

DG8SAQ VNWA Tutorial

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

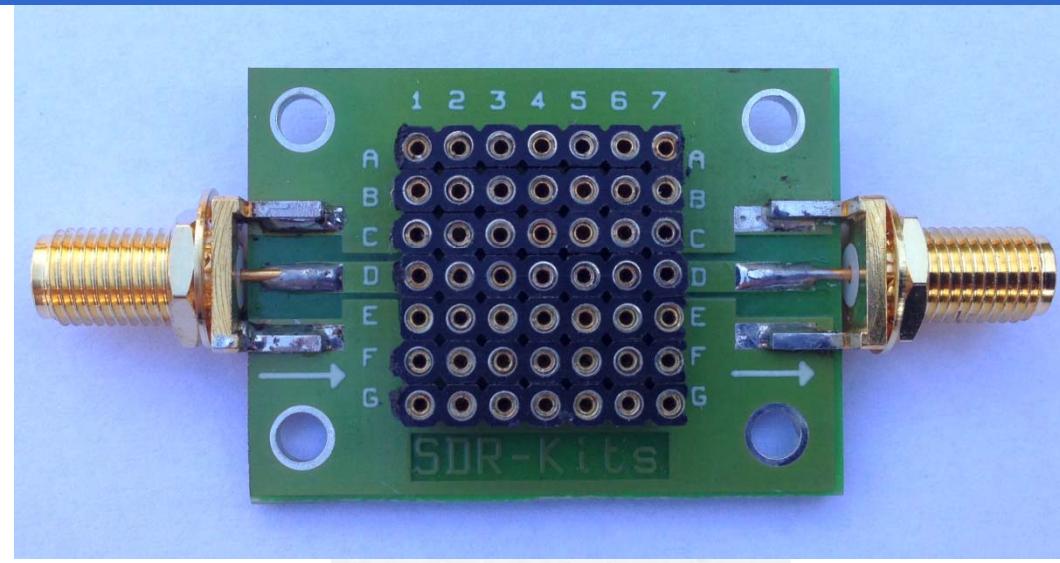
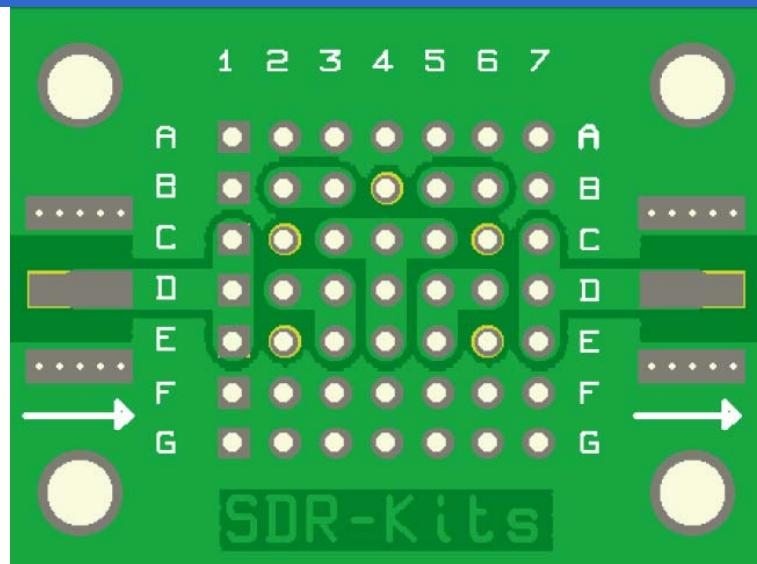
Tom BAIER

DG8SAQ

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



Test Board for HF Experiments



**Calibration
Standards:**

Open = n.c.

Short:



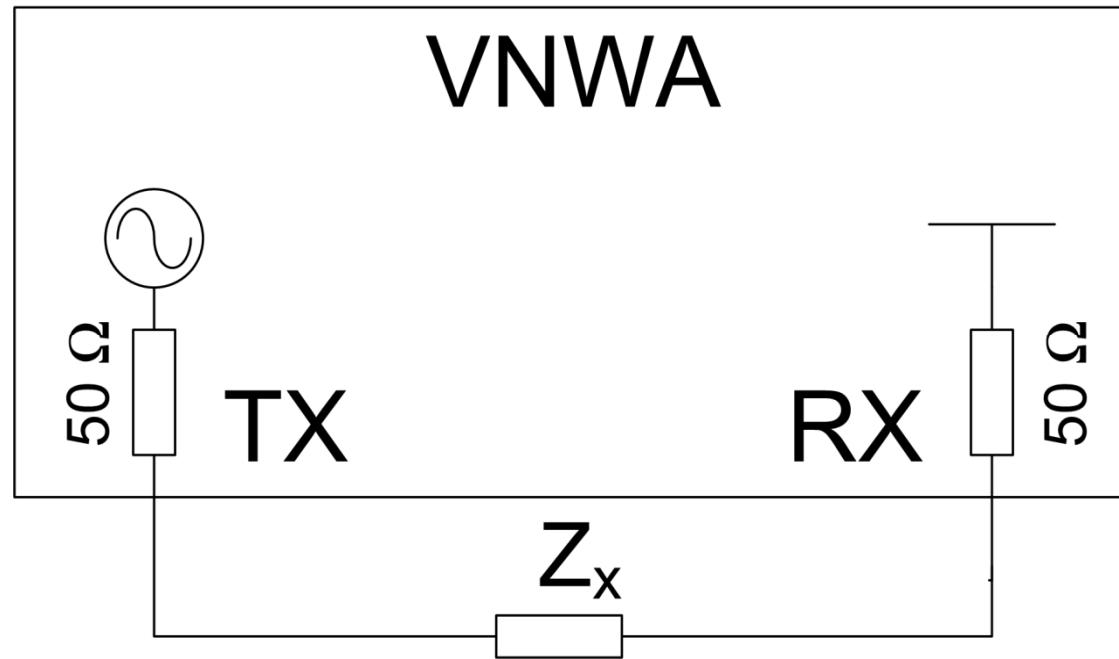
Load = 47Ω:



Thru:



Measuring „Load“-Resistor without SOL-Calibration?

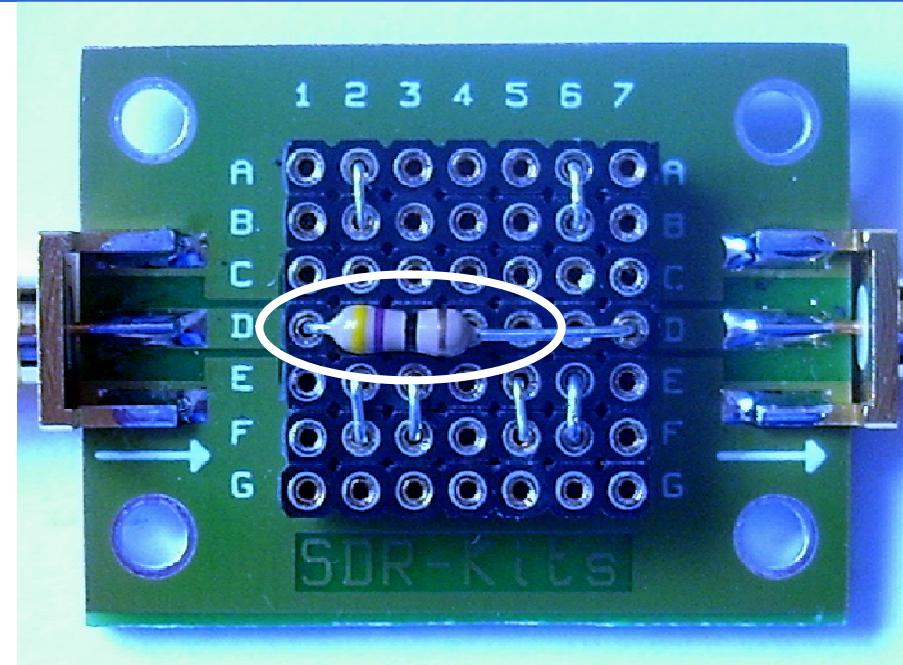
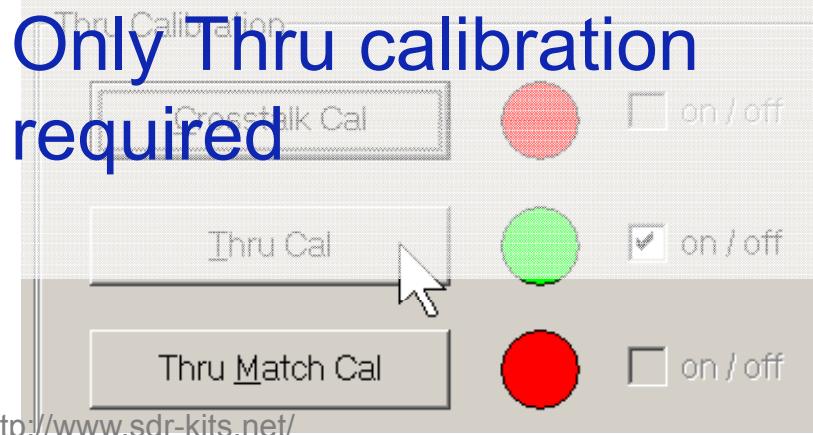
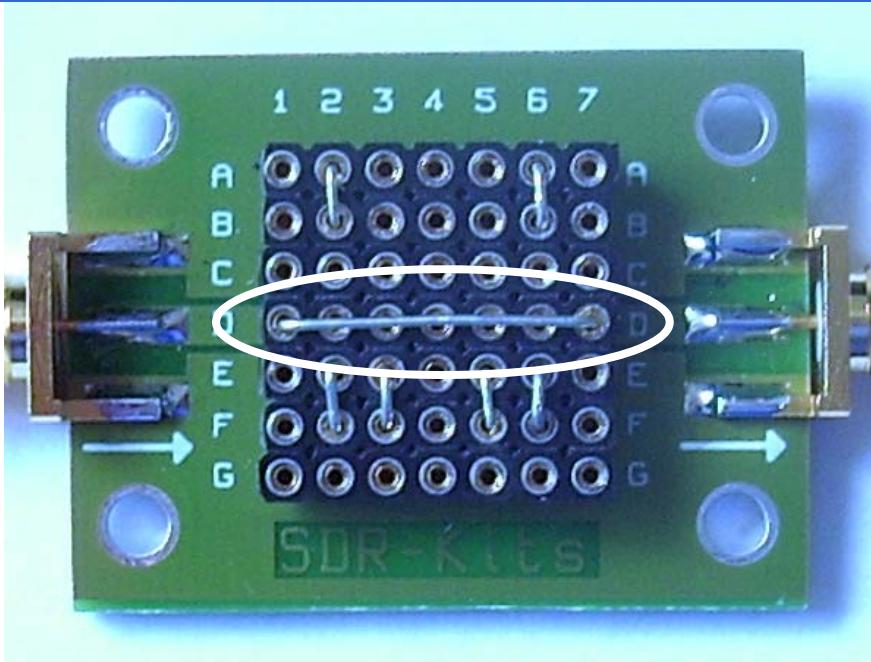


$Z_x = 47 \Omega$ yield $\approx 3,4$ dB insertion loss.

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

➤ only Thru
calibration
required!

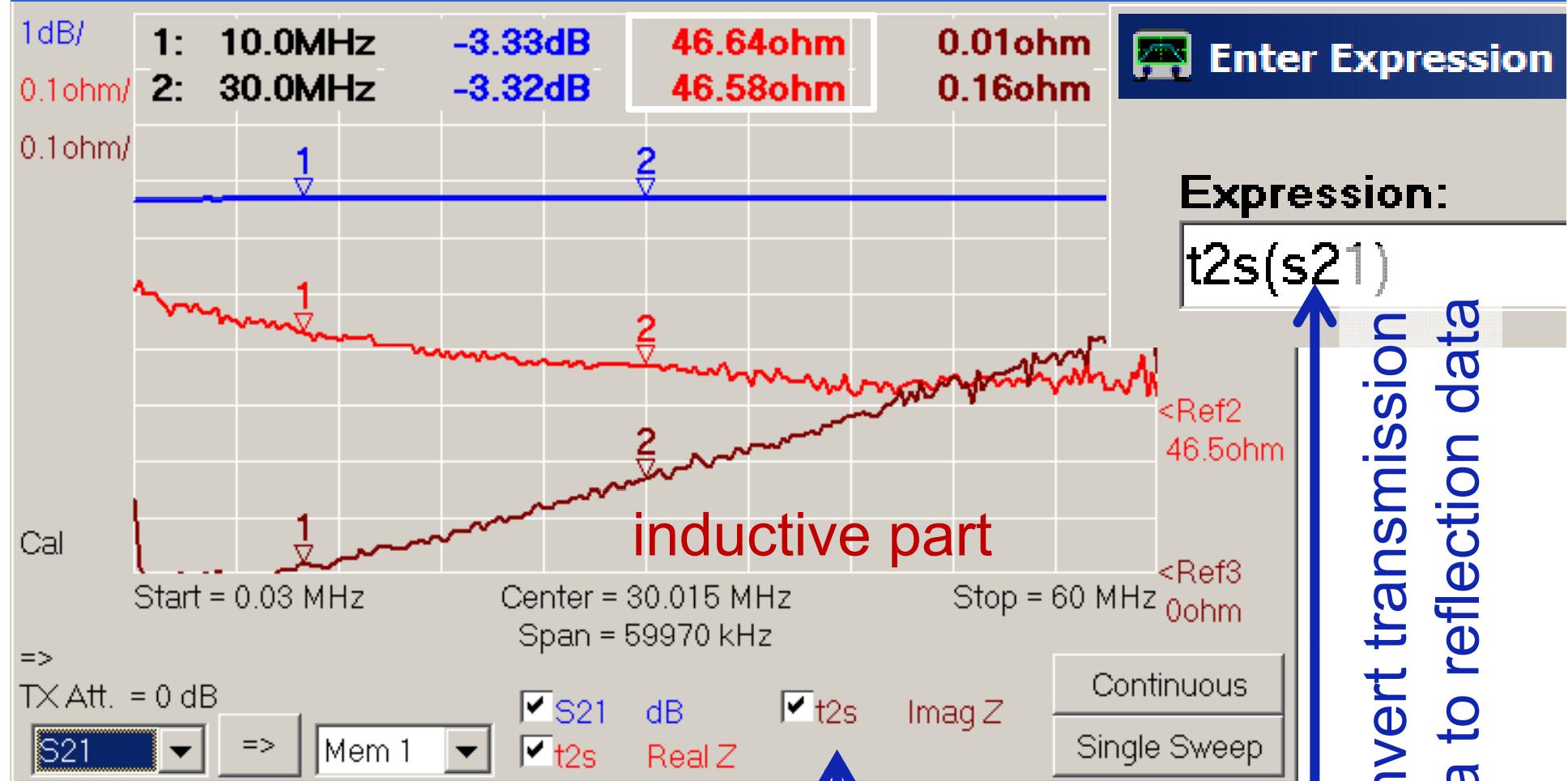
Measuring „Load“-Resistor in Transmission ($=S_{21}$ -Measurement)



Measurement:
Resistor between
TX and RX

Measuring „Load“-Resistor

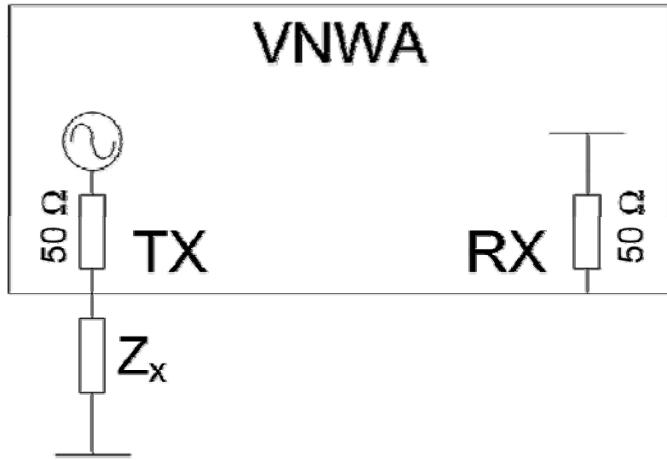
Result = 46,6 Ω



Analysis with Custom Trace

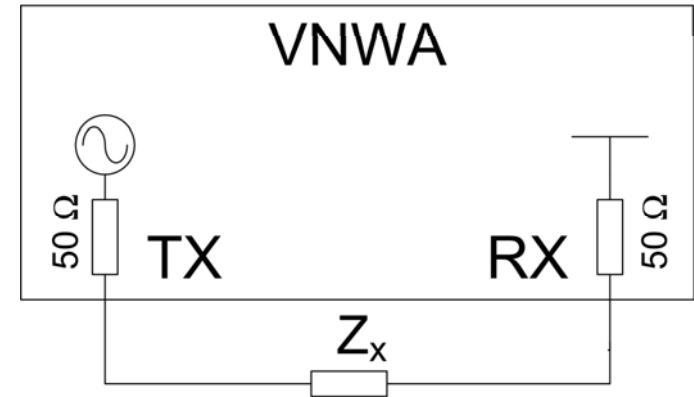
Convert transmission
data to reflection data

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** X

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_{II} = fF

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

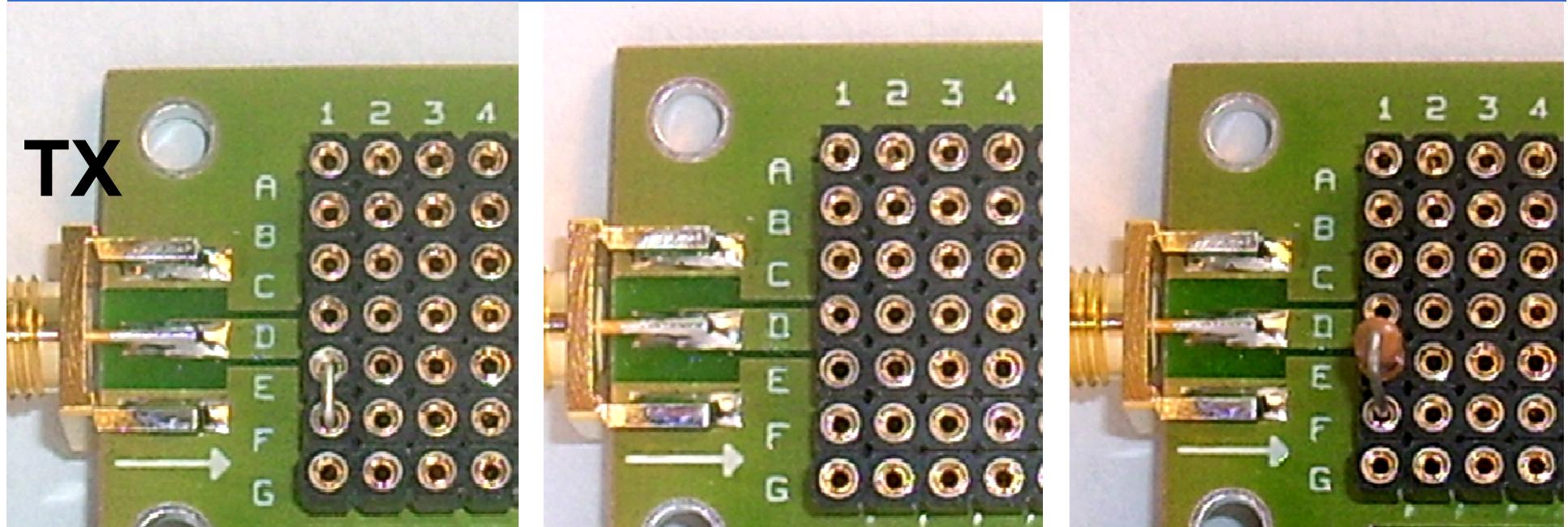
THRU Calibration Standard Setup

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

Short

Open

Load

Thru Calibration

Open

Crosstalk Cal

Thru Cal

Thru Match Cal

on / off

on / off

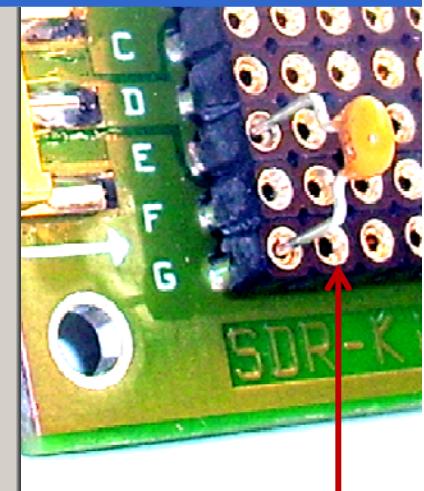
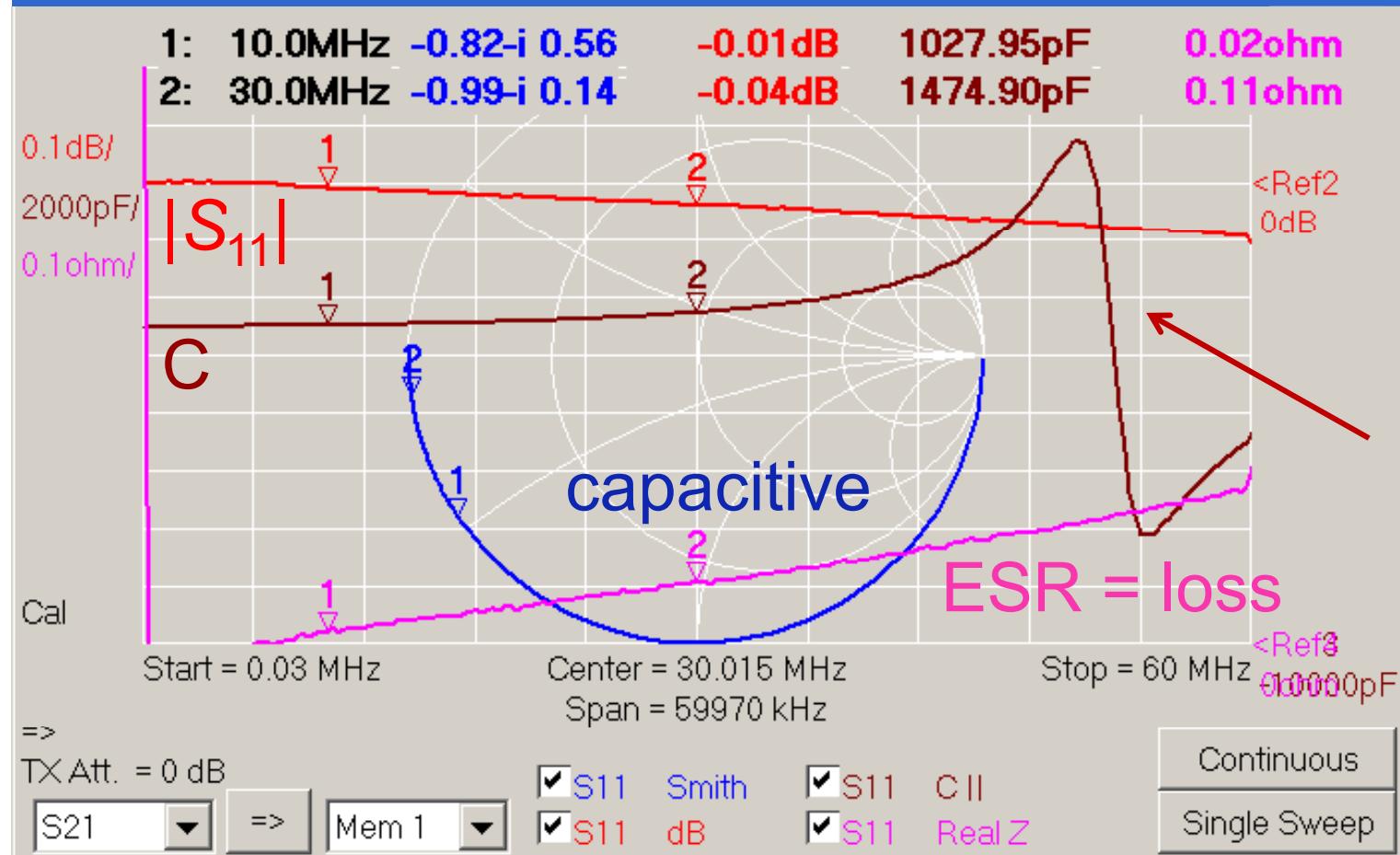
on / off

<http://www.edroneit.com/>

Invalidate All Thru Calibrations

Load

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



Resonance due to component wires

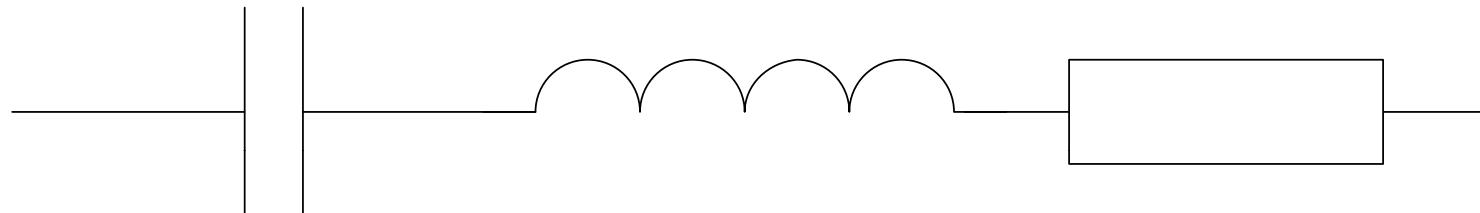
Capacitor reflects almost total power, $|S_{11}| \approx 0 \text{ dB}$

Modelling of Measurement Result in VNWA using Custom-Trace

 Enter Expression 2 for trace 2:

Impedance to Reflecion coefficient
Expression:

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



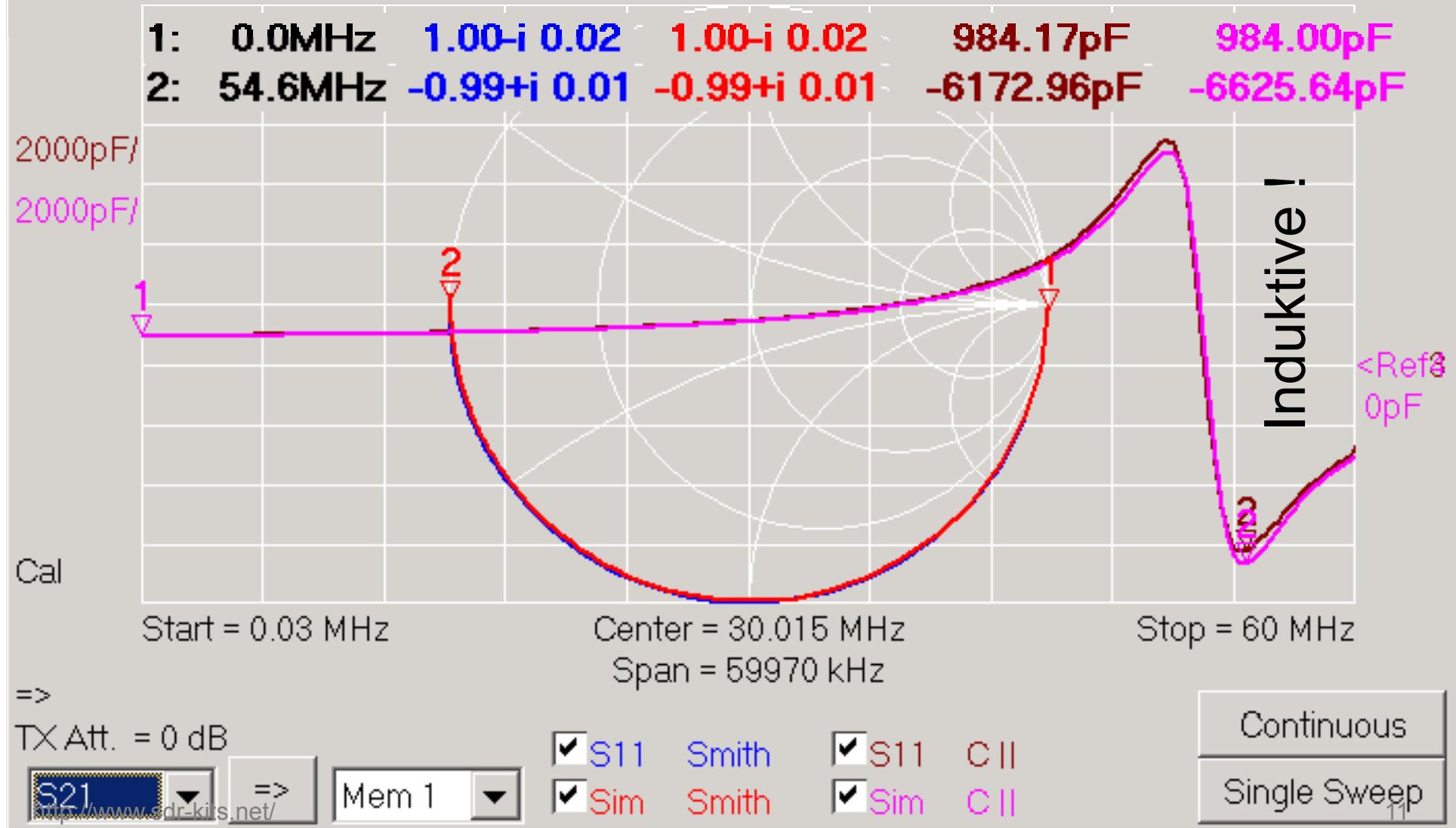
0,984 nF

9,3 nH

0,22 Ω

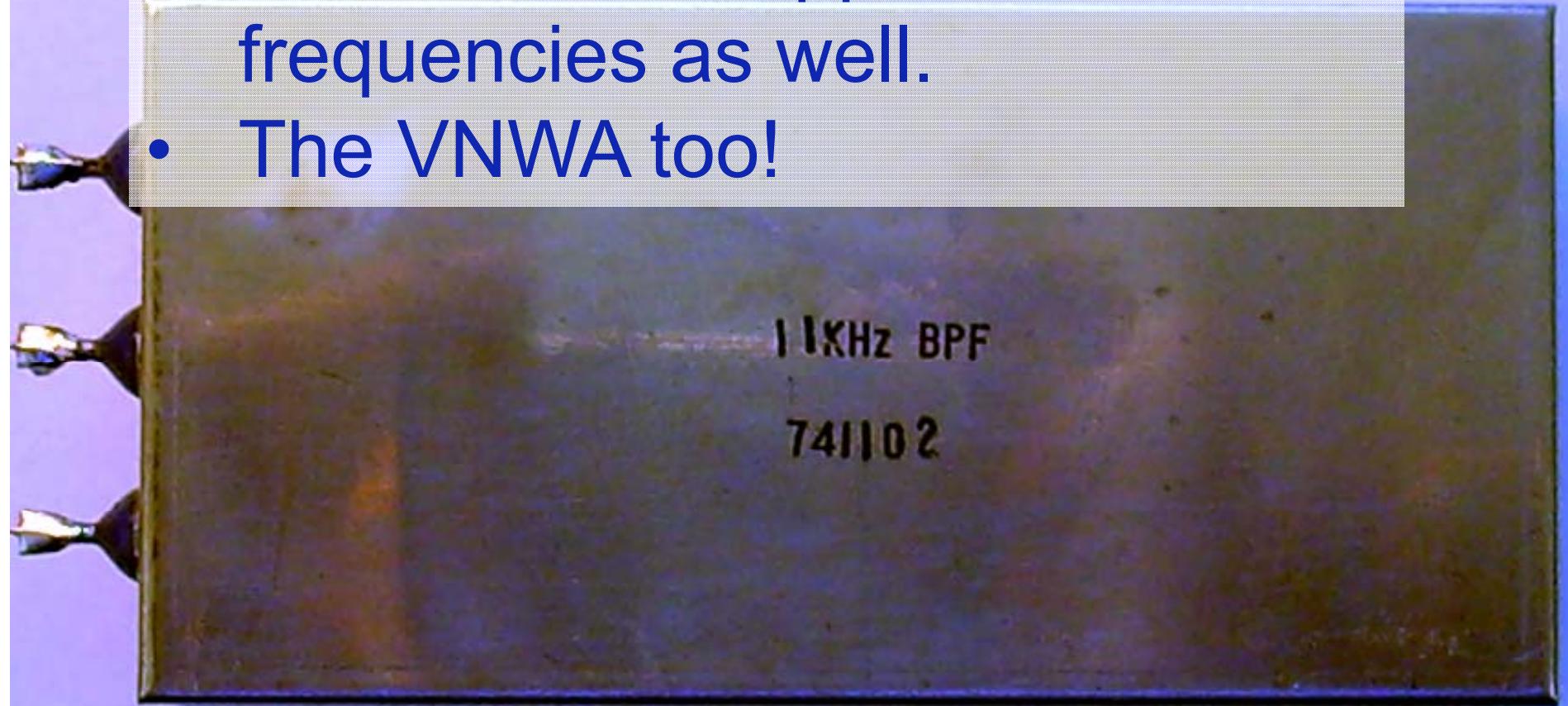
einfaches Modell

The Model is quite accurate!

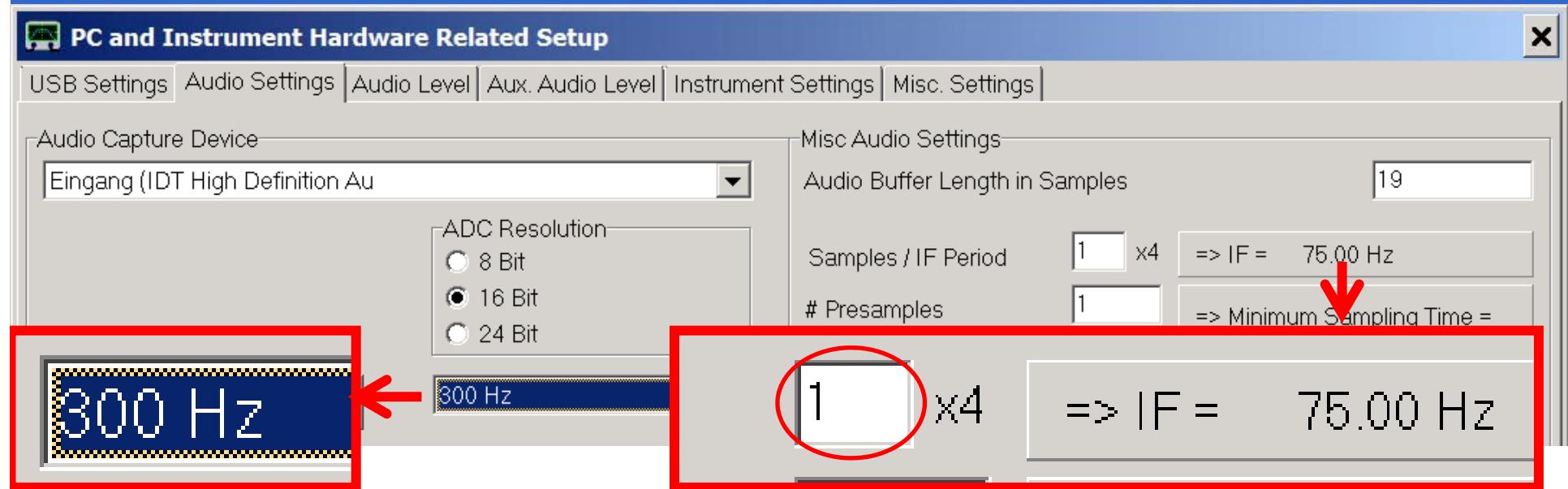


Two Port Measurement of a 12 kHz Band Pass Filter

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

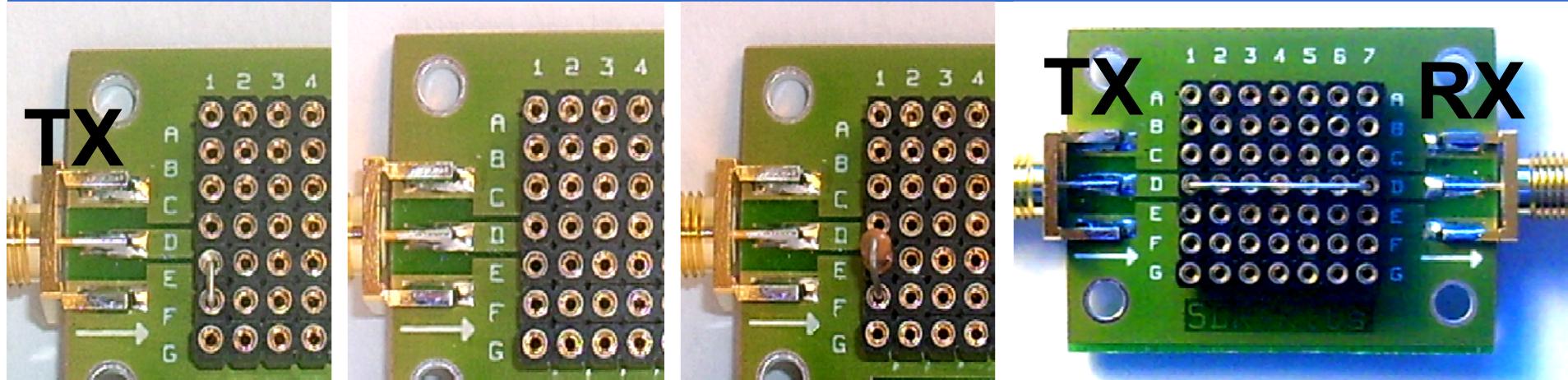


Special VNWA Settings for low Frequencies



**Lowest sample rate 300 Hz IF must be within Codec
→ Nyquist limit 150 Hz frequency range
→ Measurements down to (20 Hz...16kHz)
≈150 Hz possible**

SOLT-Calibration for 2-Port Measurements

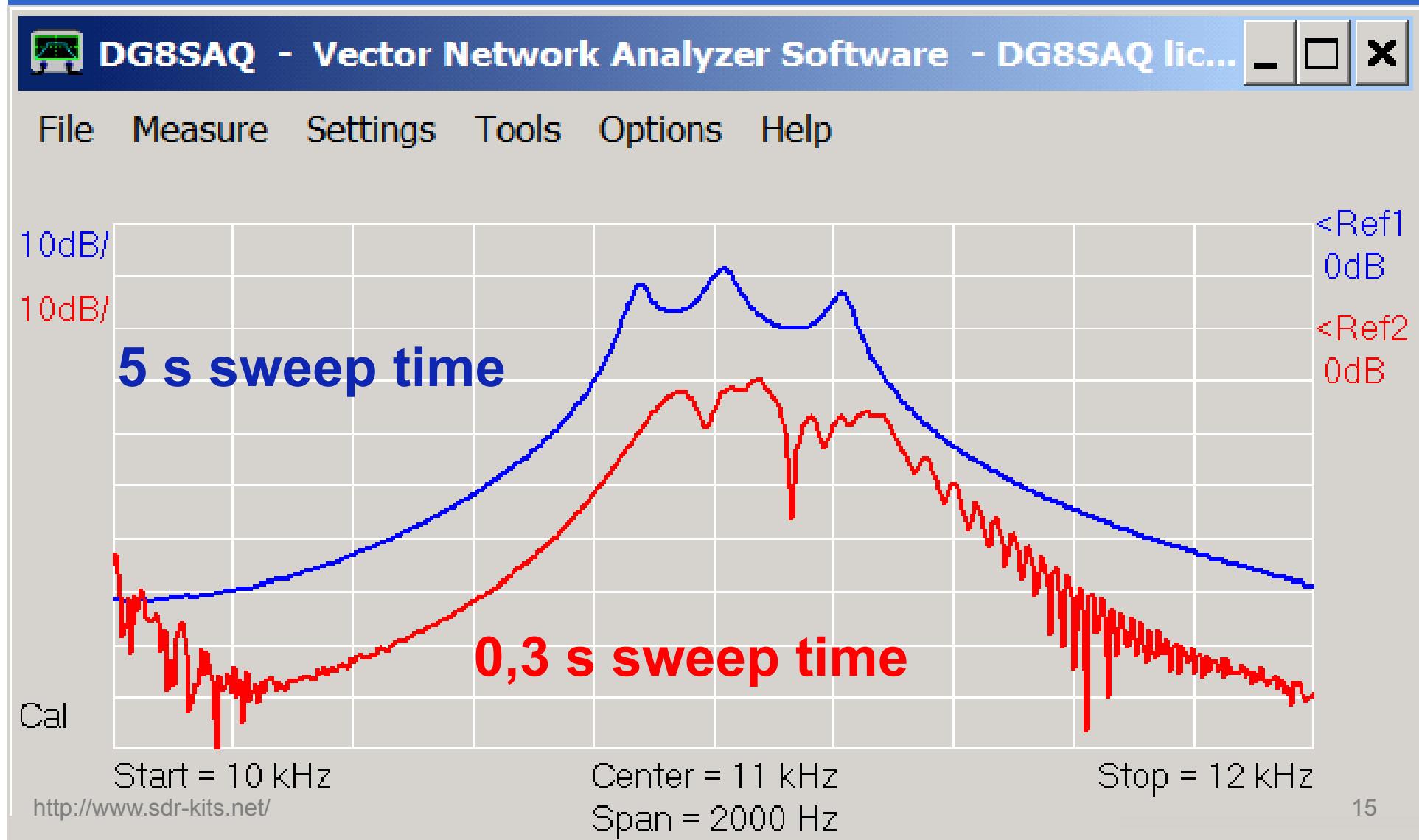


Reflect Calibration **Short** **Open** Thru Calibration **Load** **Thru**

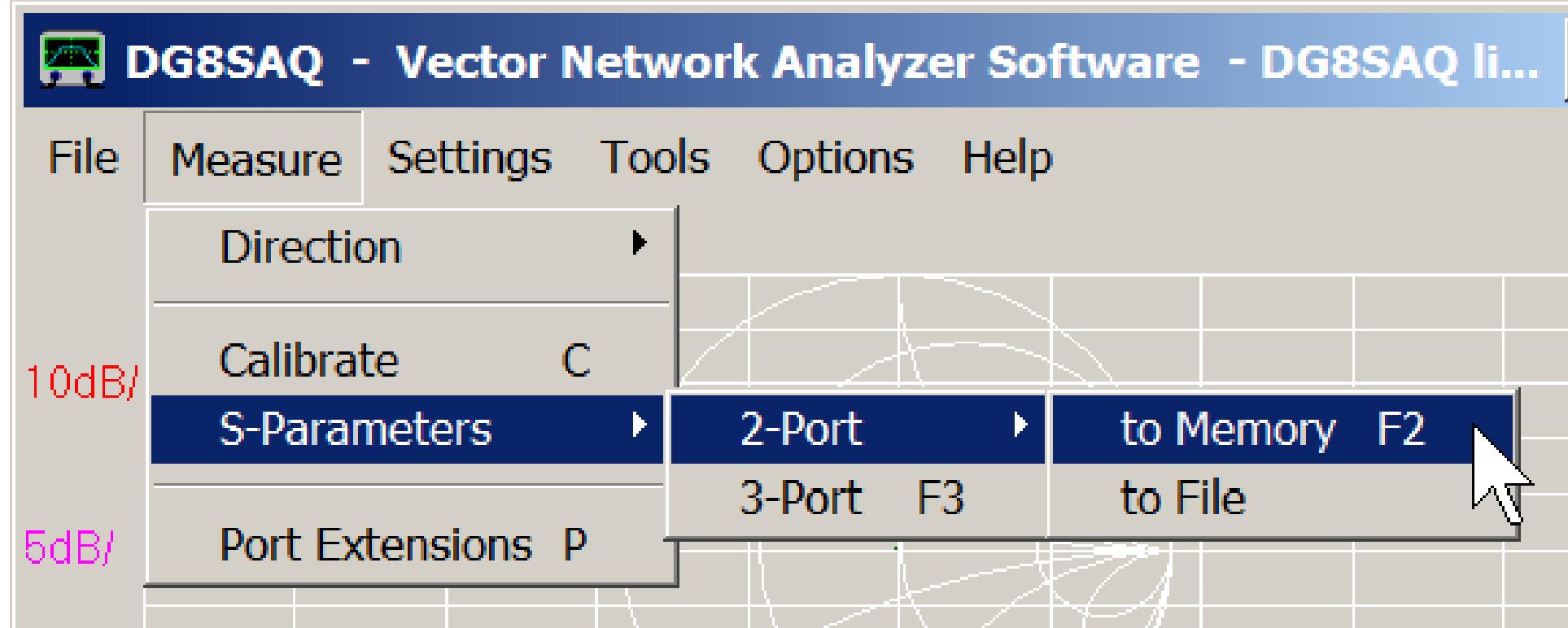
<input type="button" value="Short"/>	<input checked="" type="radio"/> M	<input type="button" value="Crosstalk Cal"/>	<input type="radio"/> on / off
<input type="button" value="Open"/>	<input checked="" type="radio"/> M	<input type="button" value="Thru Cal"/>	<input checked="" type="checkbox"/> on / off
<input type="button" value="Load"/>	<input checked="" type="radio"/> M	<input type="button" value="Thru Match Cal"/>	<input checked="" type="checkbox"/> on / off
Cal <input checked="" type="checkbox"/> on / off	<input checked="" type="radio"/> M	<input type="button" value="Invalidate All Thru Calibrations"/>	

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

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



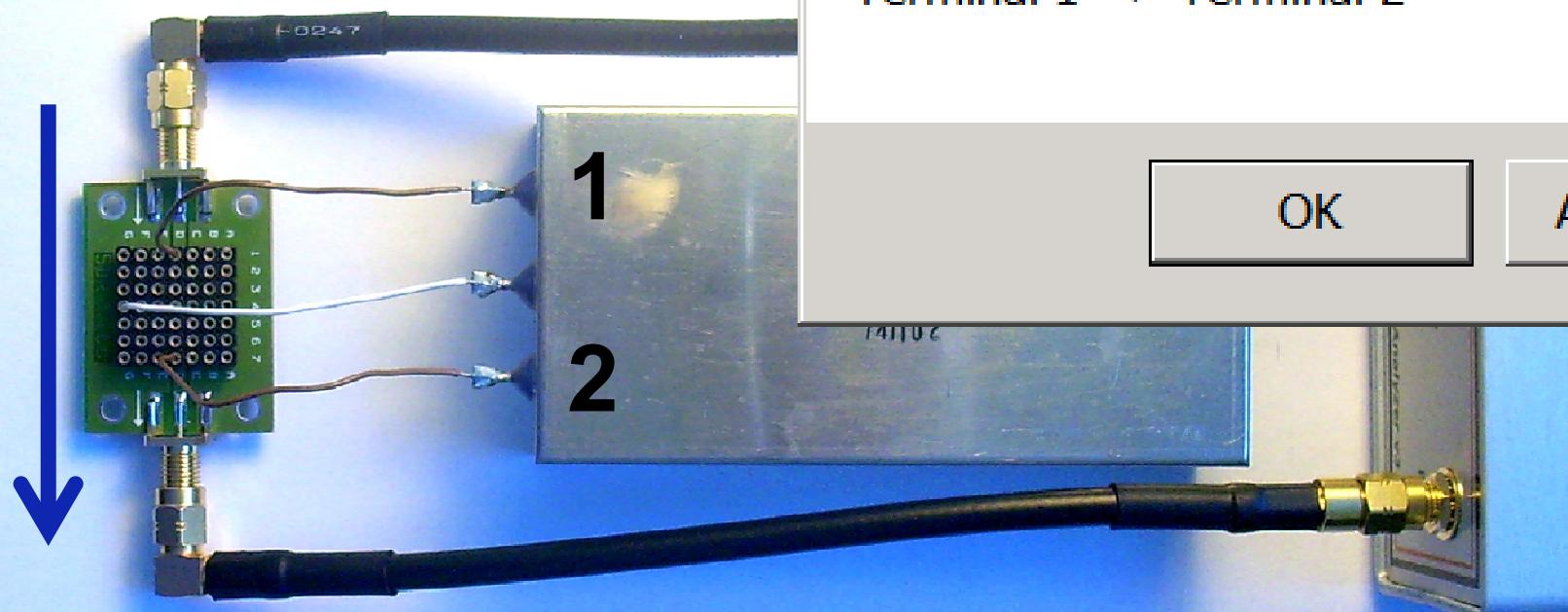
Two Port Measurement of a 12 kHz Band Pass Filter



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

TX



Multiport S-Parameter Measurement

Terminal 1 => Terminal 2

OK

Abbrechen

S_{11} , S_{21} measured

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

Multiport S-Parameter Me

Terminal 2 => Terminal 1

OK

2

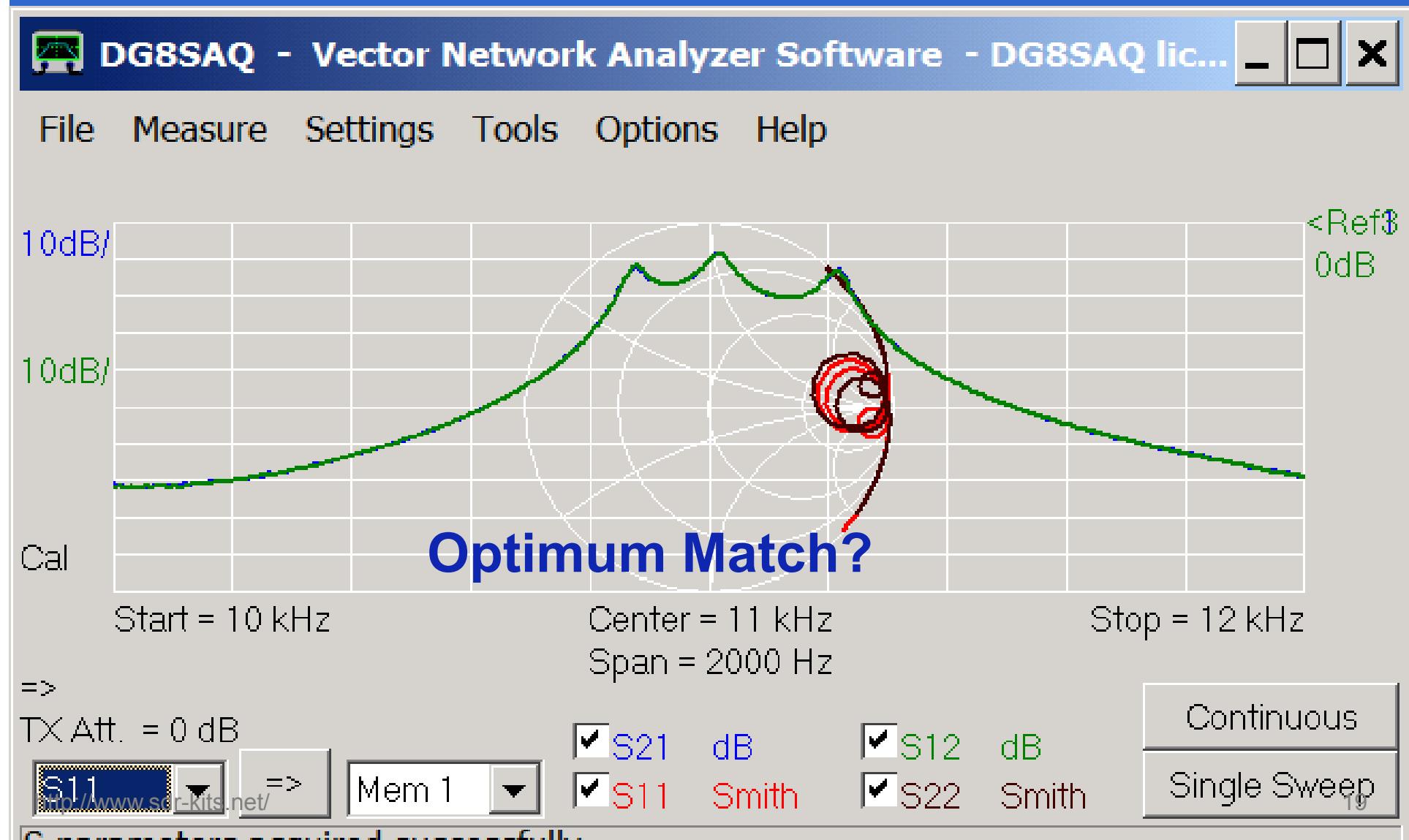
1

TX

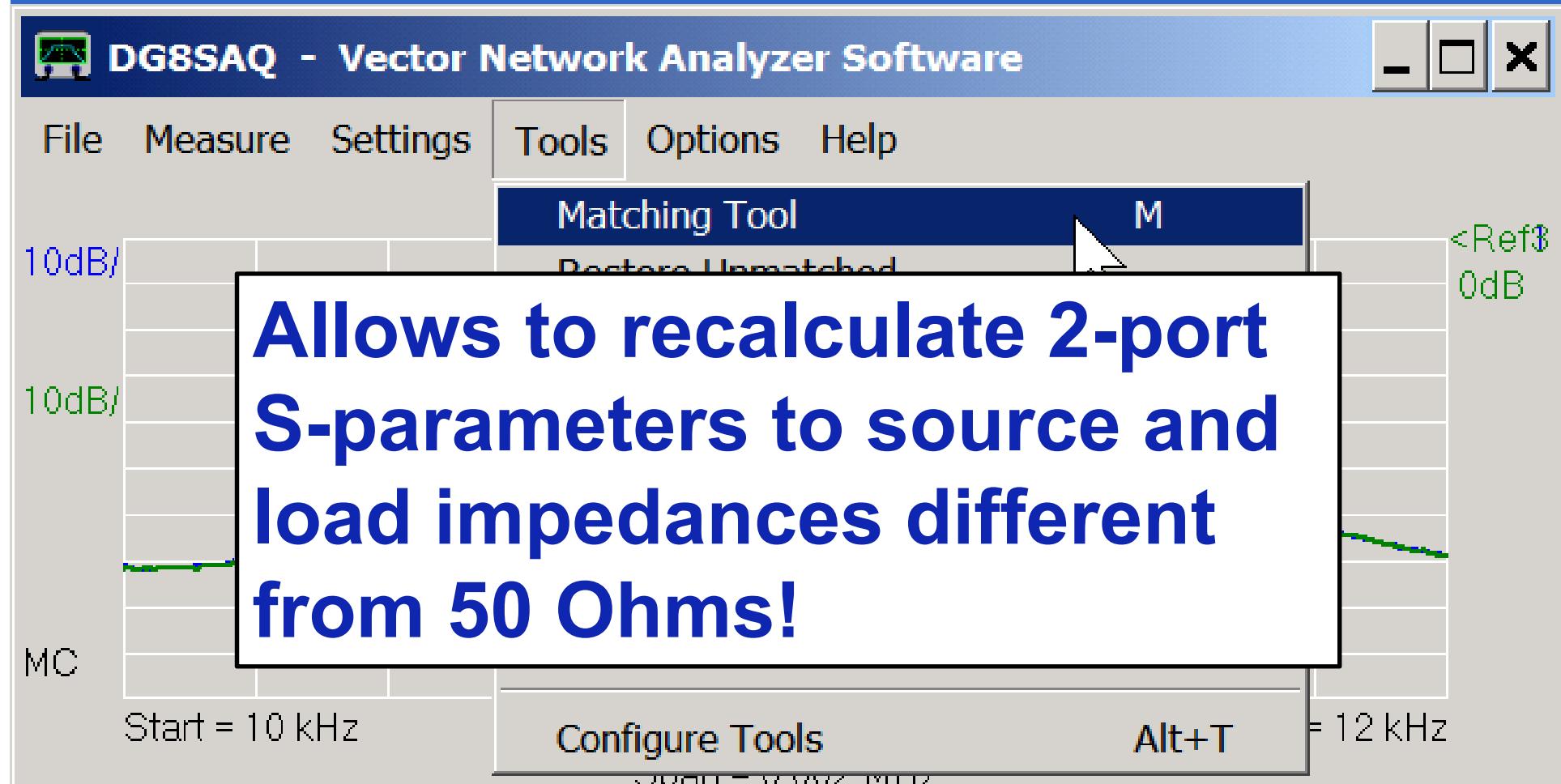
RX

S_{12} , S_{22} measured

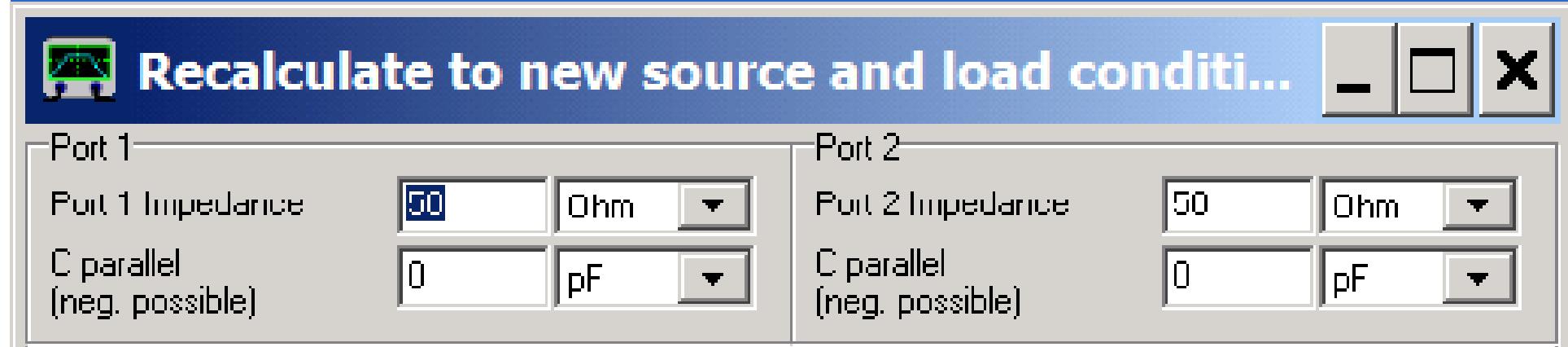
What are measured 2-Port S-Parameters good for?



VNWA Matching Tool (1)



VNWA Matching Tool (2)



Complex conjugate of
source impedance

=

filter *input* impedance

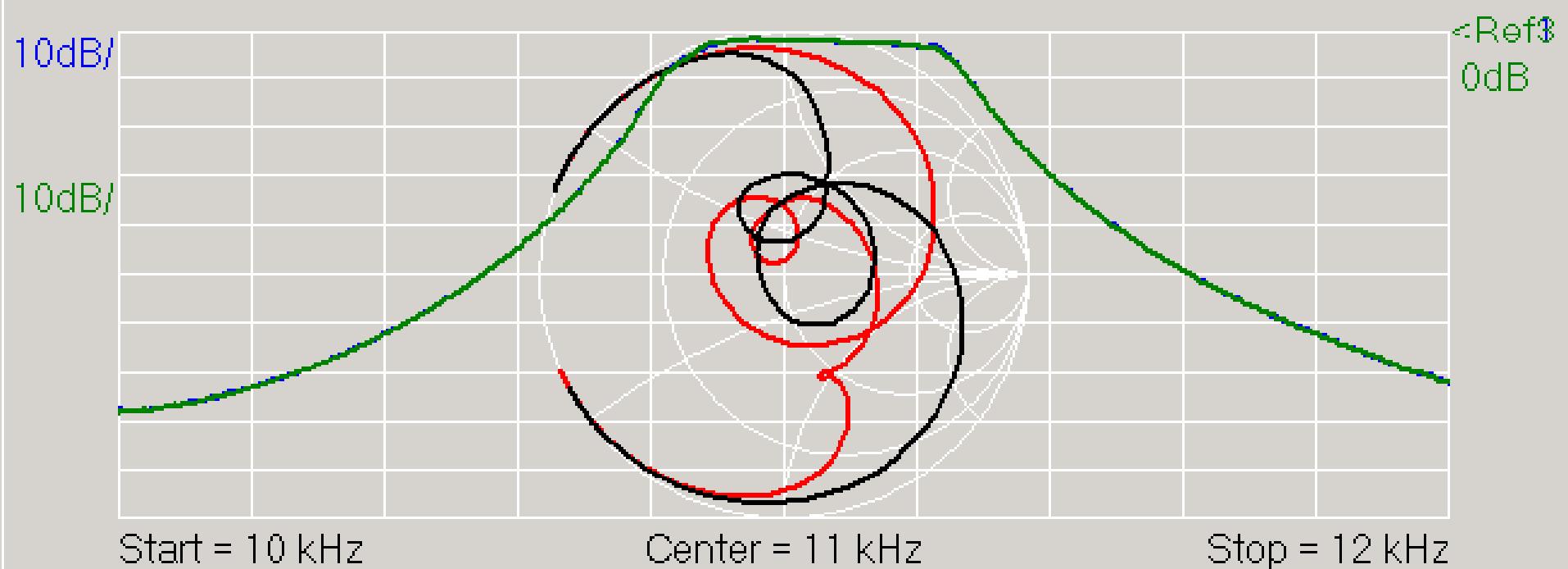
Complex conjugate of
load impedance

=

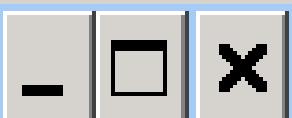
filter *output* impedance

Matching Analysis with VNWA Matching Tool

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



Recalculate to new source and load conditi...



Port 1

Port 1 Impedance

610 Ohm

C parallel
(neg. possible)

0 pF

Port 2

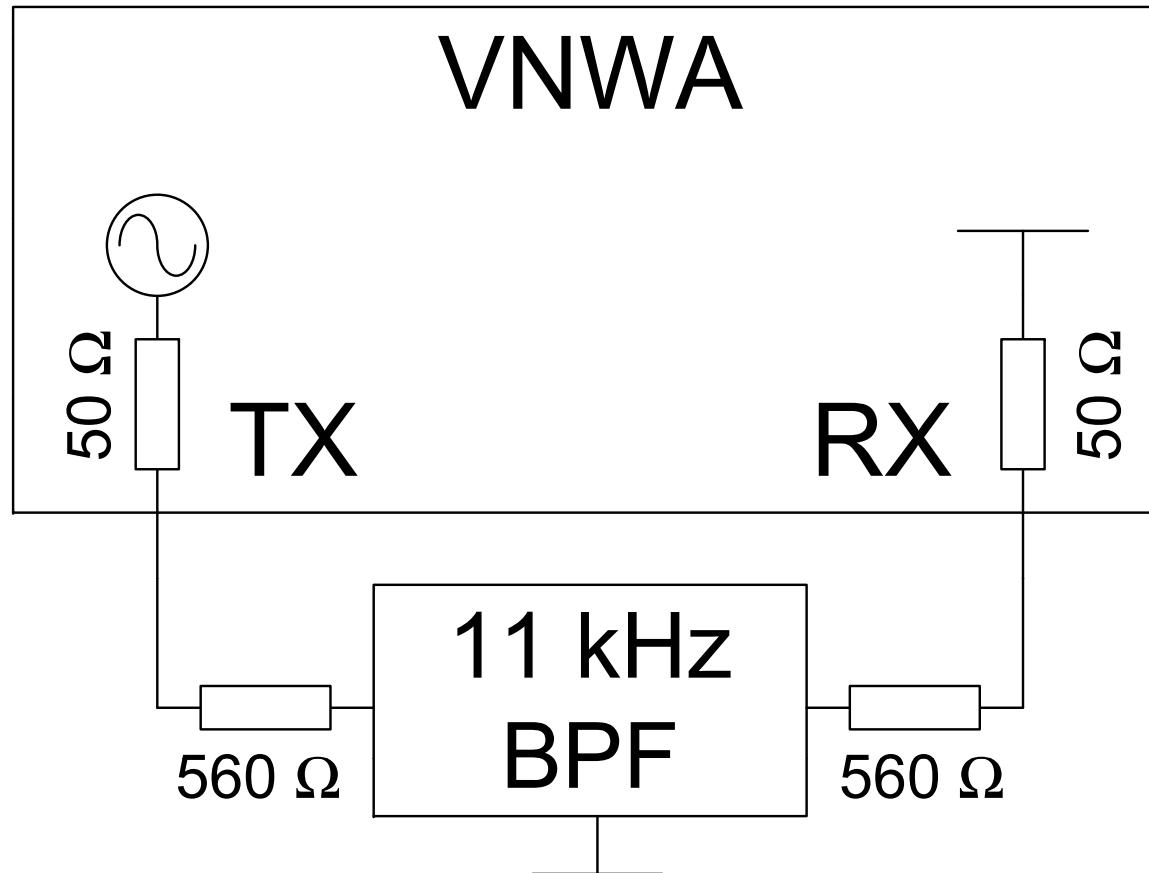
Port 2 Impedance

610 Ohm

C parallel
(neg. possible)

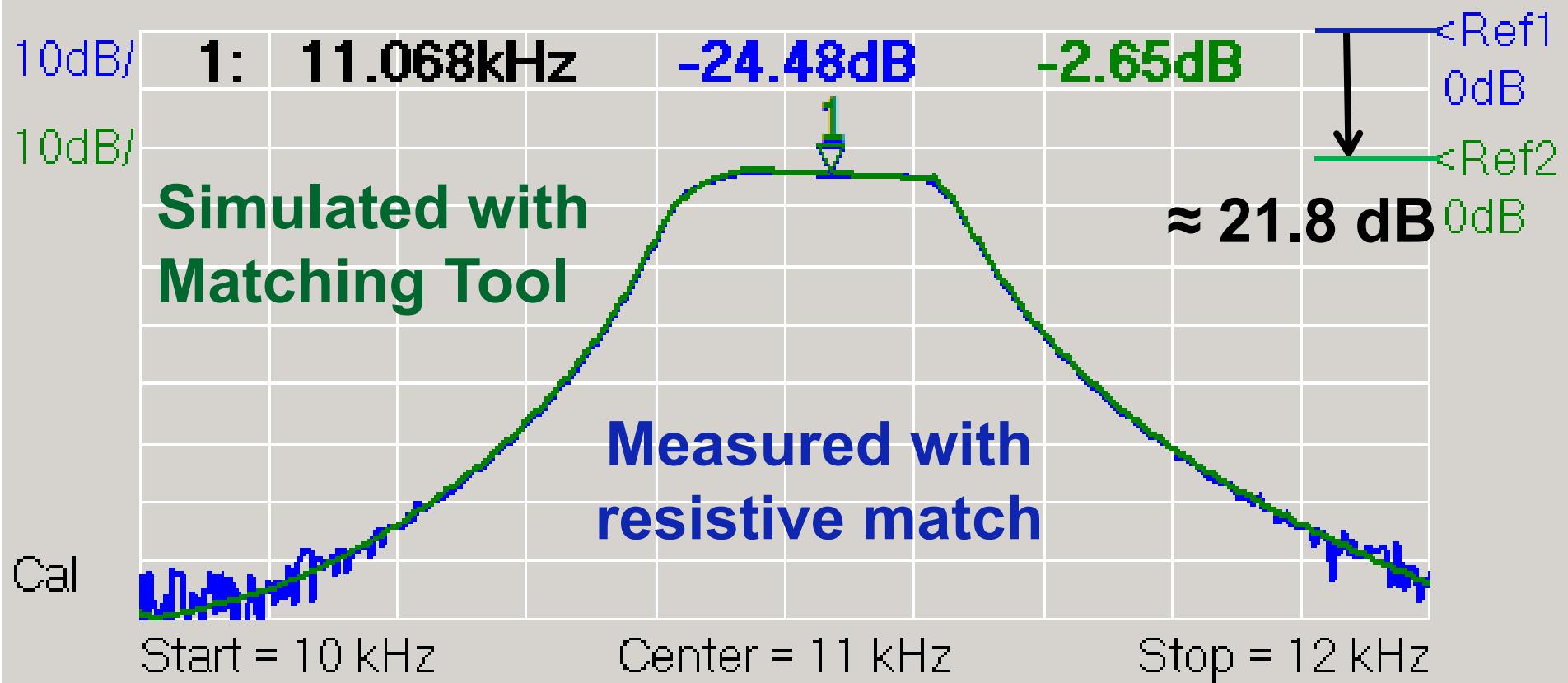
0 pF

Forced Impedance Match using Resistors



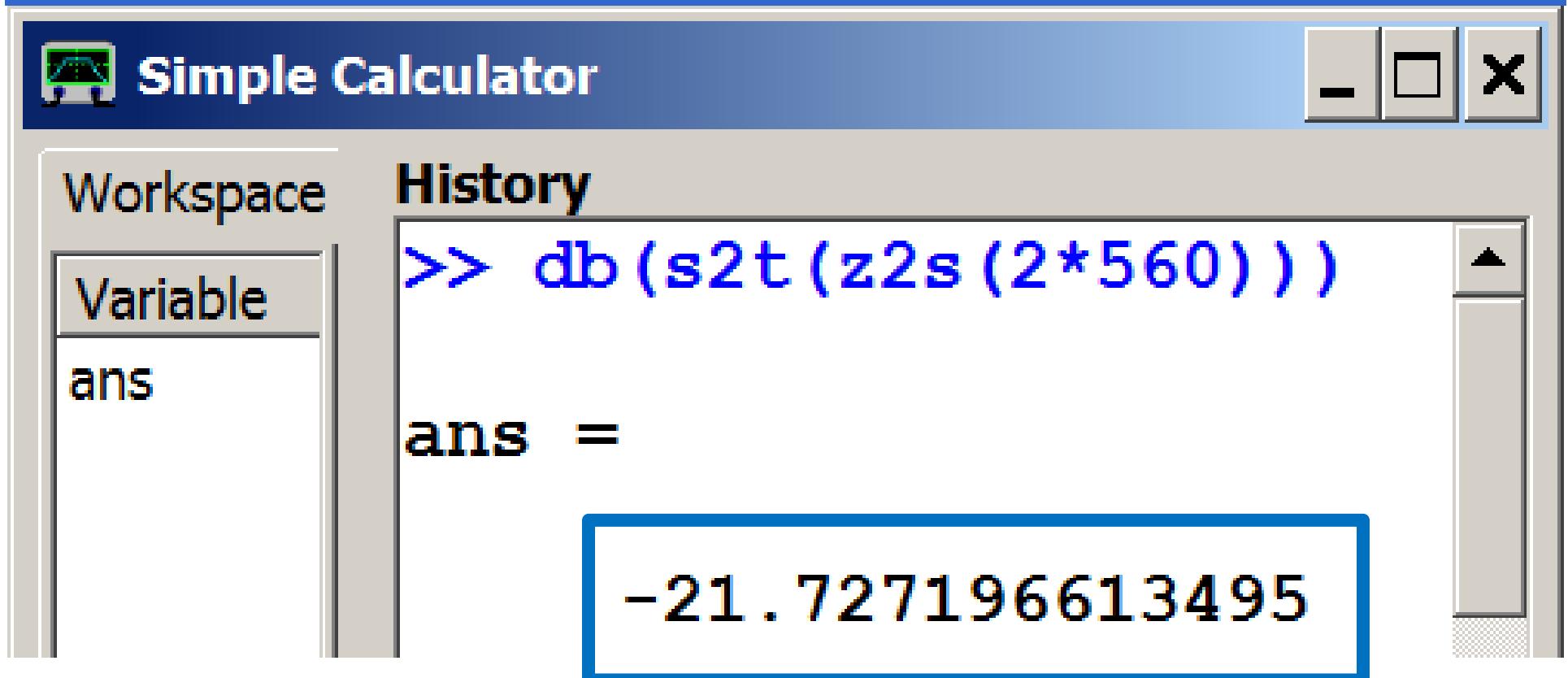
$$50 \Omega + 560 \Omega = 610 \Omega$$

Match works except for increased Loss



S21 dB
 Mem1 dB

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



21,7 dB additional attenuation ✓

This can also be „properly“ simulated! Simulation Tool QUCS



Quite Universal Circuit Simulator

- <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

simulations

Projects

Content

Components

11kHzBPF.sch 11kHzBPF.dpl

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 R=560 Ohm Z=50 Ohm

R1 Ref

R2

P2 Num=2 R=560 Ohm Z=50 Ohm

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

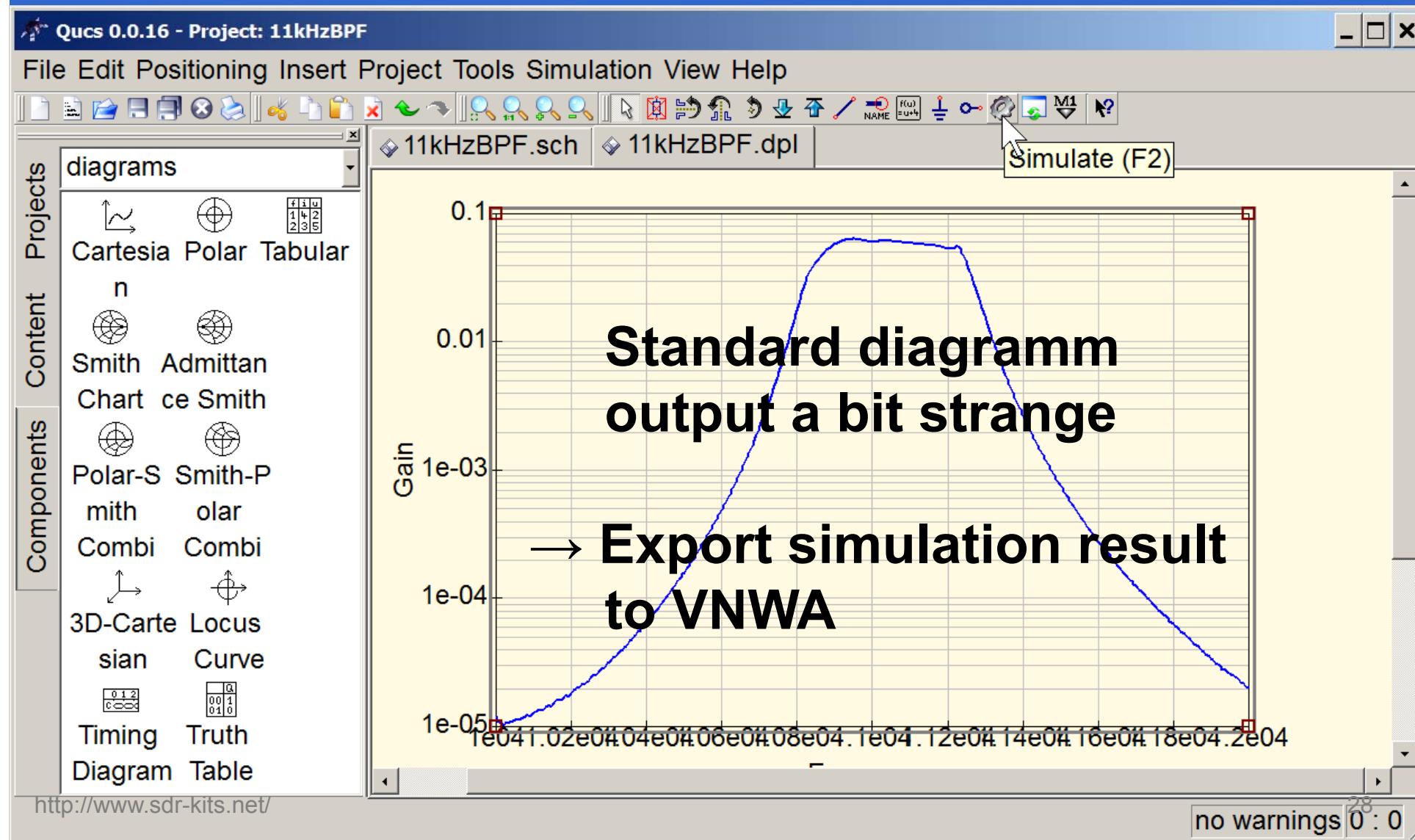
no warnings 0 : 0

The screenshot shows the QUCS (Quick Universal Circuit Simulator) software interface. The main window displays a schematic diagram of a bandpass filter. The circuit consists of two transmission lines (P1 and P2) connected to resistors R1 and R2, which are in series with each other. The input port is labeled X1 and the output port is labeled file. The parameters for the resistors are R=560 Ohm and Z=50 Ohm. A blue callout box labeled "S parameter simulation" contains the following parameters:

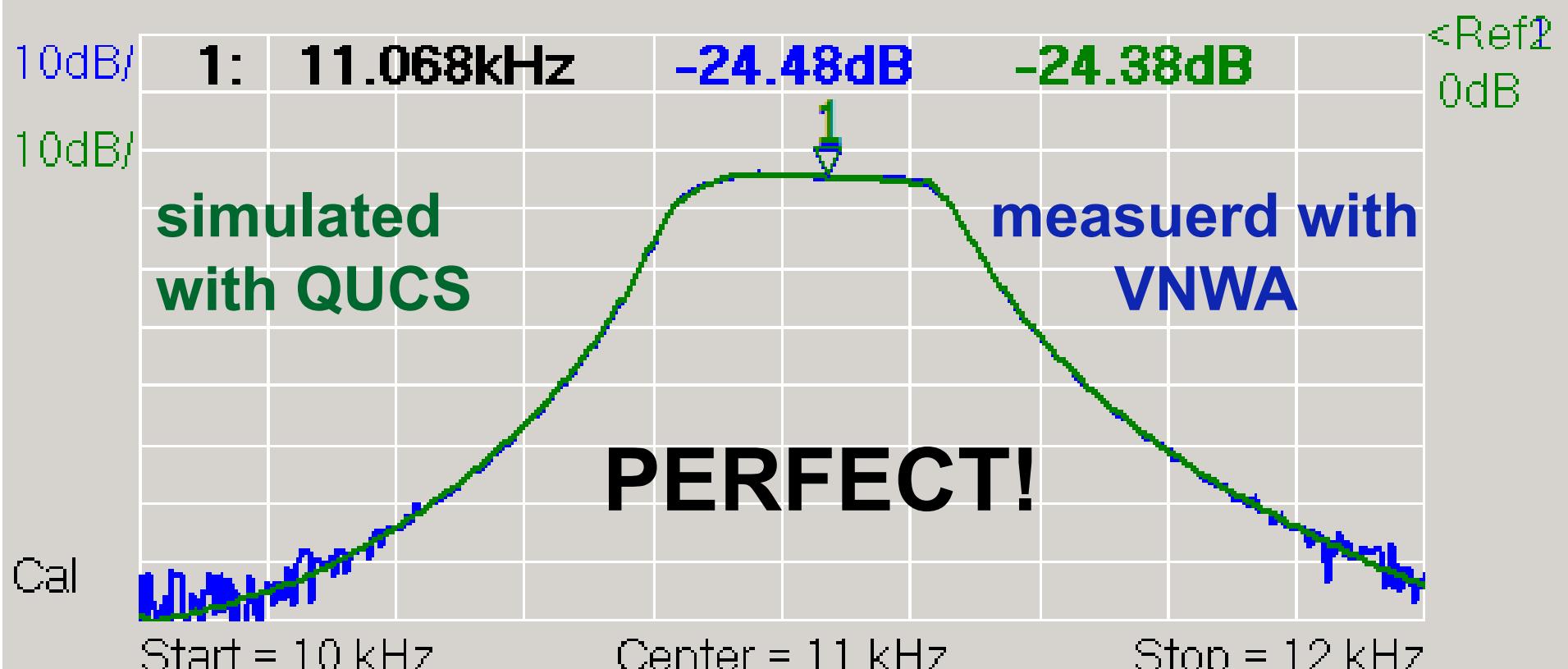
- SP1
- Type=lin
- Start=10 kHz
- Stop=12 kHz
- Points=400

A large blue arrow points from the text "measured S-parameters from s2p-file" towards the "file" terminal of the circuit diagram.

Matching Simulation in QUCS



Comparison QUCS-Simulation vs. Measurement



- S21 dB
- Mem1 dB

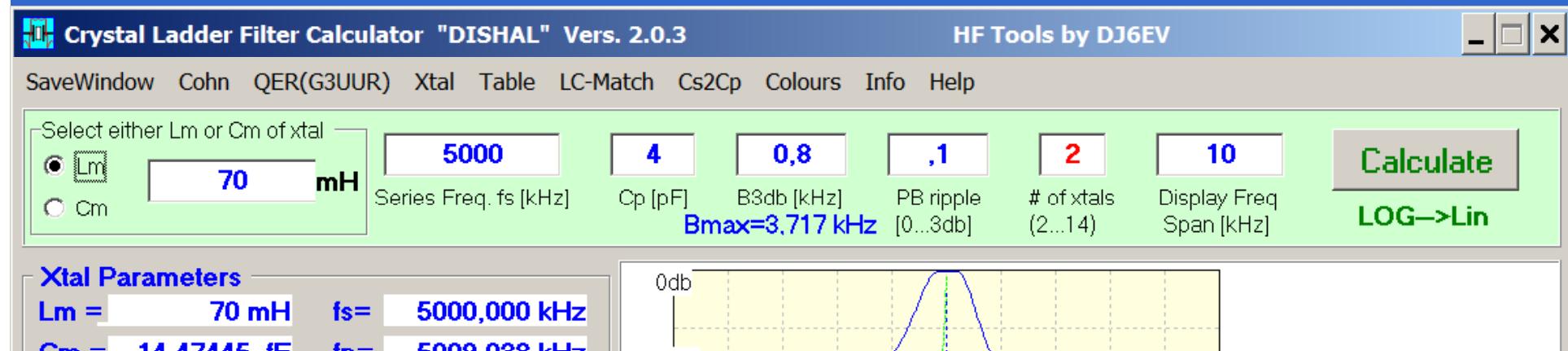
Free Filter Design Software (1): Elsie – for LC-Filters

 Elsie Student Edition - Welcome !

This is the Student Edition of
Elsie

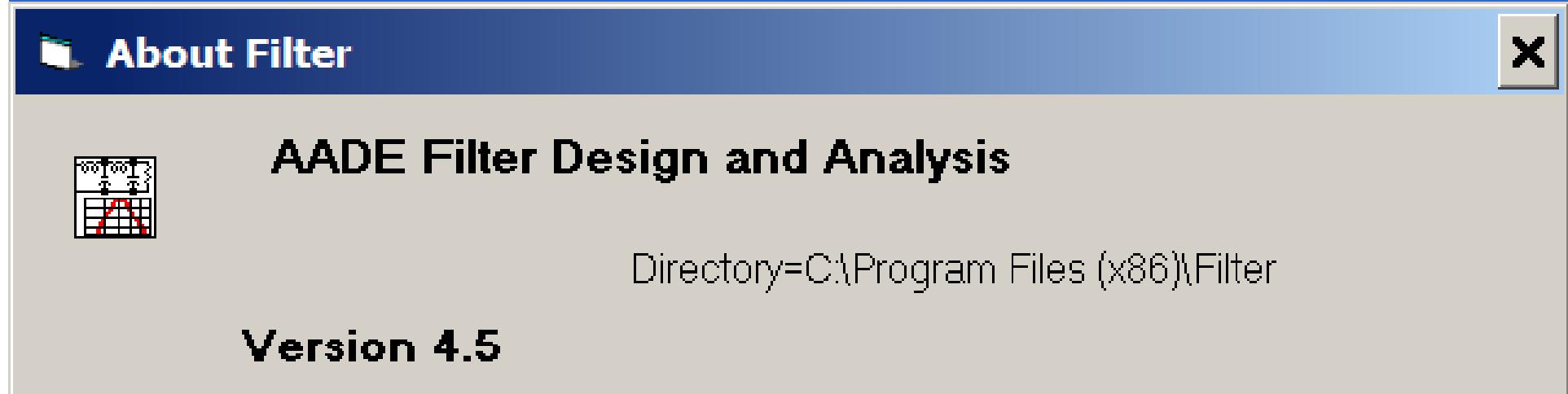
- <http://tonnesoftware.com/elsiedownload.html>
- LC-Filter Designer and Analyzer
- Student version restricted to 7 dipols
- Numerical simulation results export easily to s2p-file!

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



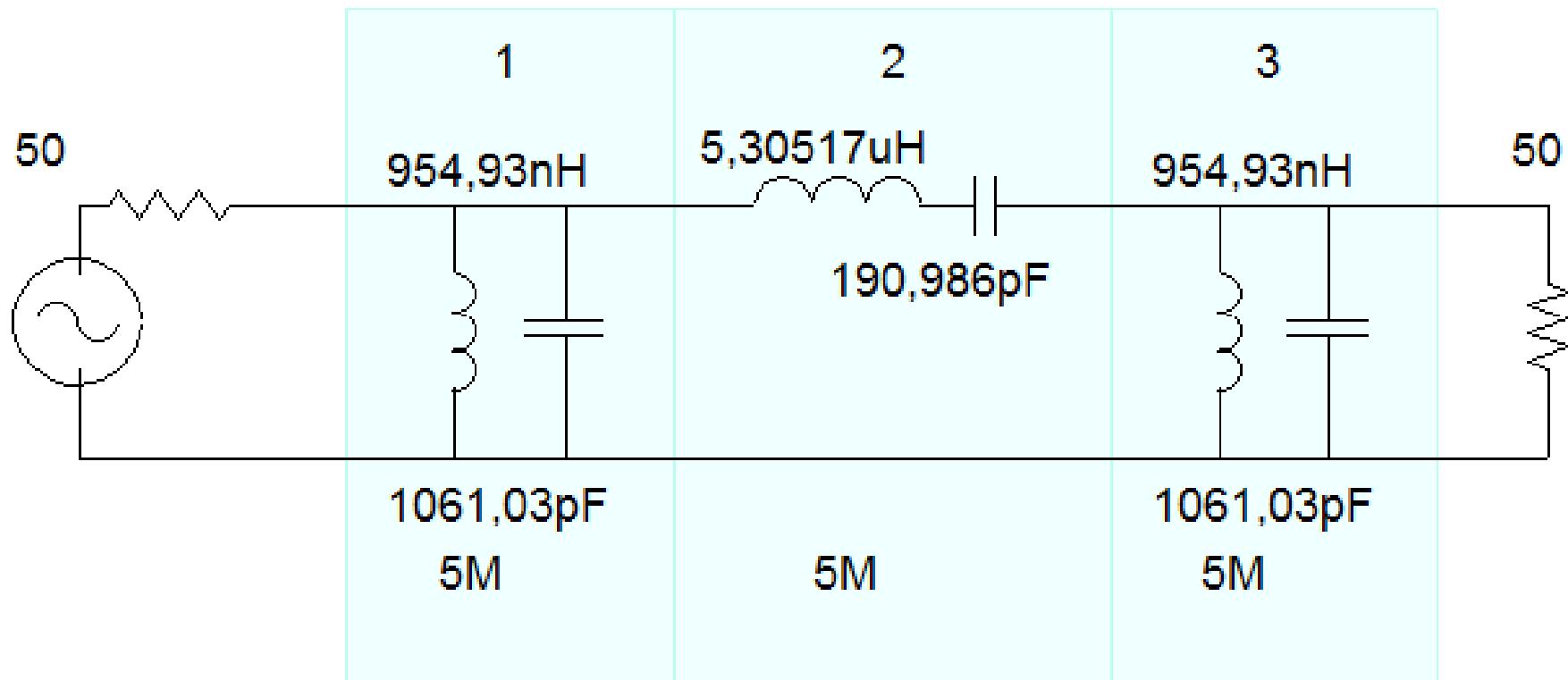
- <http://www.bartelsos.de/dk7jb.php/quarzfilter-horst-dj6ev>
 - **Crystal filter designer and analyzer**
 - **Simulates without crystal losses**
 - **S₂₁-simulation results can be exported**

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



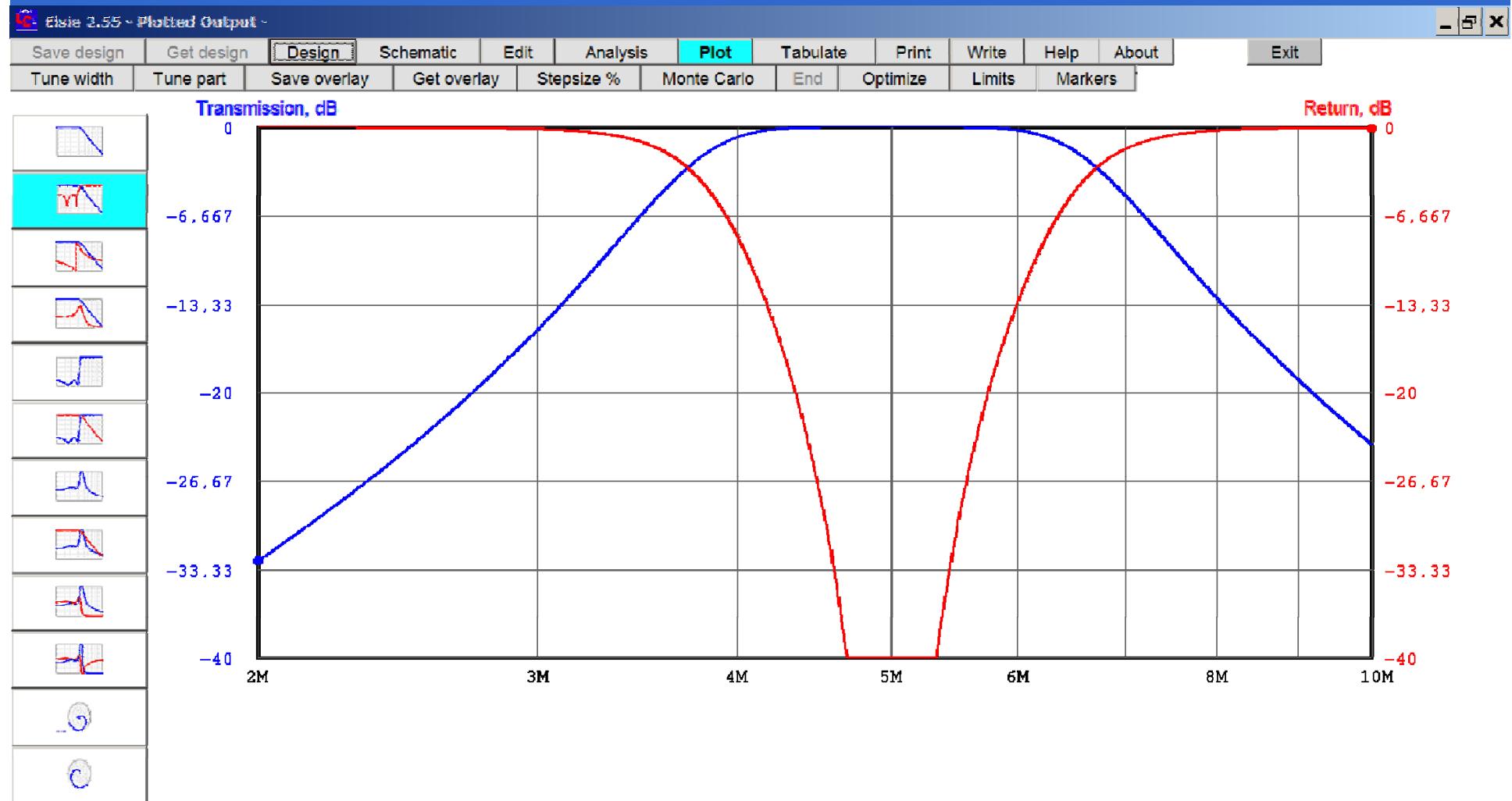
- <http://aade.com/filter32/download.htm>
- **Univeral filter designer and analyzer**
- **Free, but with nag screen**
- **Easy to use**
- **Numerical simulation results cannot be exported**

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



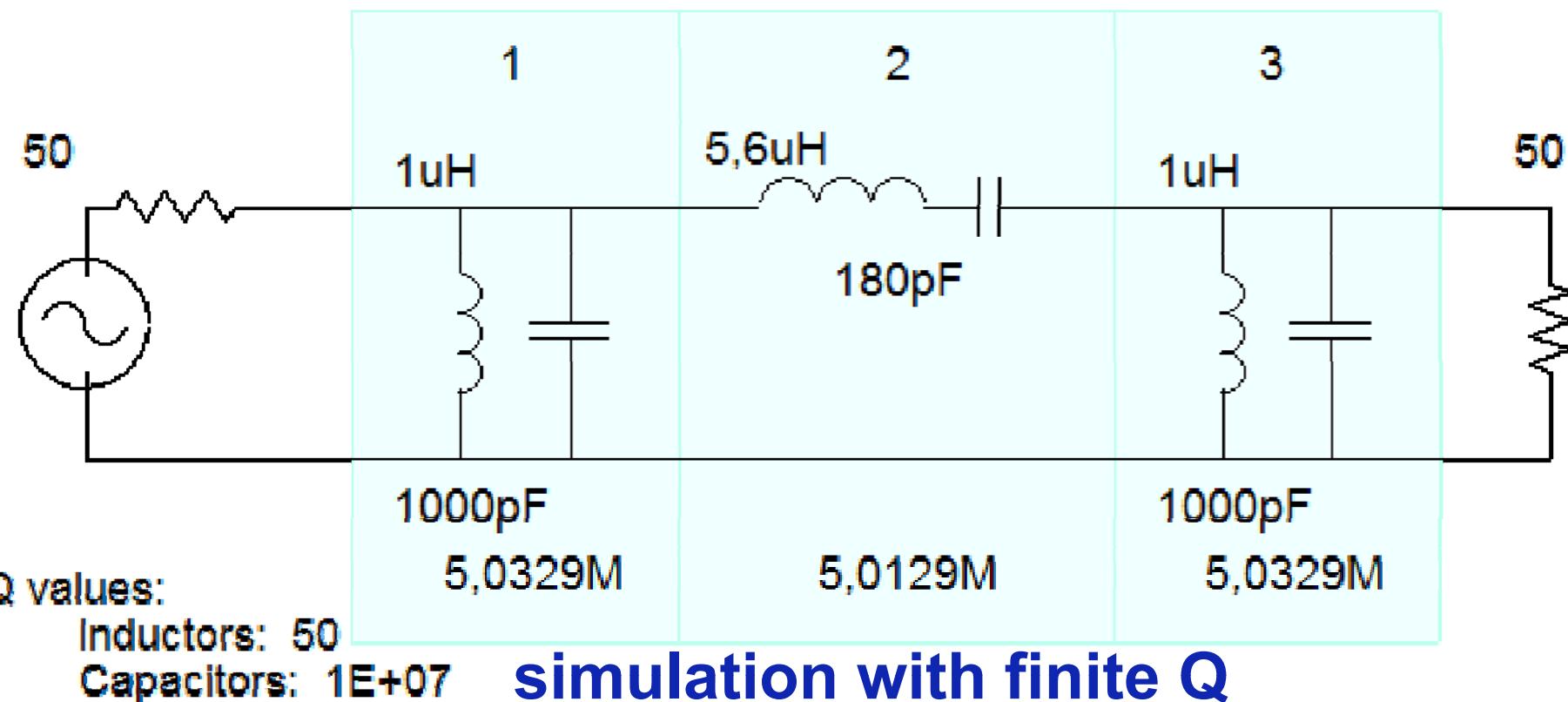
Filter Design with Elsie

Elsie Simulation Result



Modify Components to standard Values and finite Q ...

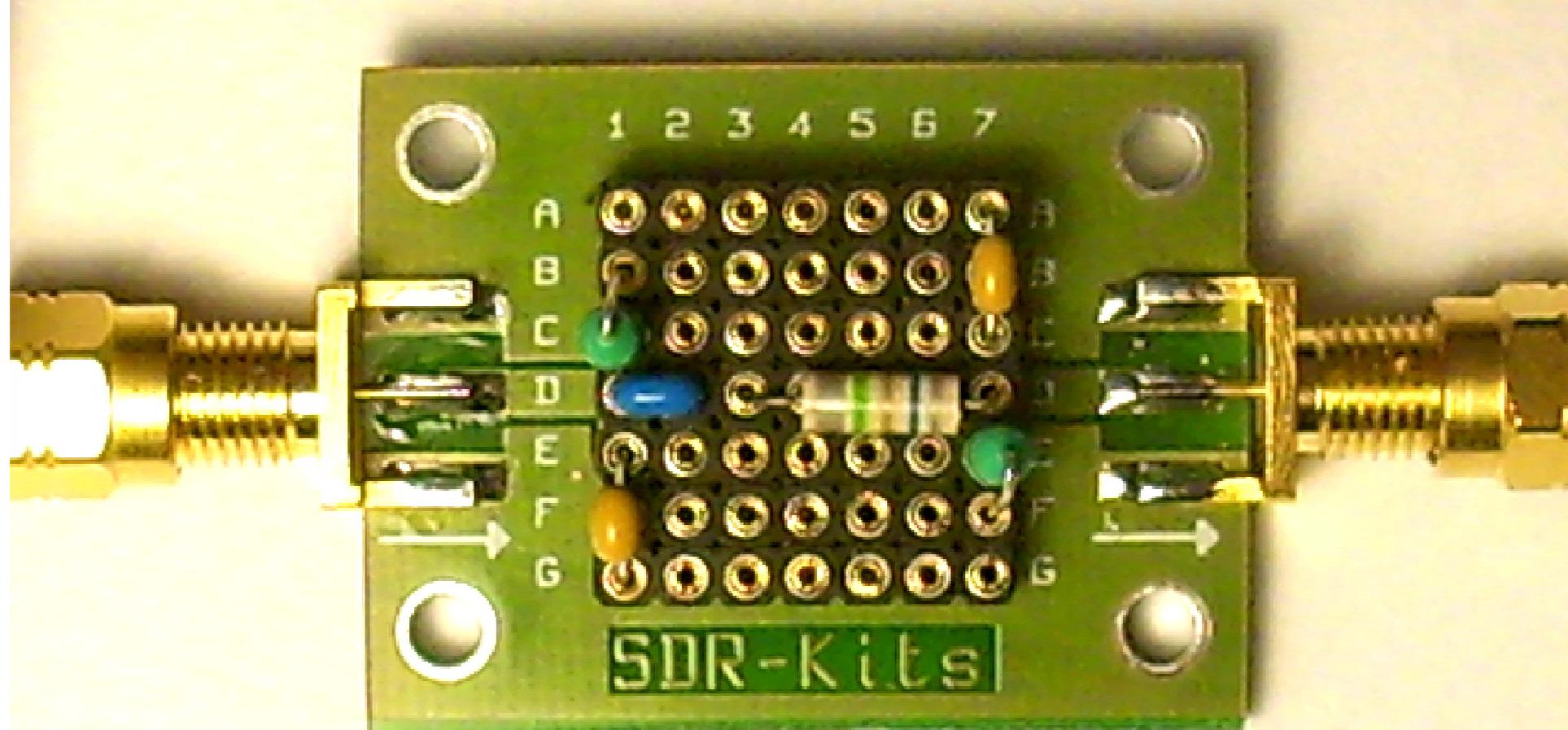
Schematic **Edit** Analysis Plot Tabulate Print



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

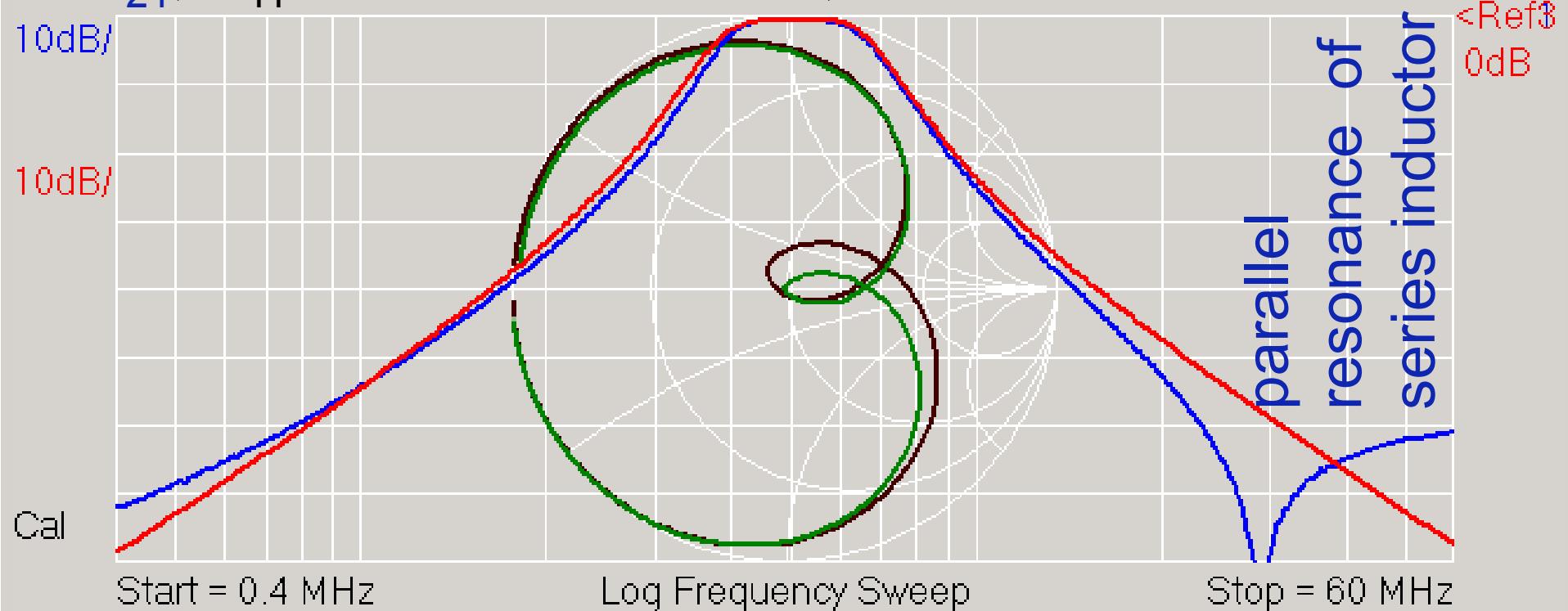


Filter Hardware



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

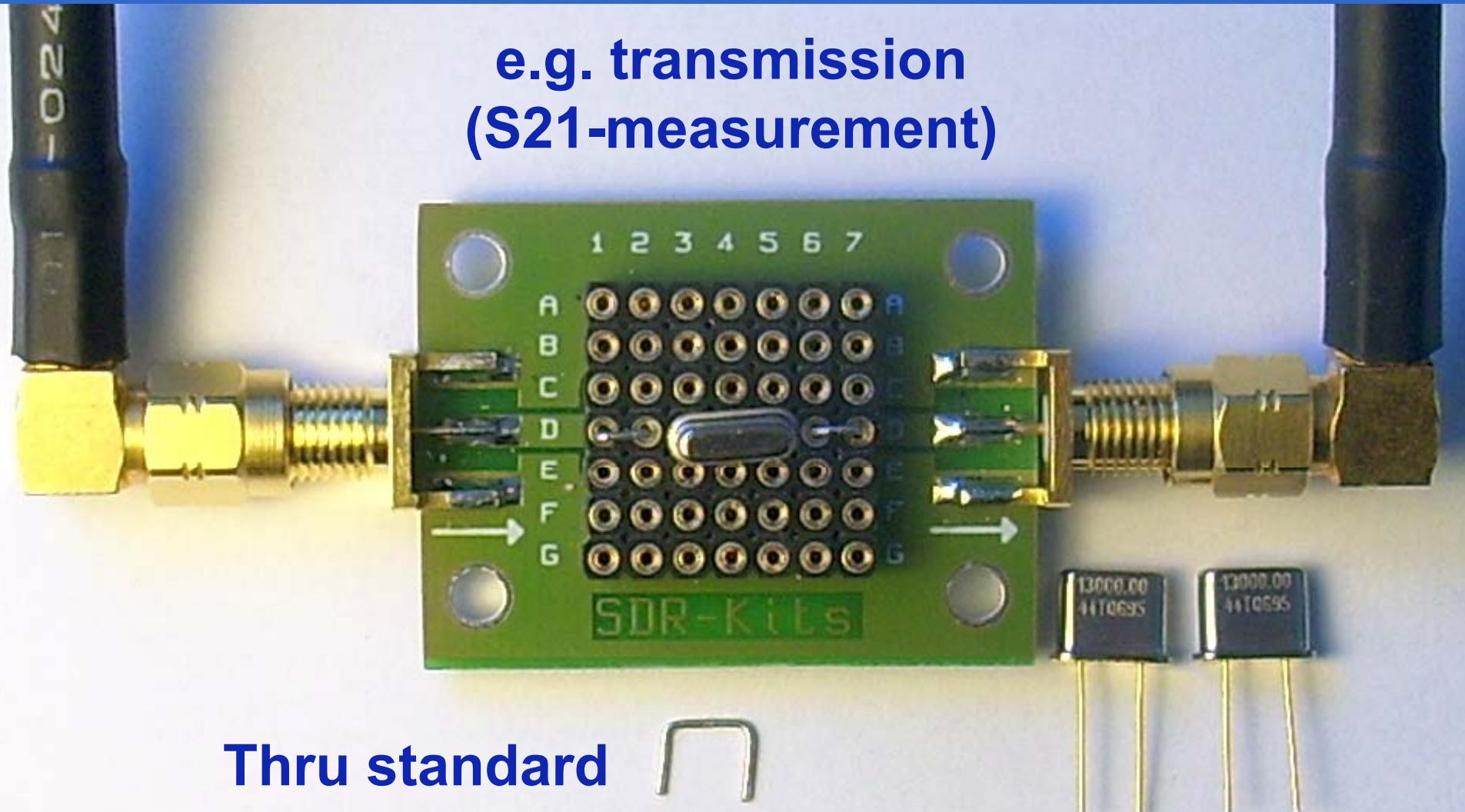
Plot2 Smith

Continuous

Single Sweep

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... X

Equivalent Circuit

L = 23.22917 mH
C = 6.456461 fF
R = 27.285283581 Ohm
C0 = 2.4657104121e-12 pF
 $f = 1/2\pi\sqrt{L \cdot C}$ = 12.995886978 MHz
 $R \cdot Q = \sqrt{L/C}$ = 1896.7918117 x1000 Q = 69517

auto-optimize

source = S21 Test Jig Impedances = 50 Ohms

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	.		$\sqrt{ }$	x^2	μ
tab	bksp	CLR			n
ENTER		Cancel	p		

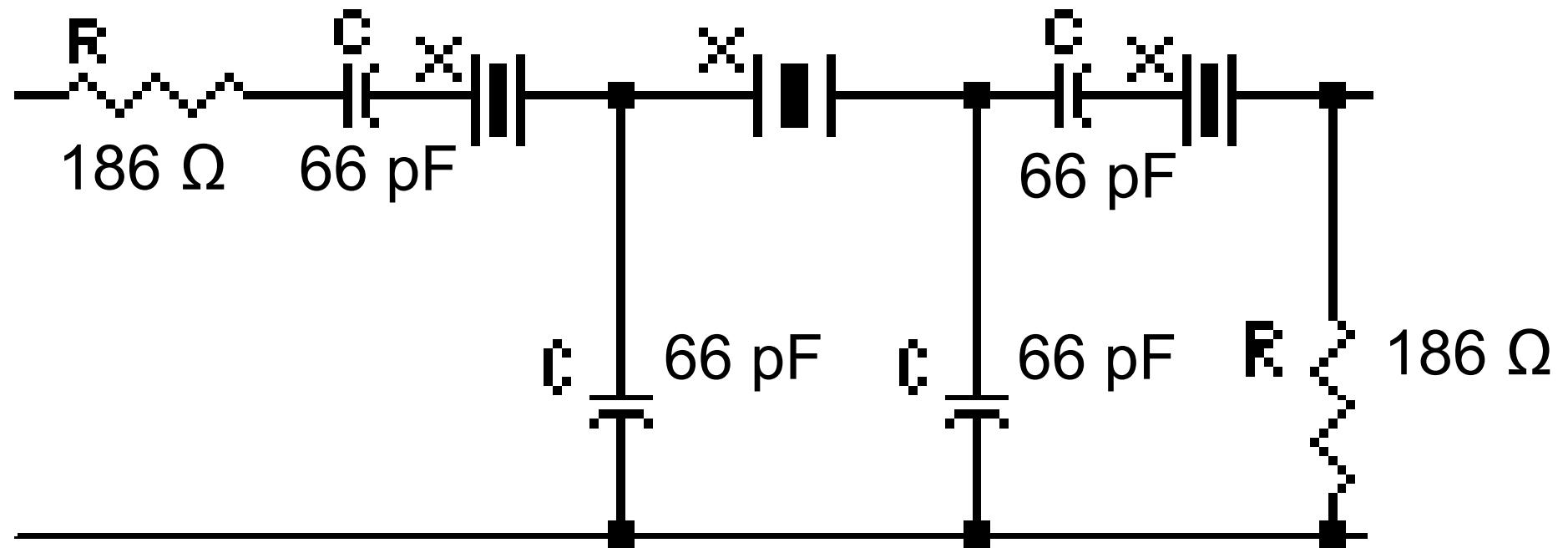
Daten vom VNA Crystal Analyzer übertragen

C_p = 2,46804p
 L_s = 23,499m
 C_s = ,00638p
 Q_x = 48,842K

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

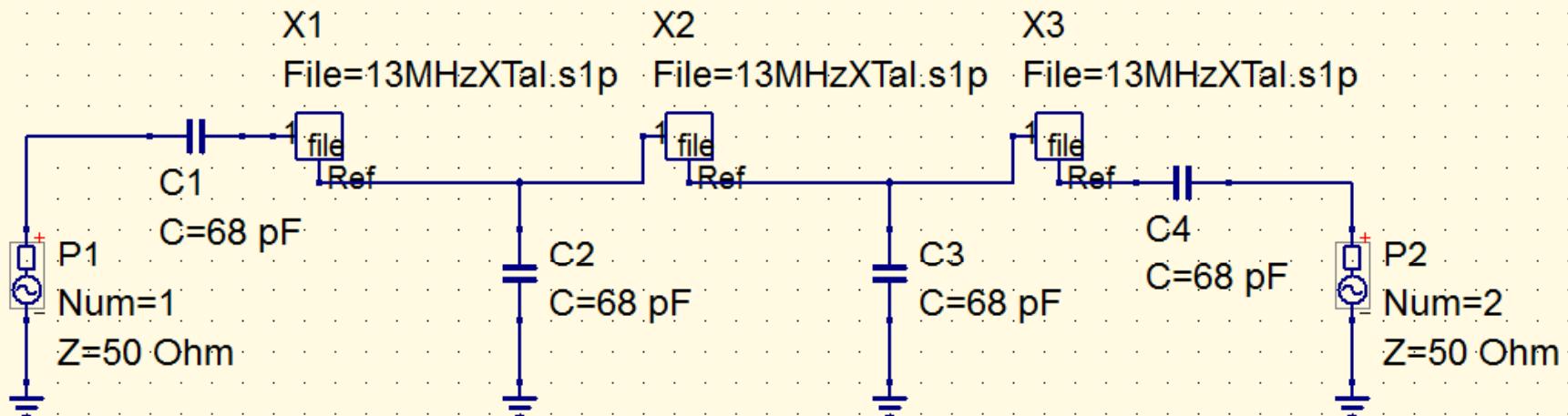


Simulation in QUCS at 50 Ω using standard Component Values

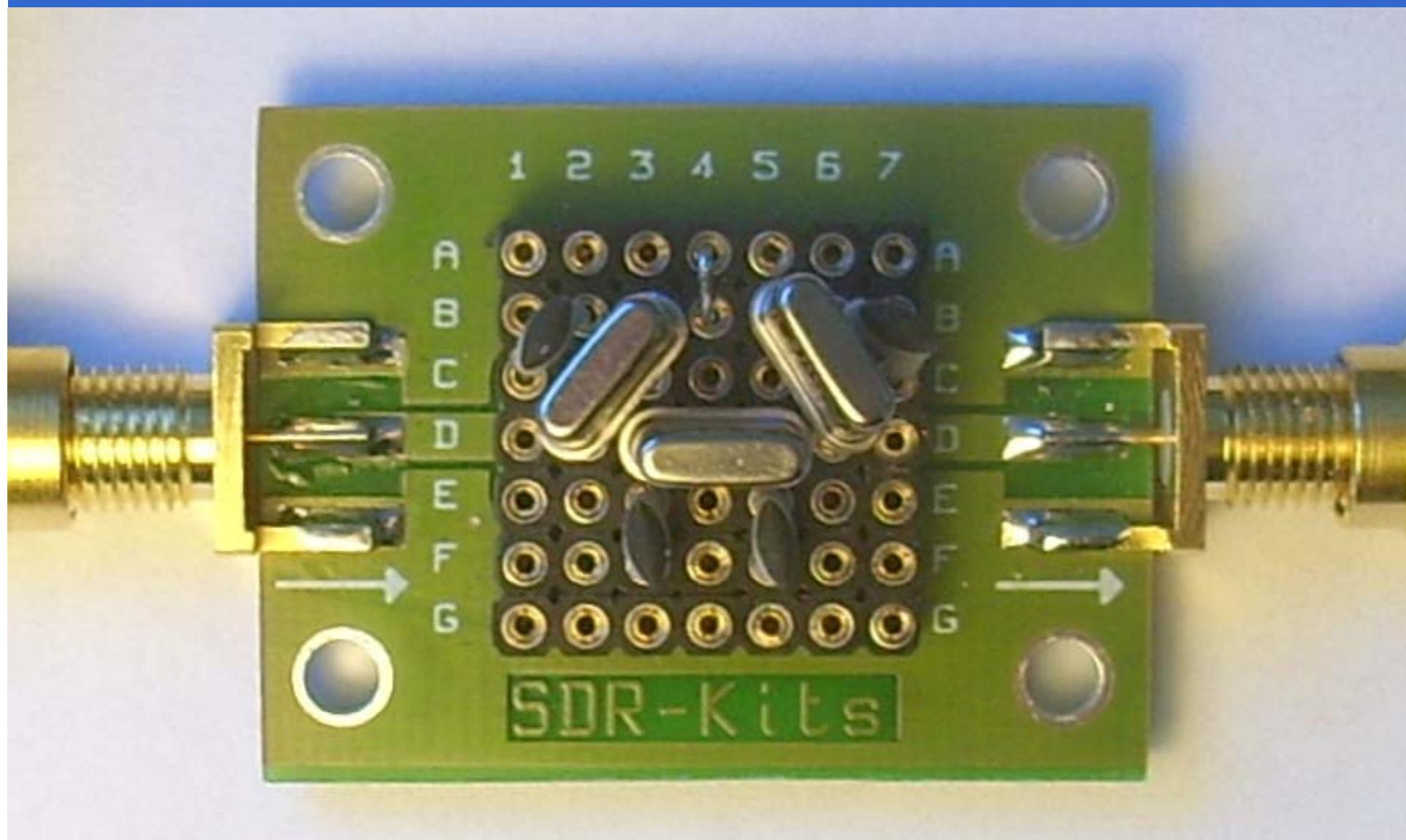
S parameter simulation

SP1
Type=lin
Start=12.987 MHz
Stop=13.007 MHz
Points=800

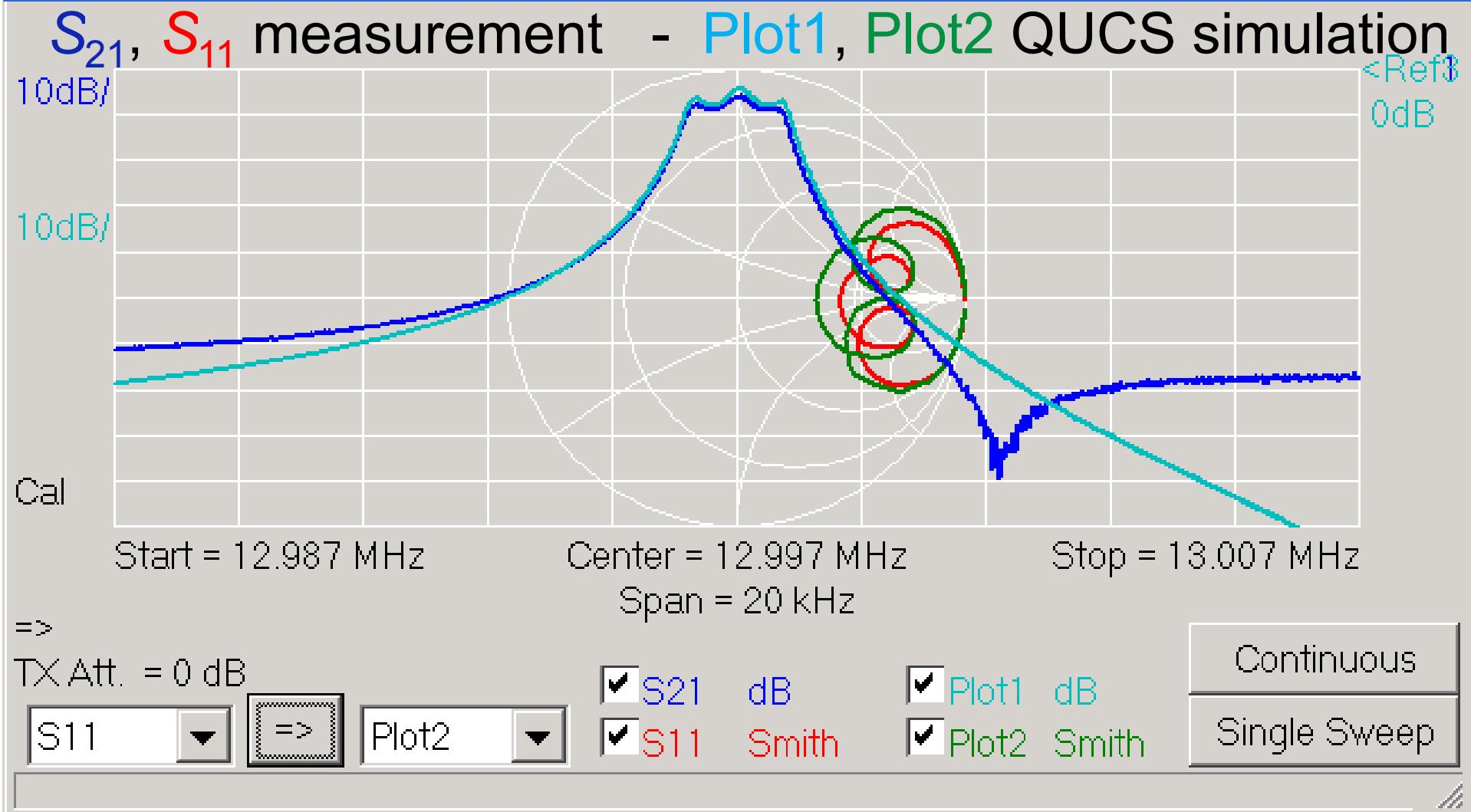
Crystals simulated with
s1p-file obtained by VNWA
measurement!



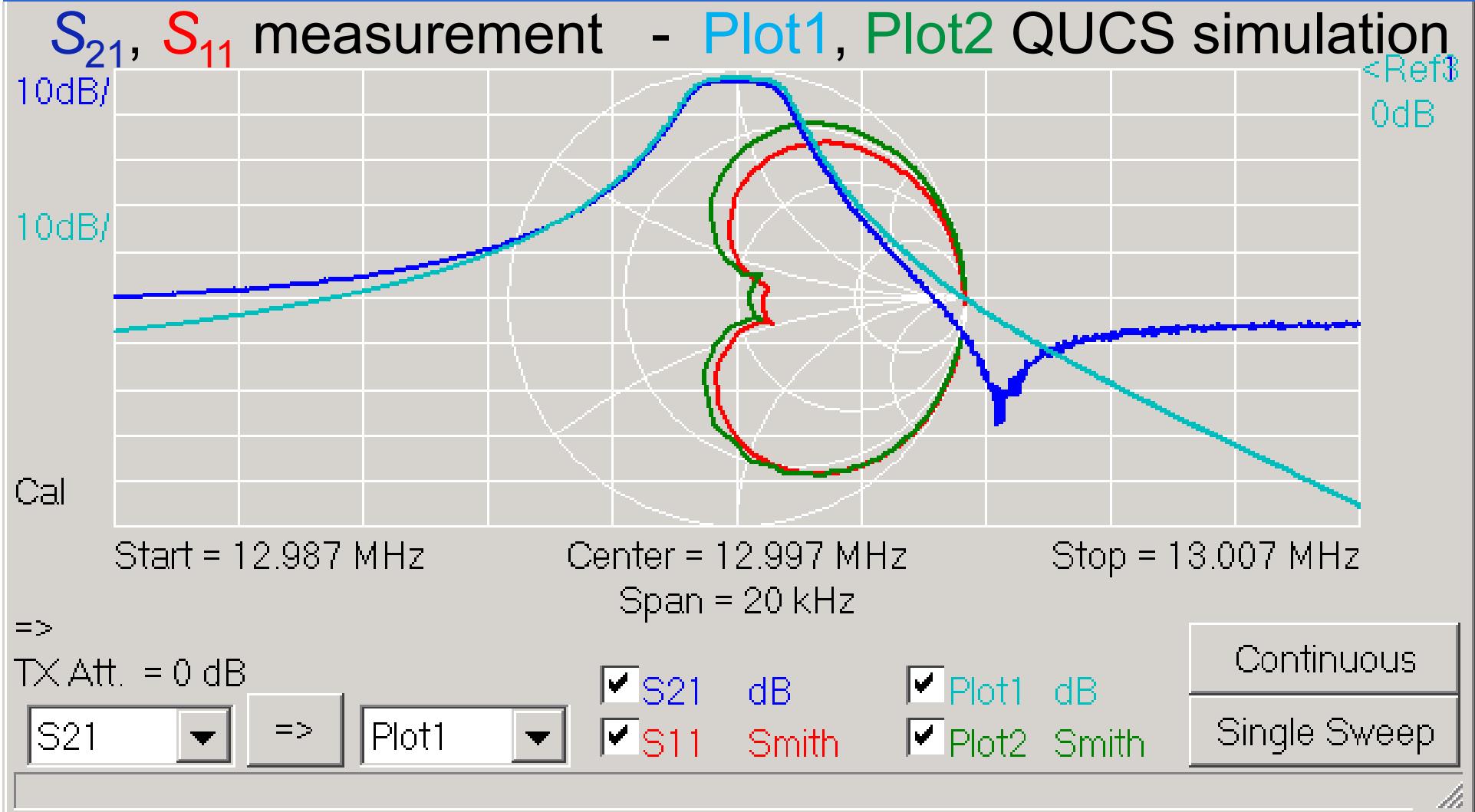
Crystal Filter Hardware



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!

