ps	69.4ps	69.3ps	68.4ps	68.9ps	68.5ps
+delay	AVG=0.19deg	0.15deg	0.22deg	0.18deg	0.22deg	0.23deg	0.19deg	0.19deg	0.17deg
>50MHz	AVG=69.20ps	68.62ps	69.11ps	68.65ps	70.01ps	69.94ps	68.93ps	69.43ps	68.97ps



Above the FS_ref measured



Above FS1 measured



Above FS-dot1 measured

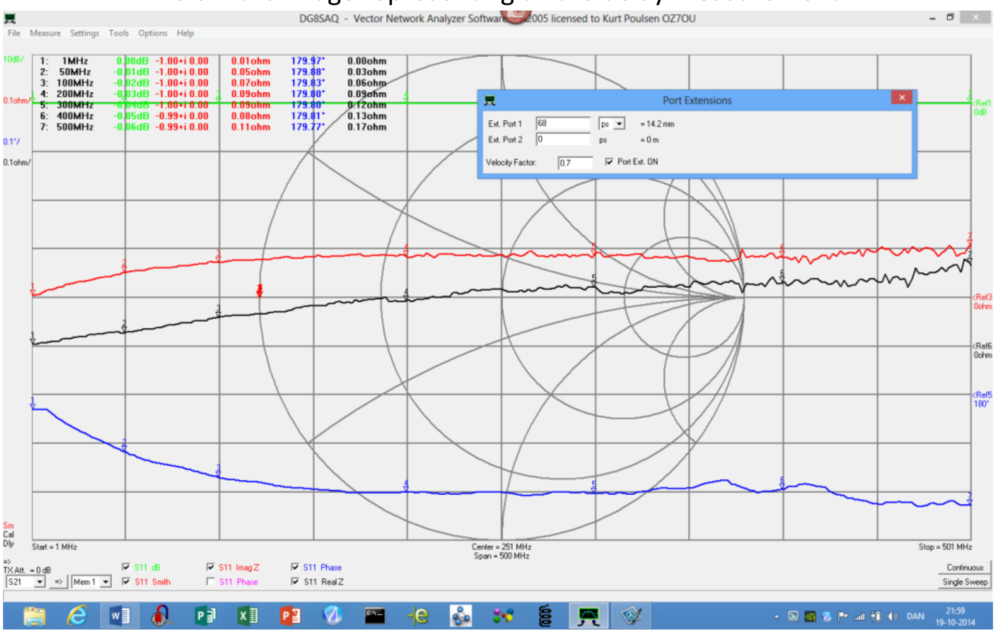
Summary for the Female Short:
Use a delay of 68.75ps + - 0.6ps at 1 MHz
Use a delay of 69.25ps + - above 50MHz

To check how accurate such measurements are the above test totally redone the day after with complete new calibration and adaptor swapping performed. See below the summary. The accuracy is within 0.05ps which indeed is satisfactory result for repetition of a test.

Measurement of delay for the female short consisting of the female-female adaptor terminated with a male short.

S11 delay	FS_ref	FS1	FS2	FS dot1	FS dot2	FS dot3	FS dot4	FS dot5	Average
At 1MHz	68.0ps	68.34ps	68.15ps	69.25ps	69.20ps	69.3ps	68.9ps	68.4ps	68.69ps
+delay	0.2deg	0.24deg	0.19deg	0.25deg	0.23deg	0.2deg	0.2deg	0.18deg	0.21deg
>50MHz	68.56ps	69.01ps	68.68ps	69.94ps	69.84ps	69.86ps	69.46ps	68.90ps	69.28ps

Below the image representing all the delay measurement

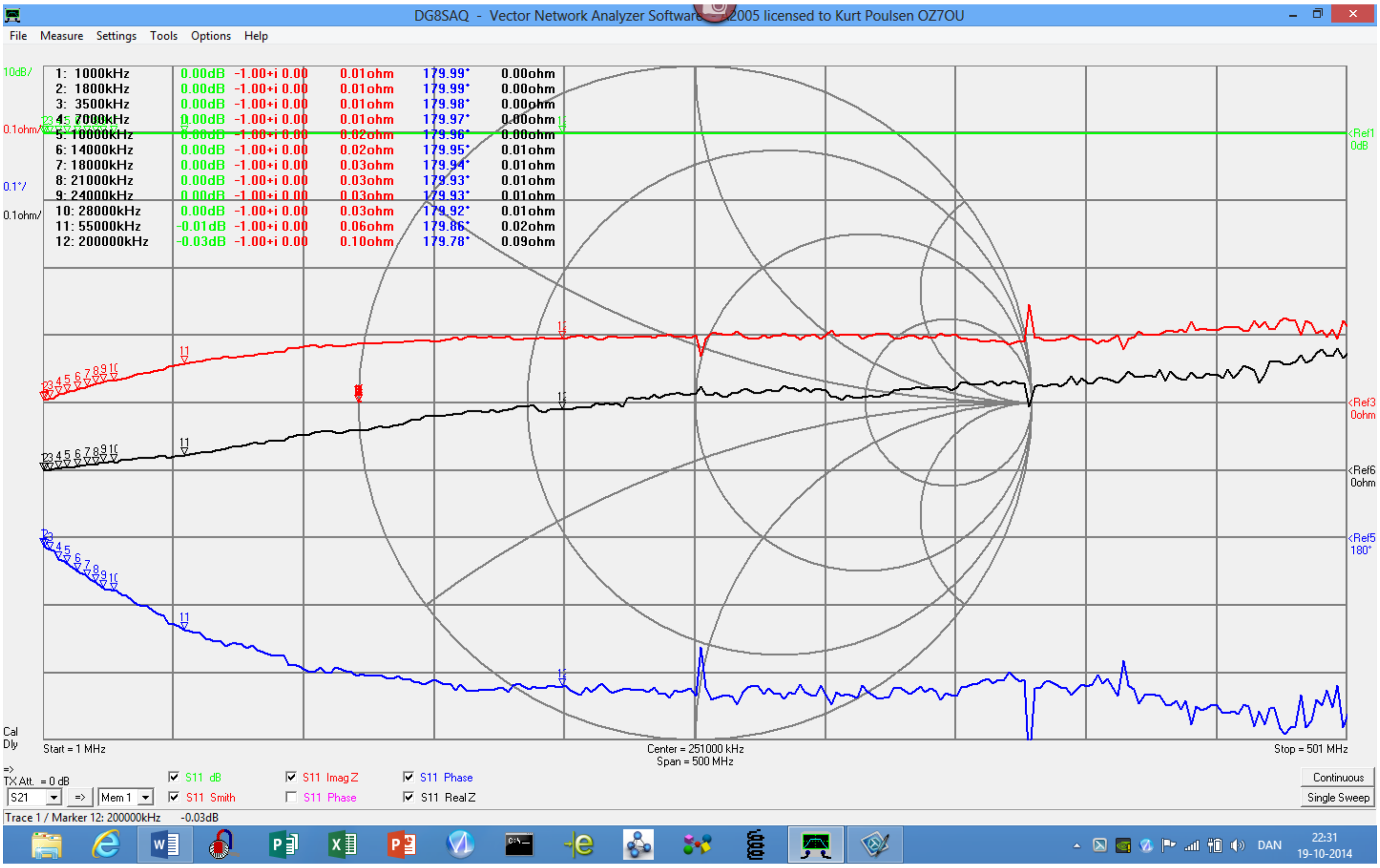


Summary for: Female short consisting of the female-female adaptor terminated with a male short.
Use a delay of 68.7ps + - 0.6ps at 1MHz
Use a delay of 69.28ps + - 0.6ps above 50MHz

What about the delay in between 1MHz and where (200MHz) the delay does not change any longer ?

1MHz	1.8MHz	3.5MHz	7MHz	10MHz	14MHz	18MHz	21MHz	24MHz	28MHz	55MHz	70MHz	144MHz	200MHz
0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.07	0.08	0.14	0.16	0.21	0.22
0ps	0.03ps	0.06ps	0.08ps	0.11ps	0.14pps	0.17ps	0.19ps	0.20ps	0.22ps	0.39ps	0.44ps	0.58ps	0.61ps
0%	4.9%	9.8%	13.1%	18%	23.0%	27.9%	31.1%	32.8%	36.1%	63.9%	72.1%	95.1%	100%

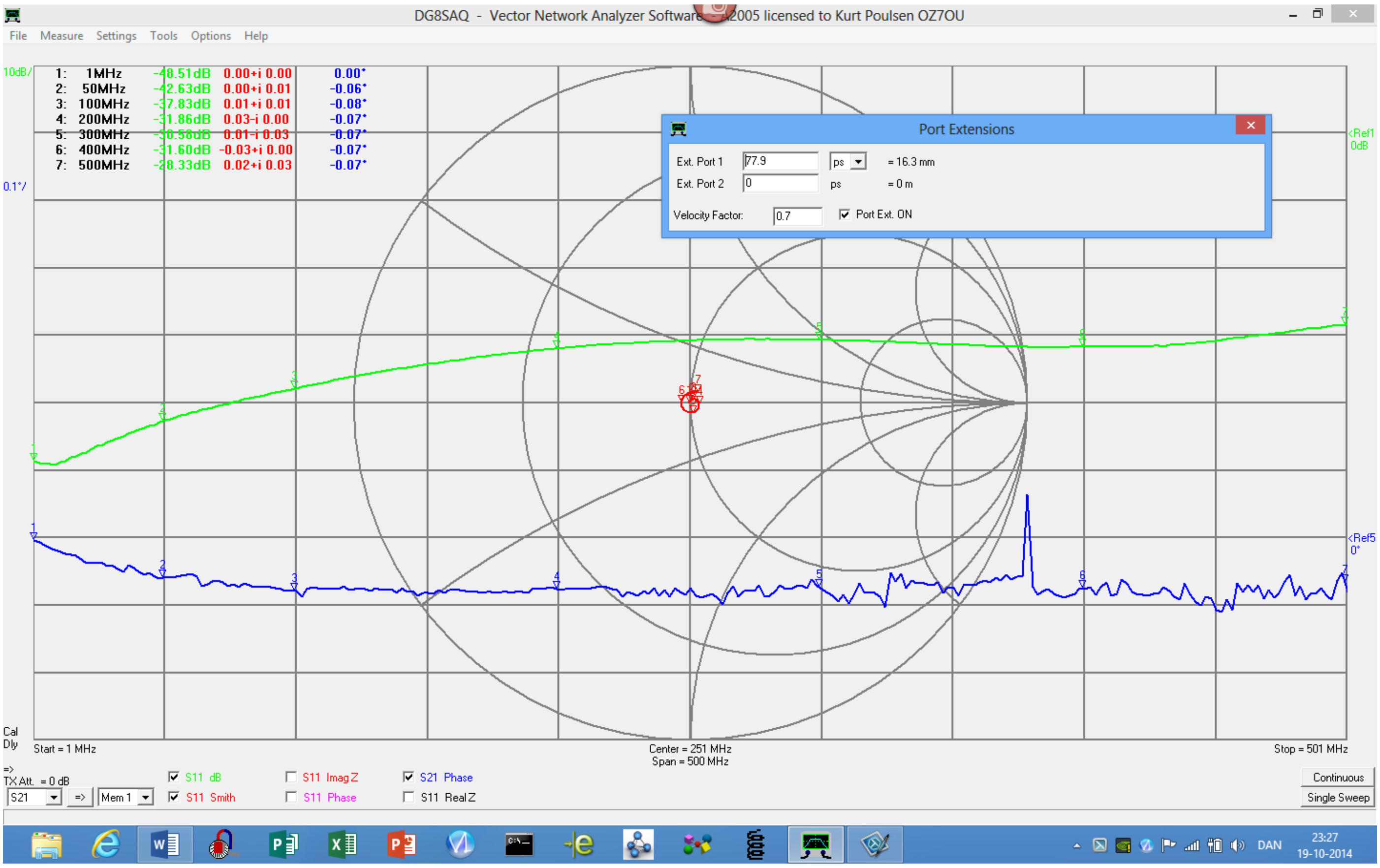
Until now no information given on the shortwave range about the increased delay in between 1Mhz and where the delay no longer increases. It has been indicated as “above 50MHz” but a more detailed analyses done, according to above table, was done by just adding some more markers and calculate the increased phase shift plotted for a number of frequencies. The table can be used as a general table, to be used for all short or open delays in any adaptor type, where the delay difference calculated at 1MHz and where it no longer increased (indicated as >50MHz) but in reality is above 200MHz. When you know the delay difference then use the percentages in the table to calculate the delay increase. Consult all the relevant images to confirm the trend is as in the table.



Measurements of the delay for Amphenol Connex male-male thru adaptors

S21 delay	MM1	MM2	MM dot1	MM dot2	MM dot3	MM dot4	MM dot5	average
At 1MHz	77.9ps	77.8ps	78.0ps	78.05ps	77.9ps	77.8ps	77.85ps	77.9ps
+delay	-0.07deg	-0.07deg	-0.06deg	-0.08deg	-0.06deg	-0.06deg	-0.07deg	-0.07deg
>50MHz	78.09ps	77.99ps	78.17ps	78.27ps	78.07ps	77.97ps	78.04ps	78.09ps

Below image represent all the S21 delay measurements performed



Summary for Amphenol Connex male-male adaptors:
Use a delay of 77.9ps + - 0.1ps at 1MHz
Use a delay of 78.1ps + - 0.1ps at >50MHz

Conclusion:

First of all remember that the delays for open and short must be entered with twice the value in the calibration setting whereas the delays for the loads are entered as they are described.
It was on purpose not to evaluate the characteristics for the full frequency range of the VNWA as the VNWA performance is optimal up to 500MHz and the delays found would be the same anyway.
Secondly the Amphenol Connex calibration components are not designed for frequencies much higher than 500MHz however useable to 1.3GHz with their natural limitation.
If better calibration standards for the VNWA are required the Rosenberger kits is as well available from SDR-Kits and a separate document available for these kits in complexity just like this document).

Kurt Poulsen 20-10-2014