

NanoVNA (Standard- Version)

A Vector Network Analyser covering
50kHz to 900MHz for under 50 Euros

Part 1:

„Getting Started Manual“ for 50kHz to
900MHz in three parts

A): The device

B): Operation using a PC with the Software
„NanoVNA-saver-v0.2.2-1.exe“ (including practical
examples)

C): stand-alone operation

Version 1.6.

Author: Gunthard Kraus, DG8GB
Tett nang / Germany, April 24th, 2019

Remark to this manual (= part 1):

Every part of the manual can be used individually and independently

Those interested in the „NanoVNA“ device (and the accessories) should read this first:

A)

Those who want to work with the **software on a PC (=NanoVNA-saver-v0.2.2-1.exe)** should start with

B)

And if you only want to work with the device itself (battery or power adapter operated) please use

C)

Information:

The software „NanoVNA-saver-v0.2.2-1.exe can be found on the Web under

<https://github.com/mihtjel/nanovna-saver/releases>

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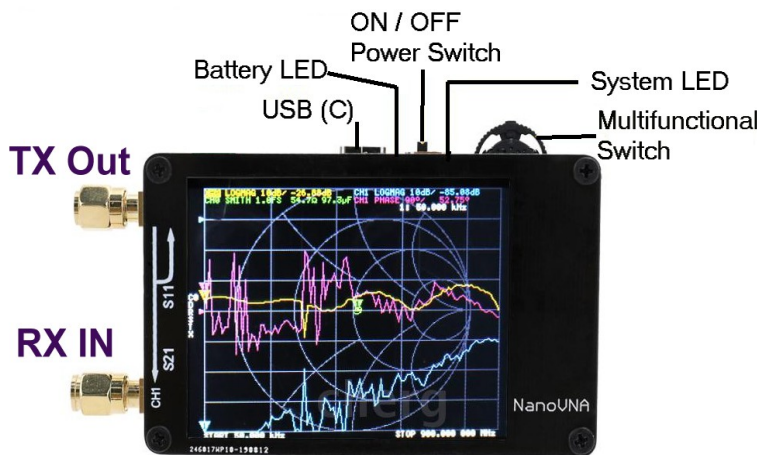
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A): The device (with battery or power adaptor)

1. A short introduction



The picture shows the small device with the size of a cigarette packet (54mm x 86mm x 12mm) including a small LCD touchscreen (2.8 inches - diagonal). It does not have a complete case it only has a top and bottom cover plate - so be careful how you handle it!

On the left there are of two SMA sockets: the RF input and output. The upper socket is the transmit port (CH0) and is the channel for S11 measurements (reflection). The lower socket is the receive input (CH1) and used for transmission measurements (S21).

In the centre of the top is a USB type "C" connector. This has a symmetrical design so it does not matter which way the USB cable is inserted. This USB port is used to supply the device with +5V and send data to a PC. The blue LED next to it serves as the "Battery LED" and lights up as soon as a supply voltage is applied. To the right is the on / off switch followed by a blue "System LED". It flashes on certain events or states and finally on the right there is the Multi Function Switch ("MFS") which has a dual function:

If it is pressed after switching on it calls up the main operator menu. Because the MFS is also a rocker switch it can be used to effect the measurement results. It can move markers along the frequency axis in both directions. That is how a certain frequency of interest can be highlighted on the screen.

The most important features:

Measurement frequency: 50KHz to 300MHz (50KHz to 900MHz, extended firmware)

RF output: -13dbm (maximum -9dbm)

Measurement range: 70dB (50kHz to 300MHz), 60dB (300MHz to 600MHz), 50dB (600MHz to 900MHz)

Port SWR: <1.1

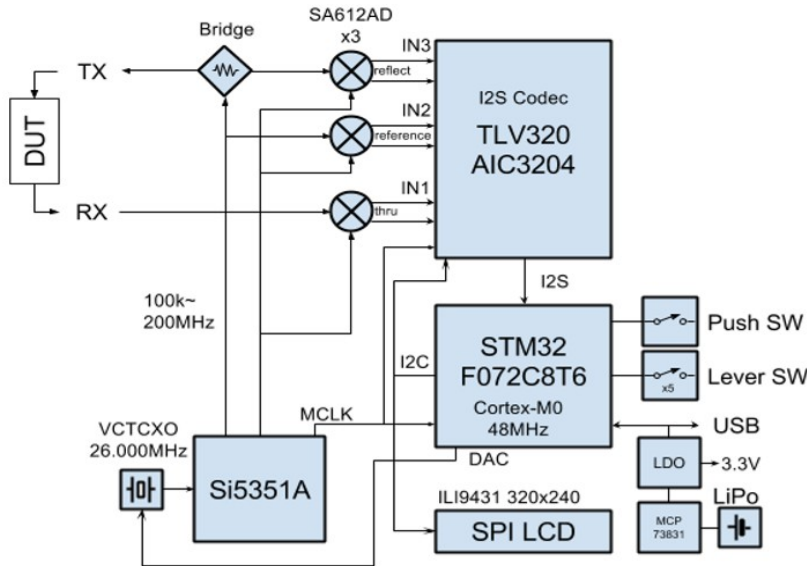
Display: 2.8 inch TFT (320x240)

USB interface: USB type C communication mode: CDC (serial)

Power: USB 5V 120mA

Number of scanning points: 101 (fixed)
Display Tracking: 4 traces. Markers: 4, Saved settings: 5
Frequency error: <0.5ppm

2. What is inside?



There is something familiar in the block diagram:

„It looks like the VNWA3 by Thomas Baier, DG8SAQ!“

That is correct, the concept of the electronics (e.g. the use of a measuring bridge and mixing the fundamental frequency of a DDS oscillator in the range from 50kHz to 300MHz, then harmonic mixing for 300MHz to 600 MHz and 600MHz to 900MHz respectively). This is followed by calculation in the

audio range of a few kHz. The software installed is very sophisticated and elaborate and is operated using menus on the small screen with submenus and further submenus.

A detailed overview of the user menu can be found in **part 3** of this manual. Take a closer look and memorise it so that you know where and how to do something without searching.

3. What do we need / what should we order?

If you search for this device on Ebay (input: e.g. "vector network analyser" or "NanoVNA"), you get countless hits, mostly in the range between 35 and 60 Euros. But you should check exactly what is included with the device.

We need:

a) Two short coaxial cables (normally: RG174) with SMA connectors on both ends

b) A USB-C connection cable to a PC

c) A **SOLT calibration set** (SOLT = Short / Open / Load / Through). It consists of four parts:

Short = Ideal short circuit in an SMA plug

Open = Ideal open circuit in the form of an SMA plug that just has a small open tube inside.

Load = Ideal SMA Termination of 50Ω

Through = SMA coupling with sockets at both ends (SMA, Female to Female adaptor)



There are also offers where a small flat 3.7V, 300 to 500mAh battery (height: about 4mm) with wire connections to soldering onto the circuit board. That was not the case for me, therefore I have purchased one on The Internet (about 6 Euros) and soldered it onto the board at the marked points. This is a Lithium polymer battery and you have to think about the correct way to recharge this type of battery.

The very nice picture (Source: Blueskysea) shows the additional shielding of the RF inputs and the detector.

Important:

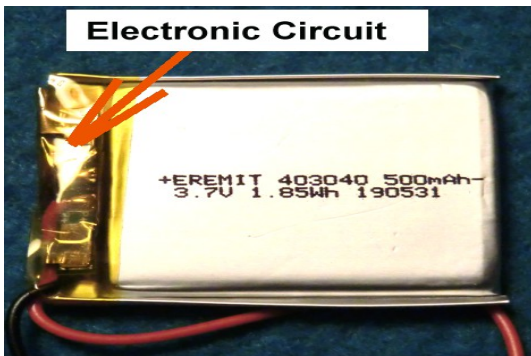
To obtain the best accuracy the VNA must be calibrated. This can be carried out later but for this **another SMA 50Ω termination and SMA Female to Female adaptor are required**. These can be purchased on The Internet.

It is also worth purchasing two **particularly high quality Teflon SMA cables approximately 30cm long (e.g. from Huber Suhner)**. The two cable included in the kit are, unfortunately, poor quality.

4. Information about the power supply of the device (battery operation or external voltage source)

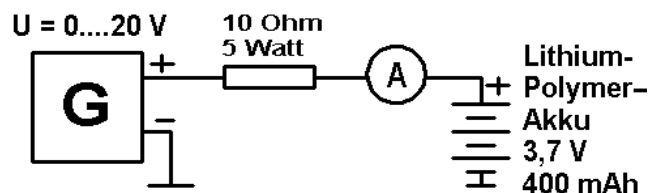
a) The simplest method is to supply the NanoVNA from a PC via the USB connection. The board contains appropriate protection for the +3.7V circuits when a +5V supply is used. A blue "Battery LED" indicates whether the supply voltage is correct and a blue "status LED" lights up when the NanoVNA is switched on.

b) There is room on the circuit board for a modern flat Lithium polymer battery and two solder points on the PCB are marked with "+ / - / Battery". The battery should not exceed 4mm in thickness otherwise the bottom plate will not fit.



I have ordered one of these batteries on The Internet (6 Euros) and discovered that it contains a tiny circuit board.

The test circuit shown was used to test the function of this circuit board:



Result:

The charging current of the battery is (even when turning up the power supply up to +20V) correctly limited to **exactly 0.35A** (1/10 of the Ah rating). If the power supply is set to +5V (USB connection) then the current drops after 1 to 2 hours until it reaches zero (battery fully charged).

First conclusion:

There is no risk of overcharging when soldering the battery onto the board and using a USB +5V supply for the NanoVNA.

The battery was soldered onto the board and the NanoVNA switched on. It took almost four hours for the screen to go dark and the electronics to stop. At a current consumption of about 110mA the battery stored energy was about 440mAh - that is about right. Once the USB connection is made to a PC it recharges the battery. This was checked after a few hours to be true!

Second conclusion:

The battery should remain soldered to the board. Without USB it provides power (e.g. outdoors when measuring an antenna). When a USB connection is made to a PC the battery is correctly recharged. A "power bank" as used for smartphones can extend the time without USB power to several days.

B): The NanoVNA on the PC

5. Remember this

If you have already and completely worked through this chapter and then switch off your PC, then this list will help you what must be done when starting for a new session.

Start your program

Connect NanoVNA and PC via USB C

Install the USB connection on the screen

Set sweep range and number of segments

Use „averaging sweep“ to reduce noise and artefacts on your diagrams

Load the correct Calibration File

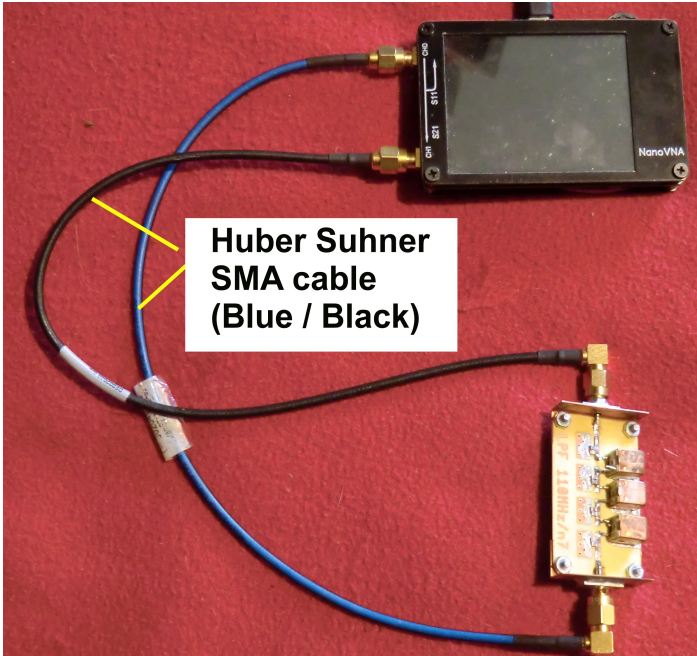
Choose the desired diagrams

Sweep and wait

Enjoy the result

6. Preparation

Unfortunately the two SMA cables included in the kit can cause trouble: not only their characteristic impedance may not be quite correct (between 52 and 54Ω instead of 50Ω when measured with a time domain reflector), but at one end the SMA connector fell off because the crimping of the plug onto the cable was poor. This means that the result of calibration often gives meaningless values.



The solution is to purchase two very high quality cables (Huber Suhner with blue black outer), these are specified up to 18GHz. They should remain permanently attached to the NanoVNA having been fitted using an SMA torque wrench purchased from The Internet. If that is done the reproducibility of the calibration for S11 will only have a deviation up to 0.1....0.2dB.

To find these cables:

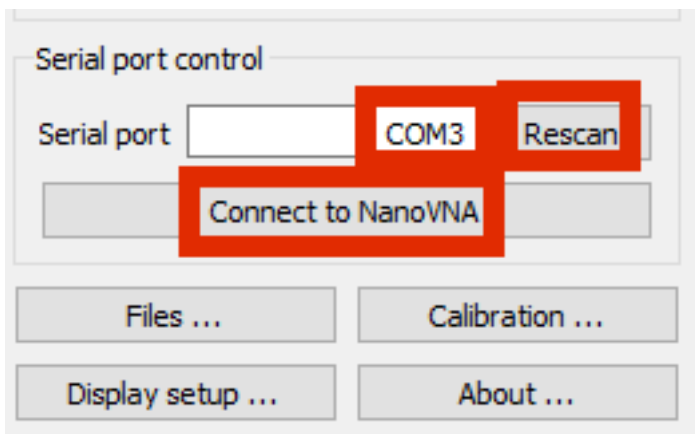
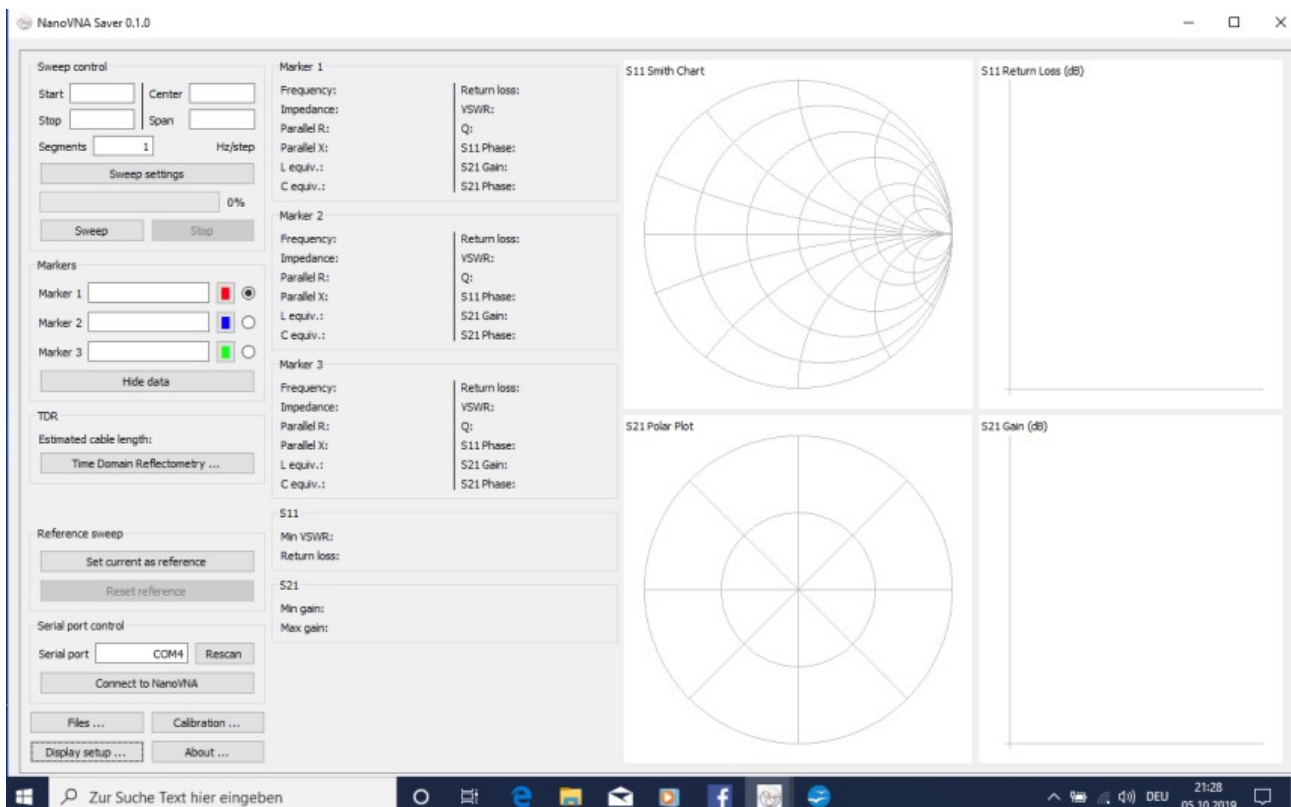
Look closely at and below all the tables at HAM radio flea market to see if the cables can be found.

7. Starting the software

Very quickly clear result can be presented with large diagrams on a PC screen for those who have access to a PC with its constant power supply for the NanoVNA. That will be described now with help and advice from Andreas Zimmermann, DG3SAZ. **All that is required is the NanoVNA, the USB connection cable and the necessary PC program.** Once the free software is downloaded from The Internet, just switch the NanoVNA on. The most popular software is called:

NanoVNA-saver-v0.2.2-1.exe

It can easily be copied to a USB stick and operated from there. After starting the program, wait 10 seconds because a dark DOS Screen appears followed by this picture:

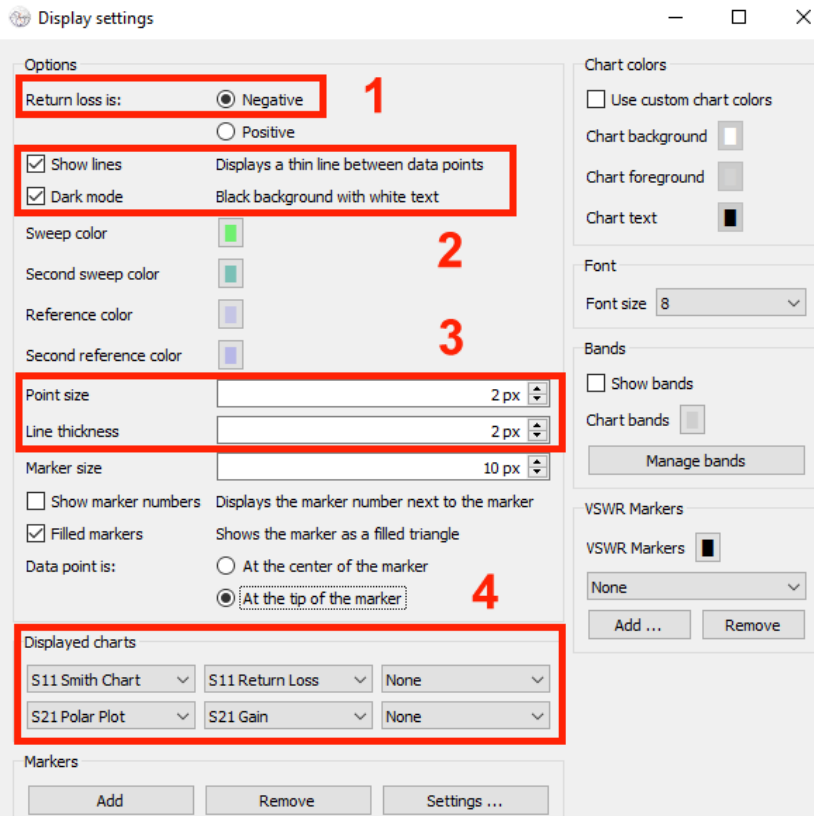


Turn the NanoVNA on and establish the USB connection to the PC by clicking on **"Connect to NanoVNA"** on the PC screen (bottom left). If necessary with rescan to make sure that the valid USB port is recognised.

If everything works the message changes to **"Disconnect"**.

8. Display settings required

This menu is called up via a button in the lower left corner of the screen. Among the many possible options, four settings are important at the beginning:



1: The input reflection S11 should be represented as a negative dB value.

2: Thin lines should be shown between measuring points and the diagram background should be black. (This can be changed for any colour – and the same for the curves).

3: Point size and line width are preset to 2 pixels. Please change if necessary.

4: Up to 6 diagrams can be displayed at the same time on the screen (mostly four are enough). For each individual diagram the following options can be selected:

S11 Smith Chart

S21 Polar Plot

S11 Return Loss

S21 gain

|S11|

|S21|

S11 |Z|

S21 phase

S11 phase

S21 Real / Imaginary

S11 VSWR

S11 & S21 LogMag

S11 R + jX

TDR

S11 Quality Factor

None

S11 Real / Imaginary

Please examine the rest of the options in the menu.

9. Sweep Settings

Sweep settings

Settings

Single sweep
 Continuous sweep

Averaged sweep

Number of measurements to average: 3
Number to discard: 0

Averaging allows discarding outlying samples to get better averages.
Common values are 3/0, 5/2, 9/4 and 25/6.

Sweep band

Select band: 2200 m

Pad band limits: None
 10%
 25%
 100%

Sweep span: 135.7kHz to 137.8kHz

Set band sweep

Start by clicking on „Settings“ under **"Sweep Control"** in the upper left half of the screen:

Usually a **single sweep** is used but there is the option for a **"Continuous Sweep"**.

More interesting options are in the violet frame We can have an **averaged sweep** to reduce the effects of the **noise or artifacts**. The number of readings used to calculate the average can be chosen to improve the quality of the display.

Another clever option is to specify the **number of outlying sample to discard**. This is specified as the **measured value number followed by segment Number**.

The following values must be separated by a comma. (see the

examples for demonstration in the red coloured second frame)

There is still another option:(= pink frame):

It is a **collection of all Radio Amateur Frequency Bands** and if you choose one of them, everthing for a correct simulation is automatically set. Please try it out!

10. Sweep - programming for 50 kHz to 900MHz

For this the **frequency range** and the **number of segments** are selected.

Sweep control

Start	50.000kHz	Center	450.02MHz
Stop	900.00MHz	Span	899.95MHz
Segments	20		445.5 kHz/step

Sweep settings ...

100%

Sweep Stop

Set the frequency range by the **starting frequency of 50kHz** and the **stop frequency of 900MHz**.

Concerning the **unit** you can choose between

numbers (e. g. 50000) or

exponential form (50e3) or

units (kHz, MHz).

But now: the **segments!**

This is a very clever solution. **One segment always consists of 100 steps giving 101 measurement points.** The sweep speed is constant for one segment.

If the chosen frequency range is now **divided into 20 segments**, each segment consists again of 100 steps.

So we find in our example a resolution of 445.5 kHz/step and thus the the accuracy is considerably increased (see the pink frame).

But this will also increase the calculation time and you should watch the green progress bar during sweeping.

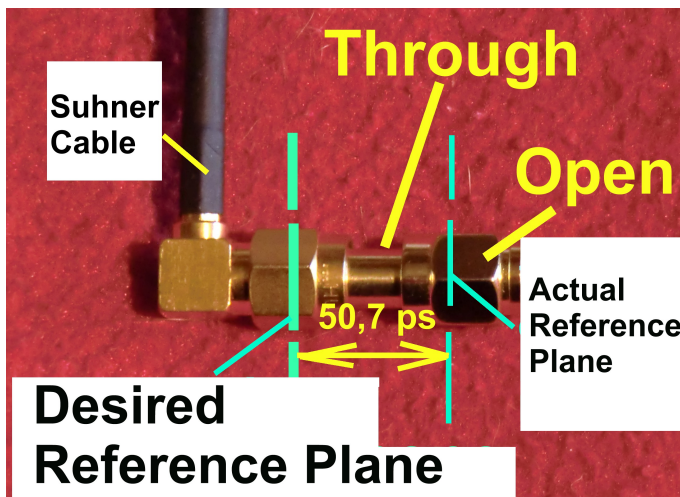
11. Start calibration with the calibration data

Kurt Poulsen, who determined the calibration data for the VNWA3 has supplied: **"Calibration data for the NanoVNA with the supplied SOLT - Calibration set "**. Thanks for that!

In our case using firmly connected, high quality measuring cables with male SMA plugs this specifies the following values to be entered for the **three SOL-standards** (Short / Open / Load) for male SMA plugs:

SHORT:	Delay = 51.16ps	
OPEN:	C0 = 50fF	Delay = 48.63ps
LOAD:	R = 49.86Ω	Delay = 61.59ps
THROUGH:	Delay = 50.7ps	

Because the three standards (= SOL) are specified as „male“ - versions you need a „Through“ adapter (= SMA female - female) for the connection to the measuring cables with male pluges. **But this causes an additional delay of 50.7 Picoseconds** = an additional phase shift...



This is the hardware setup for the OPEN calibrating process:

The **SMA - female – female - Adapter** („Through“) shifts the actual Reference Plane to the SMA plug of the OPEN standard.

This means a signal delay of 50.7 ps (equal to a phase shift) and the software has now to do the necessary correction for „back shifting“to the Desired Reference Plane.

You find the complete „Calibration Setting File“ on the next page.

Remark:

The software wants to know the resistance value of the LOAD standard as precise as possible.

If you don't own a high precision measuring set for this purpose simply use the ideal value of **50 Ω**. **This gives a small and visible but acceptable error.**

I own an old but very accurate analogue Wheatstone Bridge. So I found my personal LOAD Standard value of **49.85 Ω for the following list.**

Here comes the „Calibration standards“ list with the values to be entered:

Calibration standards

Use ideal values

Short

L0 (H(e-12))	0
L1 (H(e-24))	0
L2 (H(e-33))	0
L3 (H(e-42))	0
Offset Delay (ps)	51.16

Open

C0 (F(e-15))	50
C1 (F(e-27))	0
C2 (F(e-36))	0
C3 (F(e-45))	0
Offset Delay (ps)	48.63

Load

Resistance (Ω)	49.85
Inductance (H(e-12))	0
Offset Delay (ps)	61.59

Through

Offset Delay (ps)	50.7
-------------------	------

Saved settings

bug fixed_Poulsen_02

Load Save Delete

Step 1:

Click „Calibration“ on the screen

Step 2:

Delete „Use ideal values“ (= pink frame)

Step 3:

Enter all data values.

Step 4:

Search for „New“ in the small window for the settings name, click on „Save“ and enter another name for the Calibration settings (green frame)

E.g.: I use

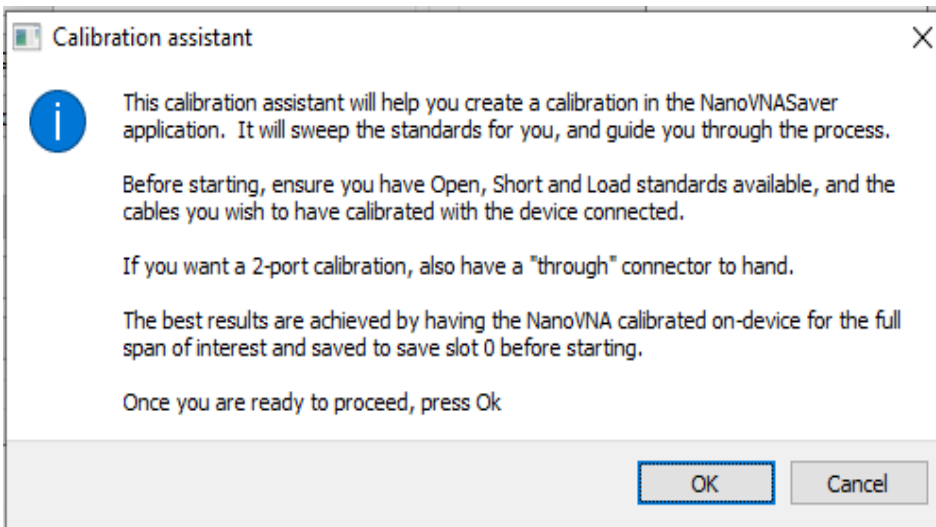
bug fixed_Poulsen_02

Step 5:

Click on „LOAD“.to use these settings

12. SOLT Calibration

At the **middle of the Calibration Menu** you find the „**Calibration assistant**“ which guides you during the SOL calibration process for S11.



The SOLT calibration kit must be available.

The pictures show a practical tip for storing the SOLT components. It is an empty pill box that came as a small gift from my pharmacy.

The letters "S", "O" and "L" have been scratched onto the three standards using a needle.



OK starts the procedure, just follow the instructions. Please do not lose patience if it takes a long time. The green bar in the sweep field shows the progress!

The "SOL" process announces each stage (Short / Open / Load), continue with "Yes". Finally the missing calibration for S21 uses "Isolation" and "Through".

If everything is done, click on „**apply**“ to terminate the calibration process

Important:

You should also save this calibration using a name to your choice.....might be that in the future more special calibrations for other frequency ranges are necessary...

Example: my calibration file is named

Poulsen_Suhner 30cm_50k – 900MHz_20Seg

But:

Never forget to load the correct Calibration File for your actual project when you start your PC next morning or the next time....

And now follows a final proof to test the success of this work!

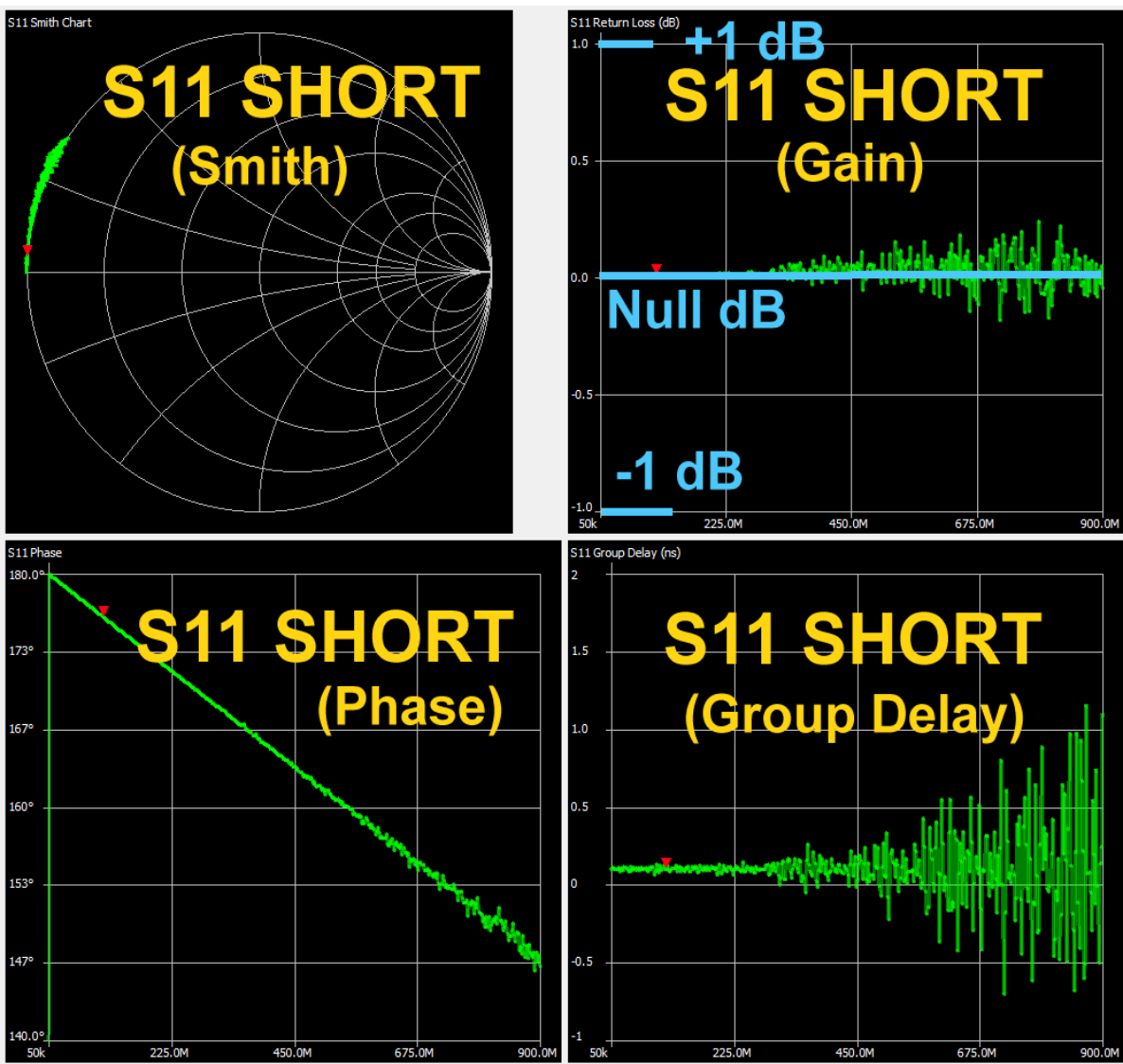
13. Testing the calibration quality

Attention:

The curves are only reliable and reproducible if you have used a SMA torque wrench for every SMA connection (torque = 0.45Nm)

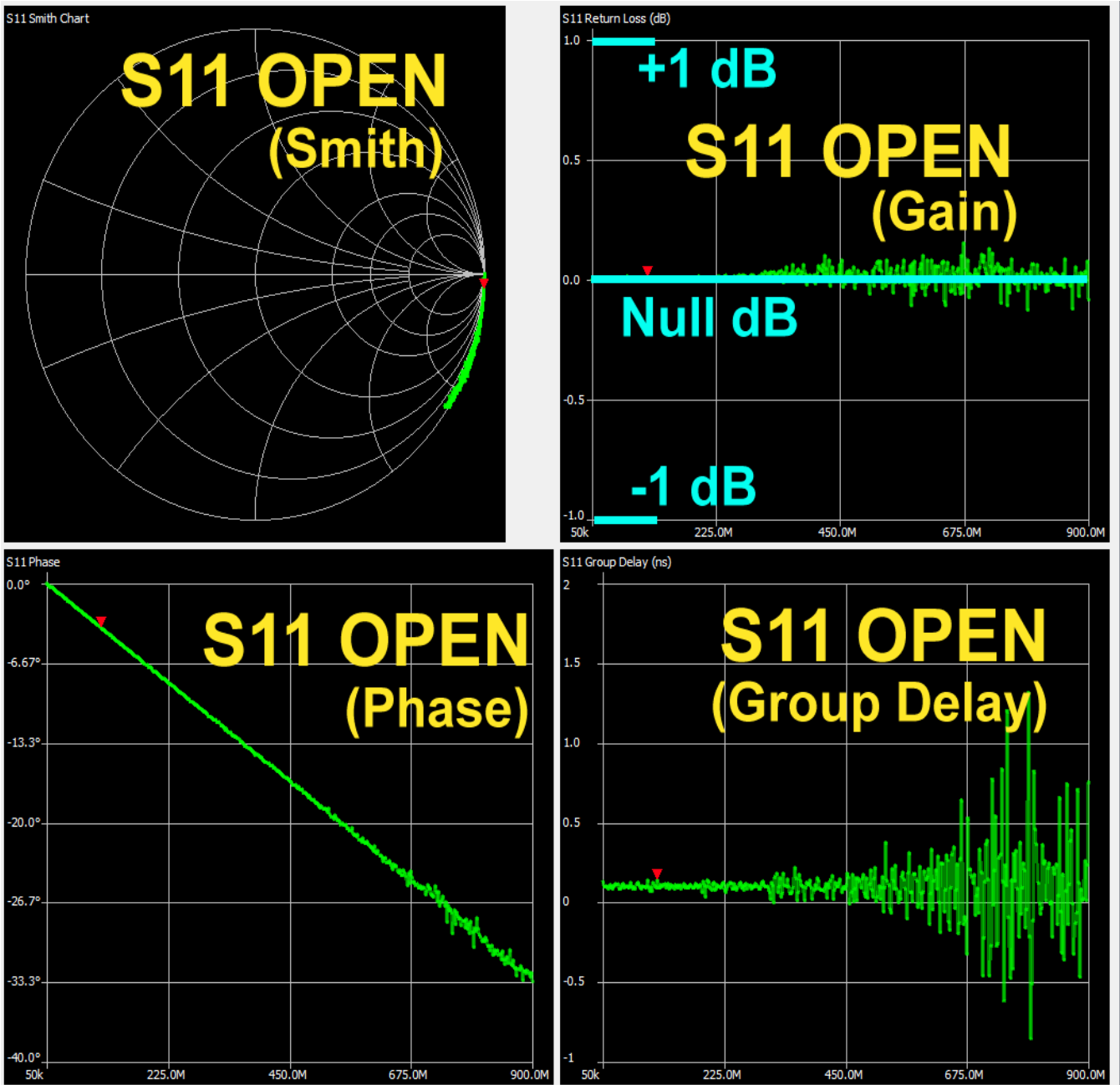
Let's start with the **SHORT** standard and use all new features of software version v0.2.2-1
The frequency range is always 50kHz900MHz.

Remark:
You can use the scroll wheel of your mouse to zoom the diagrams!



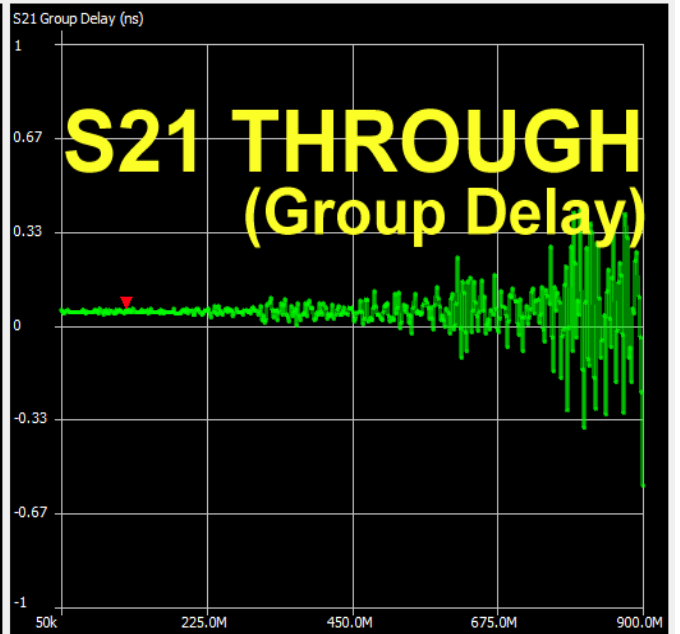
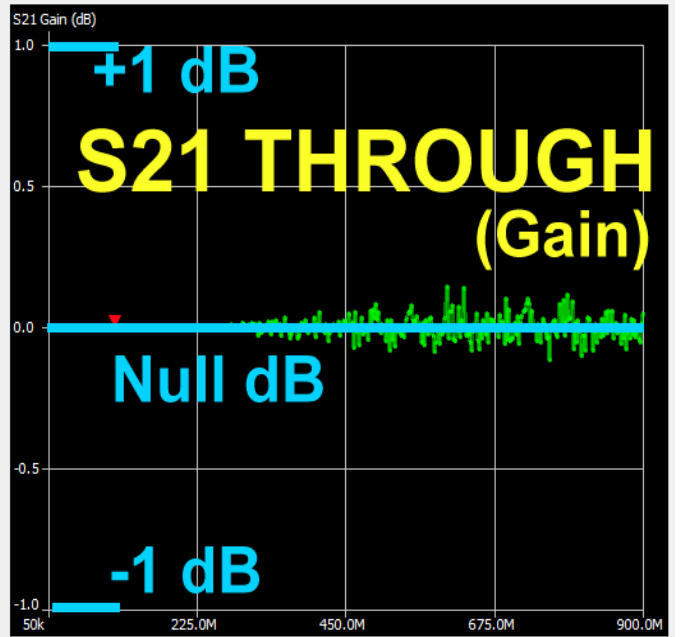
Not so bad....

Now the OPEN-Standard from 50 kHz to 900 MHz:

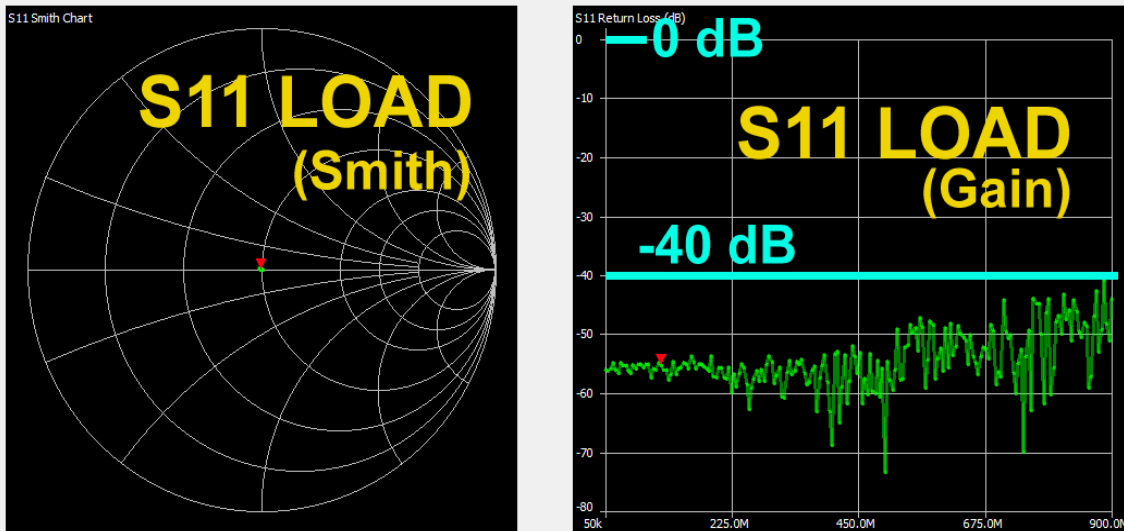


OK.

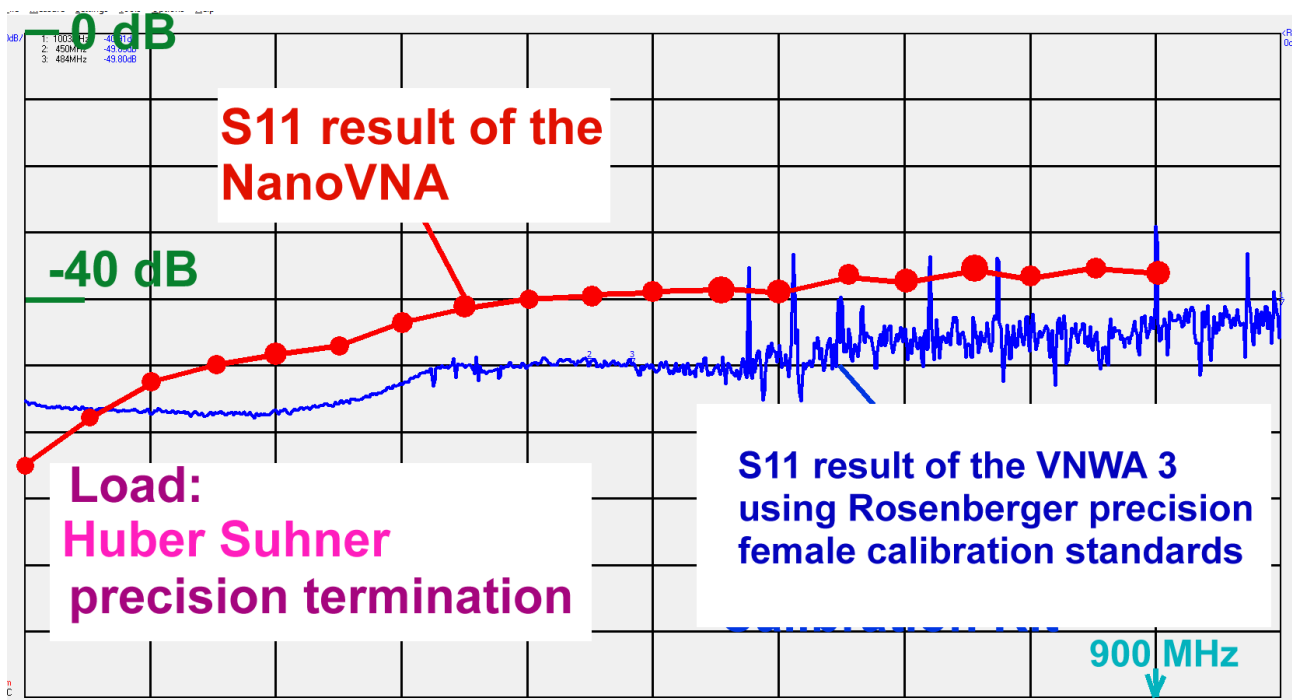
Connect the two Huber Suhner measuring cables via the **Through** adapter together to get **S21**:



At last: the reflection coefficient **S11** of the **LOAD** standard:



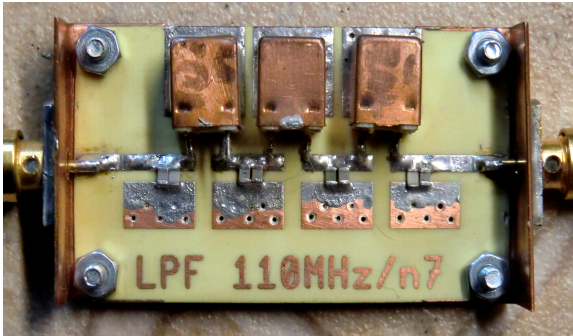
Compare the quality of the NanoVNA to the well known VNWA3 regarding the **S11** values of a Huber Suhner High Precision Termination:



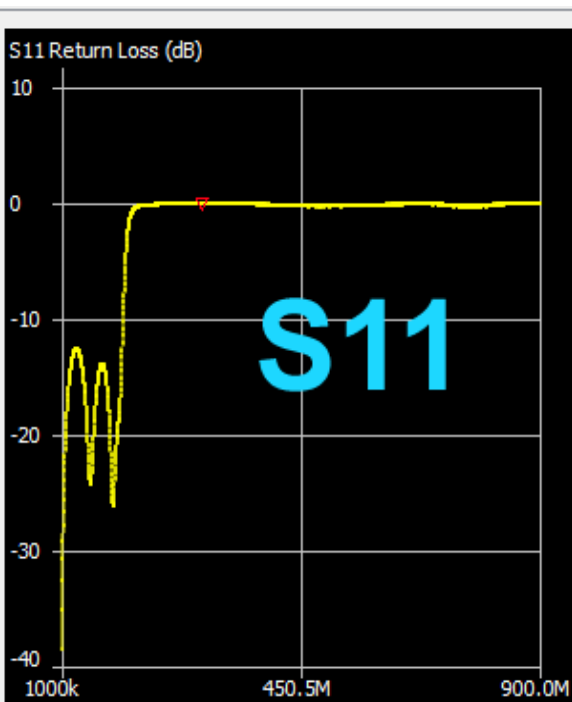
Remark:

When testing in the frequency range up to 12 GHz you'll know at once why the Huber Suhner is the favorite solution and not the LOAD Standard supplied with the kit (...but Suhner is more expensive...).

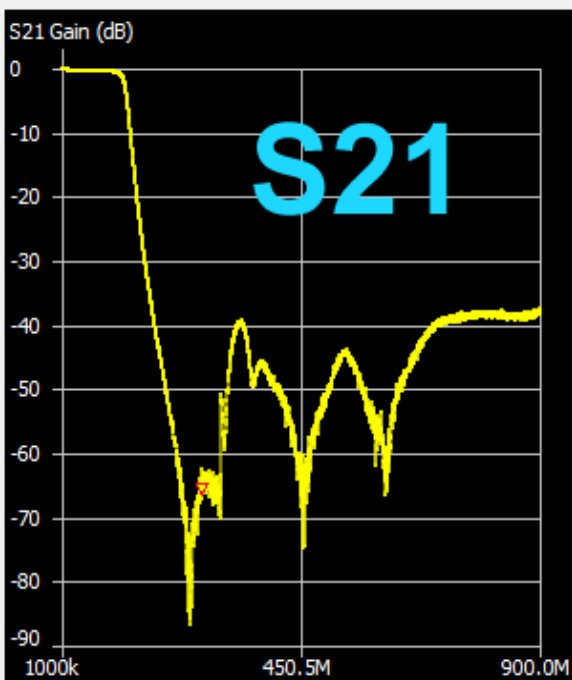
14. Testing a 110 MHz - Lowpass Filter



The SMA sockets are soldered to two bended copper sheets. Thus the central conductor of the socket touches the central Microstrip Line and is then soldered. This gives a transition with low reflection.



This is **S11** for the 50kHz to 900 MHz frequency range. The **passband** can be identified without any efforts (= low reflection) and in the **stop band** we get a **total reflection** with **S11 = 0 dB**



S21 decreases after leaving the pass band down to -80 dB. But even up to 900 MHz the maximum value is -38 dB (= minimum stop band attenuation)

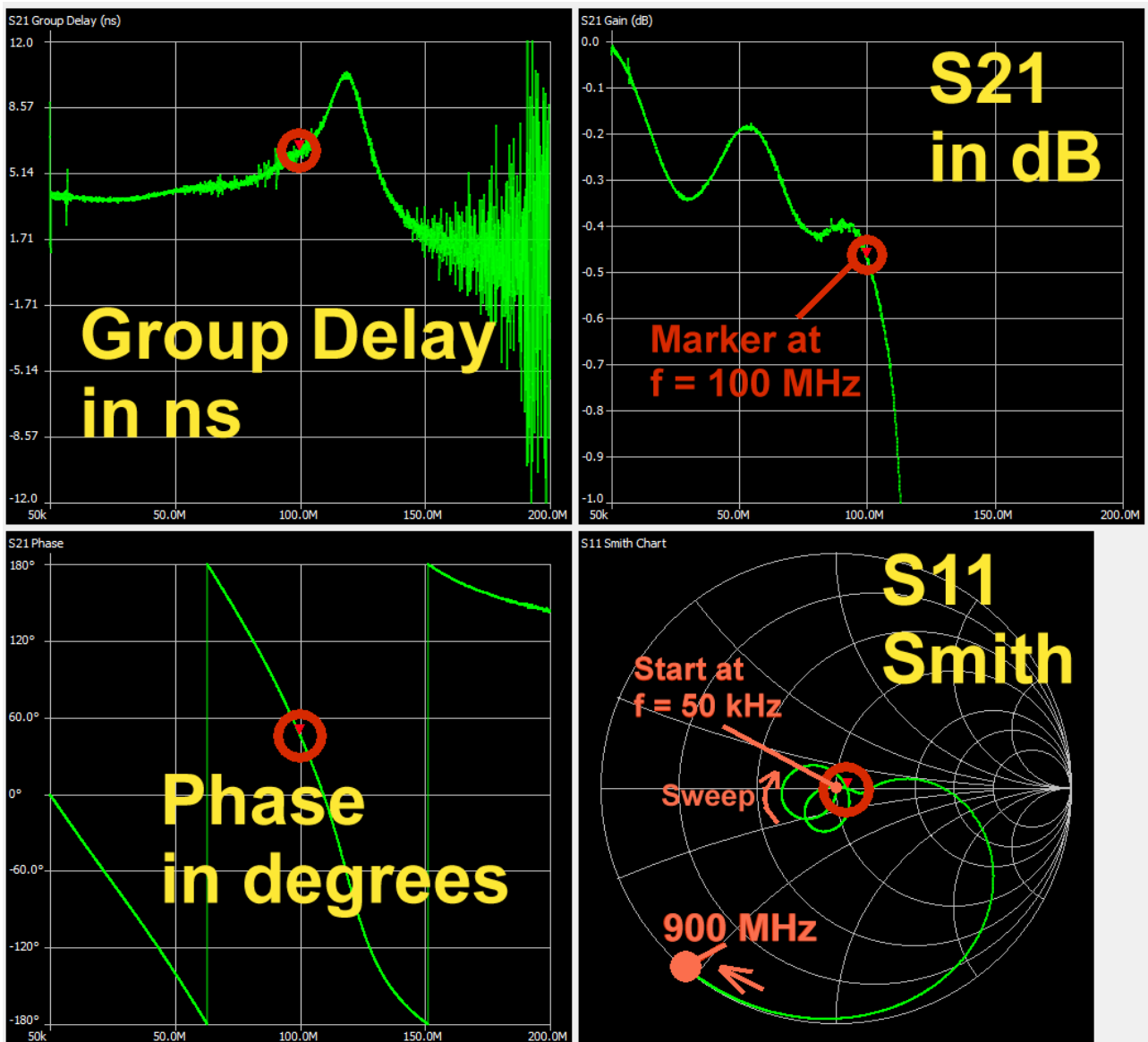
The decrease of the stop band attenuation at rising frequencies is caused by self resonant effects of the used parts.

15. Attenuation and Group Delay in the Pass Band of the LPF

If you want to see these features: first click right on the S21 gain diagram and open „Frequency Axis“ to reduce the frequency span to **50kHz ...200MHz**.

Afterwards click once more on the diagram and choose „Data Axis“. Set the data axis range to 0....-1 dB-

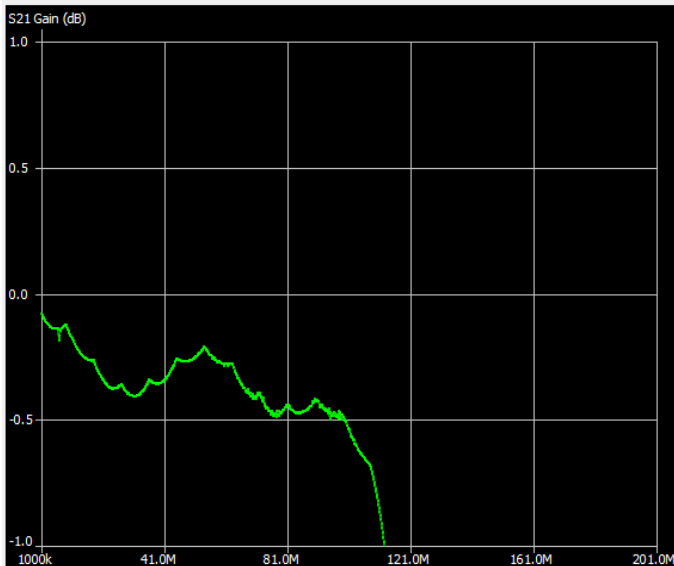
Add Marker 1 set to $f = 100\text{MHz}$.



Warning:

Never change the span of the frequency axis in the diagram by entering new values for start or stop frequency followed by a new sweep **without a new calibration procedure!**

Otherwise:



In this case you could loose the SOLT calibration if you do not exactly hit the saved frequency values in the calibration file.

So the screen will look like this in such a case!

Remember:

You can save five independent calibrations in the registers c0...c4 on the NanoVNA board itself.

But if you work with the NanoVNA -saver software you can create and save on the PC as many calibrations as you like.

The „original calibrations c0...c4“ of the board are frozen and you have again acces to them when disconnecting the board from the PC and using the Recall - command.

16. Markers

Marker 1 (below the Sweep Menu) has been activated for a frequency of **100 MHz**. Use the mouse (= drop and drag) for shifting to other frequencies in a diagram.

Marker 1	
Frequency:	99.8956 MHz
Impedance:	54.1 +j2.211 Ω
Admittance:	54.19 +j1326.0 Ω
Series R:	54.1 Ω
Series L/C:	3.523 nH
Series L:	3.523 nH
Series C:	-720.58 pF
Parallel R:	54.19 Ω
Parallel L/C:	2.113 μ H
Parallel L:	2.113 μ H
Parallel C:	-1.202 pF
VSWR:	1.094
Return loss:	-26.985 dB
Quality factor:	0.041
S11 Phase:	27.11°
S21 Gain:	-0.471 dB
S21 Phase:	44.64°

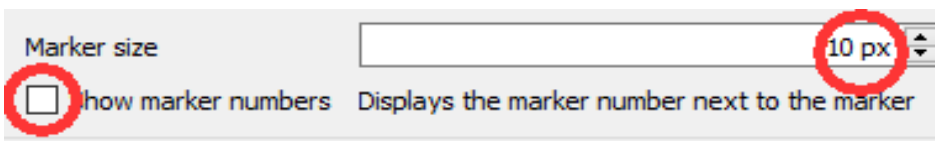
Up to three Markers can be used independently.

Enter the frequency and choose the colour of a marker. At once this marker is displayed on all curves.

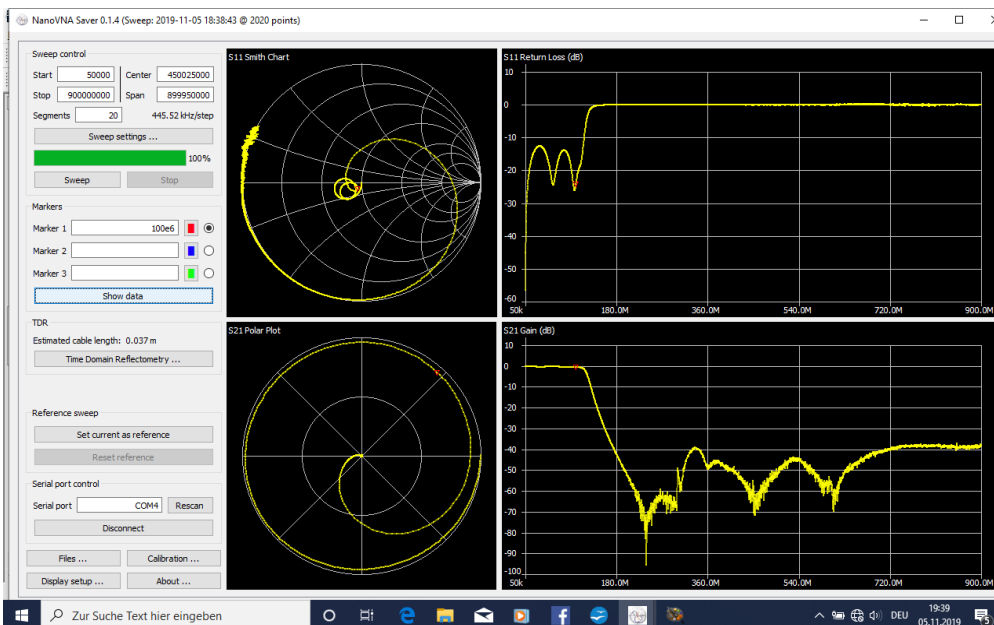
At the side of the sweep menu you find this list of all marker properties which can be displayed.

a) When entering a marker frequency the program chooses the nearest adjacent frequency which

can be found in the calibration file (for instance: entering **100 MHz** gives a frequency value of **99,8956 MHz** in the marker list)

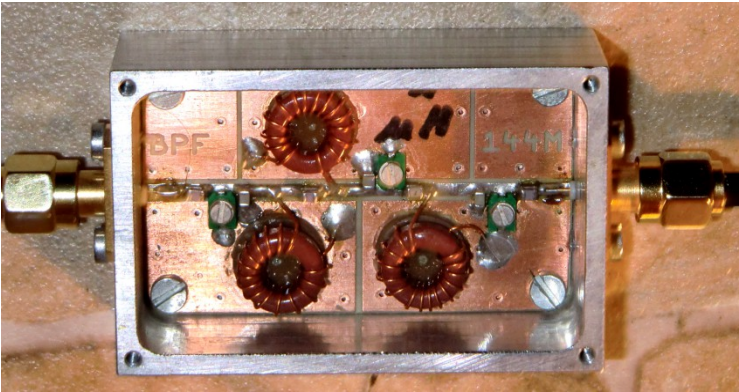


b) Marker size, colour, number and type can be set on the marker menu and on „Display settings



c) If you hit „hide data“ the marker property list disappears and all 6 diagrams can be displayed.

17. A Bandpass for 10.7 MHz



That is it!

A Chebchev BPF with a centre frequency of 10.7 MHz, realised with Amidon ferrite ring cores ($Q = 150$).

The Aluminium case is milled.

Step 1:

Generate a SOLT Calibration File for a frequency range of 5 MHz to 15 MHz using 20 Segments.

Step 2:

Save this file under a new name, e.g.:

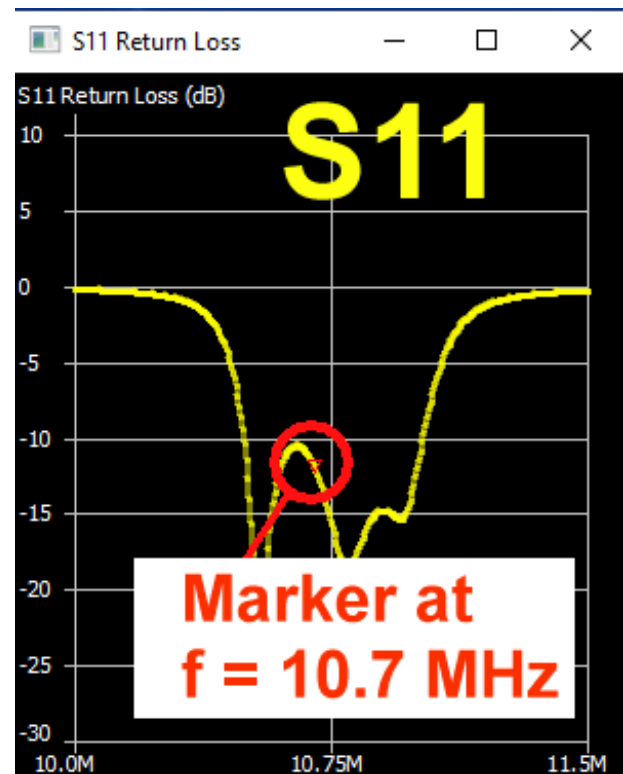
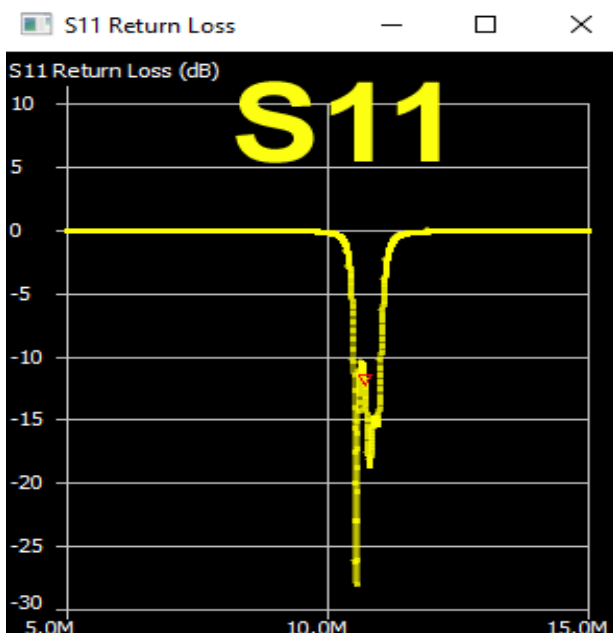
„Suhner 30cm_Poulsen_5M-15M_20Seg“

and load it.

Step 3:

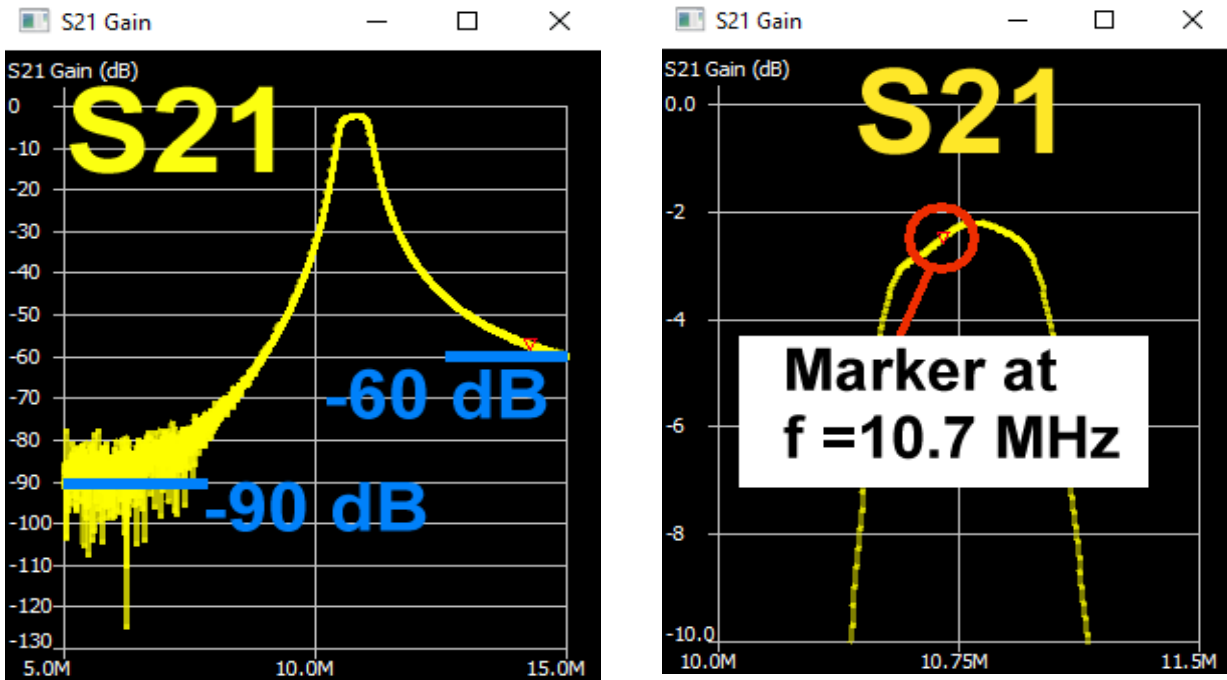
Start a sweep from 5 MHz up to 15 MHz using 20 Segments and add Marker 1 for 10.7 MHz

Result for S11



The left illustration uses a frequency range from 5....15 MHz, the right one from 10...11.5 MHz

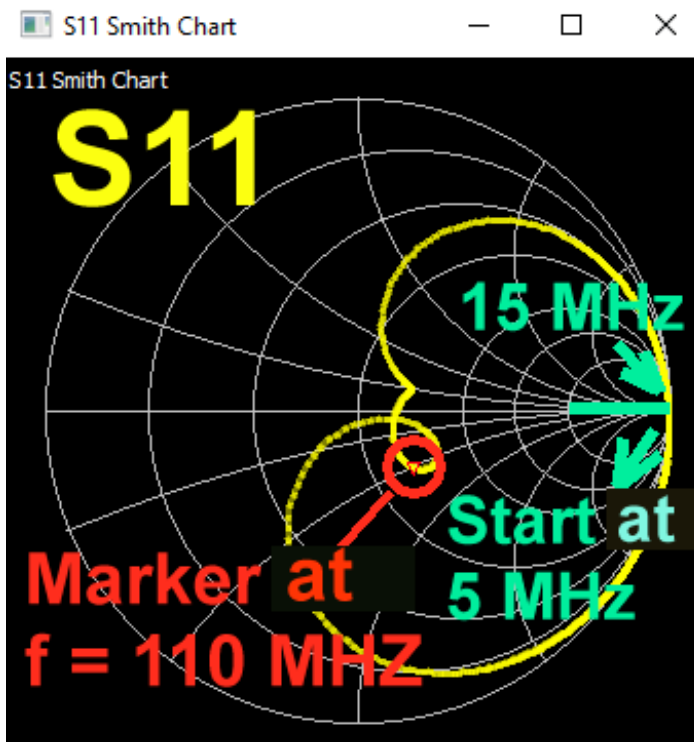
The same procedure for S21:



The left illustration shows a remarkable **stop band attenuation of -90 dB for $f = 5$ MHz** and **-60 dB for 15 MHz**.

In the right illustration you see the pass band with a minimum attenuation of **2.1 dB at $f = 10.9$ MHz**. (..it is true: the alignment procedure should be repeated and improved...)

In a Smith Chart you get nice loops when presenting **S11** of the pass band and you can **easily demonstrate this**:



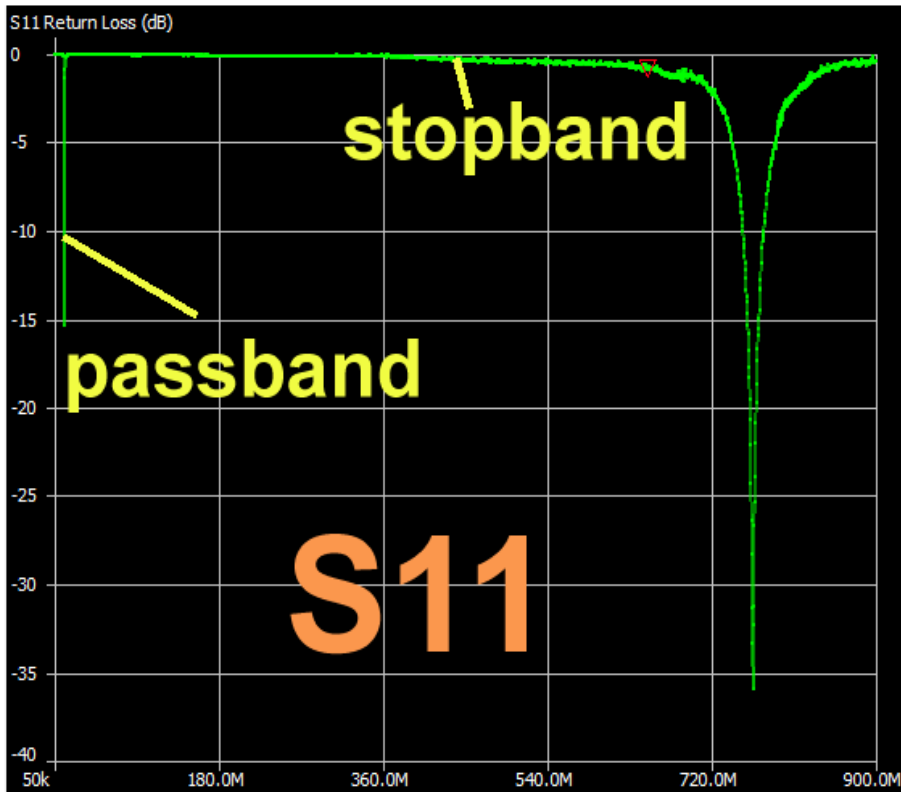
The curve starts at $f = 5$ MHz at the point

5 MHz / +1
(= right end of the horizontal axis).

Then the curve turns like a watch pointer and ends at the **same point**

(+1 for 15 MHz)

Now a special S11 and S21 test:

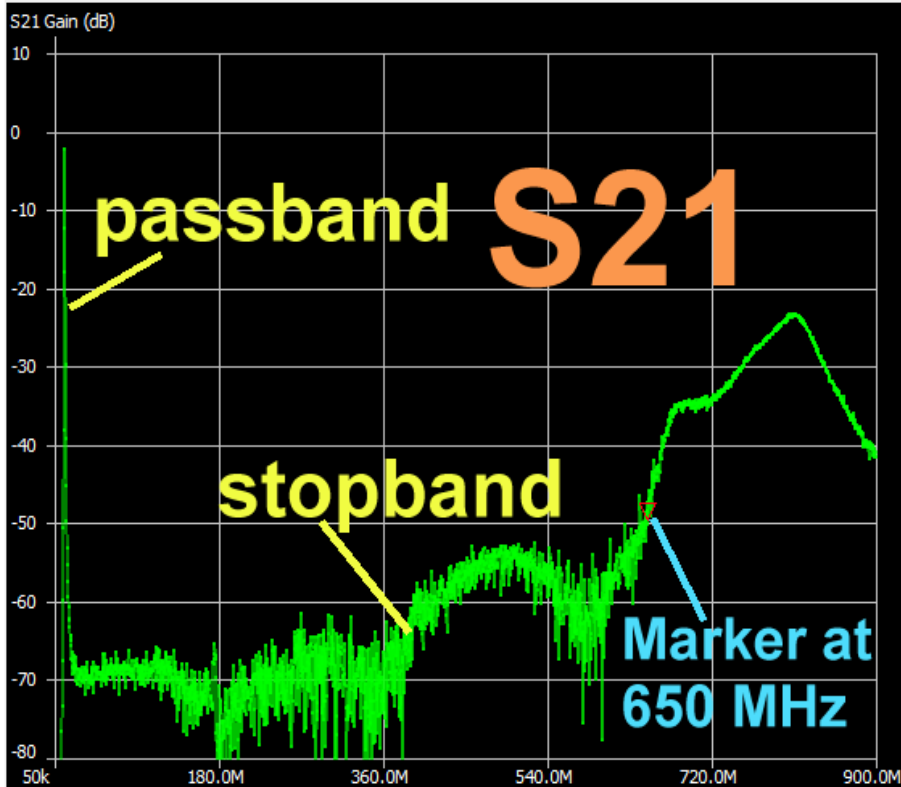


Please load the Calibration File for the range

50 kHz up to 900 MHz and sweep this range.

This gives an overview of the stop band attenuation S21 and the wide band reflection S11.

S21 is below -50 dB up to 650 MHz.



The rest is a problem caused by self resonant effects of the parts.

17.1. Automatic Analysis

Really fine because you automatically get all parameters of a filter after a sweep.
We want to have a look at the 10.7 MHz Filter from the last chapter. But pay attention to work through the preparation in the correct manner.

Step 1:

Do a **SOLT calibration with a higher resolution for a reduced frequency span**. My new Calibration File is applied and saved as

Suhner 30cm_Poulsen final_50k - 50MHz_20 Seg_avg = 3

This file contains the following information:

Suhner cables, length = 30cm

Calibration settings = newest version from Kurt Poulsen (see last chapter)

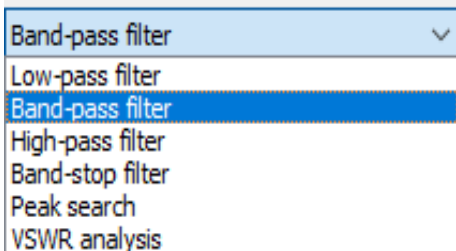
Sweep range from 50kHz to 50MHz

Sweep range divided into 20 Segments

After opening „**Sweep settings**“ the „**Averaging Sweep using 3 values**“ was selected.
This reduces the influence of noise

Step 2:

A sweep from 9.5 MHz to 10.5 MHz with 20 Segments is used.



Step 3:

Open the menu „**Analysis**“ (at the middle of the lower border of the screen) and delete „**Run automatically**“.

Then choose „**Band-pass-filter**“ on the left menu.

Now mark „**Run automatically**“ again

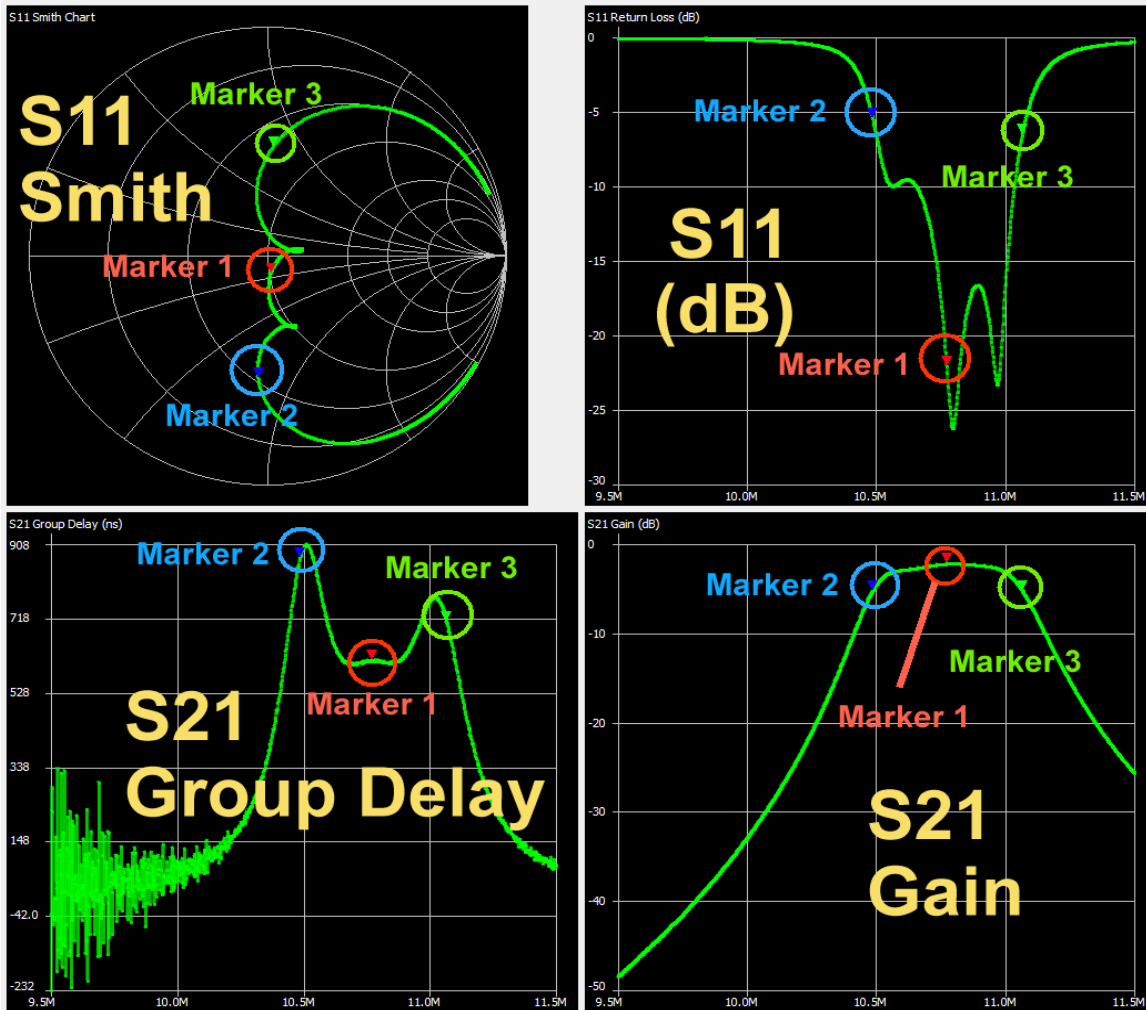
Step 4:

Set Marker 1 at the centre frequency of 10.7MHz.

Step 5:

Start the sweep.

This is the result:



All details shown in the left hand window are described on the following page:

„1“ = Marker frequencies.

„2“ = Marker 1 indicates the exact **centre frequency** (10.771488MHz) with a gain of S21 = -2.207dB

„3“ = Marker 2 gives the **lower corner frequency** (10.485MHz). S21 has decreased by 3dB and is now -5.207 dB

„4“ = Marker 3 gives the **upper corner frequency** (11.065774MHz). S21 has decreased by 3dB and is again -5.207dB

„5“ = Minimum value of VSWR (1,103 or S11 = -26.227dB at 10.7962MHz)

Maximum value of S21 = -2.185 dB at f = 10.8002MHz

Minimum value of S21 = -48.421 dB at f = 9.50190MHz

2

Sweep control

Start: 9.5e6 | Center: 10.50MHz
 Stop: 11.5e6 | Span: 2.00MHz
 Segments: 10 | 1.980kHz/step

Sweep settings ...

100%

Sweep | Stop

1

Markers

Marker 1: 10771488
 Marker 2: 10485028
 Marker 3: 11065774

Hide data | Locked

3

Marker 1

Frequency: 10.7724MHz | Parallel L: -4.9464 μ H
 Impedance: 50.94 -j7.94 Ω | Parallel C: 44.129 pF
 Admittance: 52.18 -j334.8 Ω | VSWR: 1.171
 Series R: 50.94 Ω | Return loss: -22.052 dB
 Series L/C: 1.8607 nF | Quality factor: 0.156
 Series L: -117.31 nH | S11 Phase: -78.75°
 Series C: 1.8607 nF | S21 Gain: -2.207 dB
 Parallel R: 52.18 Ω | S21 Phase: -20.69°
 Parallel L/C: 44.129 pF

4

Marker 2

Frequency: 10.4850MHz | Parallel L: -859.60 nH
 Impedance: 26.14 -j39.2 Ω | Parallel C: 268.04 pF
 Admittance: 84.94 -j56.63 Ω | VSWR: 3.309
 Series R: 26.14 Ω | Return loss: -5.418 dB
 Series L/C: 387.23 pF | Quality factor: 1.5
 Series L: -595.03 nH | S11 Phase: -94.08°
 Series C: 387.23 pF | S21 Gain: -5.256 dB
 Parallel R: 84.94 Ω | S21 Phase: 124.97°
 Parallel L/C: 268.04 pF

5

Marker 3

Frequency: 11.0658MHz | Parallel L: 969.25 nH
 Impedance: 33.03 +j40.36 Ω | Parallel C: -213.42 pF
 Admittance: 82.34 +j67.39 Ω | VSWR: 2.804
 Series R: 33.03 Ω | Return loss: -6.48 dB
 Series L/C: 580.48 nH | Quality factor: 1.222
 Series L: 580.48 nH | S11 Phase: 86.89°
 Series C: -356.36 pF | S21 Gain: -5.219 dB
 Parallel R: 82.34 Ω | S21 Phase: -162.06°
 Parallel L/C: 969.25 nH

S11
 Min VSWR: 1.103 @ 10.7962MHz
 Return loss: -26.227 dB

S21
 Min gain: -48.421 dB @ 9.50190MHz
 Max gain: -2.185 dB @ 10.8002MHz

Reference sweep

Set current as reference

More information can be found when opening the „**Analysis**“ Menu:



Sweep analysis



Select analysis

Analysis type Band-pass filter

Run analysis

Run automatically

Analysis

Band pass filter analysis

Please place Marker 1 in the filter passband.

Result: Analysis complete (1010 points)

Center frequency: 10.7715MHz

Bandwidth (-3 dB): 580.746kHz

Quality factor: 18.55

Bandwidth (-6 dB): 685.828kHz

Lower side:

Cutoff frequency: 10.4850MHz (-3.1 dB)

-6 dB point: 10.4374MHz

-60 dB point:

Roll-off: 463.356 dB / octave

Roll-off: 1539.234 dB / decade

Upper side:

Cutoff frequency: 11.0658MHz (-3.0 dB)

-6 dB point: 11.1233MHz

-60 dB point: 12.2939MHz (derived)

Roll-off: 370.049 dB / octave

Roll-off: 1229.276 dB / decade

17.2. Set Sweep as Reference

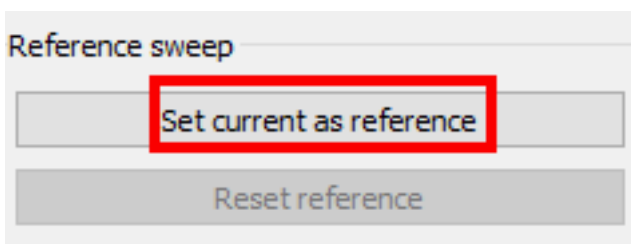
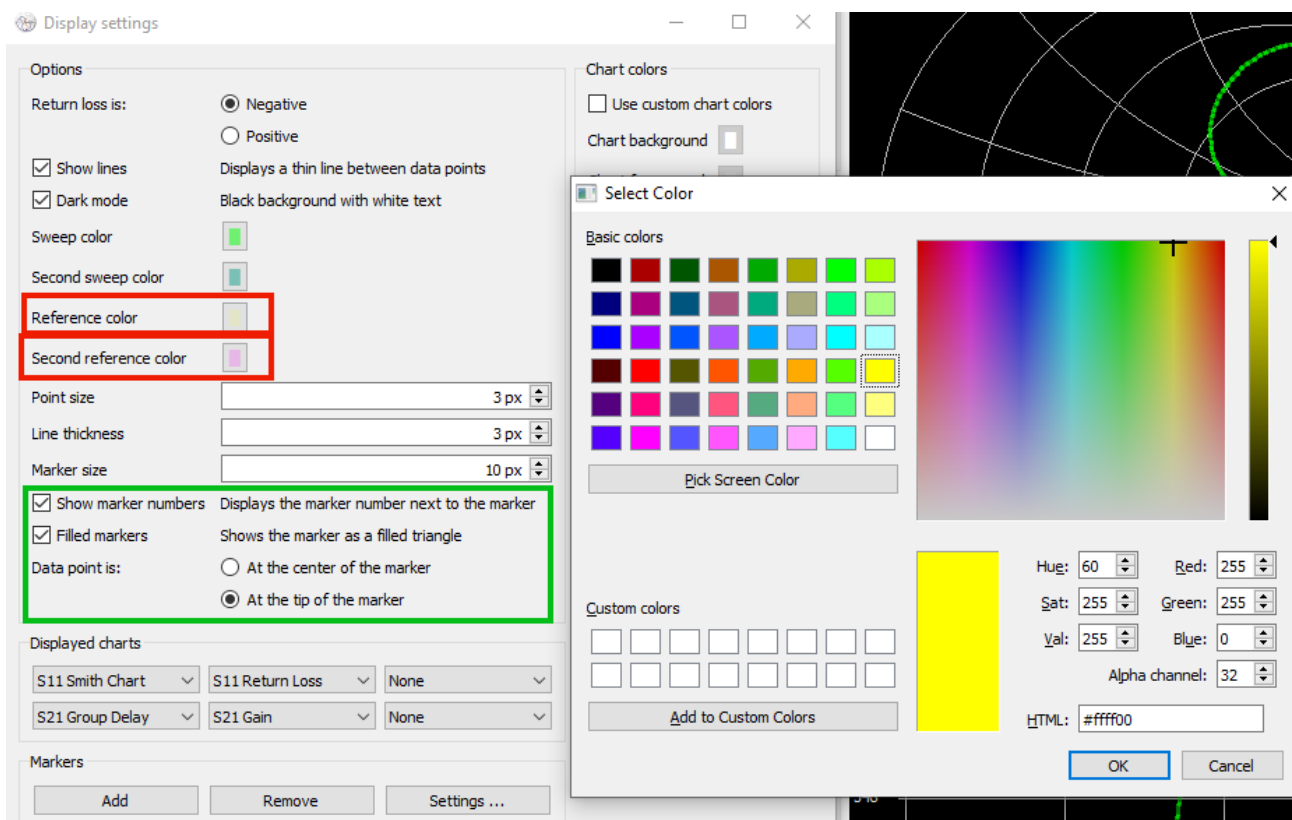
If you do that, then the next result will be shown together with the first (but with another colour). So you can compare and recognise any variation.

Step 1:

(Red frames). If you use a dark background for your diagrams you should first change to a **bright colour for the reference sweep (Yellow or Pink)**. Default is „Dark Blue“ and this does not work very well on a black screen...

Remember the content of the green frame:

Here you can modify a lot of marker properties (show marker number / hollow or filled triangle / marking the data point by the center or the bottom of the triangle)



Step 2:

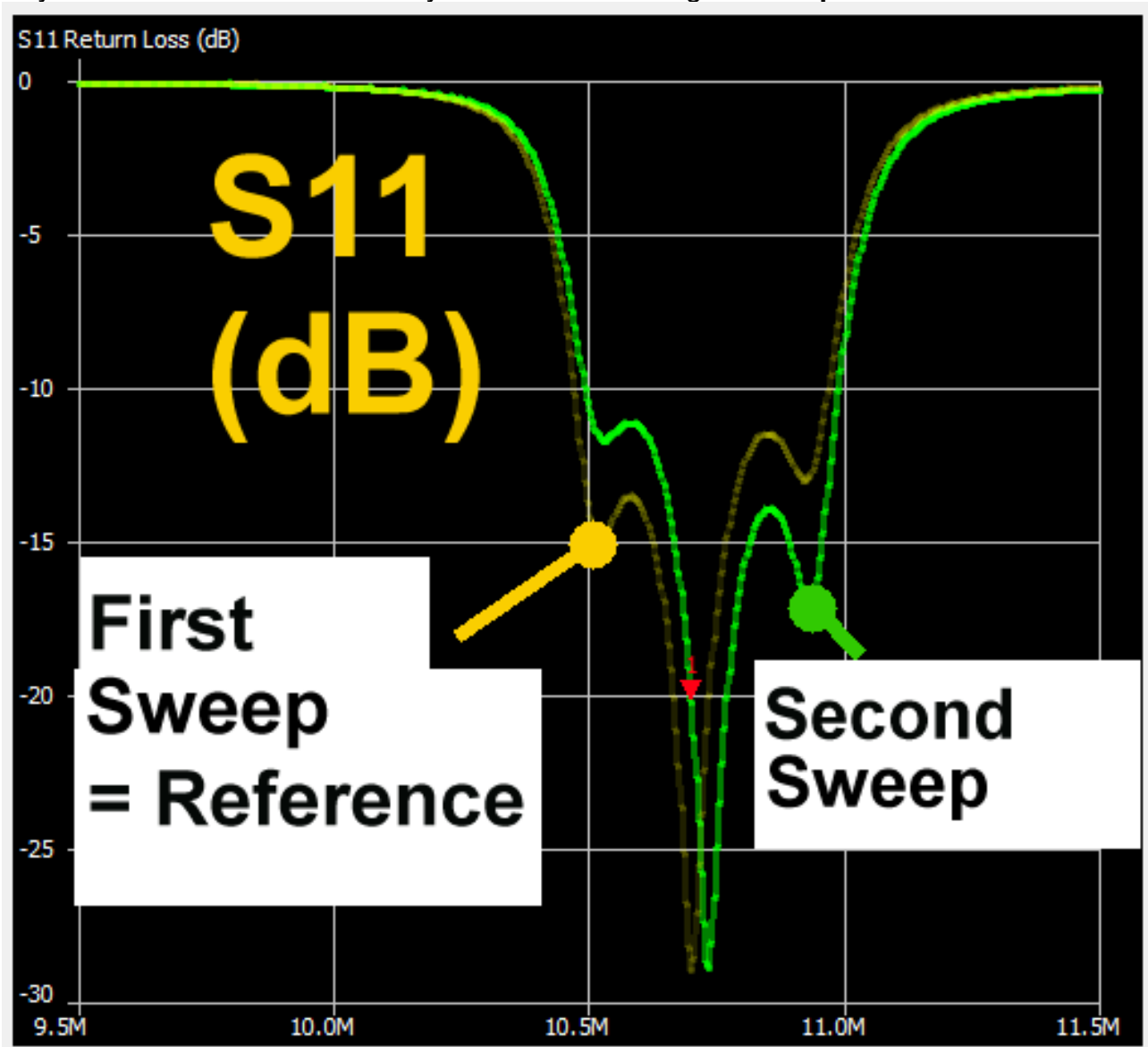
Sweep and tab on

Set current as reference

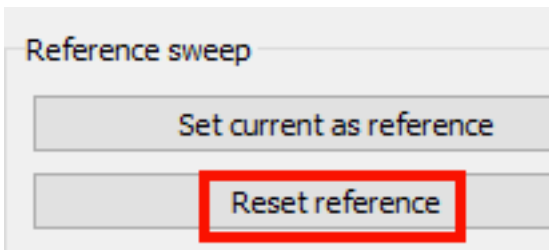
(In the lower left half of the screen)

Step 3:

After the first sweep I have misaligned the BPF slightly followed by a new sweep. Any differences caused can always be best seen using the S11 presentation:



If you want to terminate this option:



Click

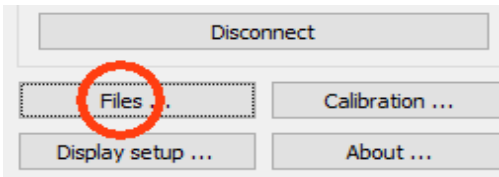
Reset reference

to delete the reference curve.

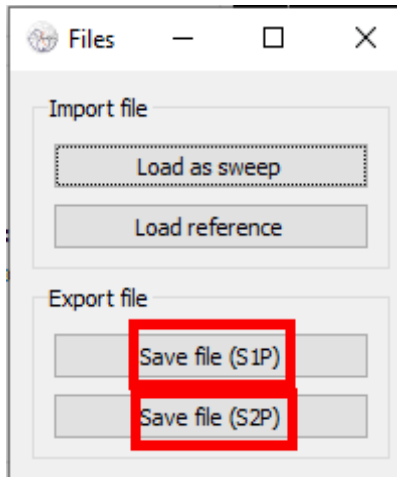
Personal remark:

The sweep speed is too low for „real time alignment of a good or misaligned filter“ and cannot be changed or increased. So the reference sweep option is better used for final testing of production filters against a good reference filter.

17.3. Saving the Touchstone Files generated



Open the „Files“ menu at the left lower edge of the screen....

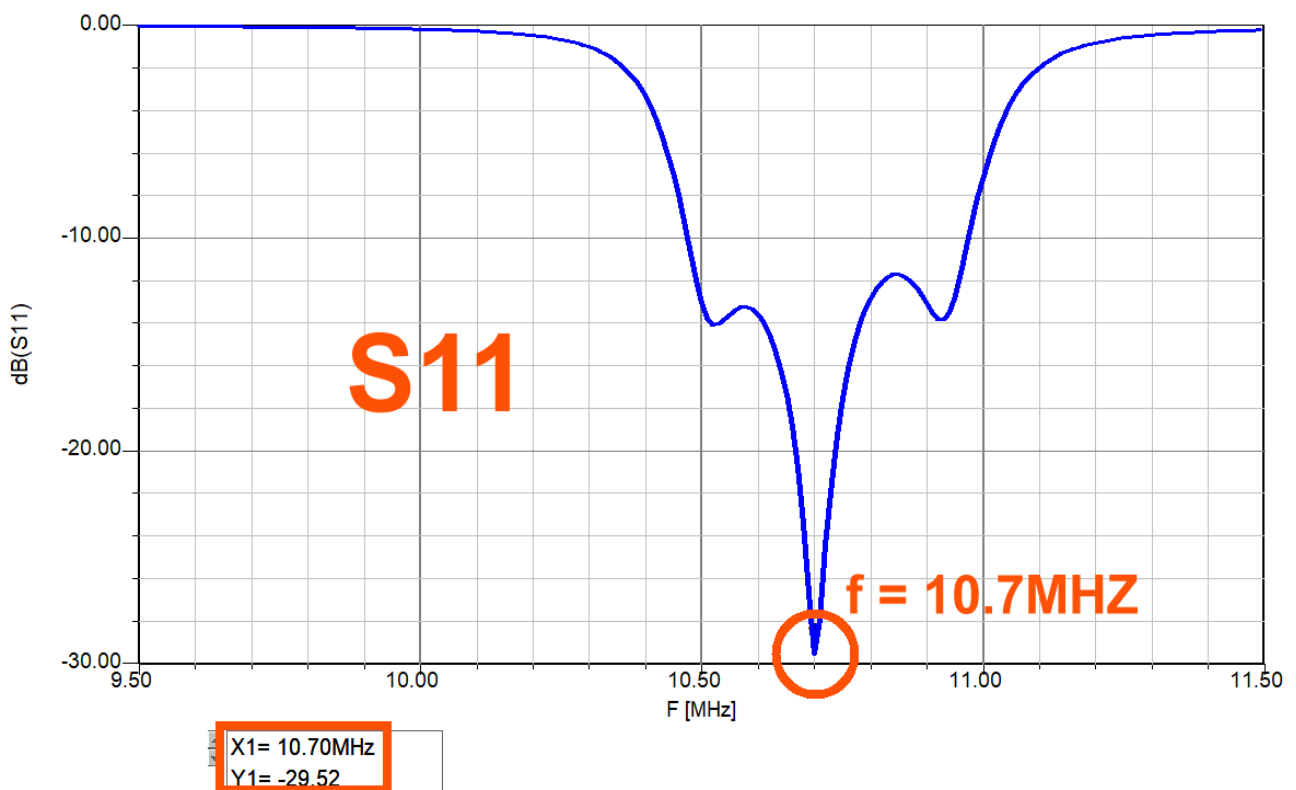


....then export and save at first the S1P File, followed by the S2P File.

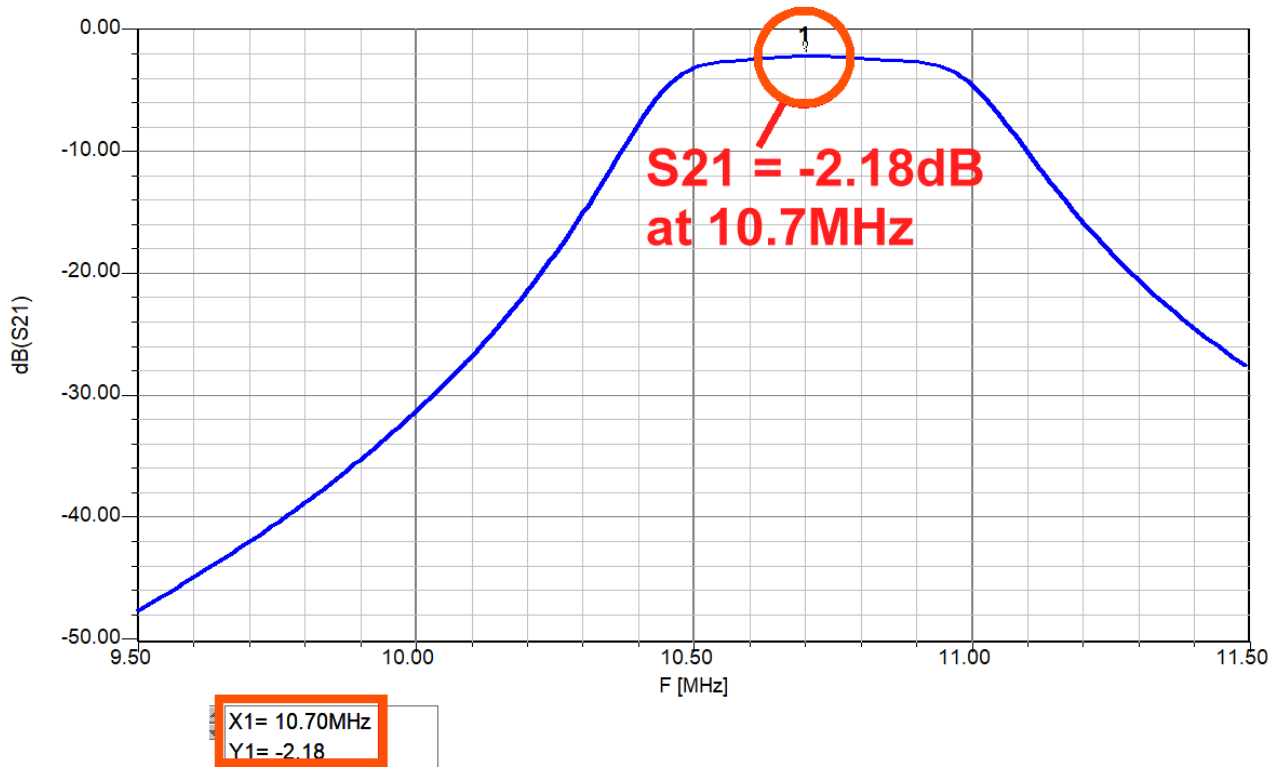
Give a name and choose a folder for saving.

After a new align procedure of the filter:

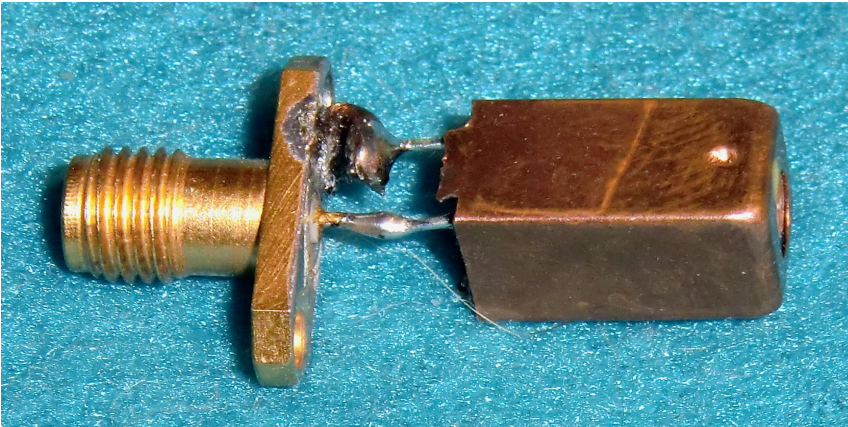
This is a **test simulation with the saved S11 file using the software „Ansoft Designer SV“** which can be downloaded from my homepage (www.gunthard-kraus.de)



This is the S21 result:



18. Properties of a shielded filter coil



See the preparation:
The coil (= an older Neosid version) is soldered to a SMA socket and then connected to channel CH0 of the NanoVNA.

What we want to know:

a) R and X for the frequency range from 50 kHz up to 100 MHz

b) Quality factor $Q = f(f)$ for this range

c) Exact values of inductance „L“, quality factor „Q“ and series resistance „R“ at a frequency of $f = 30$ MHz

Now the correct Calibration file (50 kHz ...900 MHz) must be loaded and the sweep started.

Here come the results:

a) R and X = f(f)

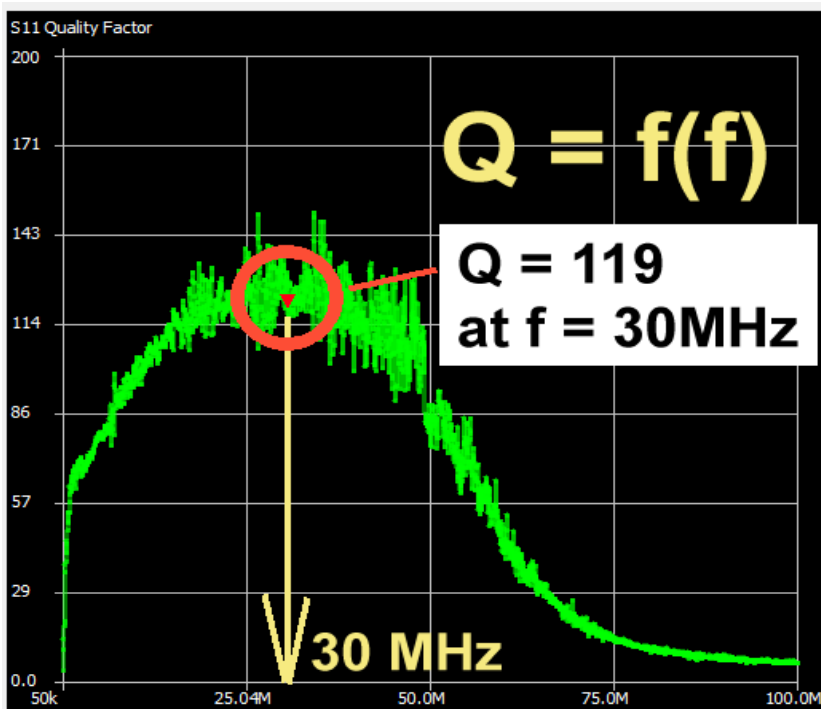


The inductance value L starts to increase at 50 MHz. (X curve is rising)

But the losses (= R curve) are exploding at frequencies higher than 50 MHz.

Due to these effects the Quality factor Q must show a maximum

b) $Q = f(f)$



The maximum value is $Q = 119$ at $f = 30$ MHz

Marker 1	
Frequency: 30.6929MHz	Parallel L: 992.48 nH
Impedance: 1.606 +j191.4 Ω	Parallel C: -27.092 pF
Admittance: 22.8k +j191.4 Ω	VSWR: 487.19
Series R: 1.606 Ω	Return loss: -0.036 dB
Series L/C: 992.48 nH	Quality factor: 119.1
Series L: 992.48 nH	S11 Phase: 29.28°
Series C: -27.092 pF	S21 Gain: -89.908 dB
Parallel R: 22.8k Ω	S21 Phase: -75.65°
Parallel L/C: 992.48 nH	

c) In the Marker 1 window you find all interesting values for $f = 30$ MHz:

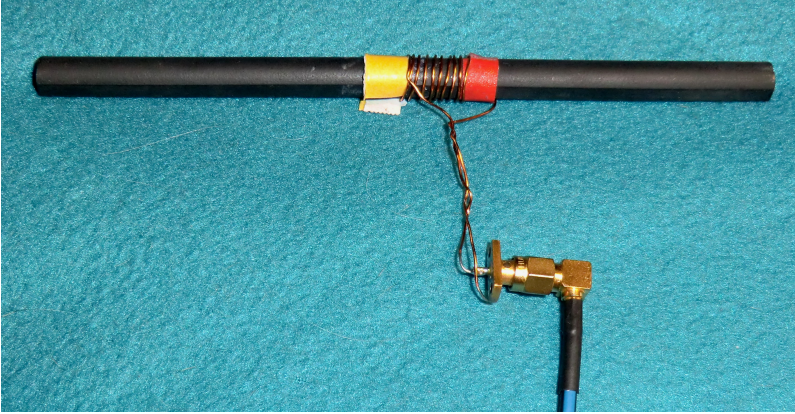
$R = 1.606 \Omega$

$L = 992.48$ nH

$Q = 119.1$

19. Ferrite Rod Antenna for VLF Experiments

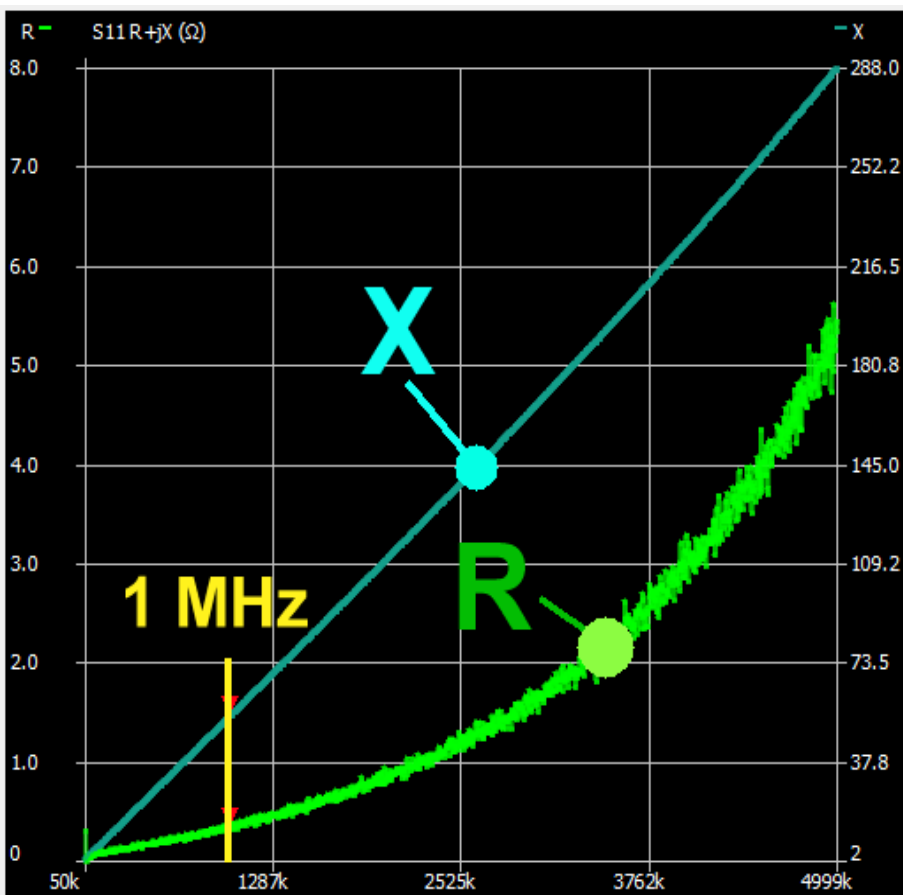
These antennas came with old valve radio sets and are a good choice for Very Low Frequency (= VLF) experiments in the range of a few Hertz up to 150 kHz or so. There you find signals of Submarine Communication, the „Schumann Resonances of the Globe“, Time and Frequency Standard Transmissions like DCF77 and so on.



You can determine every property of such a ferrite rod using your NanoVNA.

Simply use 10 turns of enameled copper wire (diameter = 0.5 mm), connect the two ends to an SMA socket and connect it to the NanoVNA.

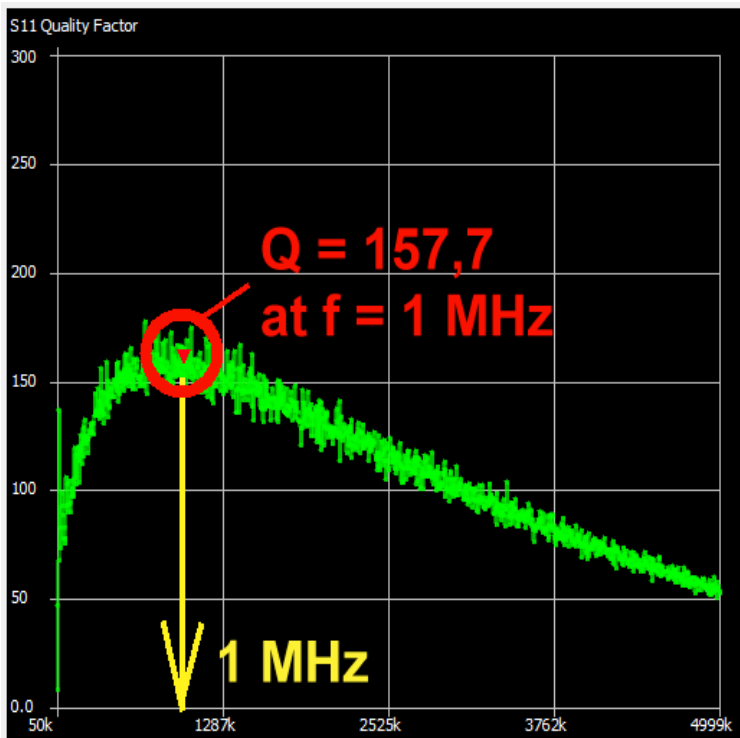
At first create a new **Calibration File** for the frequency range from **50 kHz up to 5 MHz and 20 segments**. Save this file under a new name and load it.



Now sweep **S11** and examine **R** and **X** for this frequency range.

R is low up to **1...1.5 MHz**. Then follows an **exponential rise**. This will **dramatically reduce the quality factor Q**.

(Now you recognise that **0...1600 kHz** was the used frequency range of the antenna when operating in a MW radio)



The decrease of Q in the upper range is presented in this diagram.

But Q = 157.7 at f = 1 MHz is a good result...

Marker 1	
Frequency: 1.00151MHz	Parallel L: 8.6244 μ H
Impedance: 0.344 +j54.27 Ω	Parallel C: -2.9282 nF
Admittance: 8559.0 +j54.27	VSWR: 316.485
Series R: 0.344 Ω	Return loss: -0.055 dB
Series L/C: 8.6244 μ H	Quality factor: 157.7
Series L: 8.6244 μ H	S11 Phase: 85.31 $^\circ$
Series C: -2.9282 nF	S21 Gain: -80.696 dB
Parallel R: 8559.0 Ω	S21 Phase: -9.18 $^\circ$
Parallel L/C: 8.6244 μ H	

Marker 1 at f = 1 MHz delivers all interesting information.

Using

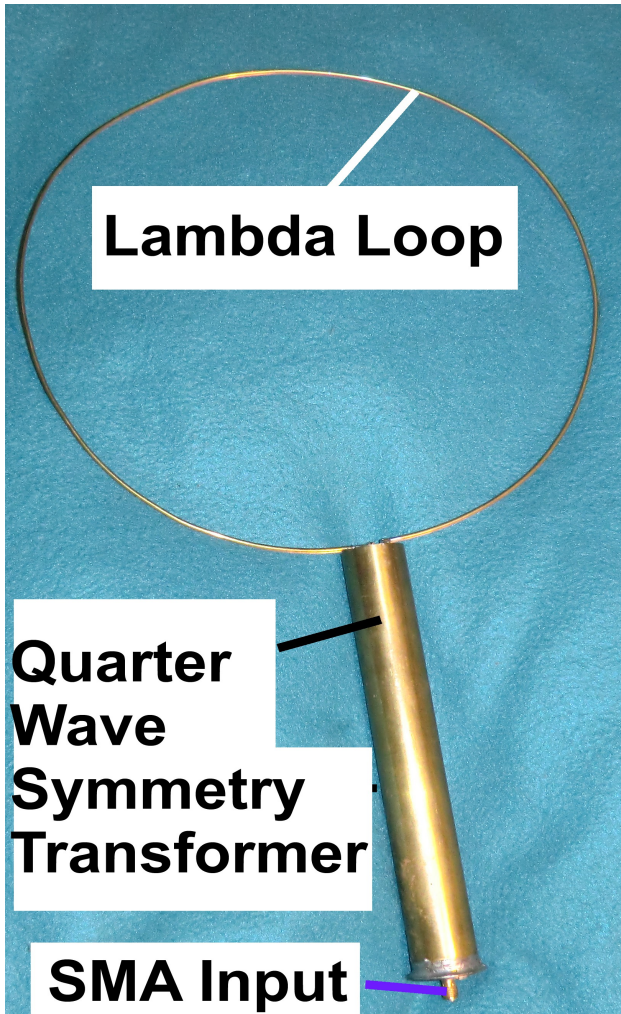
L = 8.6244 μ H and N = 10 turns

gives an „AL-factor“ of $AL = L / N^2 = 8622.4 \text{ nH} / 100 = 86.22 \text{ nH}$

Attention:

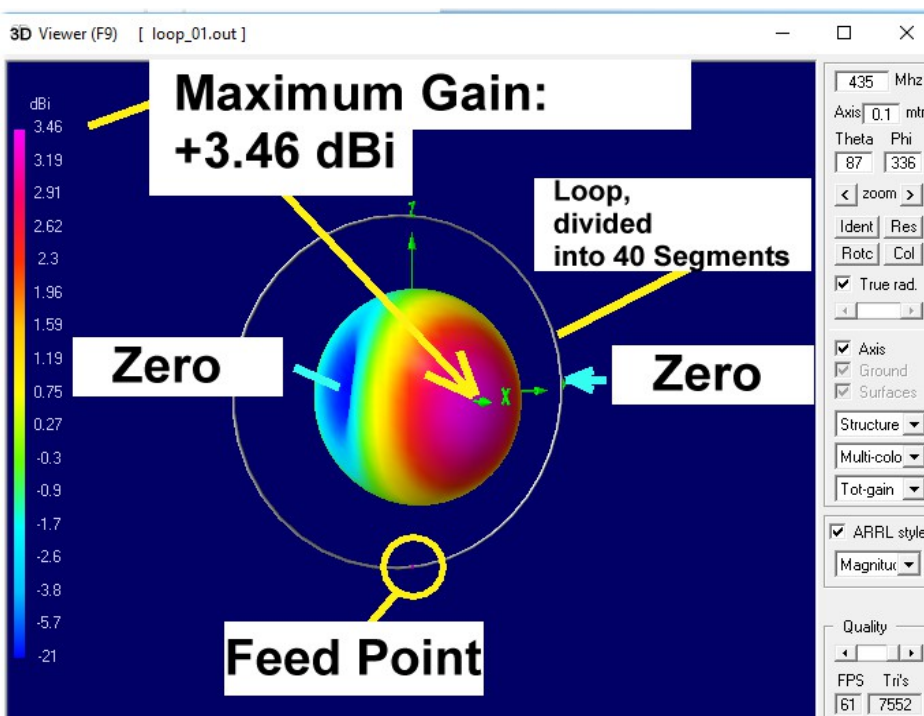
Due to fringing effects of the magnetic flux the inductance for **other turn values** will vary and not strictly follow the formula „ $L = AL \times N^2$ “. It is better to choose the turns given by the formula for a desired inductance and to test the result with your NanoVNA. Then do a correction of the turn number and measure again.

20. Lambda Loop Antenna for the 70cm - Band



This antenna consists of a wire with a diameter of 2mm and a length equal to the wavelength of a signal with $f = 433 \text{ MHz}$ ($\lambda = 693 \text{ mm}$). The wire forms a circle (diameter = 220 mm).

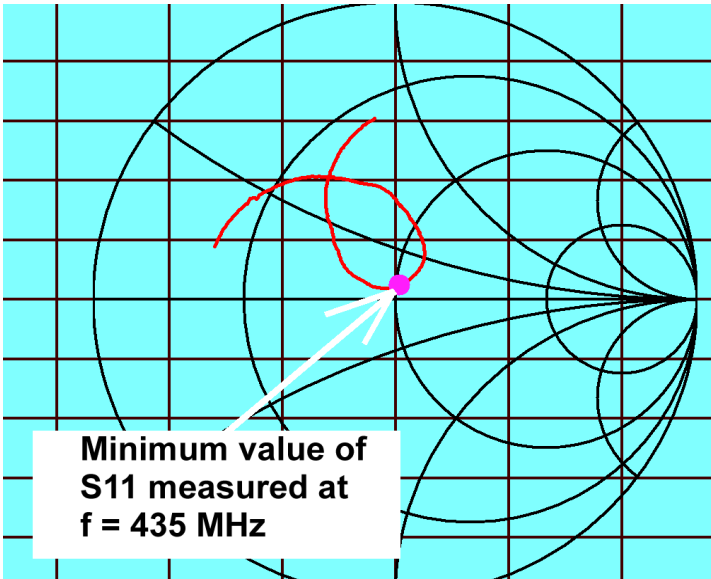
We need an impedance matching transformer which includes symmetric output for the antenna but unsymmetric operation at the SMA input socket. This is done by an arrangement using quarter wave coaxial lines.



This is a 4NEC2 simulation of the 3D radiation pattern.

Maximum gain is approx. 3.5dBi.

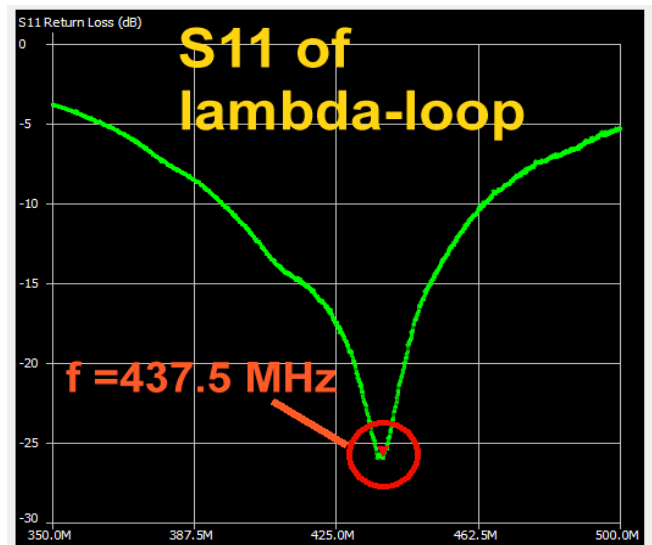
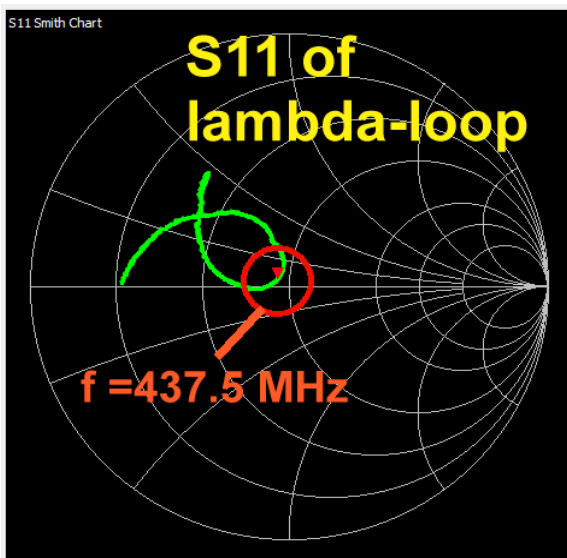
Measured S11 at the Input Socket:



Result for the VNWA3.

It is the same as for a professional measuring set (hp8410B + hp8620 +hp8745A)

Results for the NanoVNA (f = 350.....500 MHz):



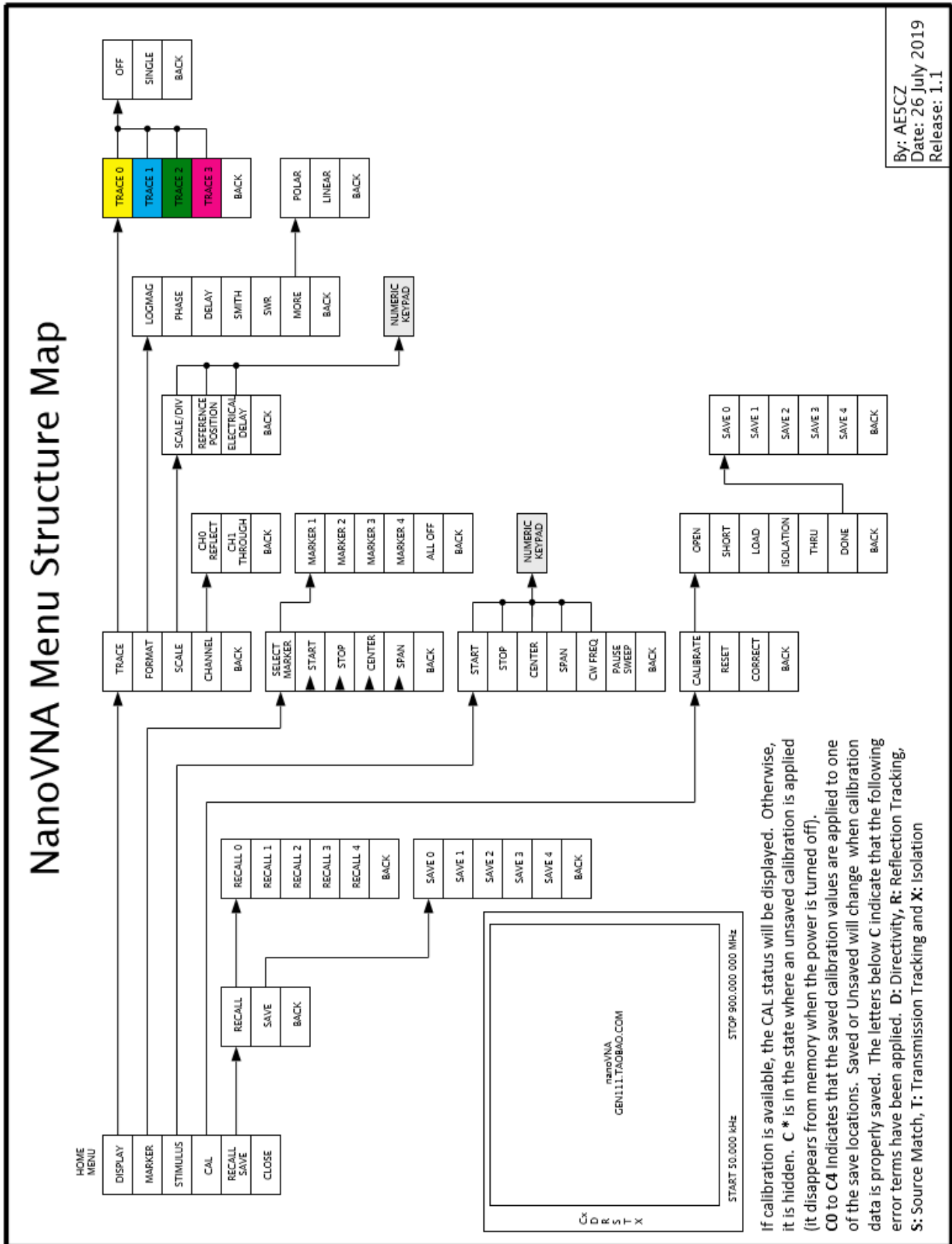
Marker 1

Frequency: 437.562MHz	Parallel L: 319.14 nH
Impedance: 45.77 +j2.394 Ω	Parallel C: -414.56 fF
Admittance: 45.9 +j877.4 Ω	VSWR: 1.107
Series R: 45.77 Ω	Return loss: -25.895 dB
Series L/C: 870.77 pH	Quality factor: 0.052
Series L: 870.77 pH	S11 Phase: 149.05°
Series C: -151.93 pF	S21 Gain: -55.417 dB
Parallel R: 45.9 Ω	S21 Phase: -23.4°
Parallel L/C: 319.14 nH	

Marker 1 is the source for further information at 437.5 MHz

C): Standalone operation

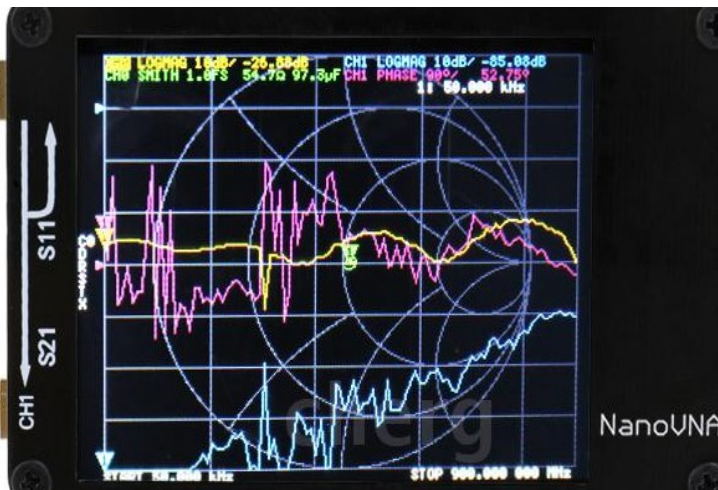
21. Operator menu for the NanoVNA



22. Familiarisation with the device

First, make sure that both RF inputs are open and switch on. If the battery is missing power the NanoVNA via the USB cable supplied connected to a laptop or PC. The computer must be turned on to provide the +5V we need for a power supply.

Unfortunately, nothing happened for me, no LED lit after switching the power switch on and the screen remained dark. This signalled the first rework because the USB C socket on the board was poorly made so that when the cable was plugged in there was no contact. It was reworked carefully by bending the tiny PCB inside the socket until it was exactly central AND the metal sheath of the shield ensured a snug fit for the plug. Do not forget to test that turning the plug through 180 degree also makes contact.



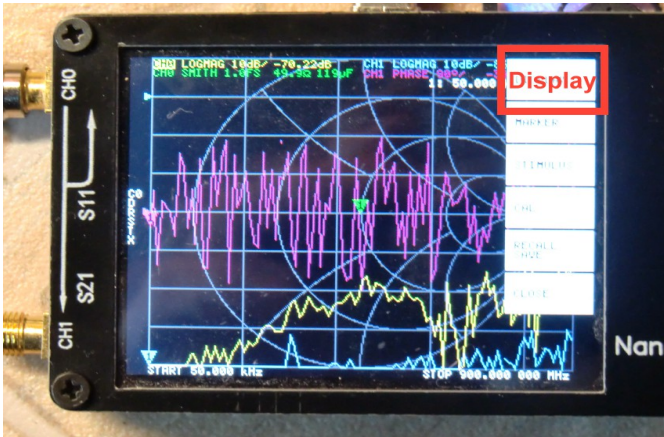
Now it really shows life (the Battery LED flashes blue).

Fit the LOAD resistor on the TX output (Channel 0).

As shown in the picture, **three differently coloured curves and a Smith Chart** are displayed on the NanoVNA screen.

The corresponding information text is tiny with this small screen size but everyone has to see how they gets along with it (I've been working for a long time, for example, soldering using a stereo magnifier).

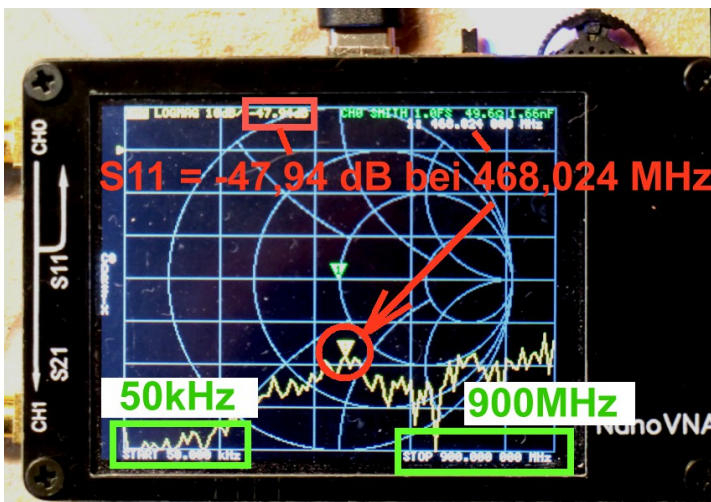
23. The first successful measurement: LOAD properties



Leave the LOAD resistor on the TX port and tap on the screen with your finger or a "stylus" ("Stylus" = pen with rubber cap or a pencil fitted with small eraser).

This opens the main operator menu on the right edge of the screen giving access to the four curves by tapping on **"Display"** then on **"Trace"**. Select the purple curve first and tap **"OFF"**. In the same way the blue curve at the bottom of the display can be removed.

The screen should now only show S11 in the Smith Chart and Cartesian form from 50kHz to 900MHz.



Now press the **Multi Function Switch (MFS)** to the right and hold it there. The marker moves from the start at 50kHz towards the higher frequencies. Try $f = 468\text{MHz}$, it will show 468.042MHz. The display has a scale on the left hand side with 10dB divisions as well as the top "Zero dB point".

The S11 data ("LOGMAG") for the Cartesian curve fluctuates around -47dB. But it will only be the result for the very first measurement displayed.

The Smith Chart only shows one marker for such a small reflection this is in the centre of the chart (50Ω). The corresponding series connection for the input impedance at 468MHz is shown on the top, far right as:

49.5 Ω in series with 1.7 to 4 Nanofarads

No wonder there is such a big spread. With such small voltage levels and the noise that can be seen. Because this noise increases with frequency it is better to use the middle of the S11 curve to estimate from the Cartesian diagram.

Task:

Move the marker (by pressing the MFS to the left) to 144MHz and determine the S11 values there.

24. The sweep options

The main menu has an option "**Stimulus**". When this is chosen there are the following options:

- a) Using "**Start**" and "**Stop**" we sweep over the chosen range
- b) Using "**Centre**" and "**Span**" we select a certain centre frequency as well as a span around this centre frequency
- c) Using "**CW Freq**" a fixed frequency is used.

Finally there is the option to switch between "**Pause**" and "**Sweep**"

24.1. Start-stop - operation

101 frequency points are always used. If the range of **460MHz to 470MHz** is required:

Step 1: Open the "Stimulus" menu

Step 2: Tap on "**Start**" followed by a tap on the **right edge of the box showing the displayed frequency (right bottom corner of the screen)**. This will open a small keyboard to enter the new starting frequency as "**460.0M**"

Step 3: Do the same again for the **stop frequency** but enter "**470.0M**"

Finished!

24.2. Centre / Span operation at 465MHz

Step 1: Open the "Stimulus" menu

Step 2: Tap on "**Center**"

Step 3: Enter the frequency "**465.0M**"

Step 4: Tap on "**Span**"

Step 5: Enter the frequency "**5M**"

Step 6: Check if it the sweep starts at **462.5MHz** and stops at **467.5MHz**

24.3. CW operation at 465MHz

Step 1: Open the “**Stimulus**” menu

Step 2: Tap on "**CW Freq**"

Step 3: Enter the CW frequency “**465M**”

Step 4: Check the result on the screen

25. Calibration

Important:

Everything practised so far would not provide accurate results and would be **meaningless without a prior calibration.**

So if the frequency range changes, calibration should be carried out IMMEDIATELY!

What does calibration involve:

a) A maximum of **five different calibrations (C0 to C4)** can be stored.



b) The currently active calibration will be shown in the middle of the left hand display border displayed as shown in the picture.

At switch on the data from C0 is automatically used

When the device is purchased a **factory calibration can be found in C0 from 50kHz to 900MHz**. With the maximum possible number of frequency points being 101 it is very coarse (step size about 9MHz). In addition it was not done with the "SOLT" (SOLT = Short / Open / load / through).components therefore it is **not perfect fit**.

The first thing to do is a basic calibration of the NanoVNA.

If you want to make measurements over a narrower frequency range (e.g. an antenna or bandpass filter), then **extra calibrations are required** with the results stored in one of the memory locations C1 to C4. These can be selected next time the associated frequency range is used and the calibration data will be setup automatically.

Before a practical example is explained take a closer look at the information on the left side of the screen. This should be checked before taking an important measurement to make sure that everything is activated. When the NanoVNA is switched on the data in memory C0 is used to activate "Error Terms" stored from a previous calibration determined. These are:

- C0** (default calibration data)
- D** (Directivity)
- R** (Reflection tracking)
- S** (Source Match)
- T** (Transmission Tracking) X (Isolation)

Note:
The topic is explained well in the Application Note

NanoVNA RF Calibration Considerations and Procedure

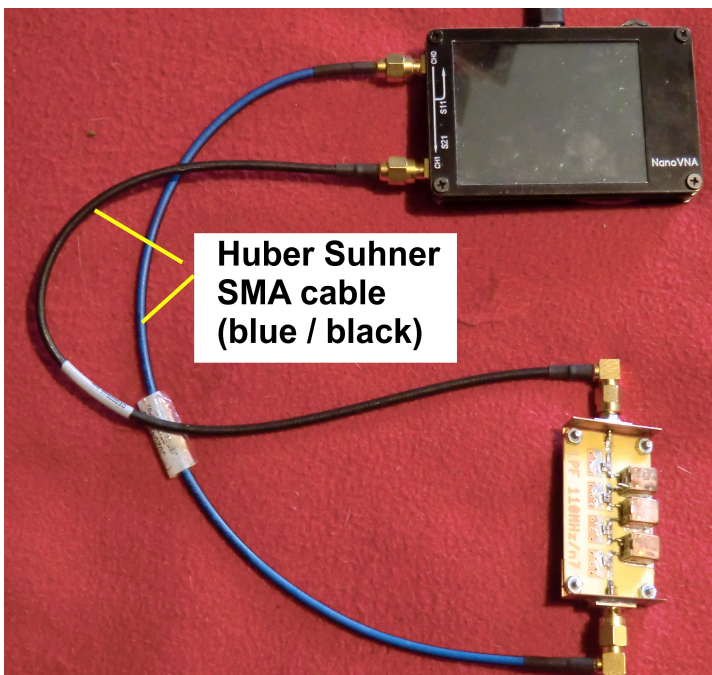
This can be found on The Internet. It is worth downloading!

26. Using measuring cables

The SMA sockets on the NanoVNA should always be protected from damage using one of these two options (changing a socket on the board in case of damage is a very delicate mission):

a) Fit an **SMA Male to Female adaptor** onto each socket using the suggested torque (torque spanners are available on The Internet). This means that the measuring cables only come in contact with these adaptors that would be easy to change if required.

b) As already mentioned, the **two SMA cables included in the kit** can cause trouble. Not only is their characteristic impedance not quite correct (54Ω instead of 50Ω as measured with a time domain reflectometer) and an SMA connector just dropped off one of mine!. This was because the crimping of the plug onto the cable was poor. The result of calibration is often meaningless until this is known



The solution is to purchase and to use **two very high quality cables (Huber Suhner with blue black outer), they are specified to 18GHz**. They should be permanently attached to the NanoVNA.

They can often be found by looking under all the tables at the HAM Radio flea markets.

27. SOLT calibration (50kHz to 900MHz) for C0 memory

1) Start the NanoVNA and permanently connect the SMA cables to the two RF ports (CH0 and CH1)

2) Open the main menu (tap the screen) and select "DISPLAY" followed by "TRACE". Select the yellow curve "TRACE 0" and then "SINGLE". Select "BACK". then tap on "FORMAT" then "LOGMAG"

3) Do the following actions for Trace 1: BACK / DISPLAY / TRACE / TRACE 1 then FORMAT and LOGMAG



Then the screen should look like this screen shot.

CH 0 = yellow curve = S11

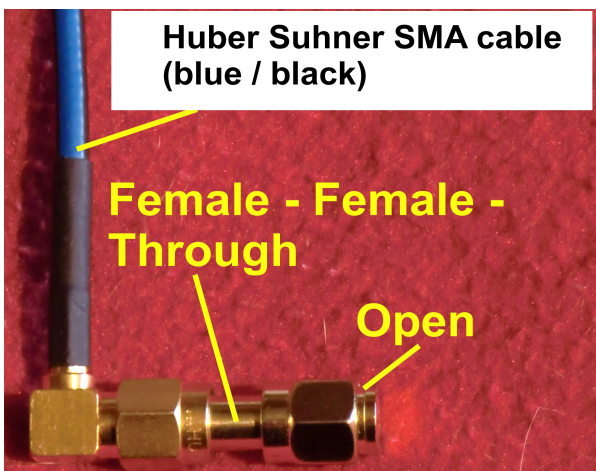
CH 1 = blue curve = S21

4) The **Start - Stop** settings required are:

50kHz to 900MHz

5) Start the calibration process with a reset so that all old calibration data is deleted: From the main menu (begins with "DISPLAY") tap **CAL** then tap on **RESET**.

6) The **CAL** menu also contains **CALIBRATE**, tap that option.



This opens a list that starts with **OPEN**. Attach the **SMA OPEN** calibration standard to the end of the cable connected to CH0 using the **Female to Female coupler**.

Tap on **OPEN** to start the calibration process. The next step continues with **SHORT** highlighted in green. Replace the "**OPEN**" standard with the "**SHORT**" standard and tap on **SHORT**. The next step continues with **LOAD** highlighted in green. Replace the "**SHORT**" with the "**LOAD**" standard and tap on **LOAD**.

Attention:

The manual recommends that, if possible, both inputs CH0 and CH1 should be terminated at the cable ends by 50 Ω.

This requires another Female to Female SMA adaptor and another terminator for CH1. This is the only way to get the last one little bit of accuracy.

The next step continues with ISOLATION highlighted in green. For this CH0 and CH1 should be terminated with 50Ω. Then tap on **ISOLATION**.

=====

The last step is **THROUGH** highlighted in green. For this the terminators are removed and both cable ends are connected using the **Female to Female adaptor**. Then tap on **THROUGH** to complete the calibration process.

=====

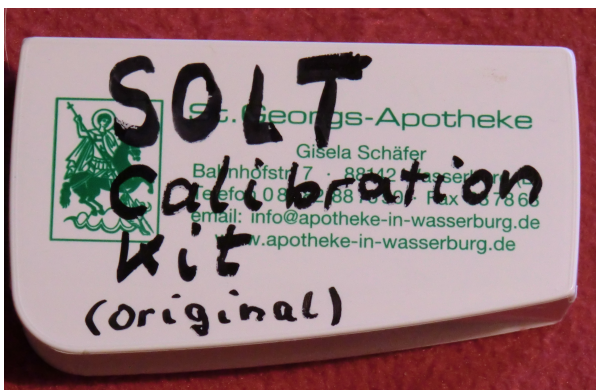
Finally tap "**DONE**" and store the result in **memory C0** with "**SAVE 0**". Now accurate measurements can begin.

To be absolutely sure, look at the left edge of the display to see if it shows the following:

C0/D/R/S/T/X

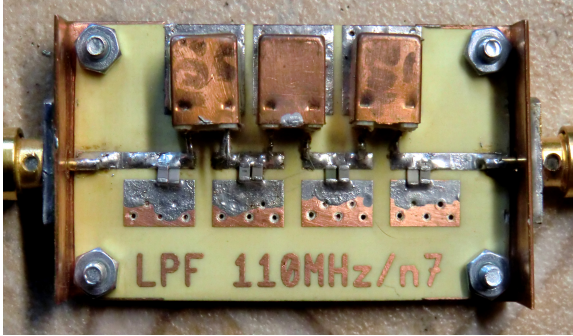
Then everything is OK.

Finally a practical tip for storing the SOLT standard kit:

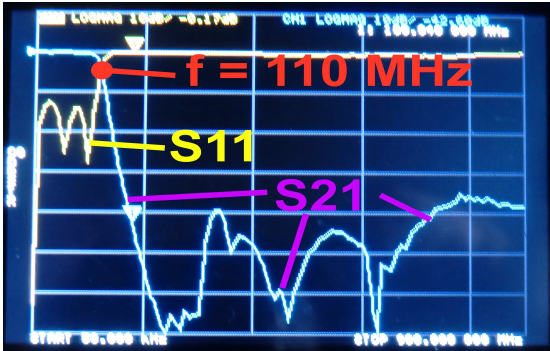


The empty pill box came as a small gift from my pharmacy. The letters "S", "O" and "L" have been **scratched on the standards using a needle**.

28. Example: A Chebyshev - low pass filter with $f_g = 110\text{MHz}$ and $N = 5$



Since the current calibration is from 50kHz to 900MHz this is a good object to measure. The picture shows the test piece. It is a printed circuit board with SMA connectors attached using right angle copper sheets. The inner conductors of the SMA connectors form a low reflection connection on the central microstrip.



As soon as the measuring cables are connected to the test piece this picture appears.

To take a closer look from 1MHz to 200MHz a SOLT calibration is required for that range:

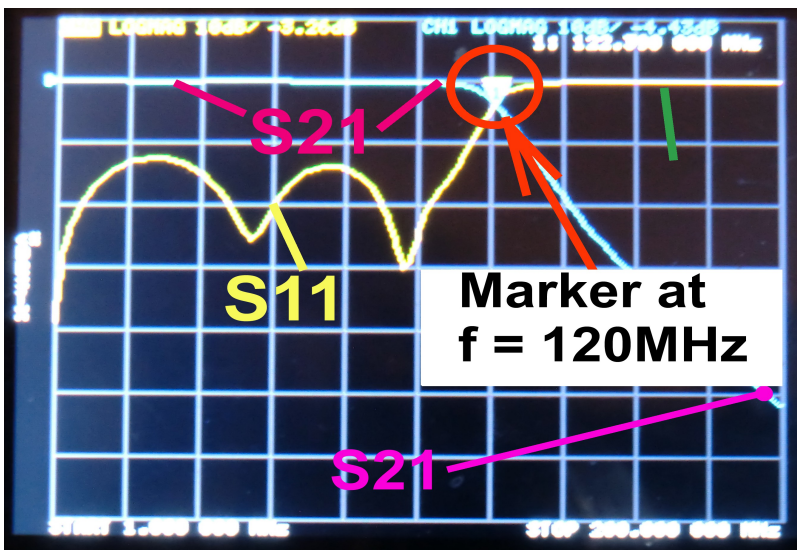
Step 1: Set the sweep range from 1MHz to 200MHz

Step 2: Check that CH0 and CH1 are on the "LOGMAG" display. If necessary switch off Trace 3 (= the Smith Chart).

Step 3: Open the main menu and then select **CAL / CALIBRATE**

Step 4: Carry out a complete SOLT calibration and save the result using **SAVE 4** in C4.

Step 5: Measure and admire the result.



Note: The frequency marker can be moved using the MFS rocker action either left or right. All the data is shown at the top of the screen.

29. Conclusions (good / bad / changes ...)

It is great: **a small, handy device with sufficient accuracy** for practical use.

Cheap price.

With a battery very handy for outdoor measurements directly on antennas.

Saves up to three older 19 inch devices (hp8410 / hp8745 / hp8620) on the work bench.

High frequency stability (0.5ppm). Absolute frequency accuracy approximately 2.5ppm

With a USB connection and the free software (NanoVNA-saver v0.2.2.-1.exe) from The Internet a PC can be used very comfortably to control the device and display the results on elaborate diagrams. It behaves like a big machine.

Then comes "Well, yes"

Very small screen with even smaller font size. Touch screen operation is not easy with a finger but better with a stylus. Better operation using a PC and the **program "NanoVNA-saver-v0.2.2-1.exe"**.

In standalone operation there are **only 101 measuring points**: this makes measuring filters difficult so careful consideration is needed for the sweep range selected. (this is no longer a criticism when using a PC)

The **Micro USB C connector** on the board is **a bit wobbly** and at first mine was unreliable. It required rework but works now fine.

The **SMA cables** supplied had a **wide tolerance (52....54Ω instead of 50Ω) and were poorly crimped**. In fact one connector fell off! High quality Teflon cables or, if necessary, Semirigid cables are recommended as replacements.

Difficult menu navigation using the NanoVNA screen compared to PC operation. It is often easier to go back to the main menu (starts with DISPLAY ..) using BACK to return and search from there for the desired option.

The **Multi Function Switch (MFS)** is a somewhat delicate device and requires very gentle use.

SOLT calibration data is not included with the purchase. This is now available for PC operation using the NanoVNA Saver software (thanks to Kurt Poulsen) as described in Part 2.