

DG8SAQ VNWA Tutorial

Experiments with the DG8SAQ VNWA and the SDR-Kits Test Board

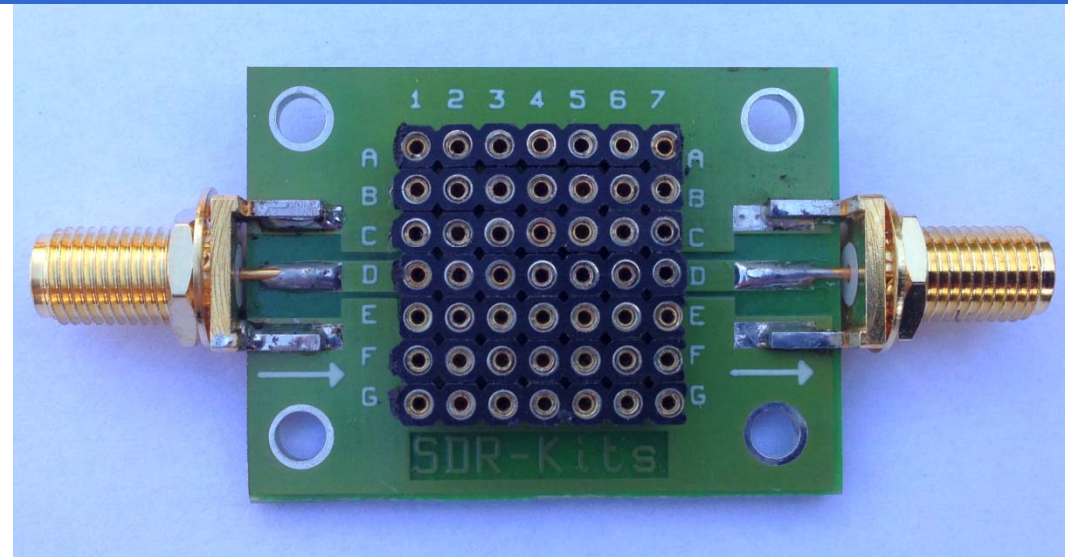
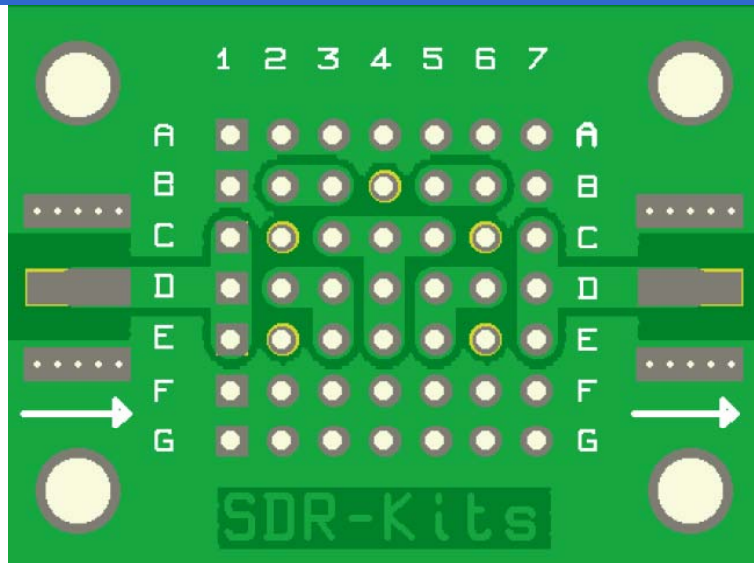
Tom BAIER

DG8SAQ

This is an excerpt from my Ham Radio 2013 presentation which has been slightly extended (slides 6, 20 and 21 added).

SDR-Kits

Test Board for HF Experiments



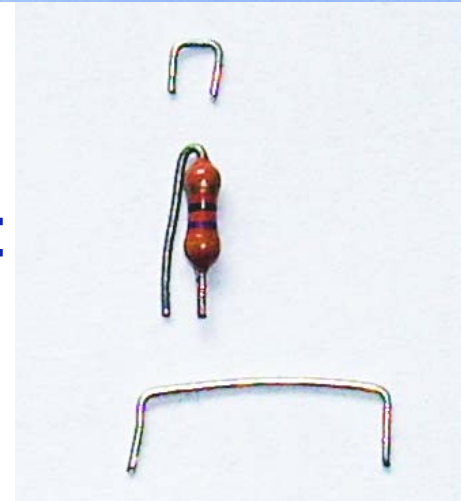
**Calibration
Standards:**

Open = n.c.

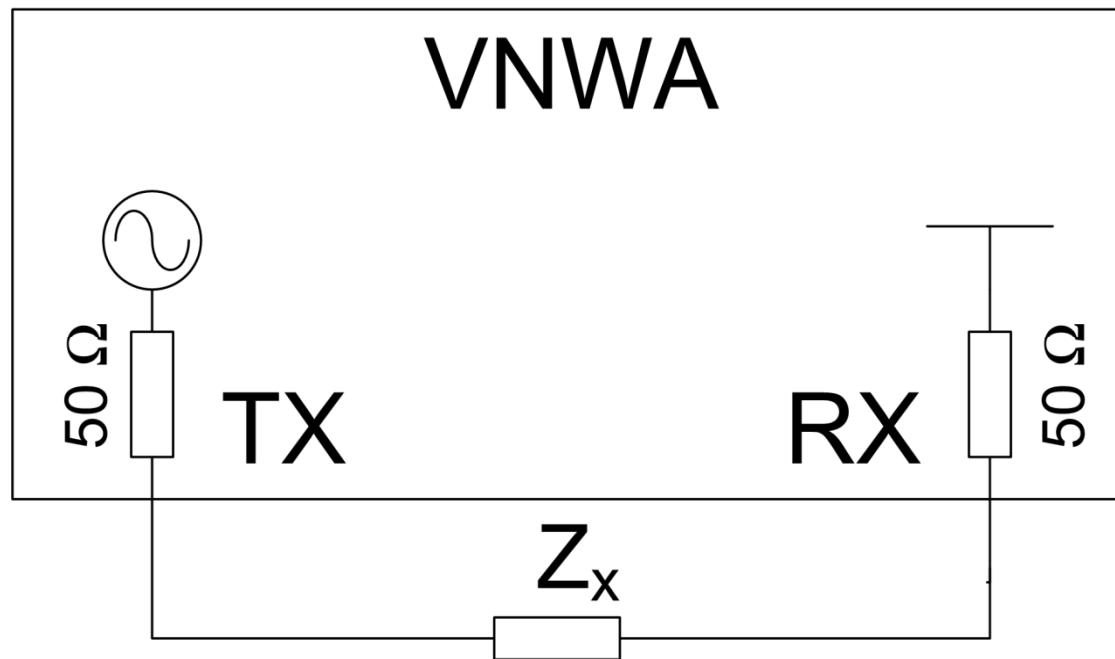
Short:

Load = 47Ω :

Thru:



Measuring „Load“-Resistor without SOL-Calibration?

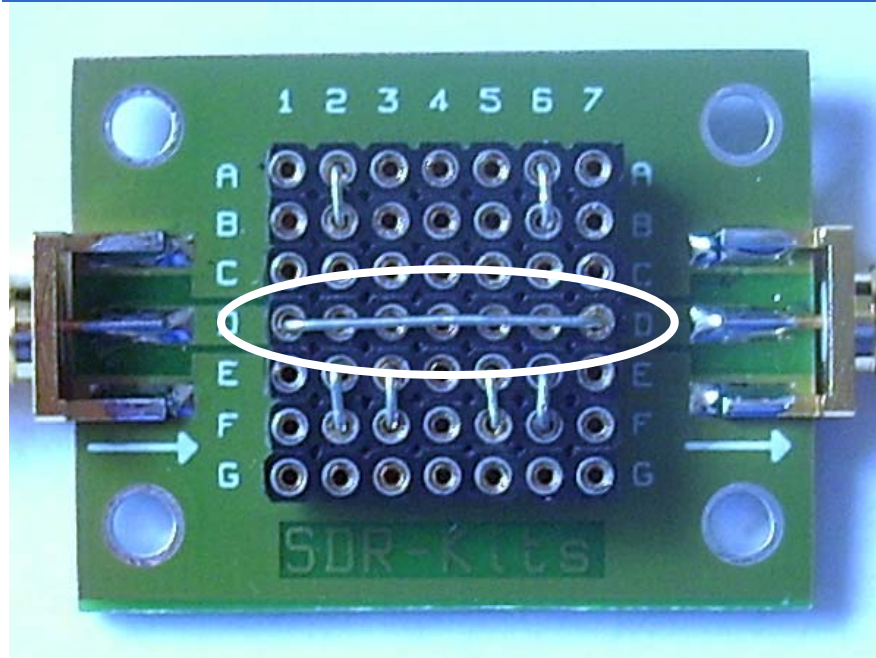


$Z_x = 47 \Omega$ yield $\approx 3,4$ dB insertion loss.

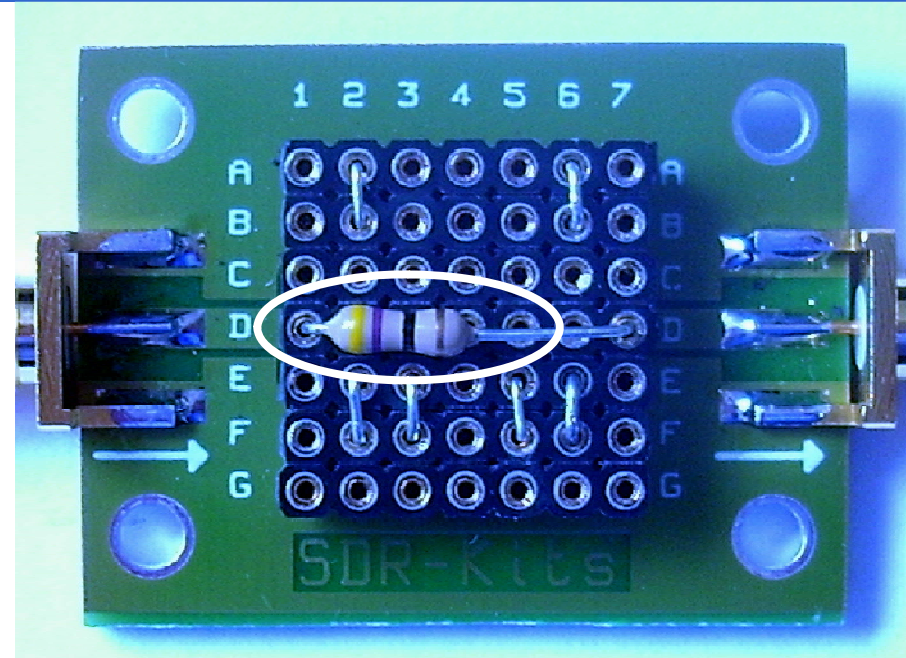
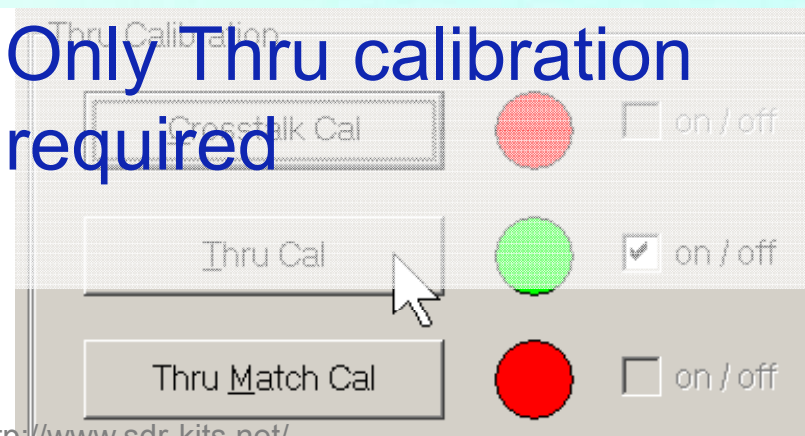
Works, because VNWA TX and RX port impedances are exactly 50 Ω .

➤ only Thru calibration required!

Measuring „Load“-Resistor in Transmission (= S_{21} -Measurement)



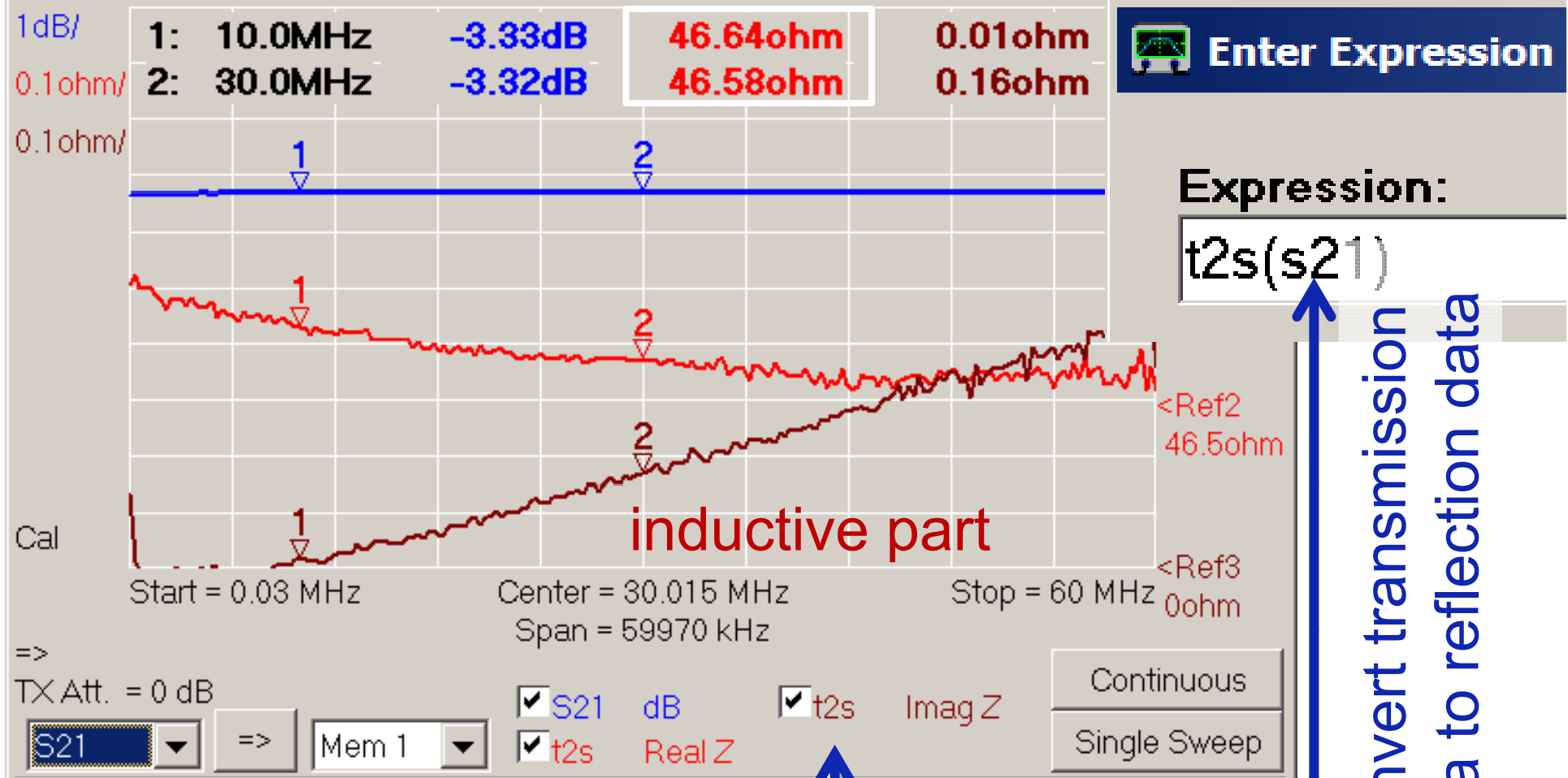
Only Thru calibration
required



Measurement:
Resistor between
TX and RX

Measuring „Load“-Resistor

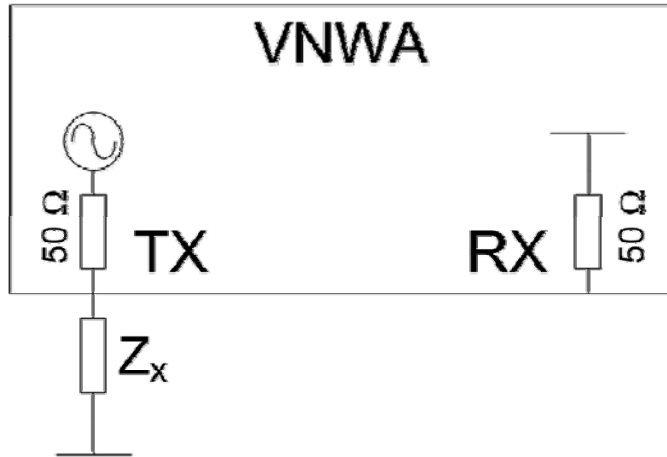
Result = 46,6 Ω



Convert transmission data to reflection data

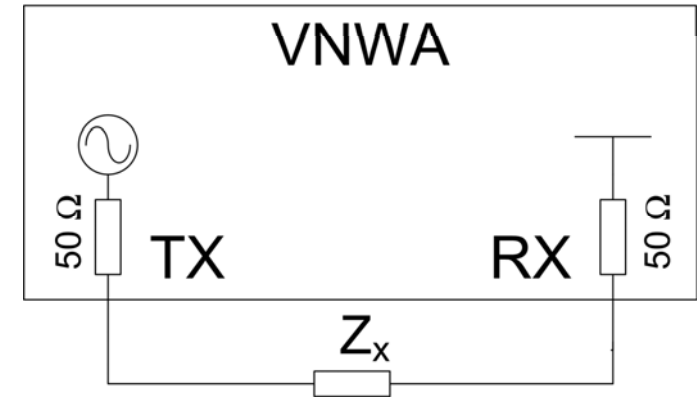
Analysis with Custom Trace

Reflection Data vs. Transmission Data



normalized
impedance:

$$z = \frac{Z_x}{50\Omega}$$



$$S_{11} = \frac{z - 1}{z + 1}$$

$$S_{21} = s2t(S_{11})$$



$$S_{11} = t2s(S_{21})$$

$$S_{21} = \frac{2}{z + 2}$$

These conversions can be performed with VNWA Custom traces.

Simple Calibration Standard Model: Only measured Load-Resistance

Calibration Settings

General Settings | Simple SOLT Model Settings | SOLT Simulation Settings | Special Settings

OSL Calibration Standard Setup

OPEN: Delay = ps => one way electrical length = 0.000 mm

SHORT: Delay = ps => one way electrical length = 0.000 mm

LOAD: R = Ohms C || = fF

Note: The Delays above are correction values, i.e. the NEGATIVE of the delays of the standards!

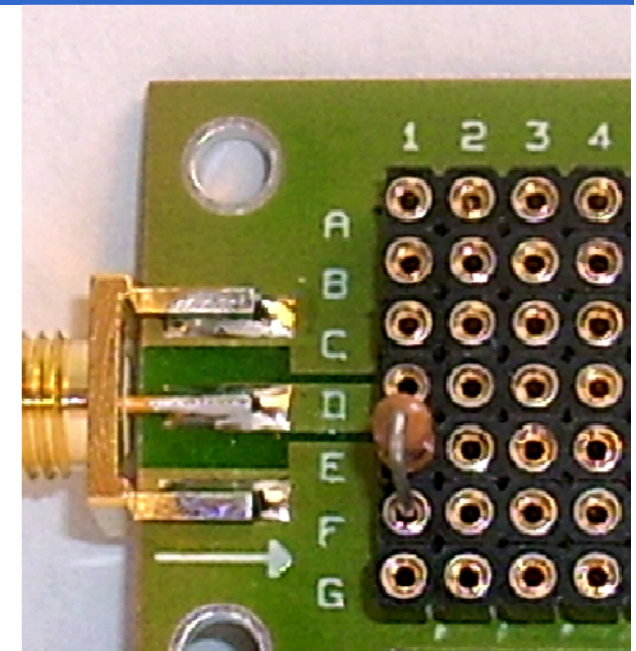
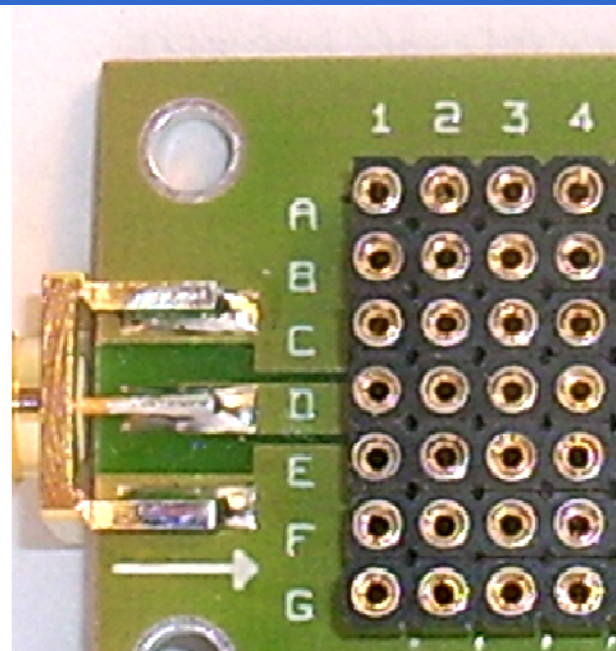
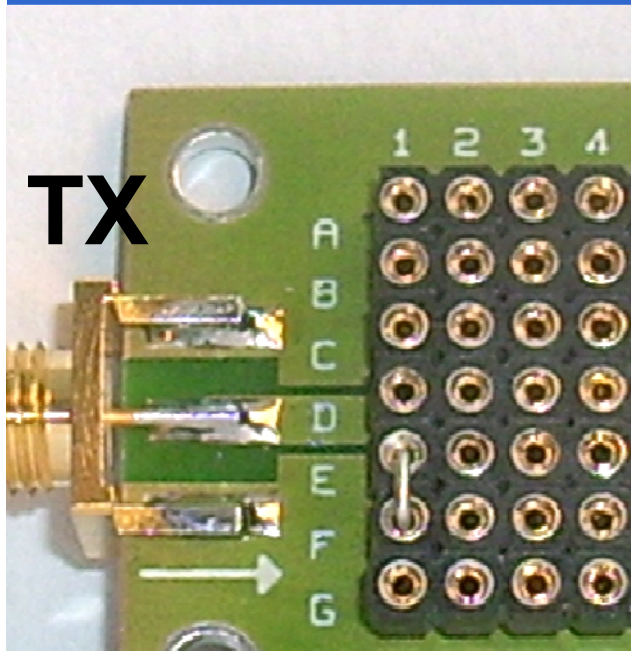
THRU Calibration Standard Setup

THRU: Transmission Factor = => attenuation = 0.000 dB

THRU: Transmission Delay = ps => electrical length = 0.000 mm

<http://www.sdr-kits.net/>

SOL-Calibration for S_{11} -Measurement



Reflect Calibration

Short 





<http://www.edron.it/soft/> 

Thru Calibration

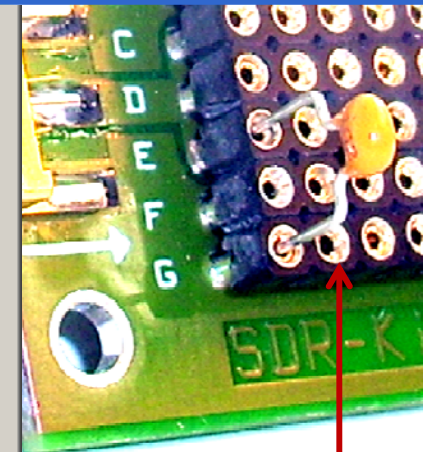
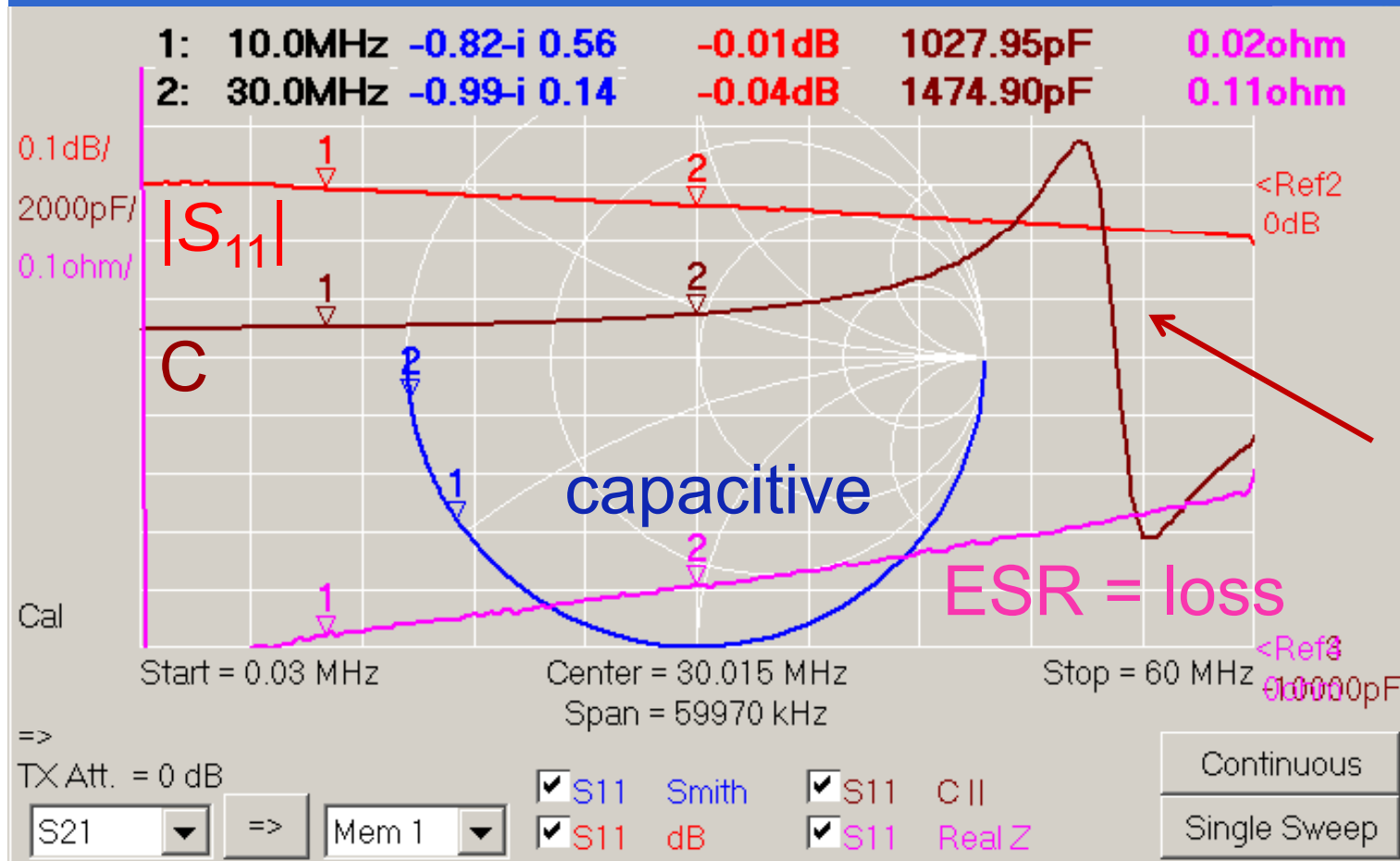
☐ on / off

 ☐ on / off

 ☐ on / off

Load

Reflexion Measurement (S_{11}) of a 1 nF Capacitor



Resonance due to component wires

Capacitor reflects almost total power, $|S_{11}| \approx 0$ dB

Modelling of Measurement Result in VNWA using Custom-Trace

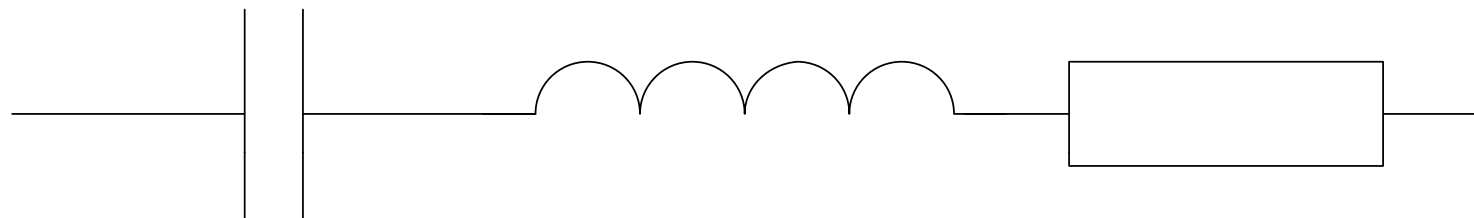


Enter Expression 2 for trace 2:

Expression:

Impedance to Reflecion coefficient

$z2s(1/(j*w*0.984e-9)+j*w*9.3e-9+0.22)$



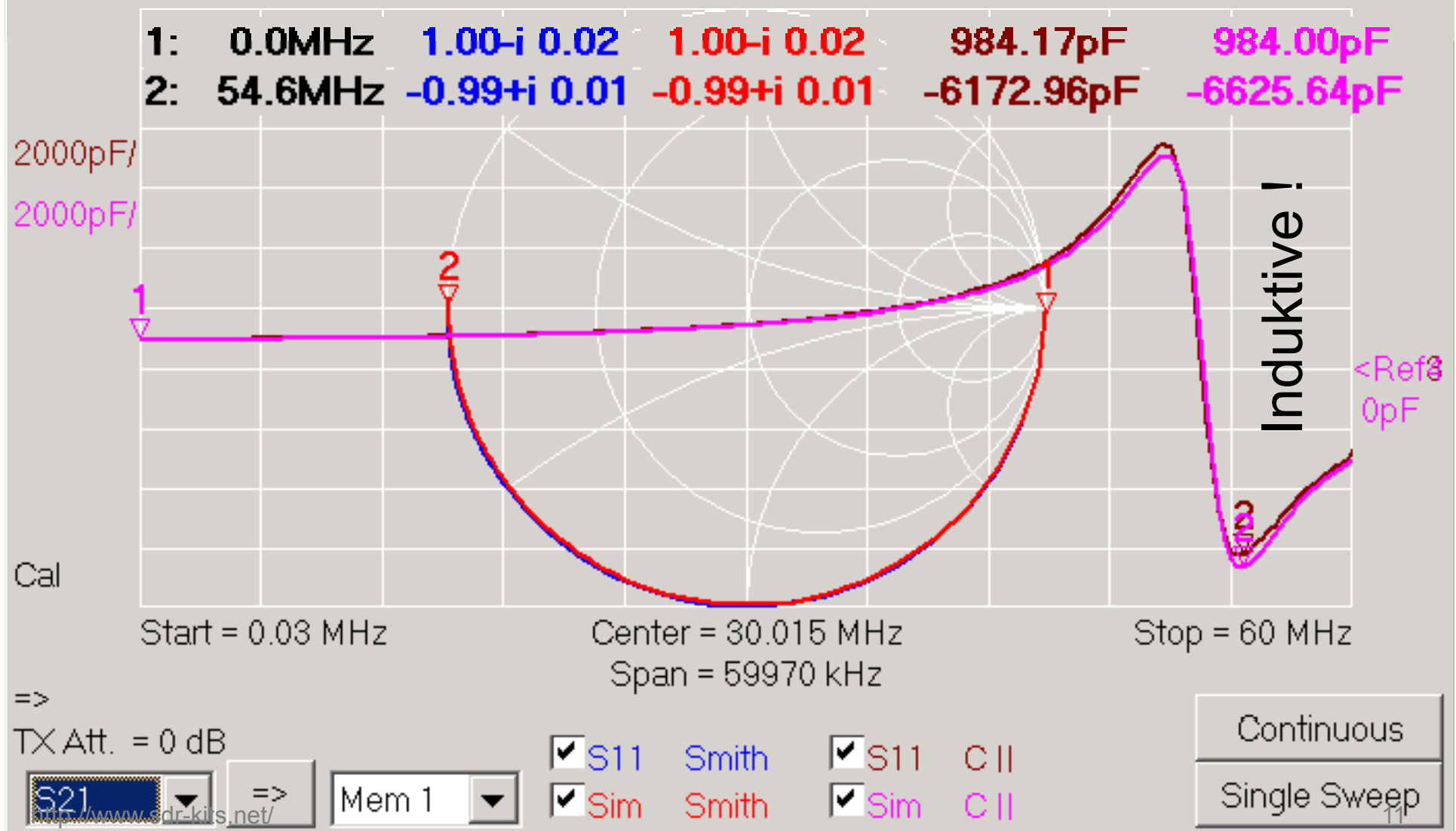
0,984 nF

9,3 nH

0,22 Ω

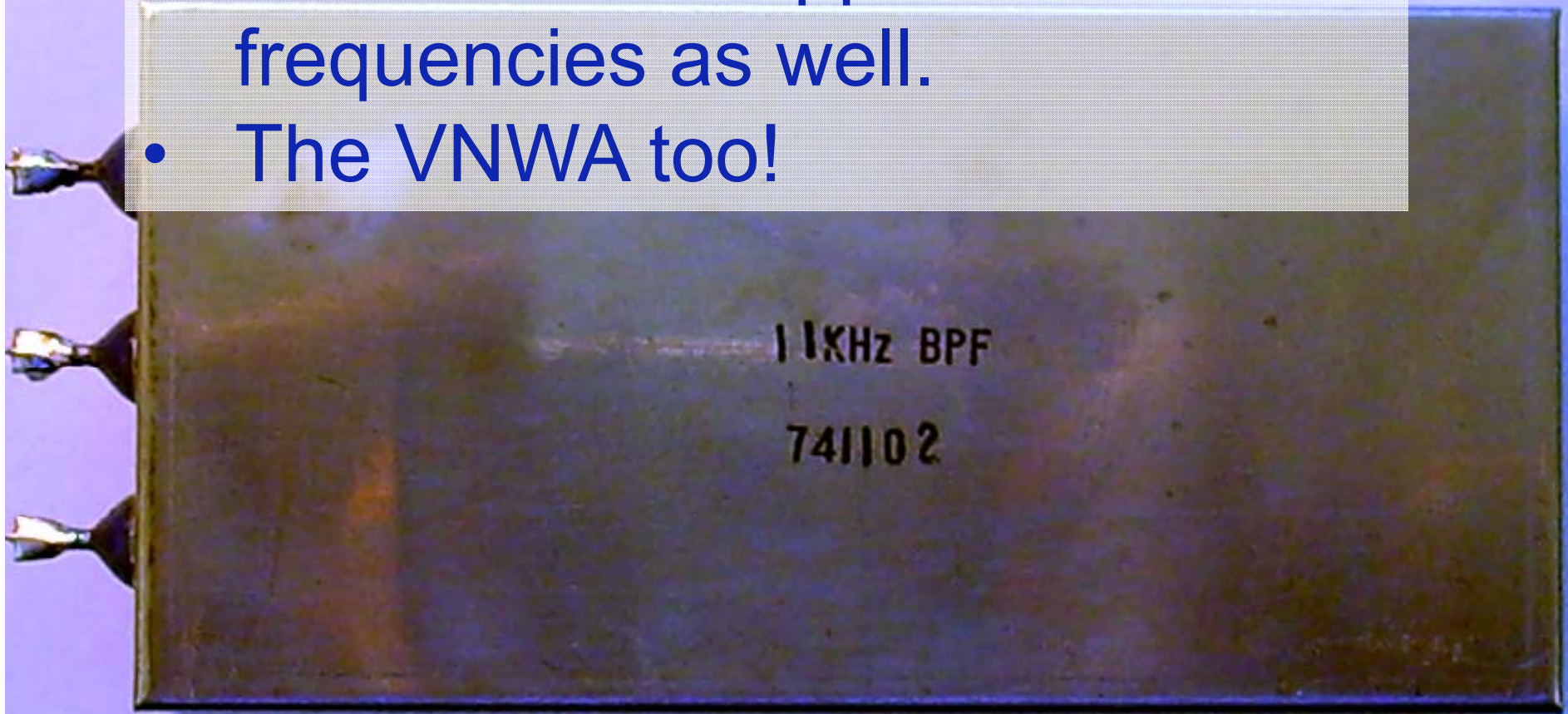
einfaches Modell

The Model is quite accurate!

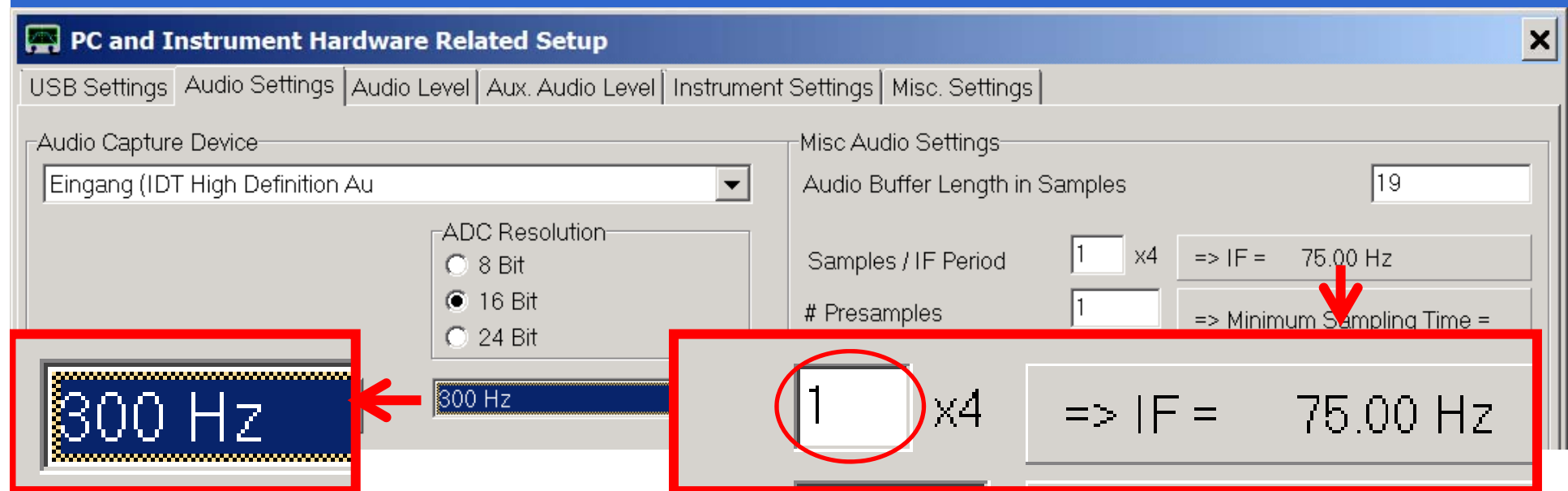


Two Port Measurement of a 12 kHz Band Pass Filter

- S-Parameters applicable to low frequencies as well.
- The VNWA too!



Special VNWA Settings for low Frequencies

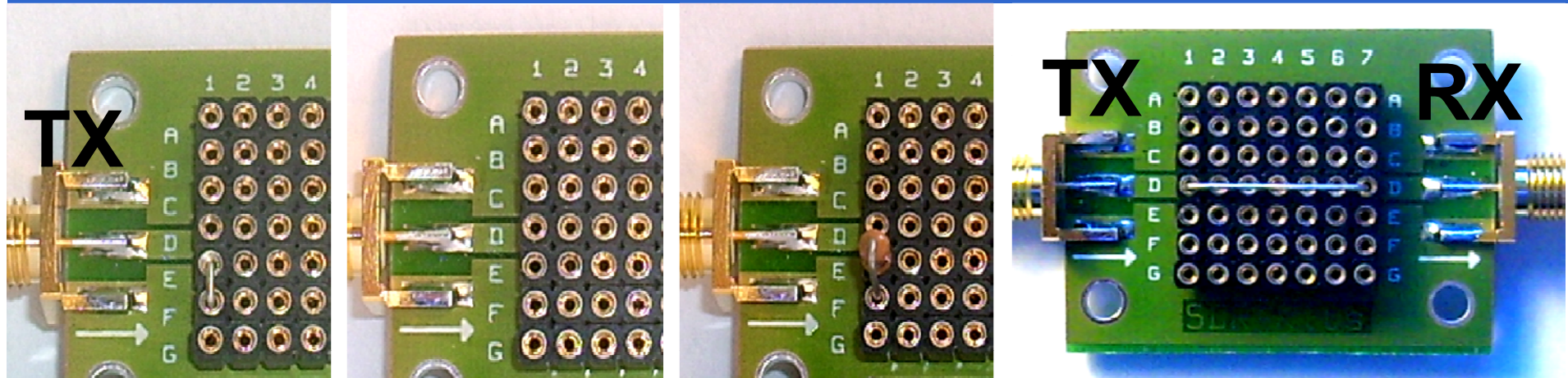


Lowest sample rate 300 Hz **IF must be within Codec frequency range (20 Hz...16kHz)**

→ **Nyquist limit 150 Hz**

→ **Measurements down to ≈ 150 Hz possible**

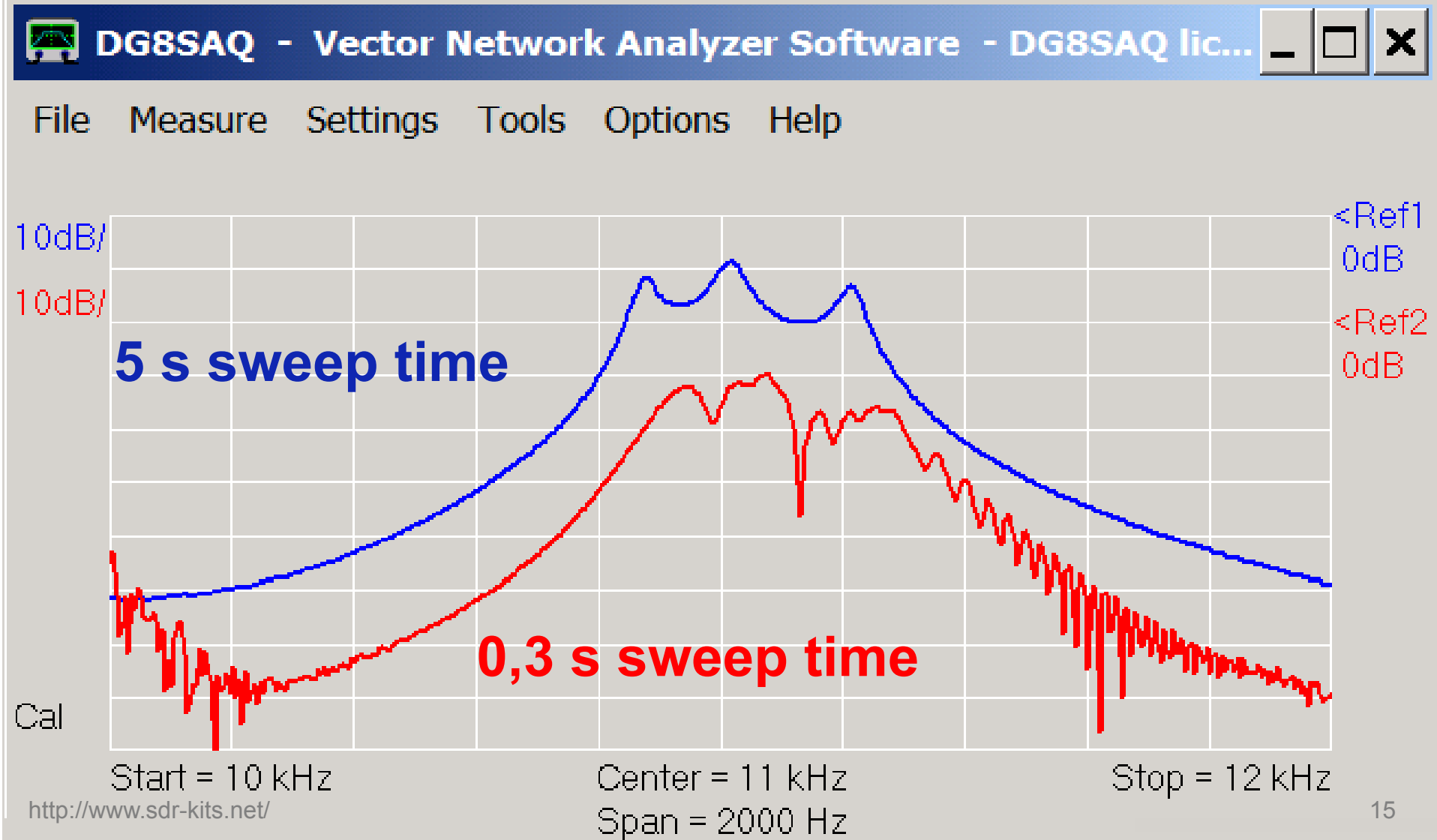
SOLT-Calibration for 2-Port Measurements



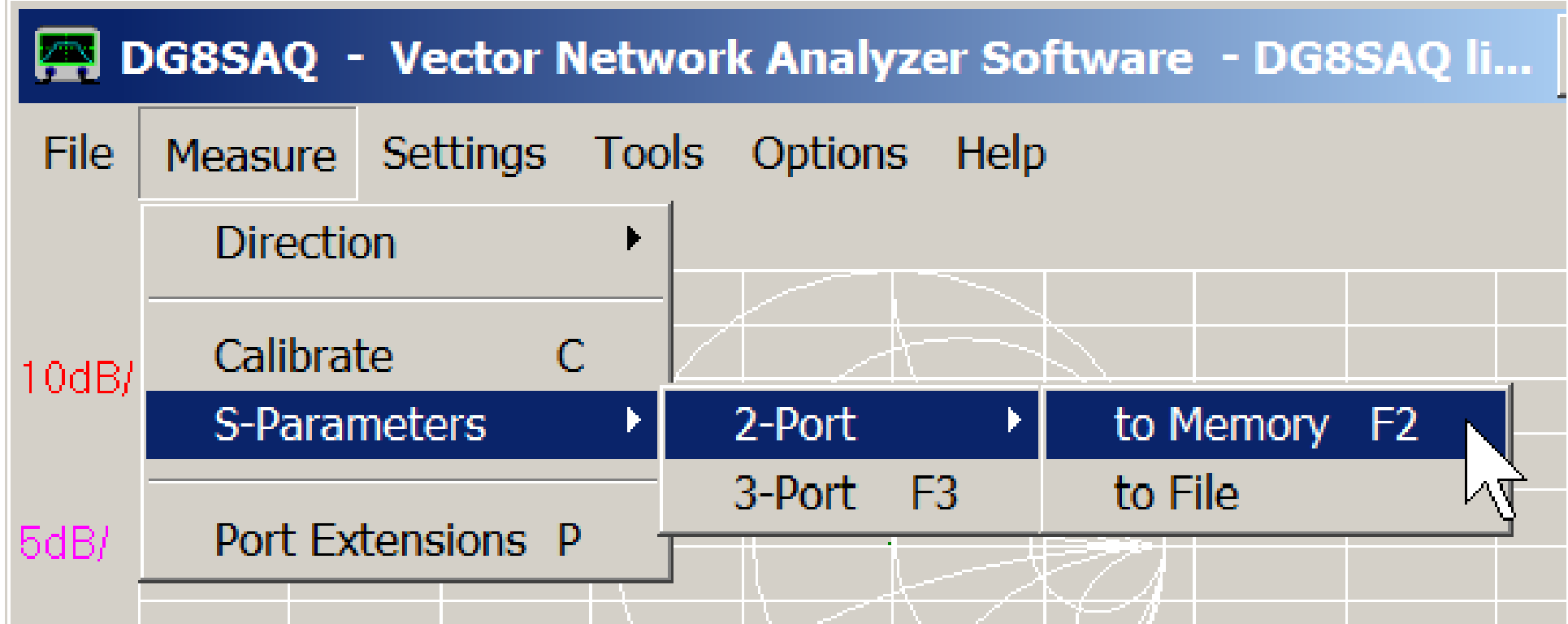
Reflect Calibration		Thru Calibration	
Short	Open	Load	Thru
<u>S</u> hort		<u>C</u> rosstalk Cal	☐ on / off
<u>O</u> pen		<u>T</u> hru Cal	☒ on / off
<u>L</u> oad		<u>T</u> hru <u>M</u> atch Cal	☒ on / off
Cal ☒ on / off		Invalidate All Thru Calibrations	

<http://www.sdr-kits.net/>

Beware: Steep Skirt Filters require Time to settle to changing Stimulus!

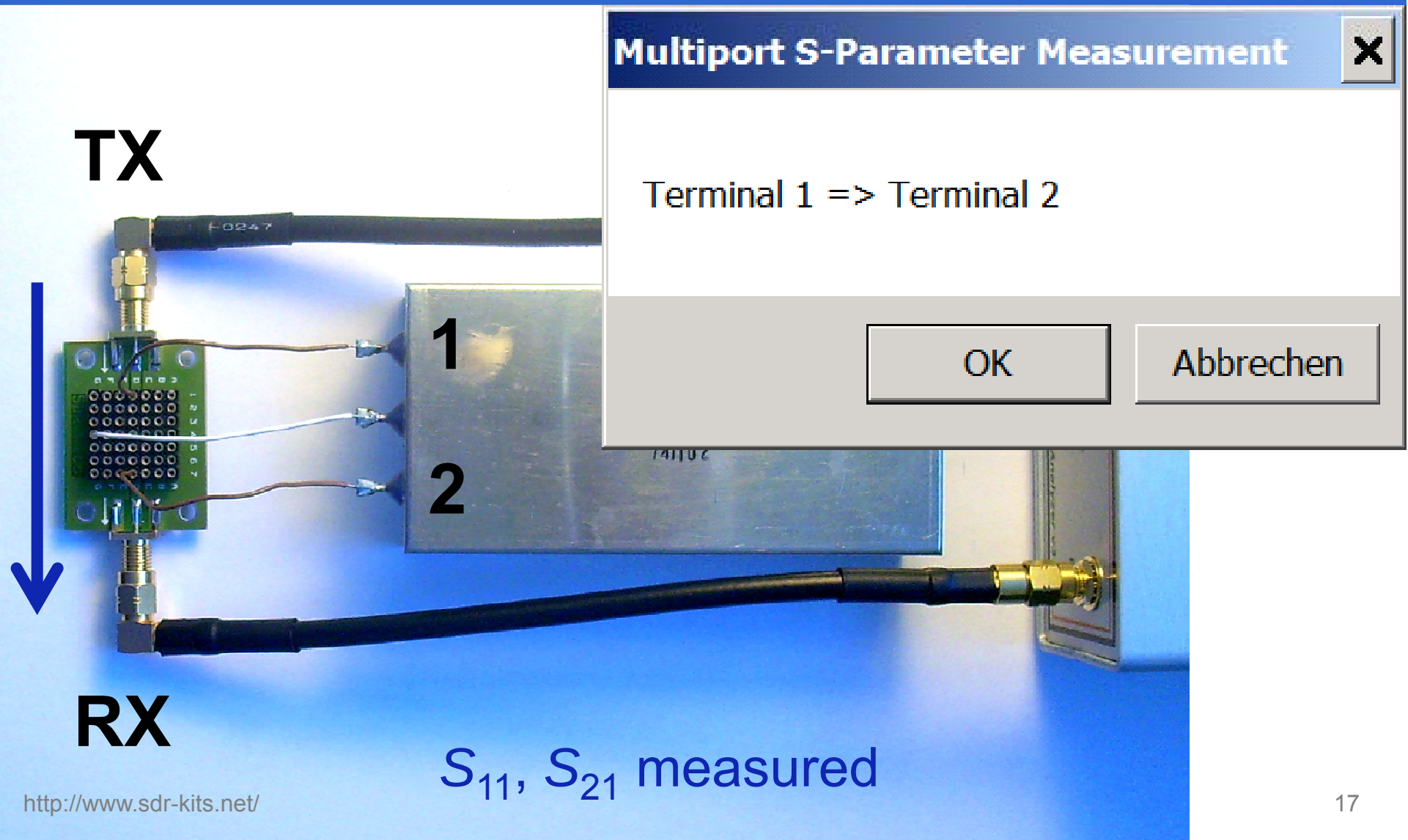


Two Port Measurement of a 12 kHz Band Pass Filter



We need to measure all four S-parameters (S_{11} , S_{21} , S_{12} , S_{22}) ...

Two Port Measurement of a 12 kHz Band Pass Filter: Forward Measurement



Two Port Measurement of a 12 kHz Band Pass Filter: Reverse Measurement

Multipoint S-Parameter Me

Terminal 2 => Terminal 1

OK

2

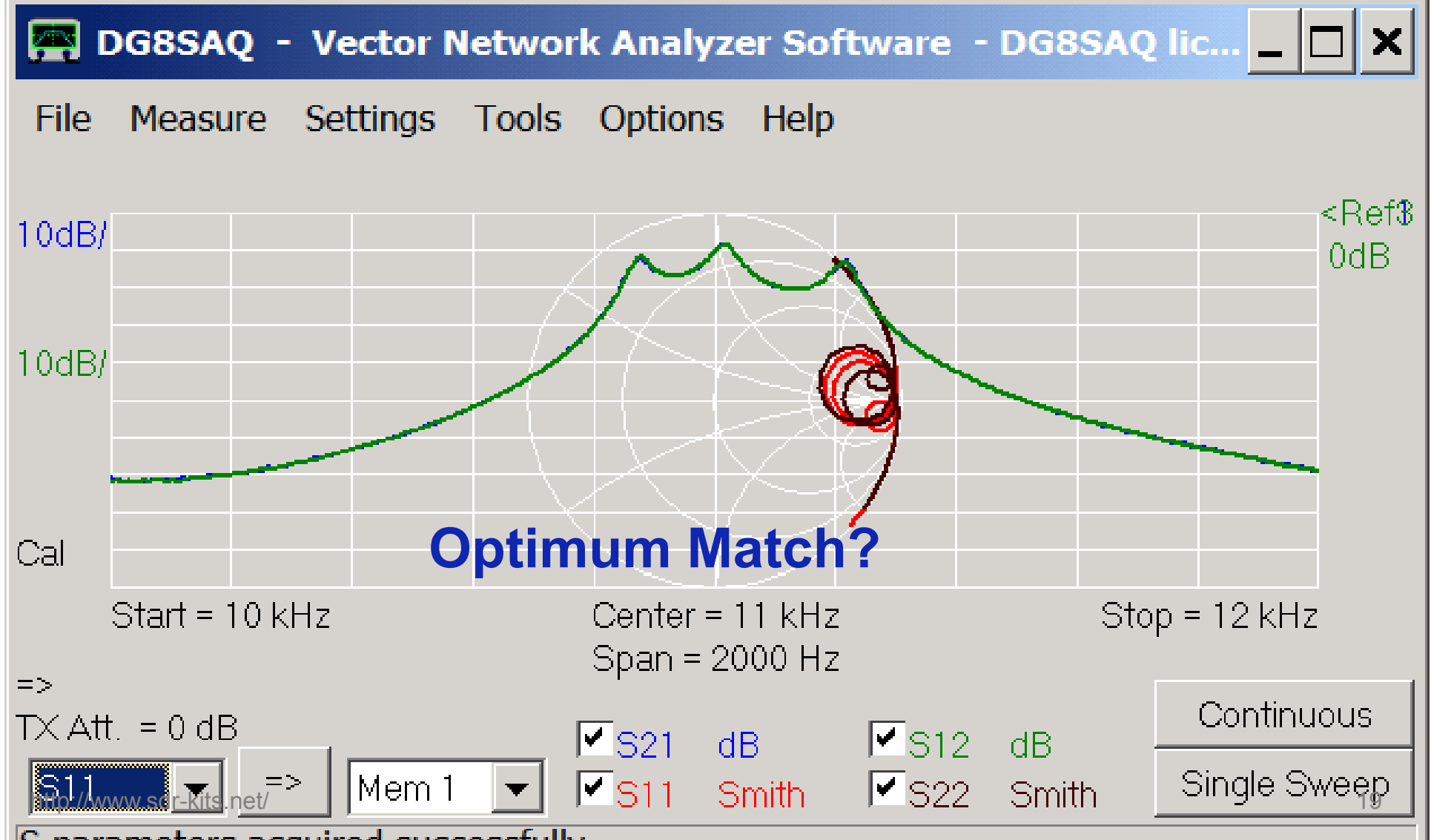
1

TX

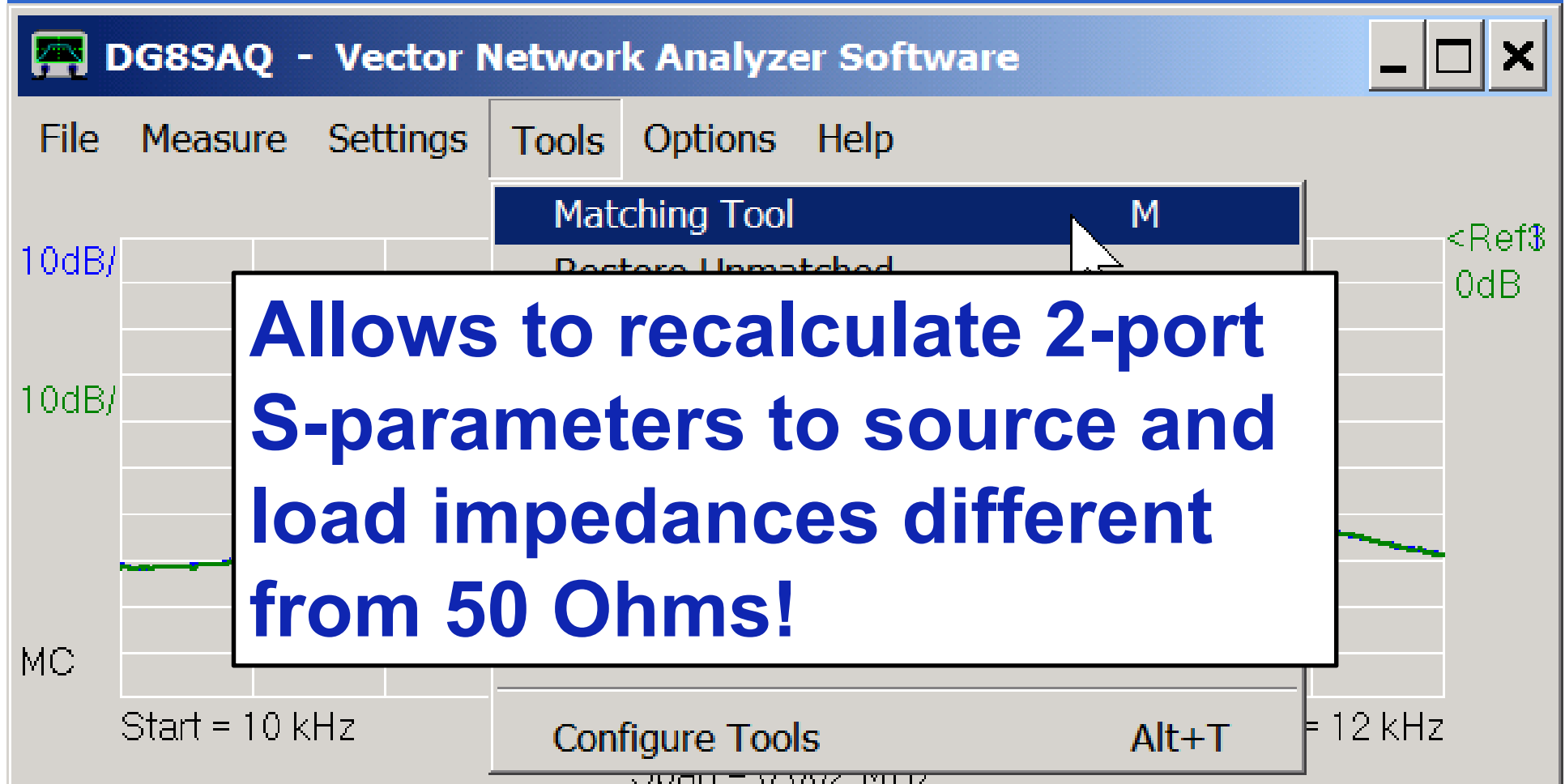
RX

S_{12} , S_{22} measured

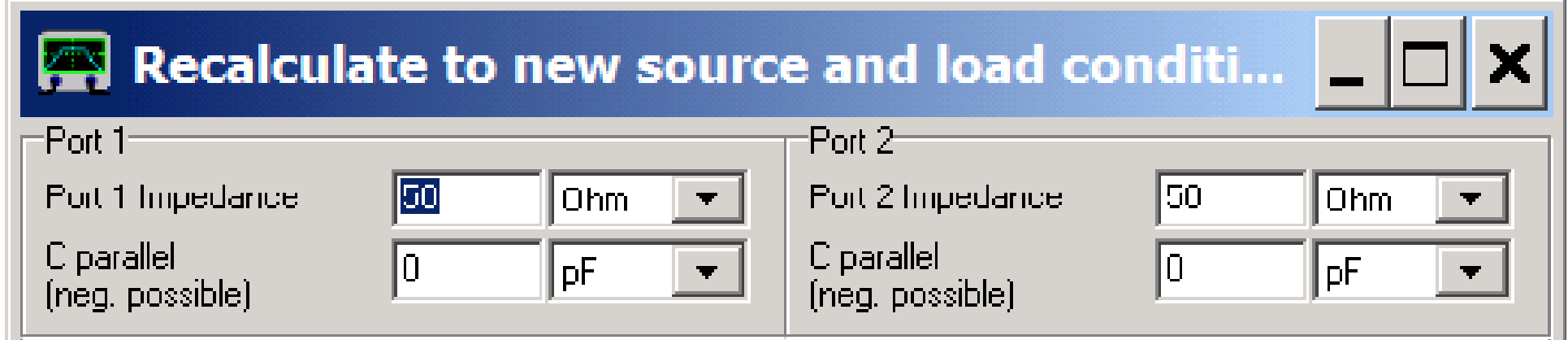
What are measured 2-Port S-Parameters good for?



VNWA Matching Tool (1)



VNWA Matching Tool (2)



The image shows a software window titled "VNWA Matching Tool (2)". At the top, there is a blue header bar with the title. Below the header, there is a toolbar with a small icon of a VNWA and a button labeled "Recalculate to new source and load conditi...". To the right of the button are three standard window control buttons: minimize, maximize, and close. Below the toolbar, the interface is divided into two main sections: "Port 1" and "Port 2". Each section contains two rows of controls. The first row in each section is for "Port 1 Impedance" and "Port 2 Impedance", respectively. Each row has a text input field, a unit dropdown menu, and a small arrow icon. The second row in each section is for "C parallel (neg. possible)", with a text input field, a unit dropdown menu, and a small arrow icon. In the "Port 1" section, the "Port 1 Impedance" field is set to "50" and the unit is "Ohm". The "C parallel" field is set to "0" and the unit is "pF". In the "Port 2" section, the "Port 2 Impedance" field is set to "50" and the unit is "Ohm". The "C parallel" field is set to "0" and the unit is "pF".

Complex conjugate of
source impedance

=

filter *input* impedance

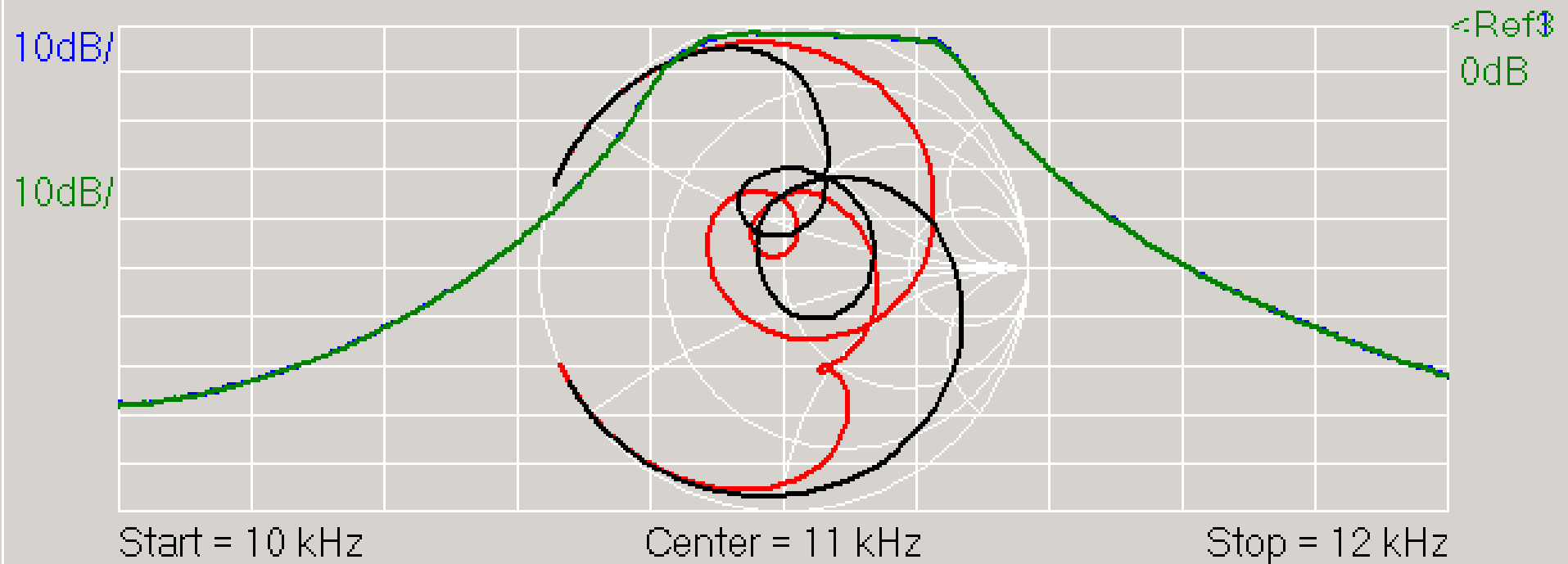
Complex conjugate of
load impedance

=

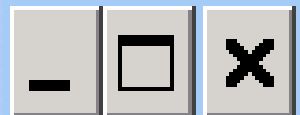
filter *output* impedance

Matching Analysis with VNWA Matching Tool

Optimum: $Z_{in} = Z_{out} = 610 \Omega$



Recalculate to new source and load conditi...



Port 1

Port 1 Impedance

610

Ohm



C parallel
(neg. possible)

0

pF



Port 2

Port 2 Impedance

610

Ohm



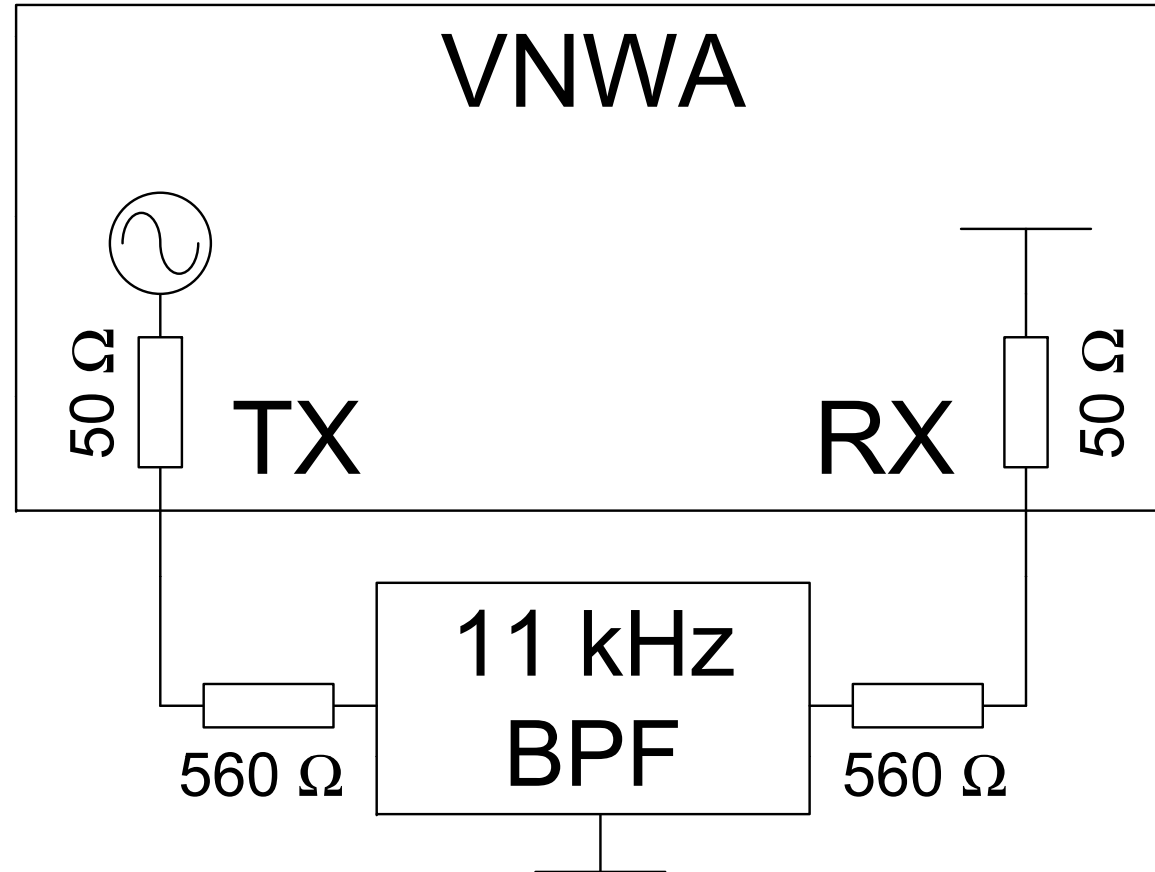
C parallel
(neg. possible)

0

pF

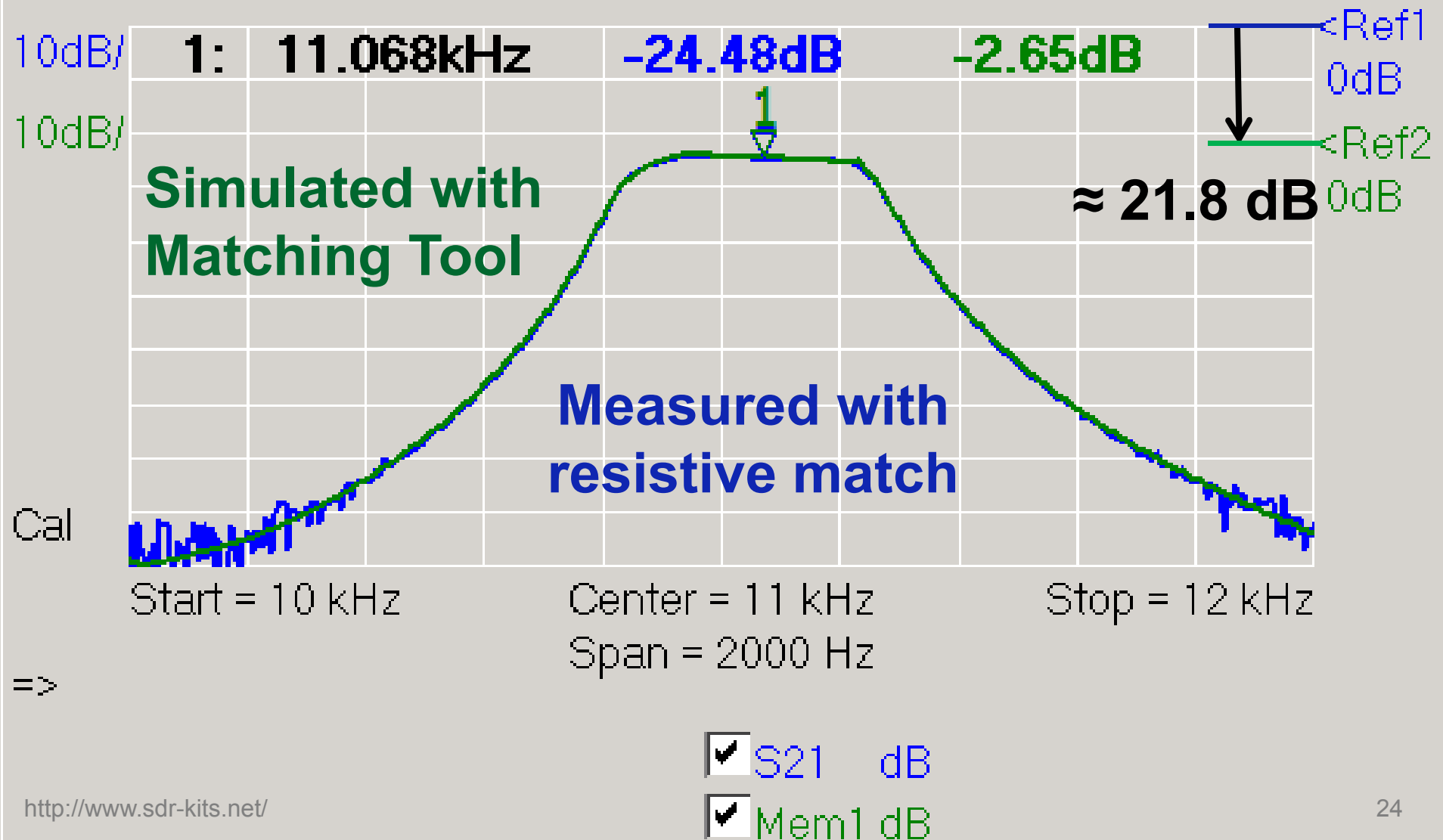


Forced Impedance Match using Resistors

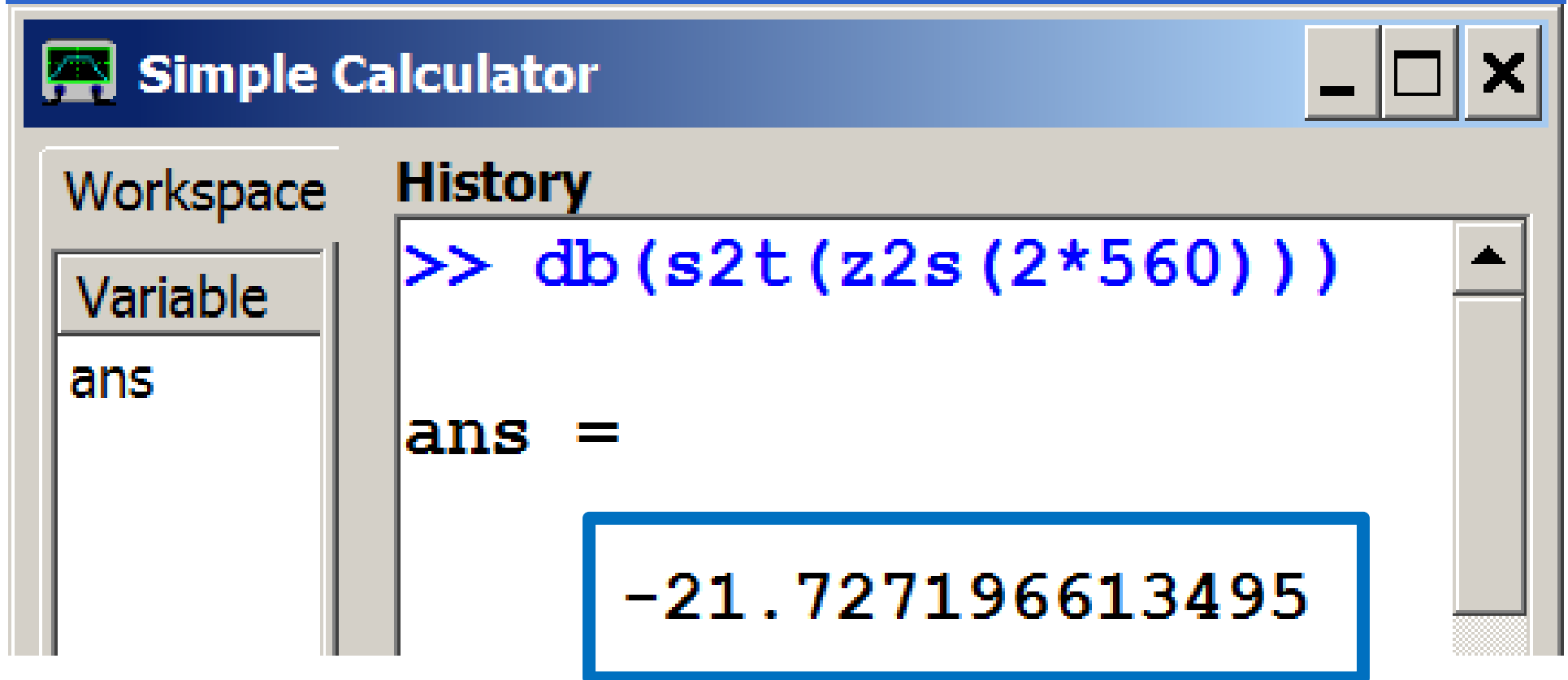


$$50\ \Omega + 560\ \Omega = 610\ \Omega$$

Match works except for increased Loss



Effect of two 560 Ω Resistors in Signal Path: VNWA Complex Calculator



The screenshot shows a window titled "Simple Calculator" with a workspace and a history panel. The workspace contains a variable named "ans". The history panel shows the calculation: `>> db(s2t(z2s(2*560)))` followed by `ans =` and the result `-21.727196613495`, which is highlighted with a blue border.

Simple Calculator

Workspace

Variable

ans

History

`>> db(s2t(z2s(2*560)))`

`ans =`

-21.727196613495

21,7 dB additional attenuation ✓

This can also be „properly“ simulated!

Simulation Tool QUCS



- <http://qucs.sourceforge.net/>
- **Universal circuit simulator**
- **Free**
- **No restrictions**
- **Easy to use**
- **Graphics and data export needs brush up**

Measured S-Parameters in QUCS

Qucs 0.0.16 - Project: 11kHzBPF

File Edit Positioning Insert Project Tools Simulation View Help

11kHzBPF.sch 11kHzBPF.dpl

simulations

- DC
- Transien
- simulation
- AC
- ac
- simulation
- S-parameter simulation**
- HB
- Harmoni
- c
- balance
- Digi
- digital
- Opt
- optimizat

S parameter simulation

SP1
Type=lin
Start=10 kHz
Stop=12 kHz
Points=400

measured S-parameters from s2p-file

X1
File=11kHz_BPF.s2p

P1
Num=1
Z=50 Ohm

R1
R=560 Ohm

Ref

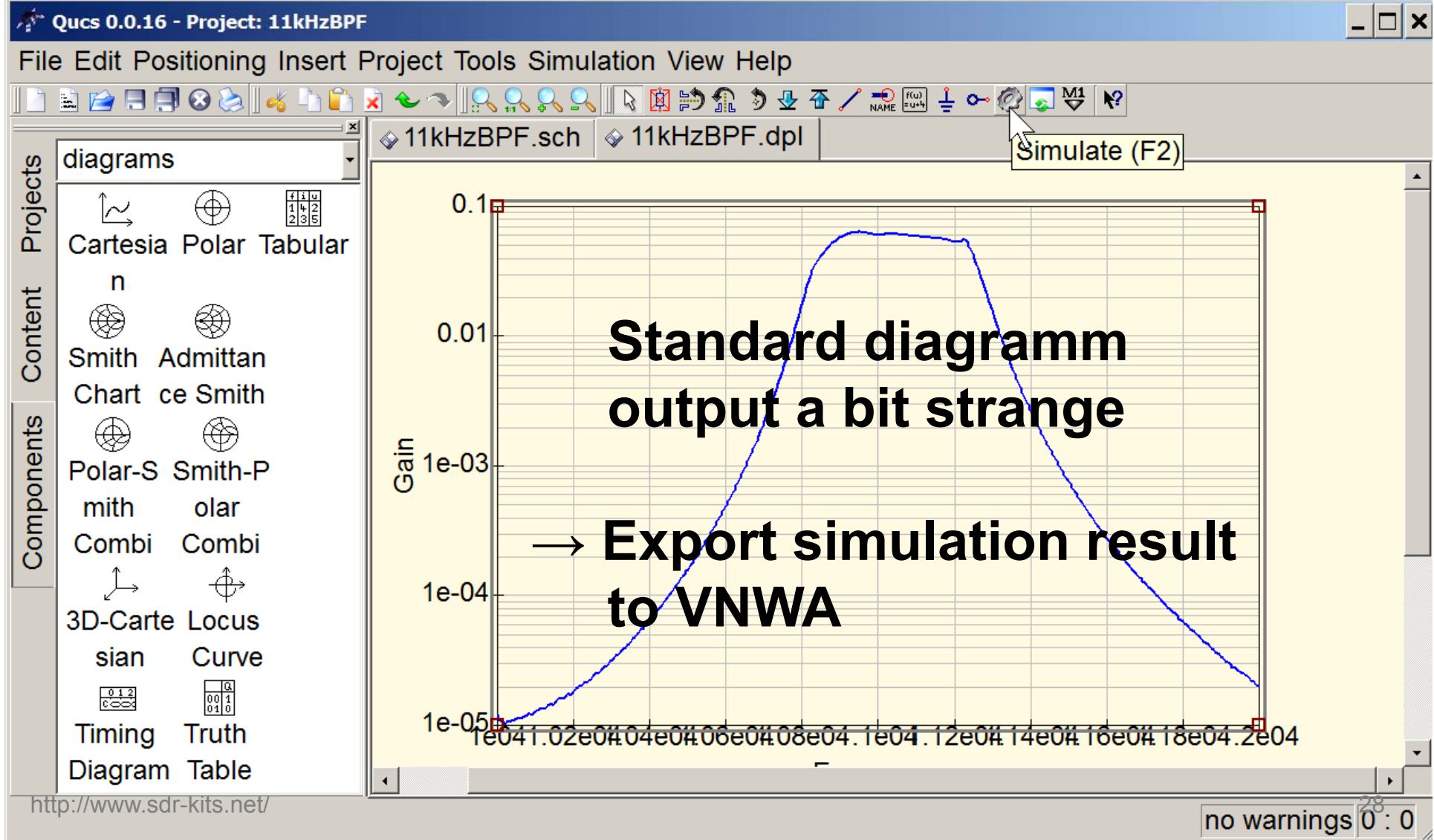
R2
R=560 Ohm

P2
Num=2
Z=50 Ohm

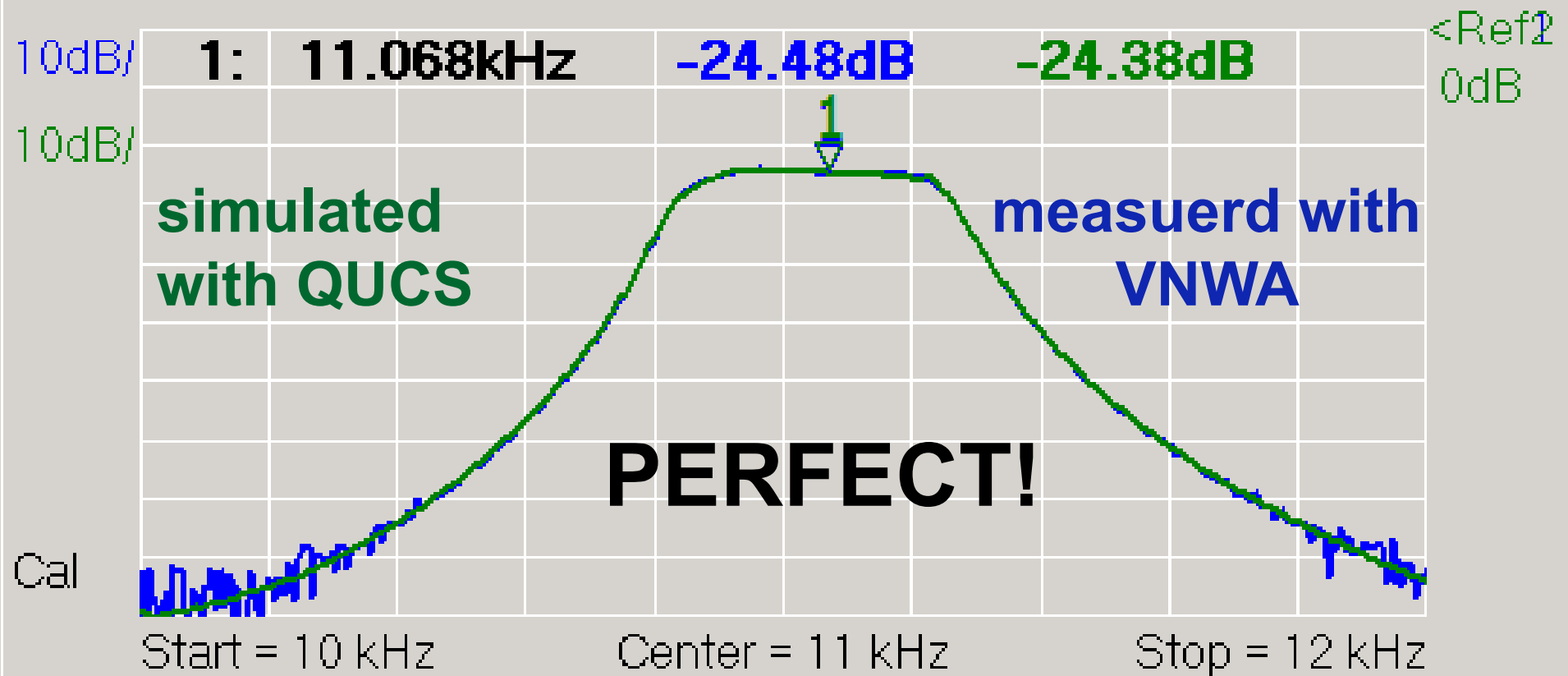
no warnings 0 : 0

<http://www.sdr-kits.net/>

Matching Simulation in QUCS



Comparison QUCS-Simulation vs. Measurement



=>

☒ S21 dB

☒ Mem1 dB

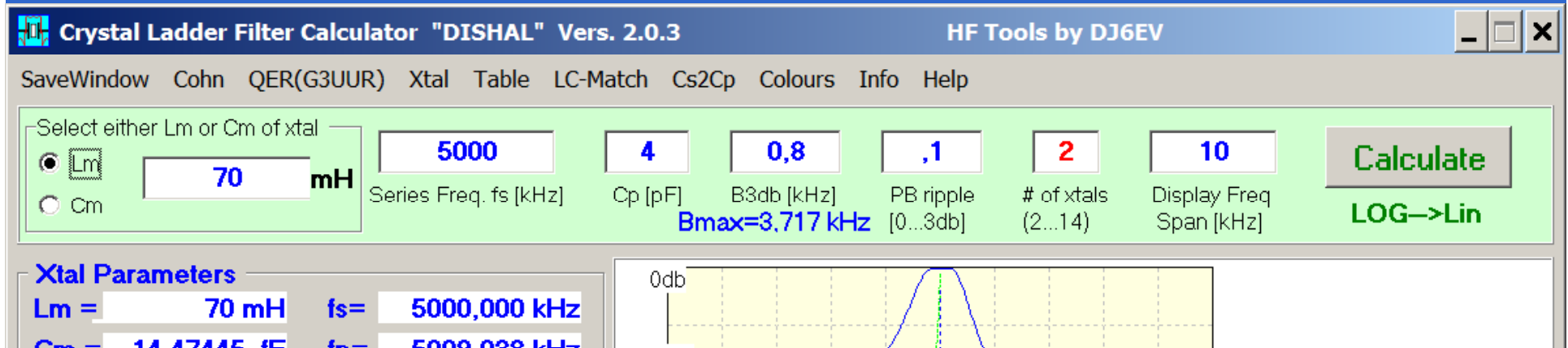
Free Filter Design Software (1): Elsie – for LC-Filters

 Elsie Student Edition - Welcome !

This is the Student Edition of
Elsie

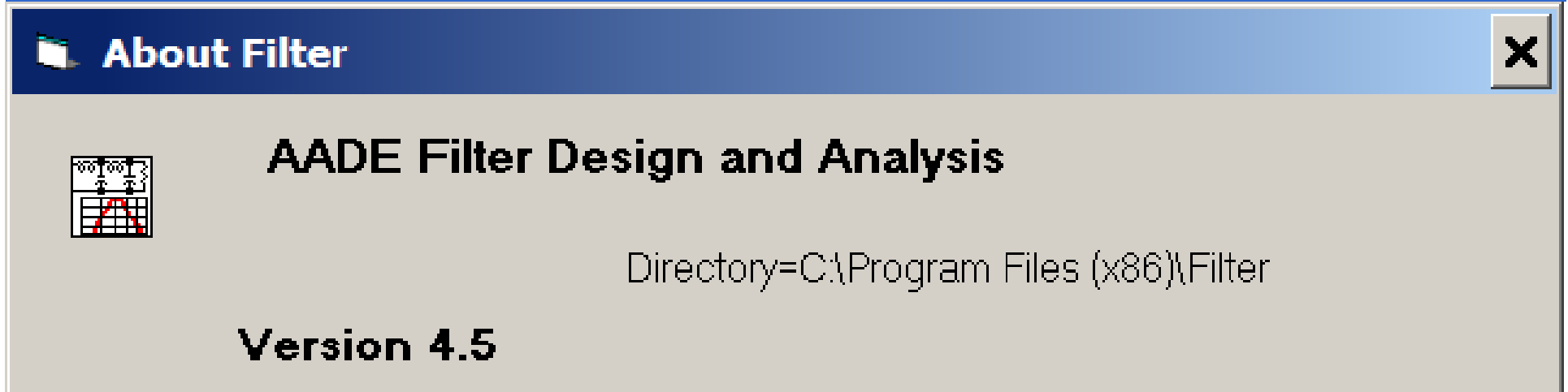
- <http://tonnesoftware.com/elsiedownload.html>
- **LC-Filter Designer and Analyzer**
- **Student version restricted to 7 dipols**
- **Numerical simulation results export easily to s2p-file!**

Free Filter Design Software (2): Dishal – for Crystal Filters



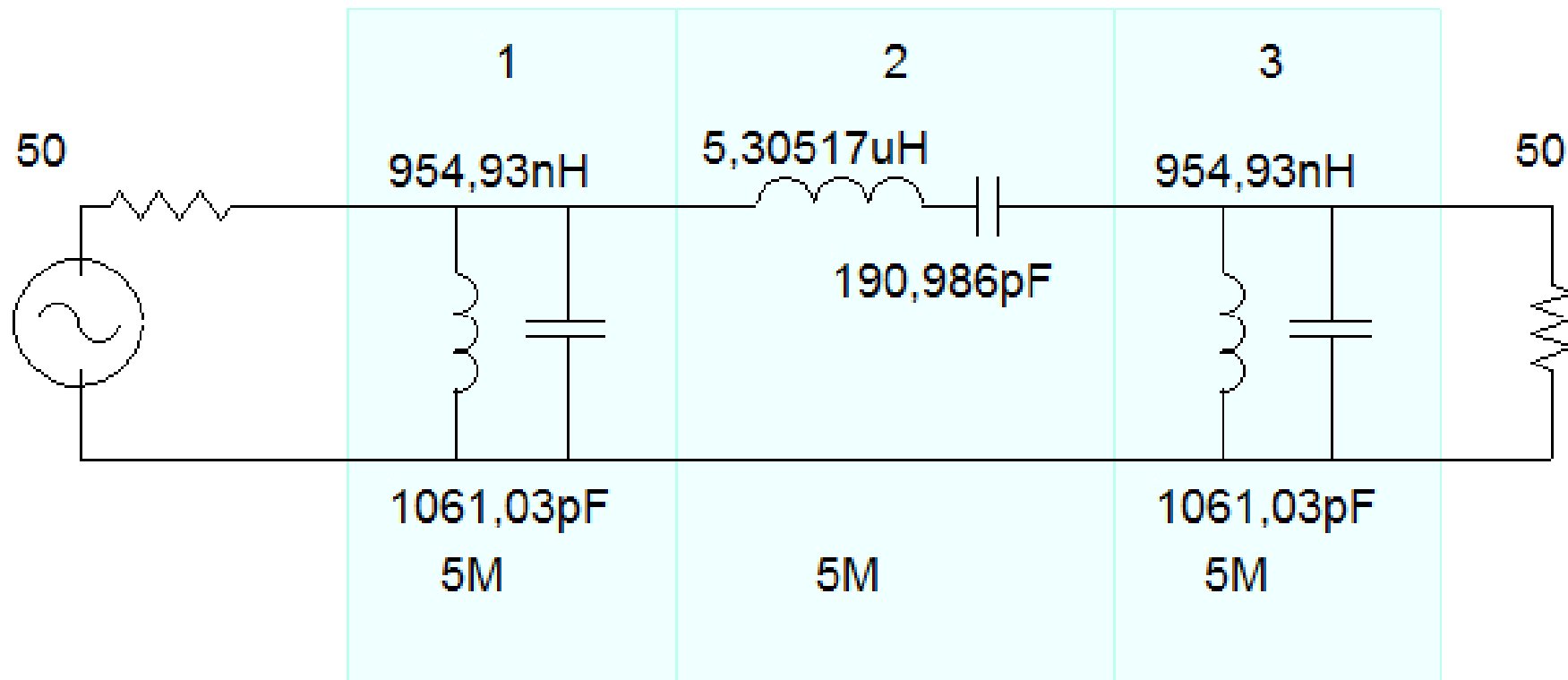
- <http://www.bartelsos.de/dk7jb.php/quarzfilter-horst-dj6ev>
- Crystal filter designer and analyzer
- Simulates without crystal losses
- S_{21} -simulation results can be exported

Free Filter Design Software (3): AADE Filter Design - for all filters



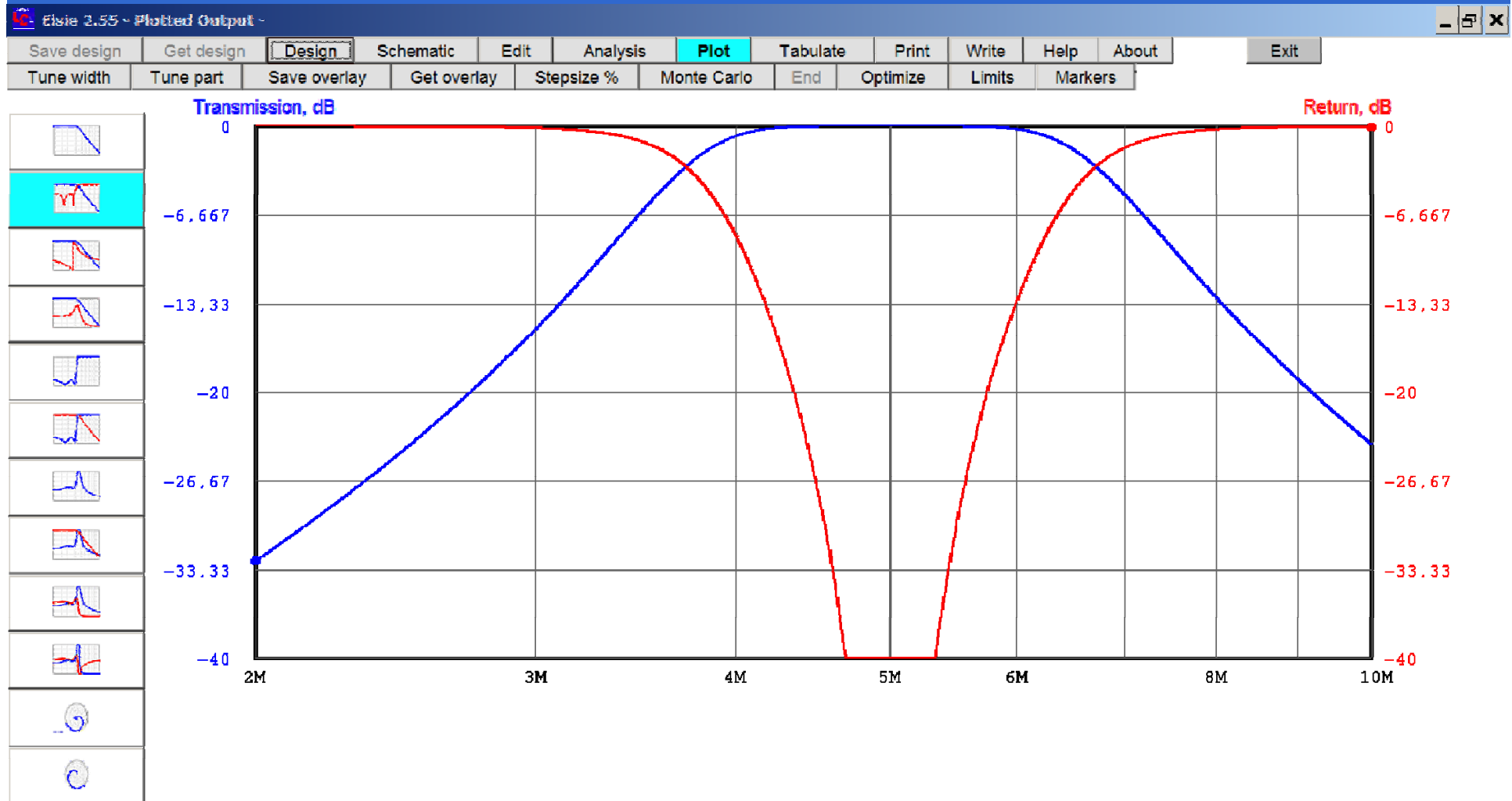
- <http://aade.com/filter32/download.htm>
- Univeral filter designer and analyzer
- Free, but with nag screen
- Easy to use
- Numerical simulation results cannot be exported

Design 3 Pole Butterworth π -Band Pass for 5 MHz with 3 MHz Bandwidth at 50 Ω



Filter Design with Elsie

Elsie Simulation Result



Modify Components to standard Values and finite Q ...

Schematic

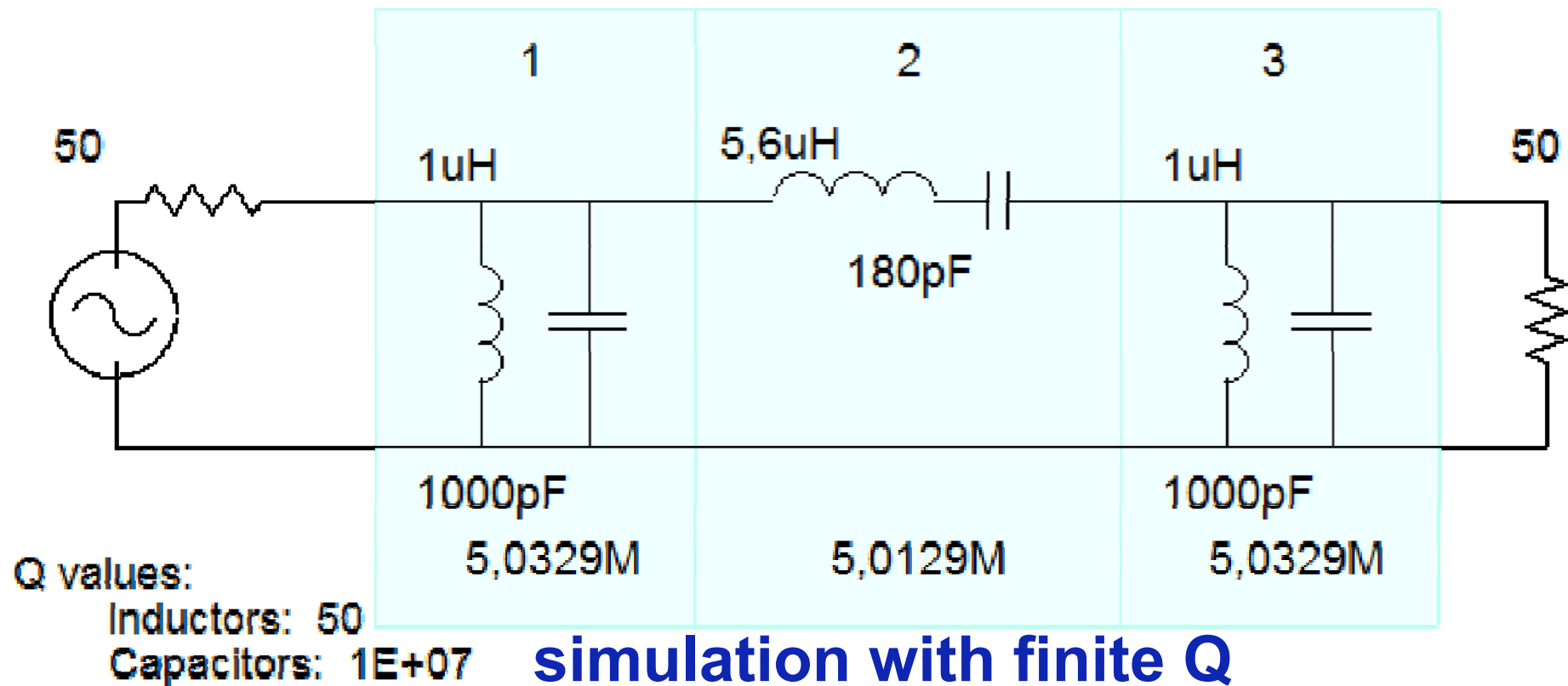
Edit

Analysis

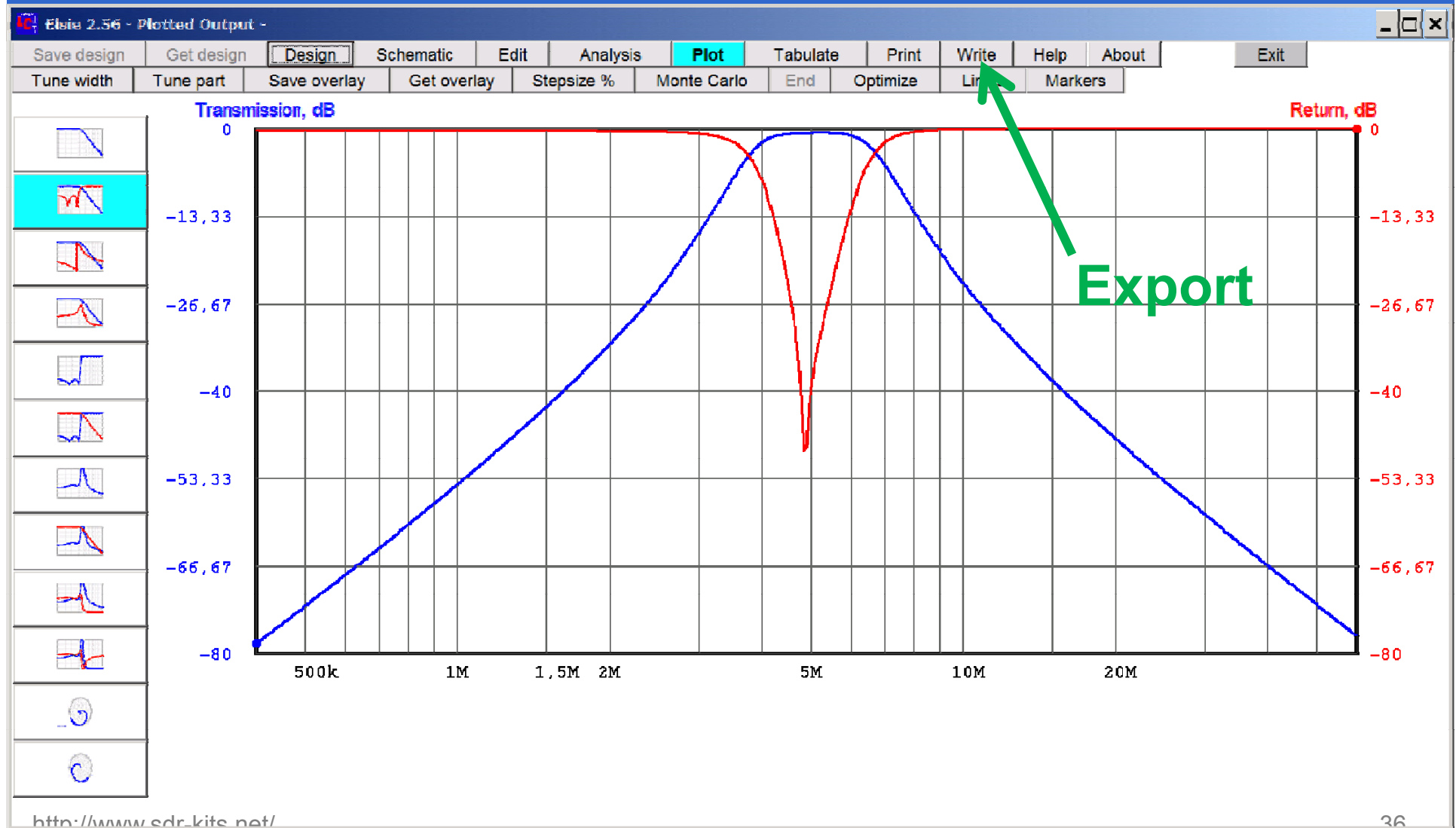
Plot

Tabulate

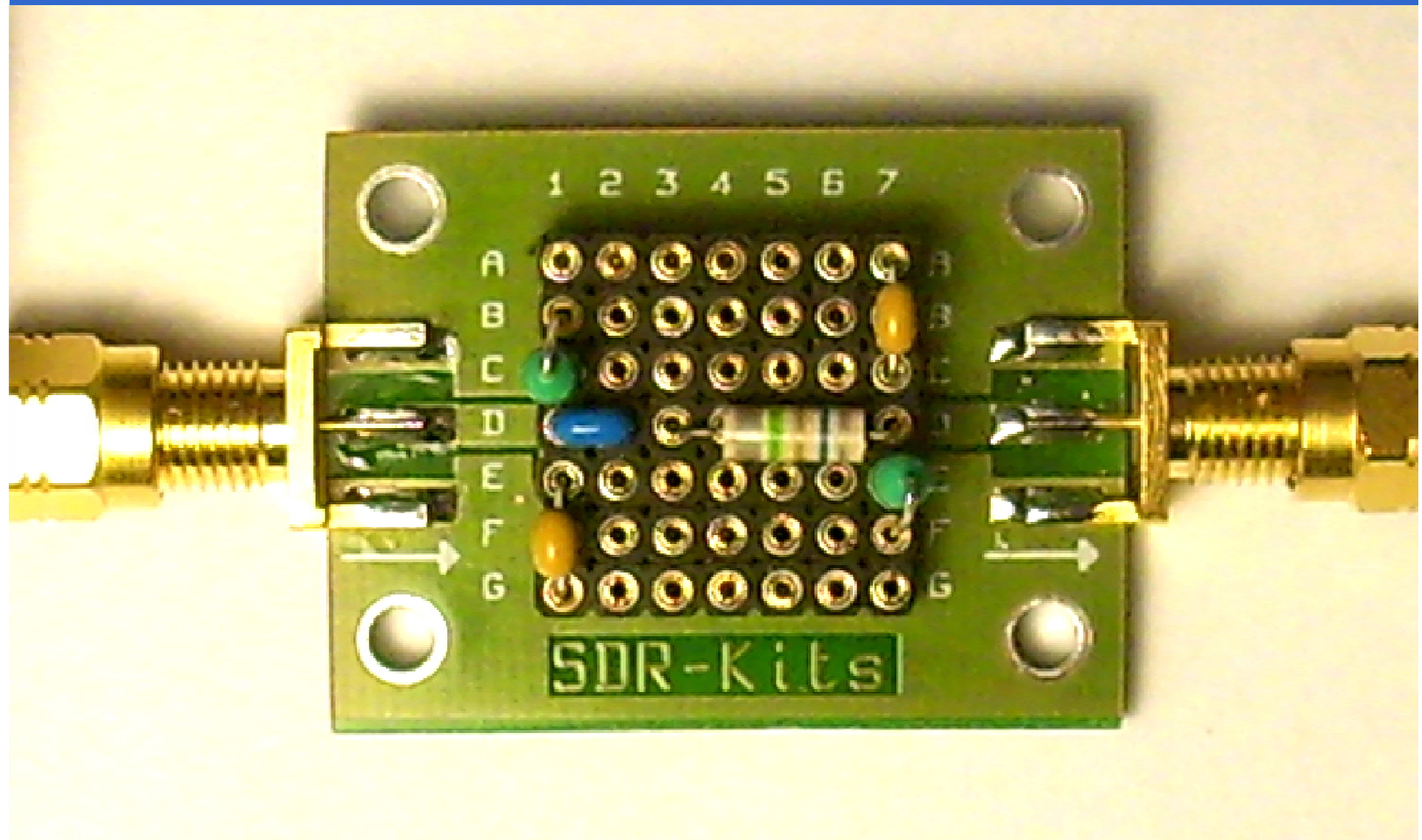
Print



...and export Simulation into s2p-file for Comparison with Measurement.

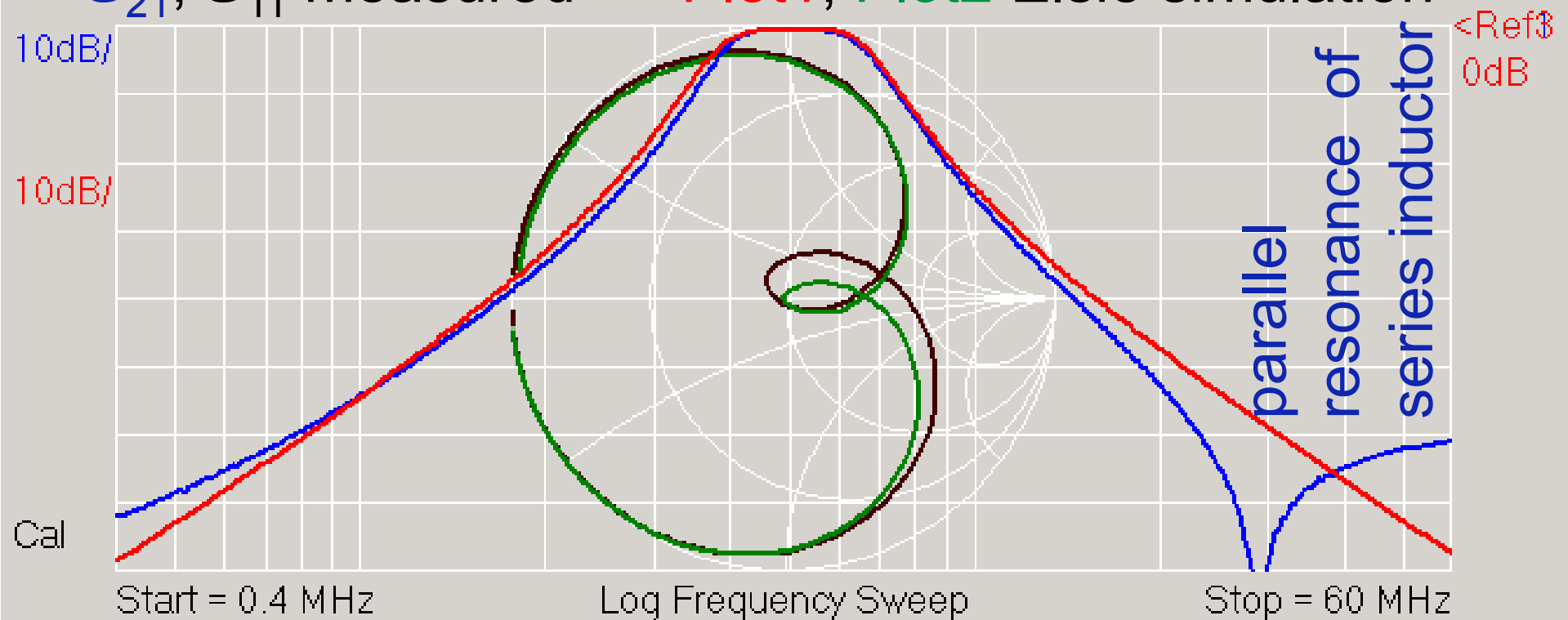


Filter Hardware



Comparison Measurement vs. Elsie Simulation

S_{21} , S_{11} measured - Plot1, Plot2 Elsie simulation



=>

TX Att. = 0 dB

S21

=>

Mem 1

☒ S21

dB

☒ S11

Smith

☒ Plot1

dB

☒ Plot2

Smith

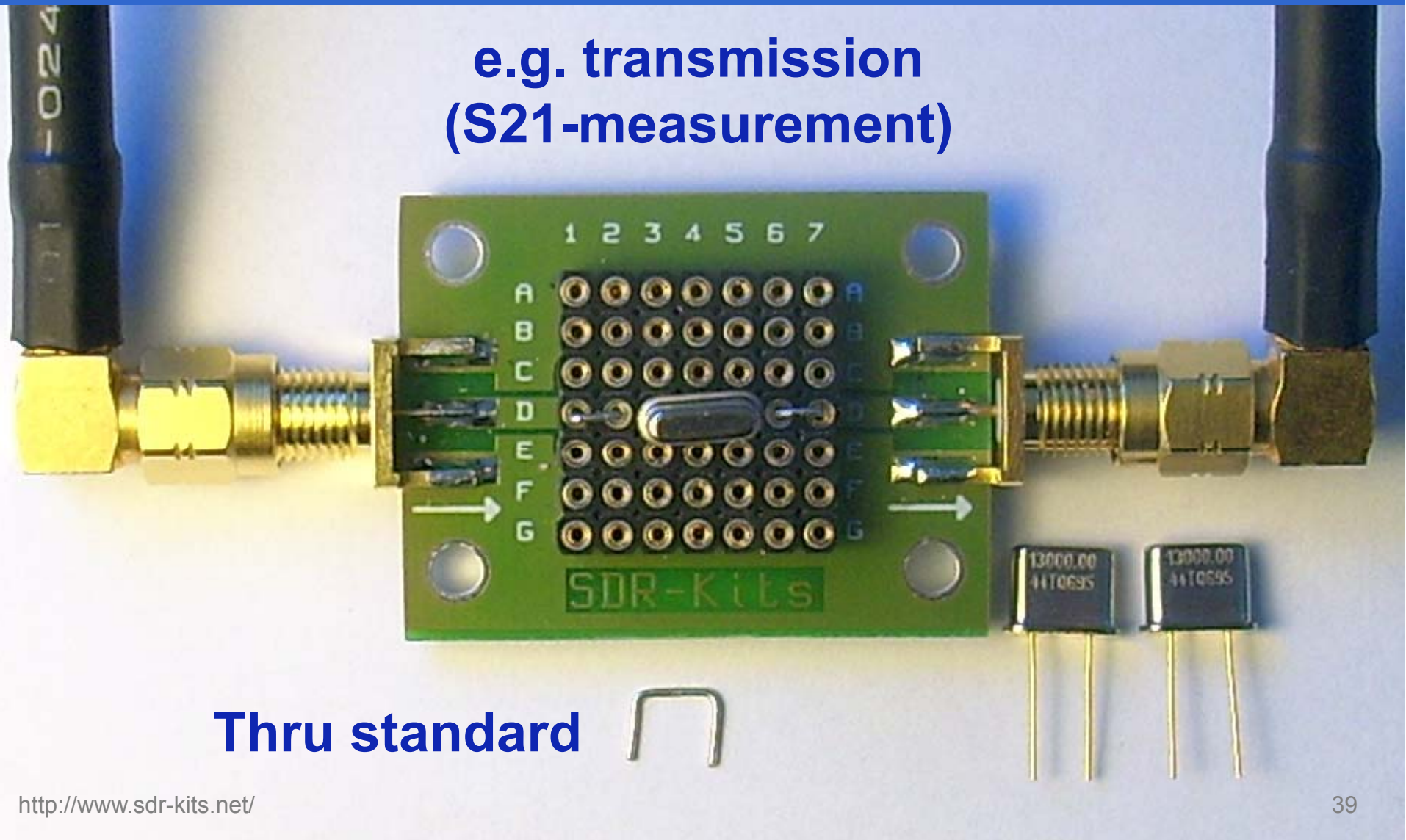
Continuous

Single Sweep

<http://www.sdr-kits.net/>

Measuring / Selecting Crystals: VNWA Crystal Analyzer

e.g. transmission
(S21-measurement)



Thru standard

The VNWA Crystal Analyzer Tool: Find 3 similar Crystals...

Crystal Analyzer - Analysis will be performed into 3-port data spaces s_11 an...

Equivalent Circuit

$f = 1/2\pi\sqrt{L \cdot C}$
 $R \cdot Q = \sqrt{L/C}$

source = S21
 Test Jig Impedances = 50 Ohms

L = 23.22917 mH
 C = 6.456461 fF
 R = 27.285283581 Ohm
 C0 = 2.46571041216 pF
 = 12.995886978 MHz
 = 1896.7918117 x1000 Q = 69517

Batch Crystal Analyzer

#	f / Hz	Q	L / H	C / F	R / Ohm	C0 / F	figure of m
1	12995915.37	48842	0.02349916516	6.382253945E-15	39.29	2.468043934E-12	0.000775
2	12995927.72	54196	0.02368969902	6.330910084E-15	35.69	2.420346928E-12	0.00116
3	12995886.98	69517	0.02322917961	6.456461114E-15	27.29	2.465710412E-12	0.0015

With these we want to build a Crystal Filter → Enter Crystal Parameters into AADE

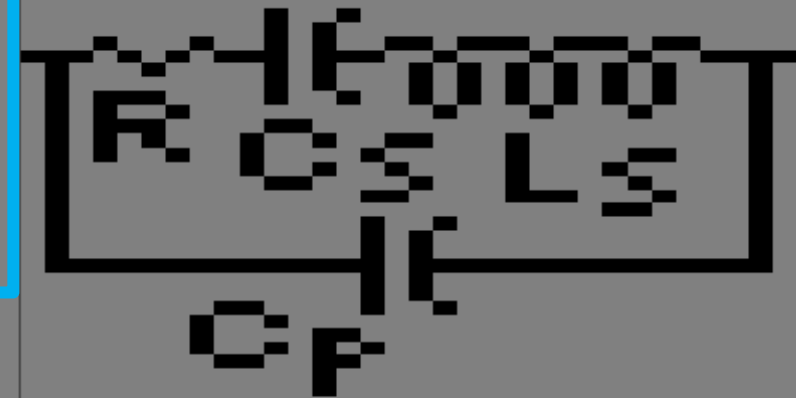
Enter data

Enter values from the keyboard or by clicking on the calculator pad shown. Tab advances to the next value.

7	8	9	+	-	M
4	5	6	*	/	K
1	2	3	%	=	m
0	.	√	x²	μ	
tab	bksp	CLR	n		
ENTER	Cancel	p			

Cp = 2,46804p
Ls = 23,499m
Cs = ,00638p
Qx = 48,842K

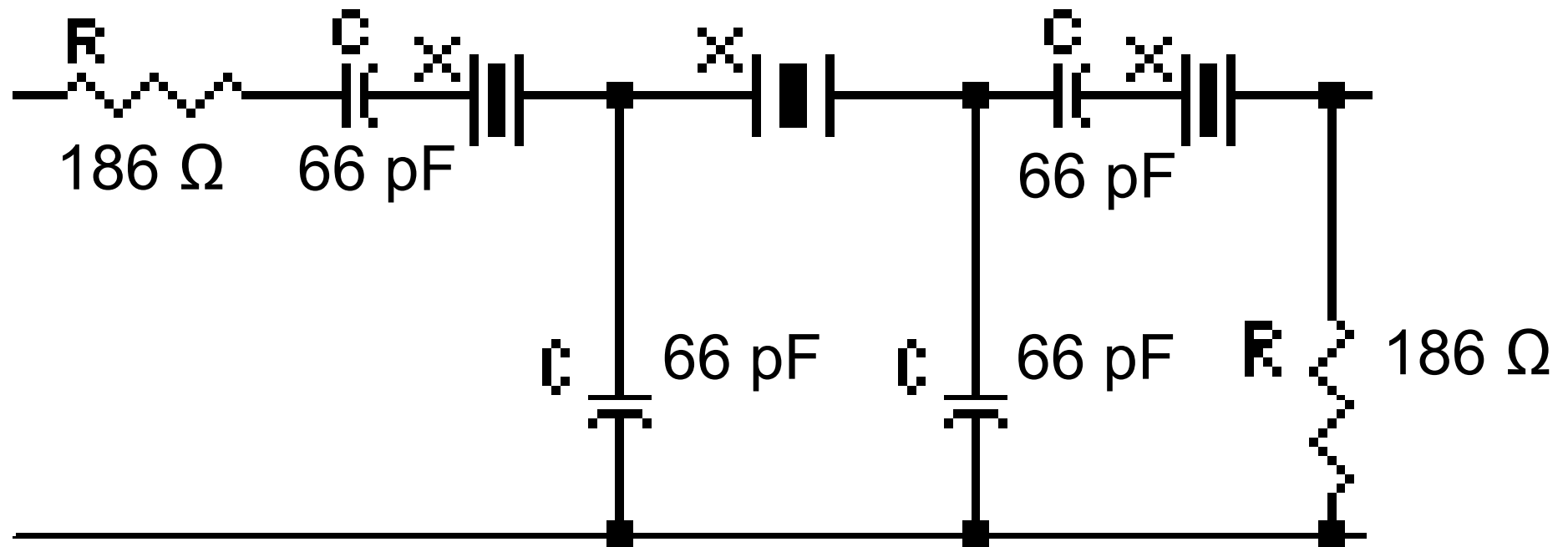
Daten vom
VNWA
Crystal
Analyzer
übertragen



Enter the crystals parallel capacitance in Farads. L/C Meter II will measure it.

#	f / Hz	Q	L / H	C / F	R / Ohm	C0 / F	figure of m
1	12995915.37	48842	0.02349916516	6.382253945E-15	39.29	2.468043934E-12	0.000775

AADE Minimum Loss (Cohn) Design



Simulation in QUCS at 50 Ω using standard Component Values

S parameter simulation

SP1

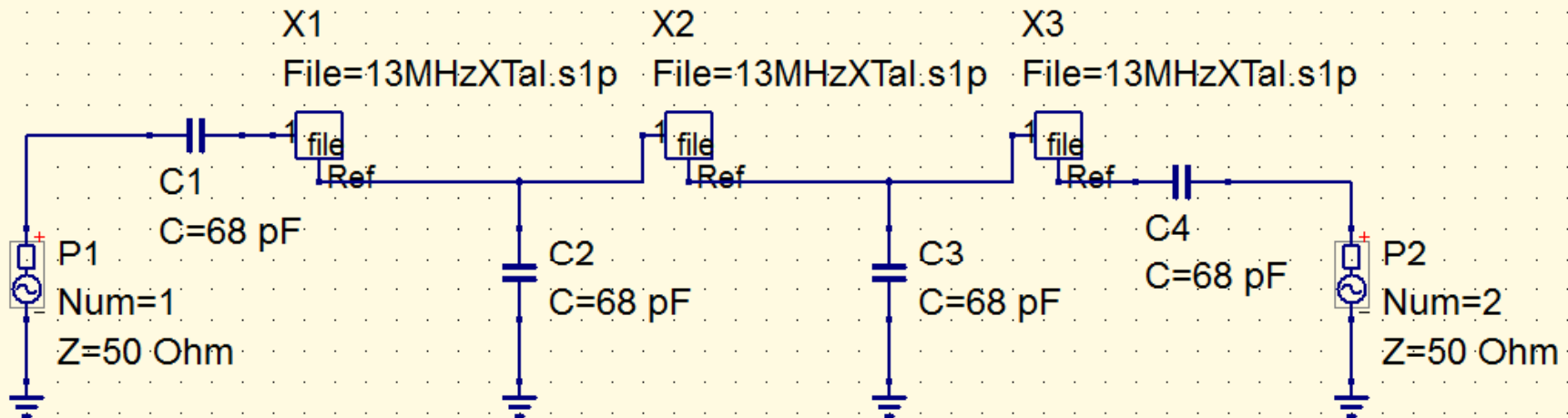
Type=lin

Start=12.987 MHz

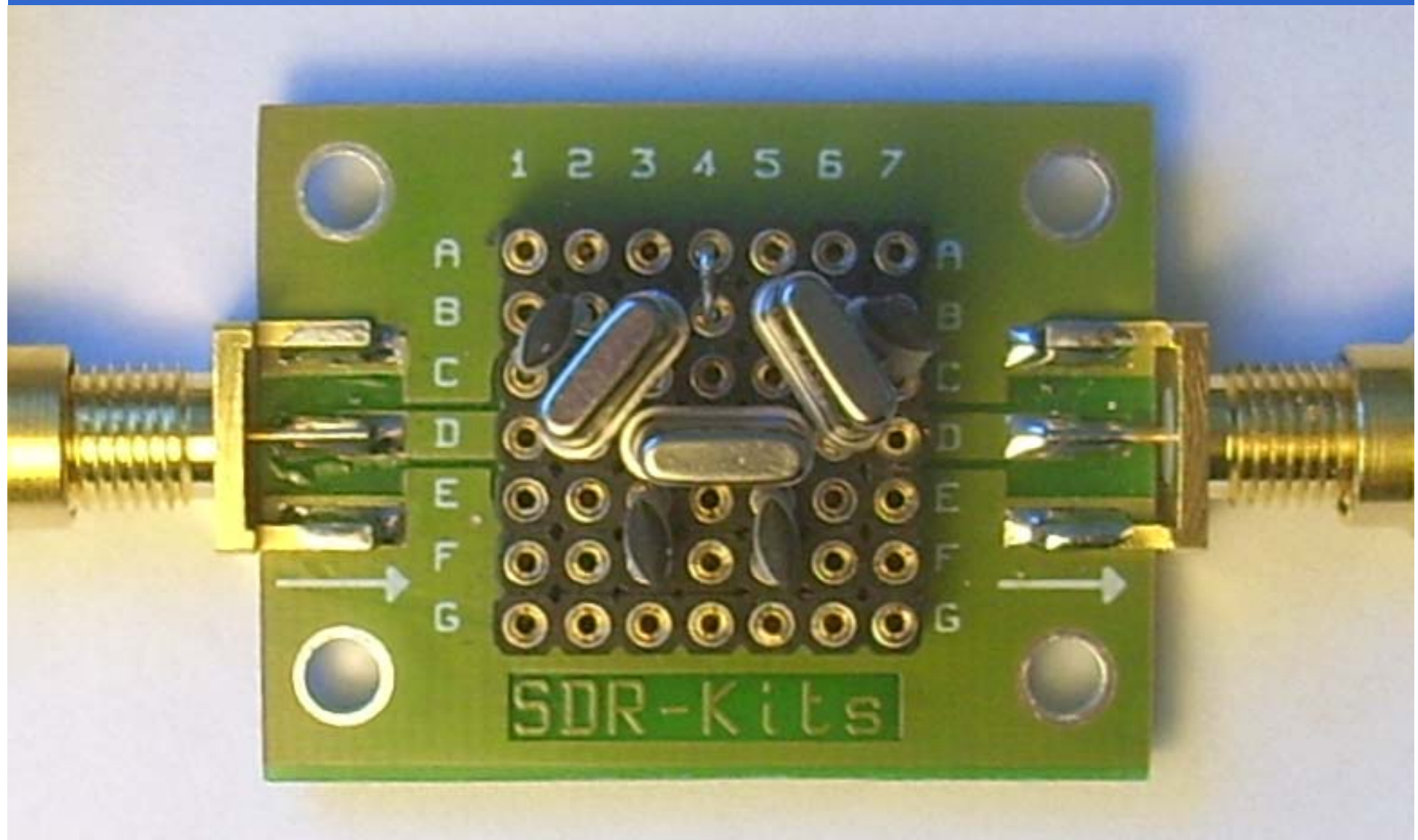
Stop=13.007 MHz

Points=800

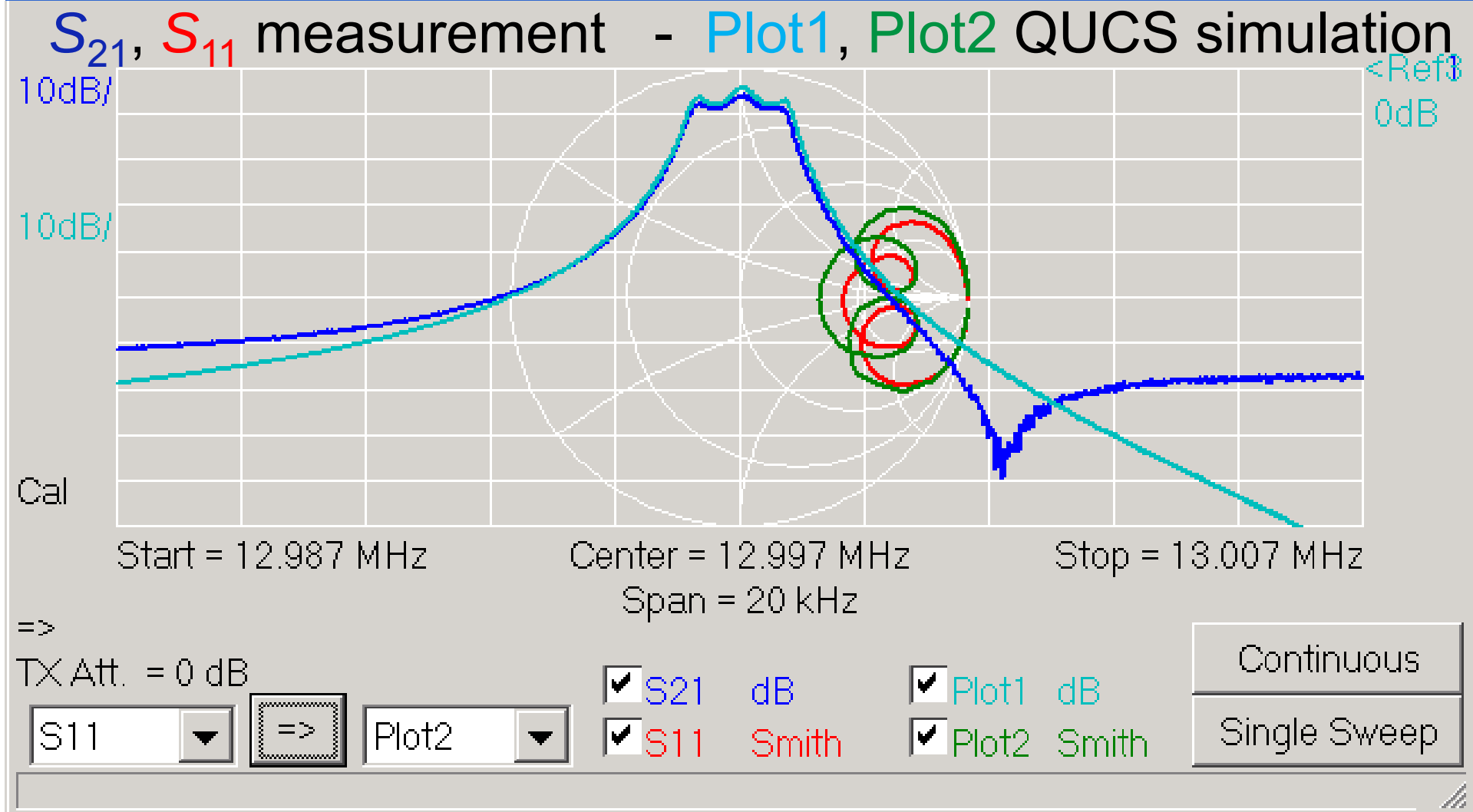
**Crystals simulated with
s1p-file obtained by VNWA
measurement!**



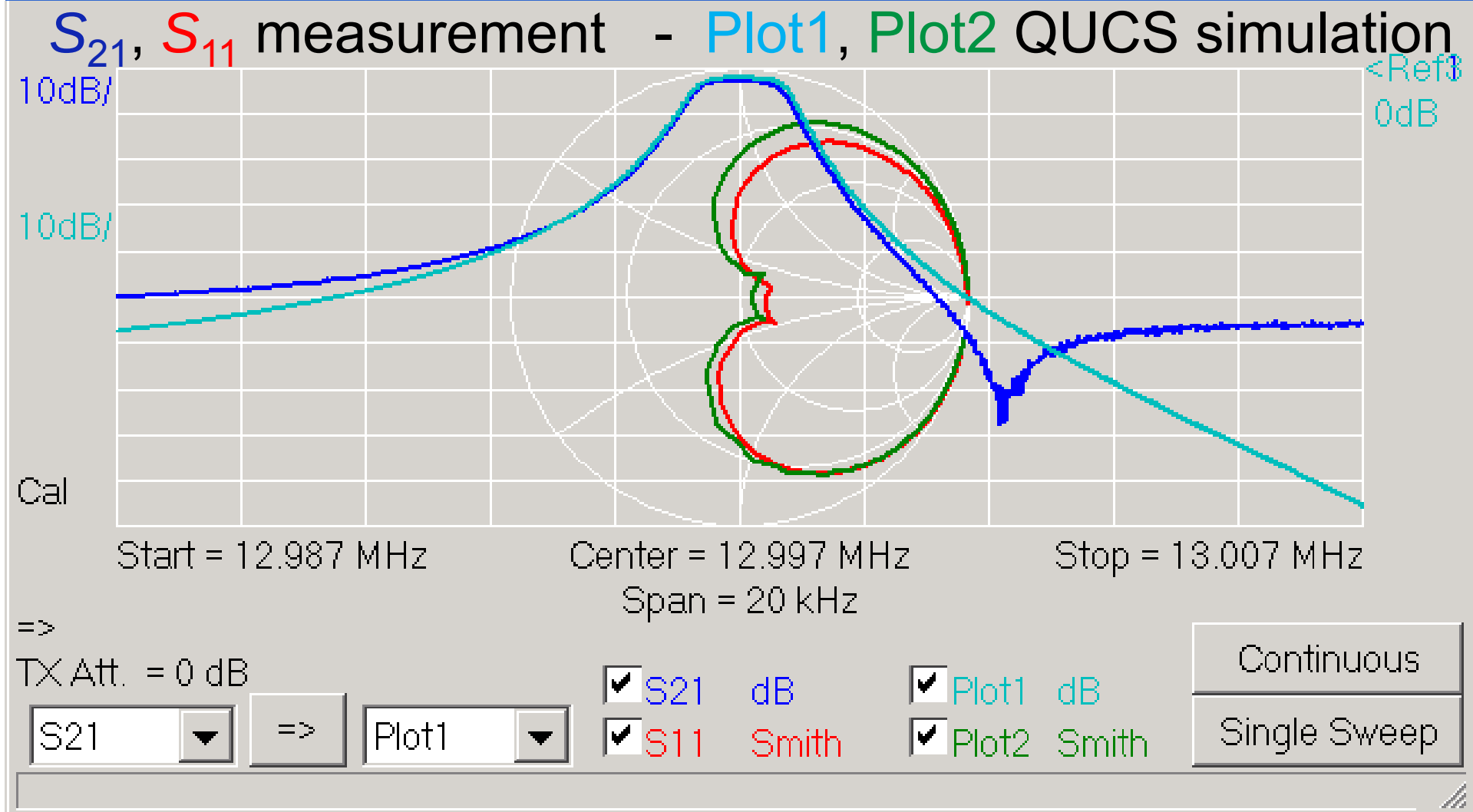
Crystal Filter Hardware



Crystal Filter: Measurement vs. Simulation at 50 Ω



Crystal Filter: Measurement vs. Simulation at 186 Ω



Now, we are able to...

- **Measure components**
- **Design filters**
- **Simulate filters**
- **Measure filters**



Try it for
yourself!