

Workshop Notes

Measuring with the VNWA & Tips for beginners and advanced users

Introduction to the VNWA

Smith Charts

Basic Measurement Examples

Measurement examples for advanced users

Version 25

Jörn Bartels, DK7JB

49088 Osnabrück

mail@dk7jb.de

<http://www.bartelsos.de>

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Workshop Notes – Volume 1

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1 Introduction

For several years, we have with great pleasure conducted workshops on dealing with network analyzers, and in particular with the VNWA of DG8SAQ. In these workshops, we show the opportunities offered by these instruments and how they help to better understand the fascinating world of high-frequencies. The first version of this document was created after Hamradio 2017 to give the participants of the VNWA workshops more hints for future reference.

Times are changing, and with it the questions of the participants, their wishes and their prior knowledge. In recent years, countless other devices have come onto the market - with very different characteristics.

This document is intended to help you to get an overview:

- What does a network analyzer do?
- What are the different types, and what advantages and disadvantages do they have?
- How can I get started?
- What should I consider if I want to buy a VNWA.
- A quick-start aid for VNWA novices who need an introduction to the VNWA application. Topics from the workshops will be discussed again.
- The following chapters, in the second half of the worksheet, are addressed to advanced VNWA users and show what else is possible with the VNWA. But the VNWA help file shows that the measurement tests described here are just a small sample of the possibilities.

I would like to encourage you to read three books, which I personally find very good:

Gerfried Palme DH8AG has written two books on VNWA with a lot of passion, in which he explains many features and leads you in detail through various experiments. I recommend the tests to be re-built and to carry out your own measurements. In my workshop notes I refer to his books in many places, as they are a very good addition or further reference.

Gerfried Palme; "Measuring with the VNWA2 / VNWA3 vector network analyzer"; www.dh8ag.de

Gerfried Palme; "Measuring with the vector network analyzer VNWA2 / VNWA3 Volume 2"; www.dh8ag.de

Joachim Müller has written a very good book about Smith diagrams. In my chapter on Smith diagrams, I will refer to this book again and again and see it as a foundation and continuation.

Joachim Müller; "Smith-Diagramm Einführung und Praxisleitfaden"; beam-Verlag

2 What is a vector network analyzer, or a scalar network analyzer?

In high-frequency technology assemblies of resistors, capacitors and semiconductors are called networks. These may be antennas, crystals, filters, baluns, transformers, lines or even an entire amplifier.

In a network analysis one typically wants to determine the transmission loss of an electrical network, such as an IF filter. To do this we apply a signal of known frequency and known power to the input of the network and measure the output power. The insertion loss is the ratio of output to input power. If one also uses a VSWR bridge, the power reflected back from the input can also be measured. The return loss is the ratio of reflected power to applied power.

In **vector network analysis** (e.g. with the VNWA of DG8SAQ) we measure not only the amounts of power of reflected and transmitted, but also the phase shifts of these two relative to the input signal. At first glance, the phases seem uninteresting, but on closer inspection much important information can be derived from the phase.

For example, transmission lines with either a short-circuited and an open end reflect 100% of the incoming power. In both cases, the reflection factor is therefore 1 (reflection coeff. is +1 for open and – 1 for short). Thus the return loss alone does not distinguish between a short-circuited and an open cable end.

With the phase information it is easy to make this distinction: an open line reflects without phase shift, a short circuit reflects with 180° phase shift.

From the return loss along with the phase shift we can calculate the true input impedance of a network, from which we can in turn calculate a network for power matching. A typical application would be, for example, the power matching of a transmitter to a transmitting antenna.

Another application would be the measurement of an unknown capacitor or a coil. This gives not only the capacitance or inductance, but also the electrical quality of the component.

If we measure an electric two-port network (such as a quartz filter) for reflection attenuation and transmission attenuation in forward and reverse directions (and the corresponding phases), then one can use these measurements to simulate the two-port electrical circuit on a computer. The surrounding circuit can then be mathematically optimized. (Source: DG8SAQ; CQ DL 3-2007)

There are also very simple devices that cannot measure the phase. They are called **scalar network analyzers** (e.g. FA NWT2). Here the most important factor, the phase, is missing. They provide a limited view of the world of high frequency but have a shorter learning curve and are slightly cheaper to buy.

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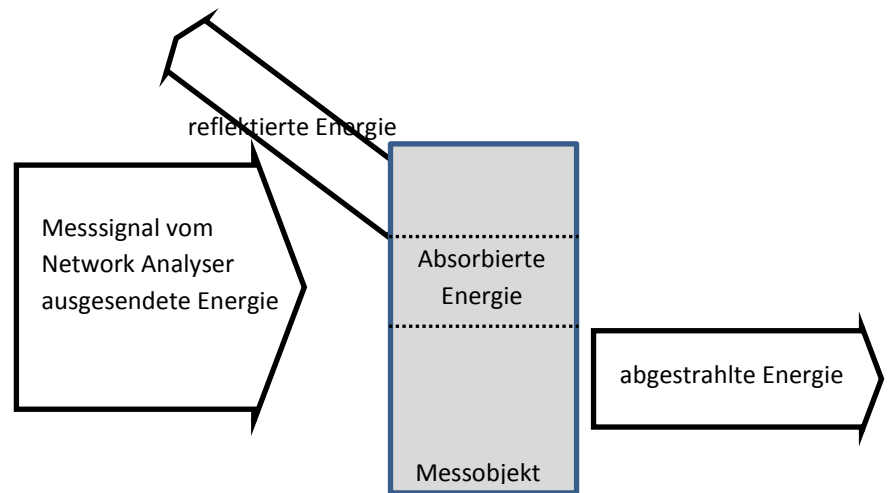
2.1 S-Parameter

The S-parameters specify how the measuring signal is attenuated / amplified or reflected by the object being measured. An amplifier has an input and an output. The measuring signal can be directed once to the input and once to the output.

- **S₂₁**: Indicates how much the measuring signal is attenuated / amplified (forward direction).
- **S₁₁**: Indicates how much the measuring signal is reflected (forward direction) and how well the input impedance is adjusted.

Now the measuring signal can be directed to the output of the device being measured. This then results in the S-parameters for the return direction.

- **S₁₂**: Specifies how much the measuring signal is attenuated (reverse direction).
- **S₂₂**: Indicates how much the measuring signal is reflected (return direction) and how well the output impedance is adjusted.



For ease of understanding, let's consider a simplified optical model. When light hits a coloured piece of glass, a part of the light is reflected, part of the light is transmitted, and some of the light is absorbed in the object. Light can also pass from the other side of the object.

The S-parameters are specified in the logarithmic scale, in dB. 0 dB means that all of the energy is reflected back or the total energy of the measuring signal leaves the object unattenuated.

Often, two different forms of graphical display representation are chosen for the four S-parameters. The normal Cartesian coordinate system for the scalar information: attenuation, amplification and reflection. But such representation is not enough because, for example, it lacks information which is necessary if you want to understand why an adjustment is particularly good or bad. For example, does the input of the circuit to be tested have an inductive or capacitive component? The second form of representation is the Smith chart. We explain this in chapter 3.

The main advantage of a vector network analyzer, as already noted, is that both amplitude and phase are measured. While a simple amplitude measurement with a scalar network analyzer is much easier to perform, a vector network analyzer such as the VNWA requires a significantly greater effort to use. A purely scalar amplitude measurement (eg with the FA NWT2) may be sufficient in many cases. An example would be the gain curve of a home-built amplifier. The scalar network analyzer provides feedback on whether the implementation is good or bad - but nothing more. A measurement with a vector network analyzer (VNWA) which comprises both the phase and the amplitude, however, allows much more about the test object to be determined. Only in this way, for example, can we tell if a mismatch is capacitive or inductive, and look for a matching circuit.

2.2 Why and how network analyser devices must be calibrated

All components of a vector network analyzer have a frequency response and phase response - each track segment and each plug, resistor or semiconductor. The higher the sampling rate, the more significant the effects. This applies to low-cost starter devices, as well as to professional devices that have the price of a small family home. Correcting these effects separates the wheat from the chaff.

Through calibration of the analyzer, these system errors are eliminated with the help of mathematics, and thus almost completely compensated. The VNWA of DG8SAQ stands out in this respect due to a comprehensive implementation of the mathematics at this point. With a lot of mathematics, a good Vector Network Analyzer can then display results as if it were directly connected without cables to the device under test (DUT). So what especially matters is excellent software which is also maintained and developed.

For successful calibration, calibration standards with known electrical characteristics (Short, Open, Load, Through) can be connected to the test leads and measured. From these measurements, an error correction is determined, which completely describes the system error of the analyzer and enables subsequent compensation of these errors. Every detail contributes to the elaborate error correction. As already noted, this process separates the wheat from the chaff.

Further information can be found here:

- chapter 5.1 "VNWA: how to create a Master Calibration" on page 30 in this document.
- Help file in the VNWA software
- In the book by Gerfried Palme DH8AG; "Measuring with the vector network analyzer VNWA2 / VNWA3 Volume 1"; Chapter 1
- "Vector network analysis using the example of VNWA3 parts 1 + 2"; Gerfried Palme DH8AG; FUNKAMATEUR FA 8/12 pp 822-825 and FA 9/12 pp 926-929

What calibration standards are used with the VNWA?

OPEN: for the Open, as the name already suggests, the measuring line is open, so terminated with nothing. The open end of the line causes a total reflection of the entire measurement signal. In this measurement, attenuations and phase shifts of the lines etc. are determined.

SHORT: With a SHORT, the measuring line is short-circuited, which also results in a total reflection of the measurement signal. The phase of the signal is rotated by 180° compared to the OPEN measurement.

LOAD: In a LOAD measurement, the line is closed with a defined load resistance (in this case 50 ohms). All measurements are compensated relative to here.

THROUGH: In a THROUGH measurement, both measuring lines (TX and RX port of the VNWA) are connected. The input port of the measuring instrument, for example, can be calibrated in this manner.

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3 The Smith Chart

In this chapter I describe the simplified basics of the Smith chart. I largely avoid formulas and allow some simplifications to aid easier understanding. First, I describe the physics around resistance, coils and capacitors, and then go to the historical background and finally explain the type of display employed in the Smith chart.

3.1 Physical basics

- Resistance - Voltage and current curve

Resistance behaves in a straightforward way. When a voltage is applied, current increases immediately. There is no phase shift.

- Capacitor - voltage and current curve

When a voltage is applied to a capacitor, it needs to charge initially. Energy is stored between the plates and at first the full current flows, and the voltage rises slowly. So the current leads the voltage, and is described by the term "capacitive reactance".

- Coil - voltage and current curve

When a voltage is applied to a coil, the magnetic field must first build up. The supplied energy is stored in this field. Current and voltage behavior is exactly the reverse as with the capacitor. Initially the full voltage exists and the current rises slowly, while the magnetic field builds up. Here, the voltage leads the current. This is described by the term "inductive reactance".

Summary: With a pure resistance, voltage and current are in phase. With capacitive or inductive reactance, voltage and current are not in phase.

3.2 History

The Smith chart was developed by the radio amateur Phillip Smith (1905-1987), who had worked as an engineer at the American Bell Laboratories. He worked with antennas and RF cables. Today's Smith chart is the result of his efforts to represent the relevant relationships clearly in a graphical way. This type of display has prevailed in the professional world for many years. Today it is one of the most important forms of representation of RF electrical characteristics. Originally matching networks were also "calculated" on the Smith chart. Today, small software programs do this. The matching tool of VNWA does such calculations in seconds

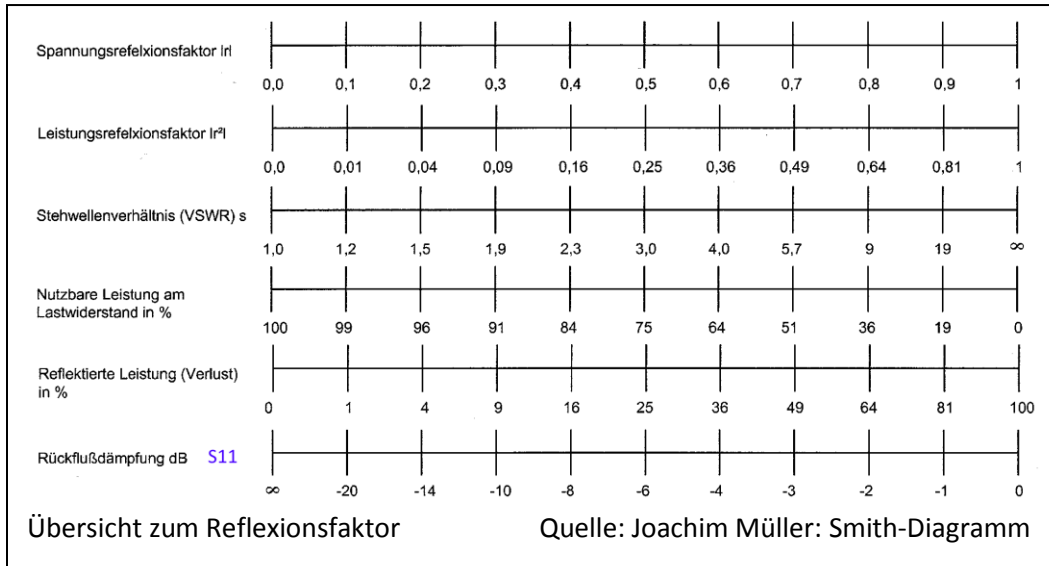
3.3 The Smith chart

As already described, the Smith chart is a graphical way to show the relationships around matching, impedance, reflection, VSWR factor and transformation to aid understanding. This powerful tool for graphic display is a bit complex and the initial learning curve is therefore difficult.

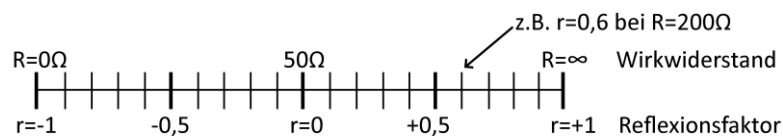
There is a very good book by Joachim Müller "Smith chart - Introduction and Practical Guide" (in German: „Smith-Diagramm – Einführung und Praxisleitfaden“). The book really is worth working through - even his proposed experiments. I want to help you with the basics, so that you find it easier to follow the statements by Joachim in his book. To facilitate this, some of the diagrams and pictures from this chapter are very similar to those in the book. Also I have conducted some examples of the experiments proposed in this book, in my workshops. The study of this matter is really worth doing on the way to a deeper understanding of the relationships in the field of high frequencies. Unfortunately, the book is only available in German.

Be aware that I have tried to simplify greatly, even if that sometimes comes at the expense of accuracy and detail. I assume that a deep understanding is only achieved when you perform the experiments from the book and from everything you read in the book by Joachim. Anyway, I am convinced that complex relationships can only be understood when dealing repeatedly with the subject - similar to a spiral. With each repetition, something more profound is learned.

If an RF signal is applied to a cable and it is not properly terminated, a part of the signal is reflected. The worse the match, the more the reflection - up to total reflection when a short circuit or an open circuit (infinite resistance) exist. We calculate the reflection factor from the ratio of the reflected wave to the departing wave. In our considerations here, we assume a 50 ohm environment. When the cable is terminated with 50 ohms, there is no reflection. The reflection factor is 0. In the case of a short circuit or an open end, thus total reflection, the reflection factor is +1 or -1 (100%).



In the following figure the reflection factor is represented on a numbered line. In the case of a short circuit it is $r = -1$ and with an open end (infinite resistance) $r = +1$. The more the cable system termination impedance differs from 50 ohms, the stronger the reflection. Associated real ohmic resistances that cause this are shown above the numbered line. From this view, the transition to the Smith chart can be clearly derived in a few steps.

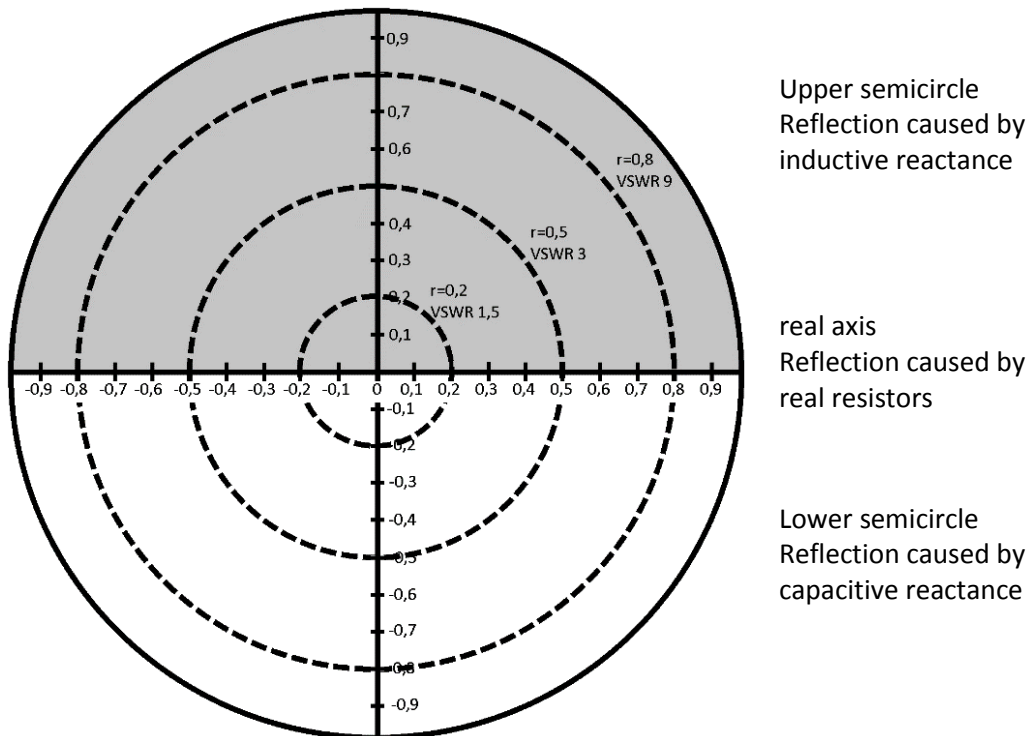


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The number line can easily be extended in another dimension to display the reflection that may be caused by reactances (inductances and capacitances). The presentation is then in the form of a polar diagram. All around the outer circle there is total reflection and therefore no values can be outside the circle!

To aid understanding I have shown VSWR values for you.

On each circle all points have the same VSWR.



Representation of the reflection factors in the form of a circular chart

We get the full Smith chart when we now successively draw the lines that have the same inductive reactance X_L , with varying values of real resistance, R . Additional lines for the same capacitive reactance X_C and the same ohmic resistance R are also added later. These lines are then also supplemented with lines of conductivity. You can now imagine that it is sometimes quite confusing, but taken step by step it should be no problem.

Why all these many lines? - For a better overview

A series connection of resistors can be easily calculated, since the values of the components are simply added together. This is the result from a group of lines in the Smith diagram that we look at on the next page.

In the case of a parallel connection of resistors, as is well known, we always have to reckon with the inverse values – inverse values are added up in order to obtain an inverse value: $\frac{1}{R_{ges}} = \frac{1}{R_1} + \frac{1}{R_2}$

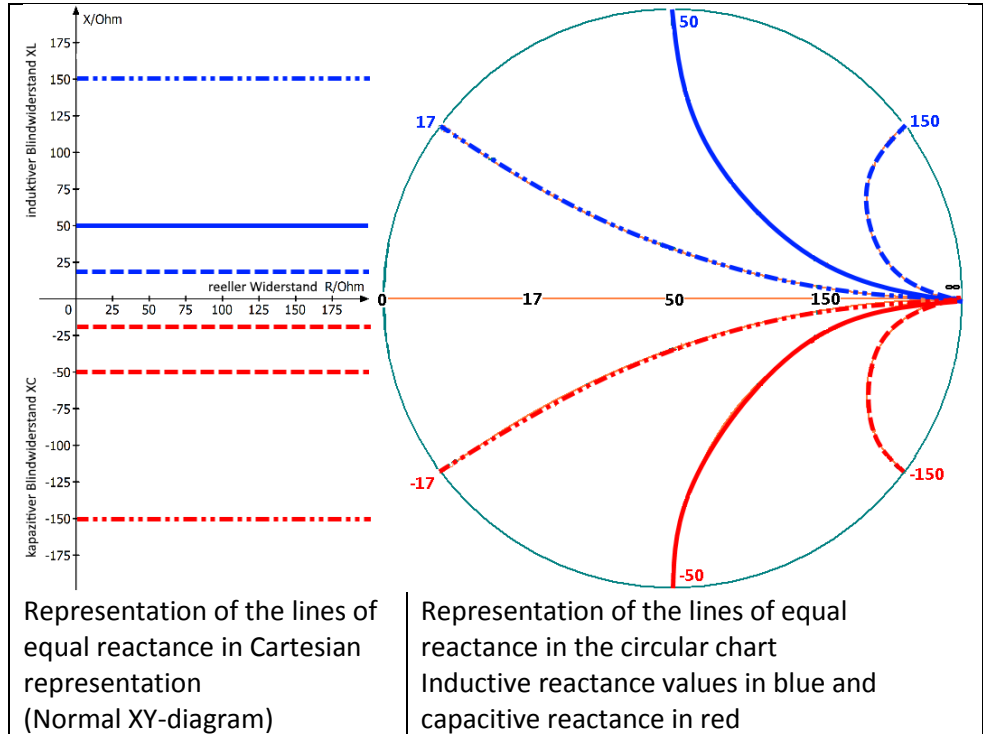
There is a group of lines in the Smith chart for this situation also, which we look at on the following page.

3.4 Consideration of resistances and reactances (VNWA: Impedance Grid)

In this chapter we look at resistance and reactance

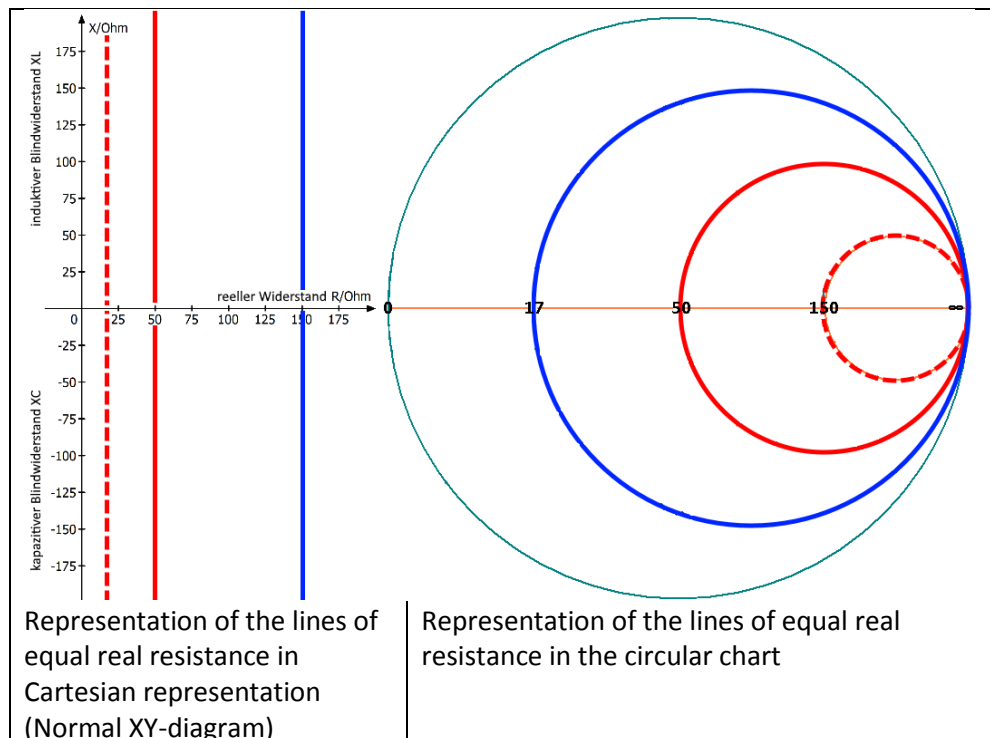
Lines of equal reactance

The left half of the picture shows a Cartesian representation (normal XY diagram), where ohmic resistance is shown on the X-axis, and inductive reactance X_L (in blue) is shown on the Y axis. In the negative region this corresponds to the capacitive reactance X_C (in red). In colour I have entered lines with the same inductive reactance. Now these lines are drawn in the circular chart. This is only possible if the lines are curved.



Lines with the same real ohmic effective resistance

Now lines with the same real ohmic effective resistance follow. In the right Cartesian chart, these are the colored vertical lines. For each line, only the reactance changes. Again, the lines have to be bent in the polar diagram. In the inductive as well as in the capacitive part of the diagram, curved lines result. This time, however, the lines are mirror-symmetric to the real axis - hence the circles.



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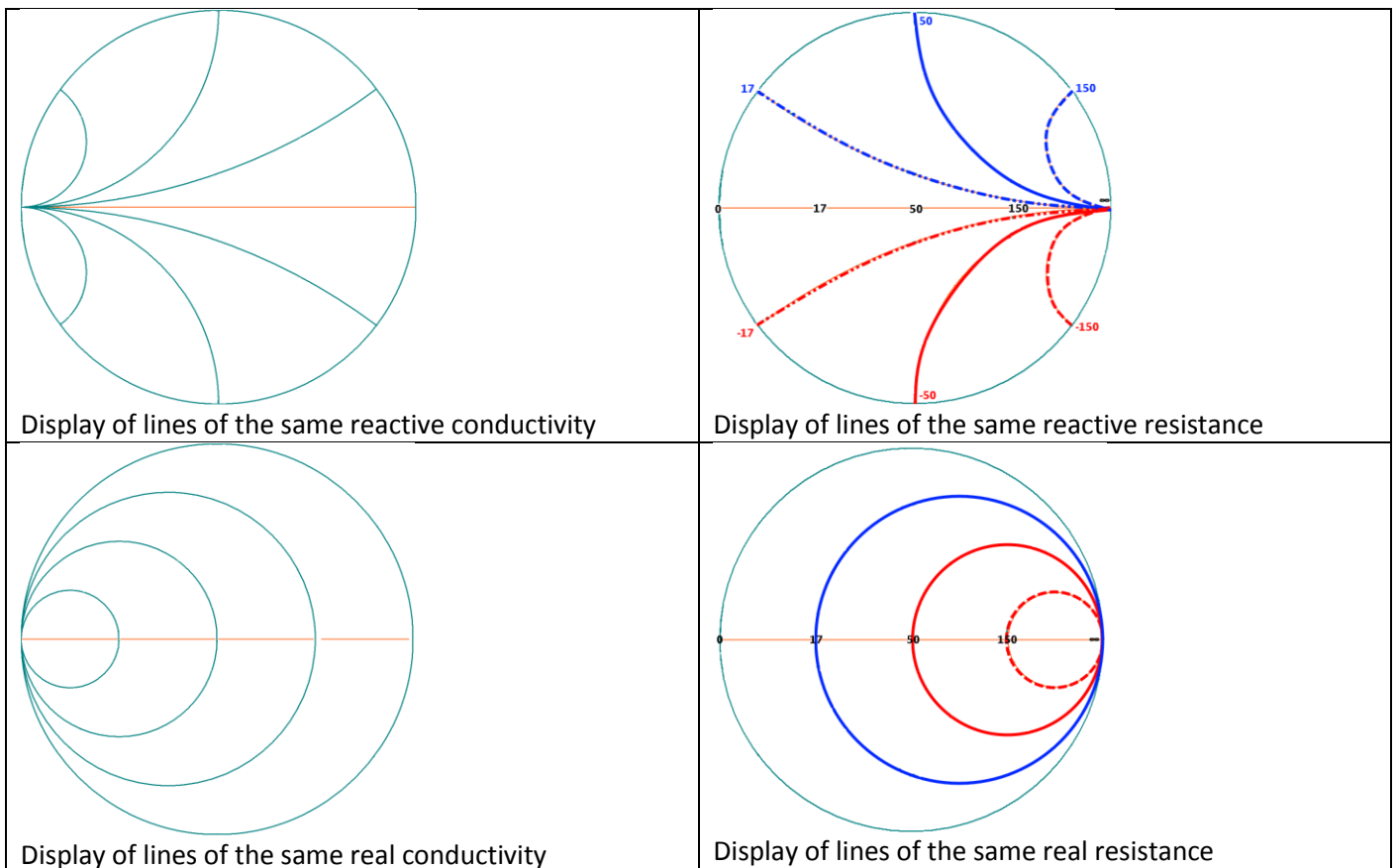
3.5 Consideration of conductance and susceptance (VNWA: Admittance Grid)

The previously presented lines help us to understand series circuits of real resistances and reactances better. In a parallel connection of resistors, the combinations are easier to understand and represent by considering conductance instead of resistance. Conductance is the reciprocal of resistance, and indicates how well an object passes an electric current (not to be confused with the conductivity).

For a parallel connection of resistors calculations are always performed with reciprocals: $\frac{1}{R_{ges}} = \frac{1}{R_1} + \frac{1}{R_2}$. Inverse values are added to obtain a total inverse value.

If one now refers all lines and values not to resistance but to conductance a reflection of the previously presented lines results (see previous page). Unfortunately we cannot dispense with these “conductance lines” as I will explain later in the chapter on how to match complex impedances with a series and parallel connection of capacitors and inductors.

For starters, it's enough that you know how these lines run in the Smith chart and that they exist. ☺
So this is a very rough overview of the subject.



All circles that represent resistance meet at the right edge ($R = \infty$). That makes sense, because the values are greater in a series circuit.

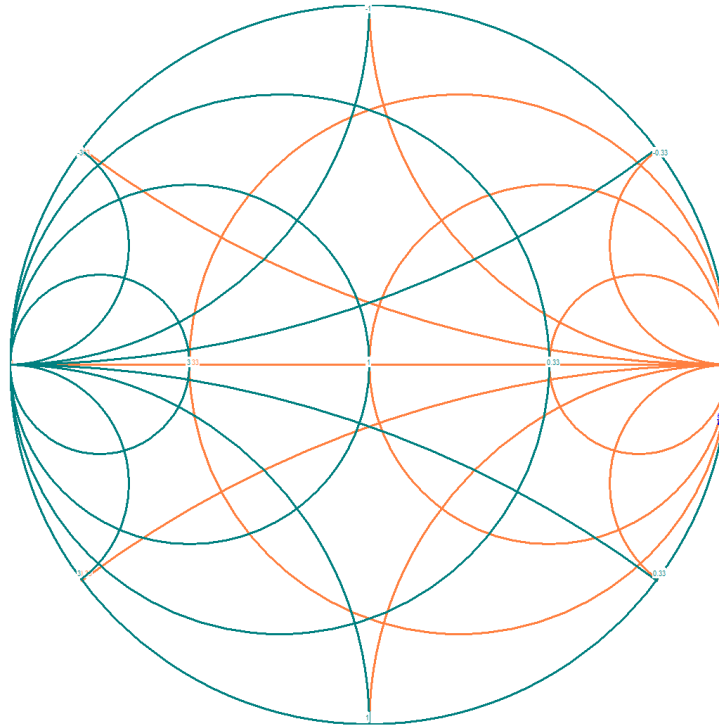
All circles of conductance meet at the left edge ($R = 0$ ohm), since in a parallel circuit, the values are smaller.

Anyone who wants to know more about this can read the book by Joachim.

3.6 The full Smith chart

Now if you superimpose all the diagrams presented above (see picture), you get the somewhat confusing Smith chart. I always hide all of the lines that are not needed at the moment and I almost always work with the Impedance Grid and not with the guide values.

This chart looks like the plan for public transport of a big city or the pattern from a magazine for making clothing...



Some mathematics

Complex numbers: In our case, we have the resistance on the x-axis and the reactance on the y-axis. They are perpendicular to each other. In mathematics, there is the number space of complex numbers, for which the same correlations apply. A real part and a vertical imaginary part. Therefore, this is also a useful place to use this number space. If we look at the complex representation of impedance, the real resistance of 33 ohms and then the inductive reactance is written behind a "j". The part with the "j" is also called the imaginary part.

Scalar Amount $| \cdot |$: Normally, amount means that the sign is not considered with the size. So only the positive number value is used. The amount is written in vertical strokes: e.g. $| -4 | = 4$

Vector amount $| Z |$: In two-dimensional space, the value is the distance between two points in space. In our case, we have real resistance on the x-axis and inductive reactive on the y-axis (see picture). The impedance is nothing more than the distance from the coordinate (zero point) to the drawn value. Distances can be calculated using Pythagoras formula, since the perpendicular values form a right-angled triangle. (Example on the next page)

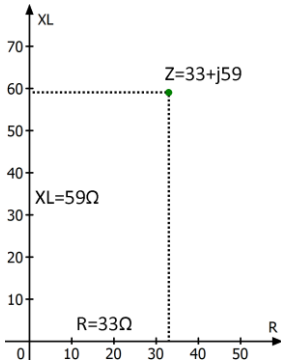
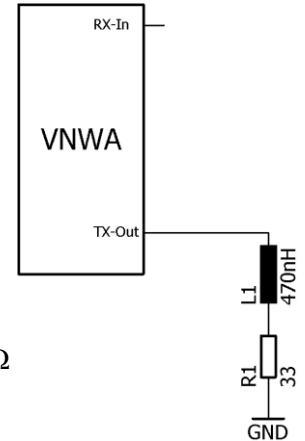
Dear mathematicians and engineers: Please forgive me for this greatly simplified presentation.

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3.7 Entering values of components in the diagram

How can we now plot real values in this Smith chart?

In the following example, a resistor (33 Ω) and an inductor (470 nH) are connected in series and connected to the TX port of the VNWA. Subsequently, an S11 measurement from 0.1 MHz to 50 MHz is performed. We first consider only the measured value for 20 MHz.



For 20 MHz (computational prediction):

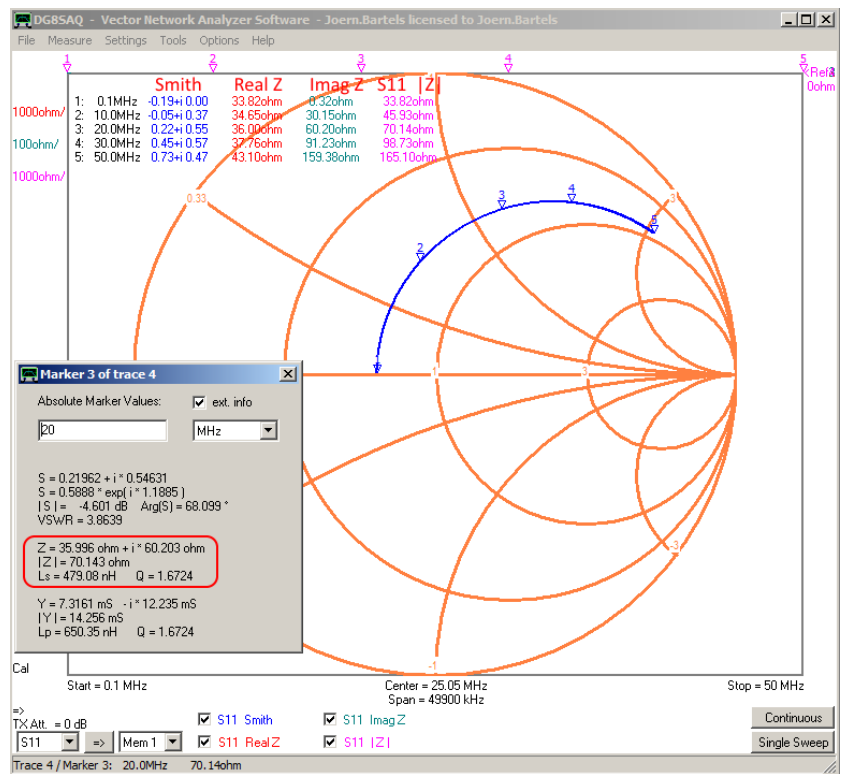
Ohmic resistance: $R=33\Omega$

Inductive reactance: $XL = \omega L = 2\pi \cdot 20 \text{ MHz} \cdot 470\text{nH} = 59 \Omega$

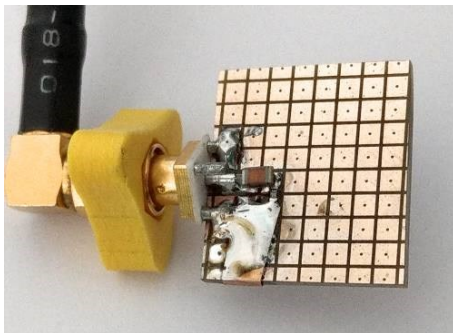
Impedance in complex representation: $Z = 33 + j59$

Impedance in scalar representation: $|Z| = \sqrt{R^2 + X_L^2} = 68 \Omega$

The real measurement: (measured from 0.1 MHz to 50 MHz)



Here is a photo of the assembly with SMD components.



In the measurement, the respective markers have been displayed and by double clicking on marker 3 the detailed information for 20 MHz is displayed (see figure). The measured values are slightly larger and can be explained by component tolerances.

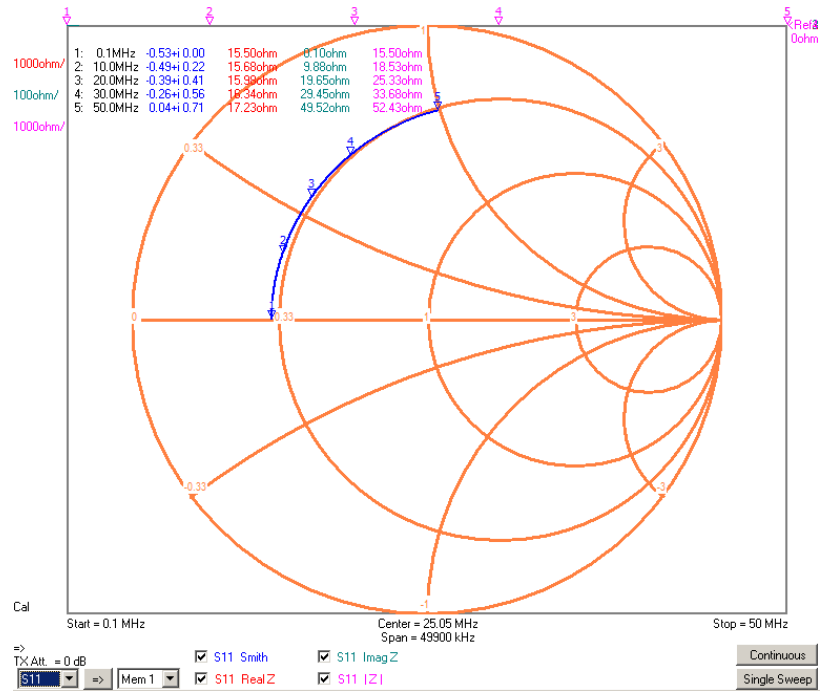
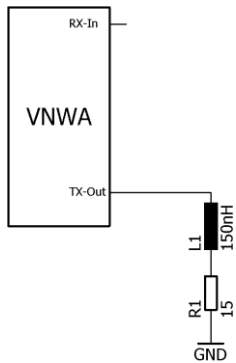
With increasing frequency, the trace moves on a circular path in a clockwise direction. The value of the resistor (33 ohms) is independent of the frequency and the value for the inductive reactance increases with increasing frequency. We are moving on a curve with the same real ohmic effective resistance, but with variable reactance. The values for other frequencies are easy to read and can be recalculated by you.

3.8 Measurement examples with real capacitors, resistors and coil

3.8.1 example 1

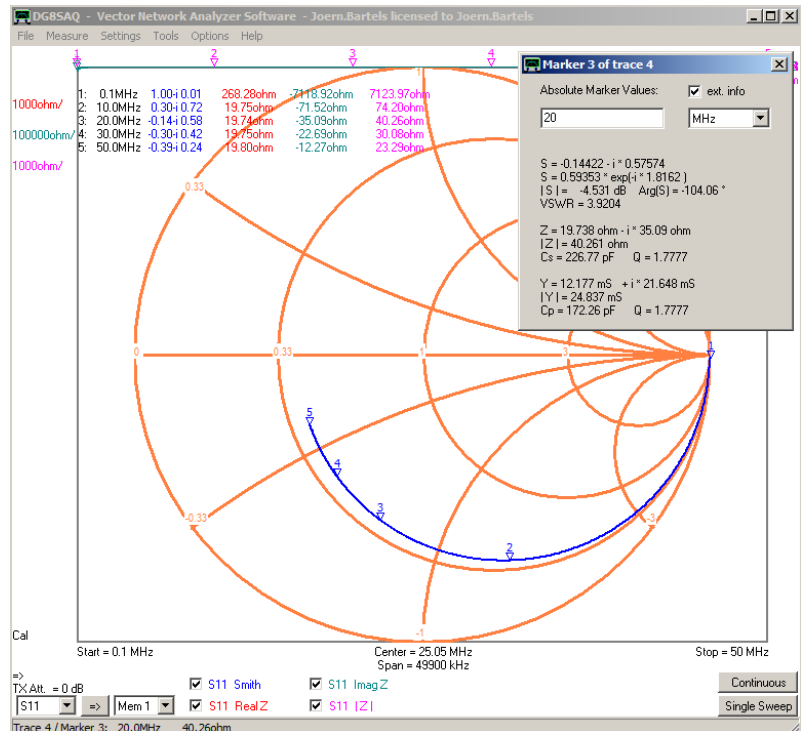
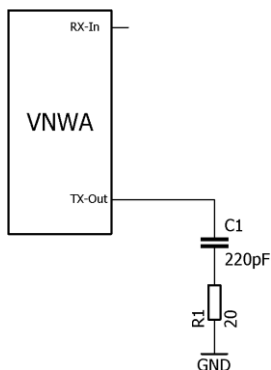
In this example, a coil (150 nH) is connected in series with a resistor (15 ohms) and an S11 measurement is performed over the frequency range 0.1MHz to 50 MHz.

As expected, the curve starts at 0.1 MHz on the real horizontal axis, since only the ohmic resistance of 15 ohms has any significant effect and the inductive reactance of the 150 nH coil is negligible. With increasing frequency the reactance of the coil increases and we are moving in a circle, each point with the same ohmic resistance value.



3.8.2 example 2

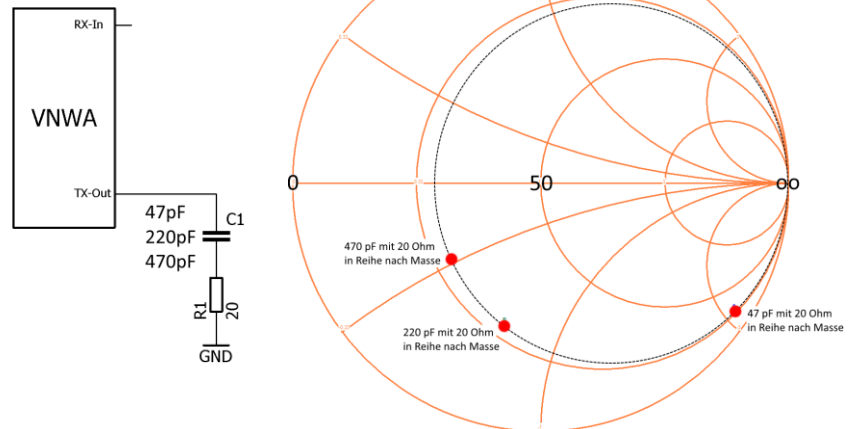
Now 220 pF is connected in series with 15 ohms. At 0.1 MHz, we start with a very high resistance on the real axis because the capacitor is still blocking current. With increasing frequency, the reactance of the capacitor becomes small and the total impedance at 50 MHz is reduced to around 23 ohms. As described on page 12, we are moving on the lower semicircles because of the capacitive reactance.



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3.8.3 example 3

In this example, measurements are performed at a fixed frequency, but with three different capacitances (see diagram). Measurements at only one frequency are somewhat difficult. Therefore, in each case I measured in the small interval from 20 MHz to 20.1 MHz, which corresponds fairly closely to a frequency point. The first two measurements are pushed into the buffers Mem1 and Mem2, so you can view everything at a glance after the third measurement. The picture shows the measured values below the red dots.



What do we observe?

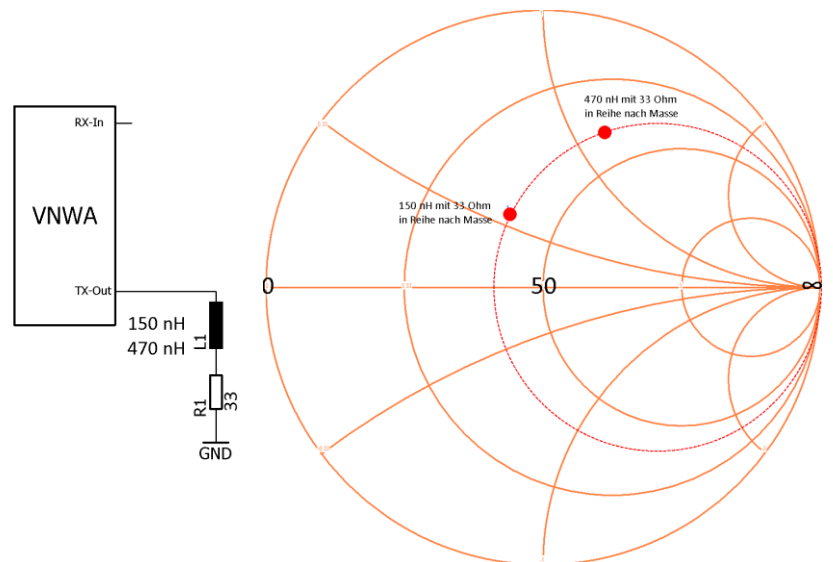
All measured values lie on a circle, which I have subsequently drawn with a graphics program as a dotted line. With decreasing capacity the 20 MHz-point moves on the circle counterclockwise. That was to be expected since capacitive reactance increases with a smaller capacitance and therefore the frequency point on the graph must approach a little closer to the "infinite-point". This relationship is needed if we are to understand the transformation of complex impedances in the next chapter.

3.8.4 example 4

This measurement is similar to the previous one. Now two different inductors are sequentially connected to a series resistor.

What do we observe?

With increasing inductance the 20 MHz-point moves on the circle in the clockwise direction. If a second inductor is connected in series with the first one, their total impedance is larger. In this way, the frequency point moves further clockwise.



This relationship is needed if we are to understand the transformation of complex impedances in the next chapter.

3.9 Parallel circuit or series circuit of inductors, capacitors and resistors

When a complex impedance of an antenna or an assembly is to be matched to a real resistance of 50 ohms, we can perform this with a series connection or a parallel connection of capacitors or coils. A purely real transformation can take place easily with transformers or baluns.

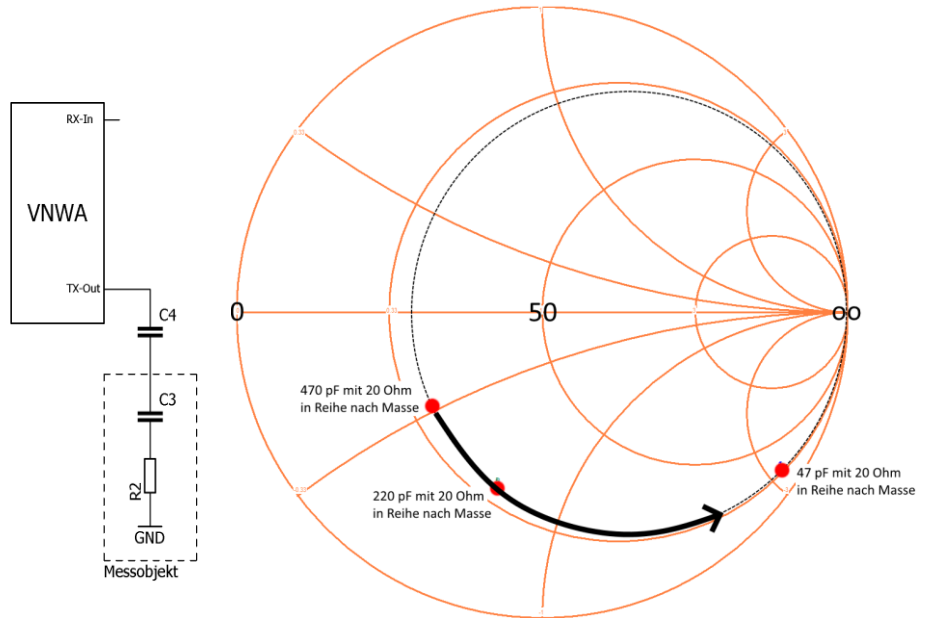
What happens if we connect a measurement object with a capacitive impedance to a series capacitor?

Through the series connection, the total capacitance is smaller and thus the total reactance becomes greater.

In chapter 3.8.3 this was simulated by measuring with different capacitances. First with 470 pF, then with 220 pF, and then with 47 pF.

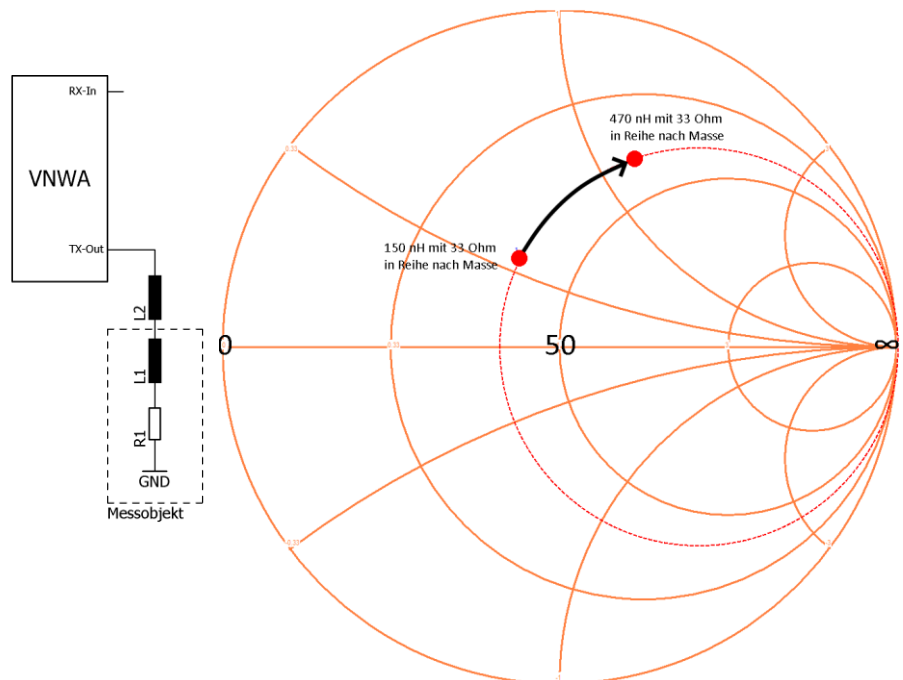
In the Smith chart, we have observed that the 20MHz point moves counter-clockwise along the circle with decreasing capacitance.

In the picture with the measurement results from example 3 this was illustrated by an arrow.



What happens if we connect a measurement object with an inductive impedance to a series inductor?

If one switches the inductance of a second inductor in series, the overall inductance is larger and the reactance increases. Therefore, the point on the Smith chart moves on the circle, but now clockwise.



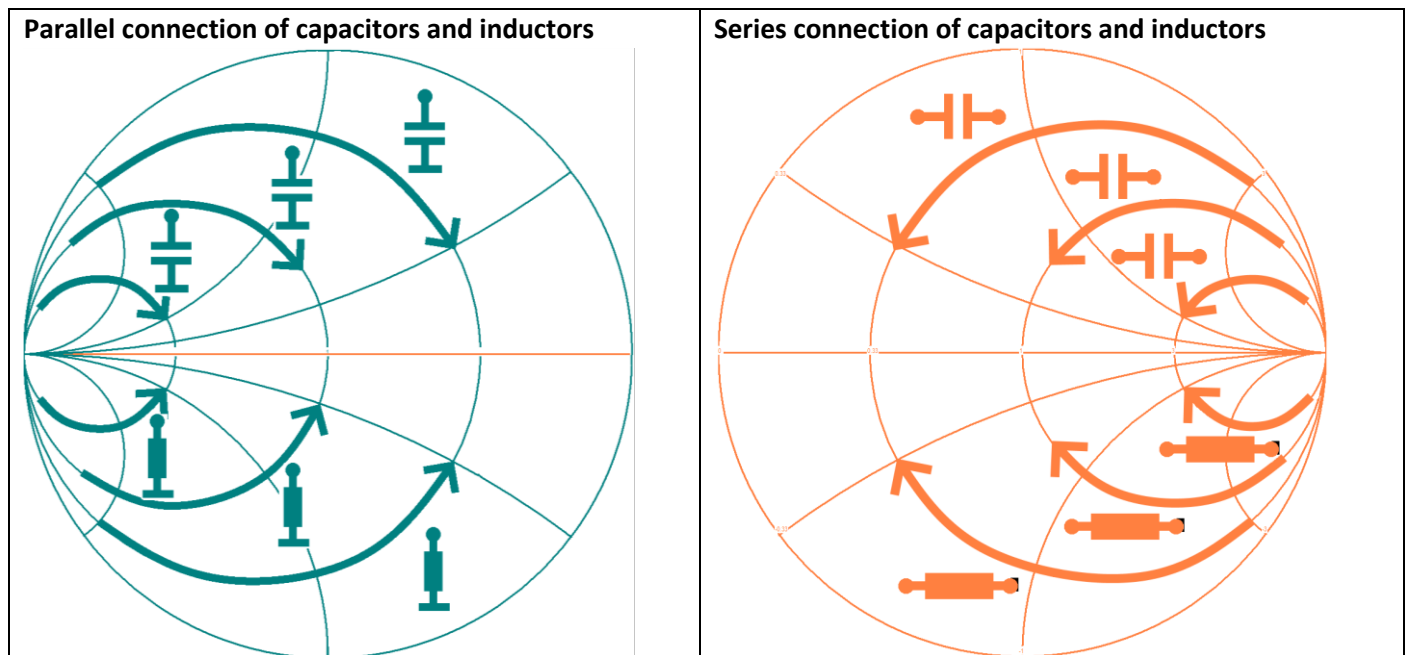
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Parallel connection of capacitors and inductors

For other combinations I refer you to my experiments and leave it to you for your own tests.

Summary

In a parallel circuit or a series circuit, the impedances for a particular frequency move as shown in the following two images. With this knowledge, we are now ready for real impedance fitting exercises.



Links to Smith charts

https://dokumente.unibw.de/pub/bscw.cgi/d351232/smith1_new.pdf

http://www.antennenkoppler.de/smith_2/Impedanz_im_Smith_teil2.html

<https://www.robkalmeijer.nl/techniek/electronica/radiotechniek/hambladen/ukw-berichte/1984/page023/index.html>

<http://www.dl8stwblog.freiraumwelle.de/?tag=smith-chart>

<http://www.dl2jas.com/selbstbau/anpassungen/anpassungen.html>

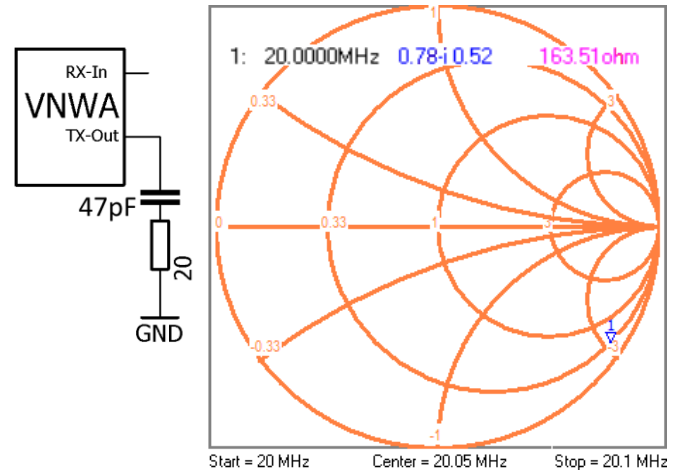
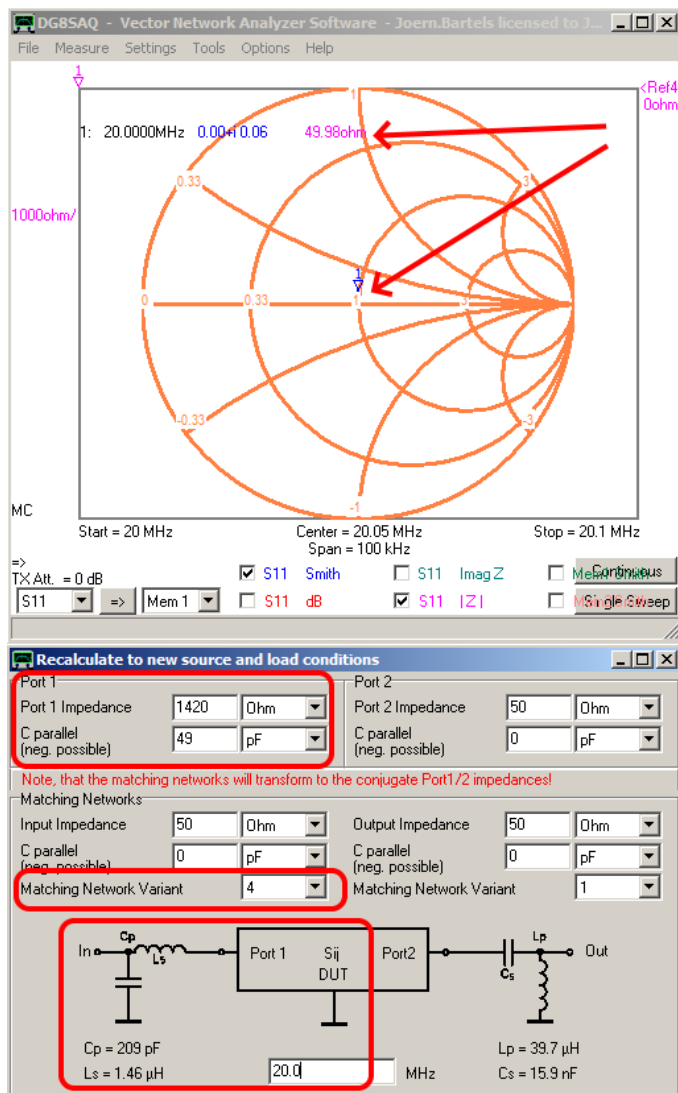
3.10 Das Matching-Tool des VNWA

The matching tool from VNWA works slightly differently than the LC antenna tuner presented in Chapter 3.11.

Since we have the VNWA vector network analyzer, the measured values can be converted into a different measurement environment. The VNWA uses its matching tool to change the normalization of the Smith chart and, in the new impedance environment, computes all four S-parameters which would then prevail and suggests matching elements.

I illustrate this with an example:

47pF is connected in series with 20 ohms, and then measured at 20 MHz with a small "Span" (right image). Then, the matching tool is called (setting on VNWA: VNWA Tools Matching_Tool). Once the measurements have been taken into the clipboard, a window opens with settings (picture below). We need only the areas marked in red. Please enter something into the required fields. If a field is clicked, the field content can be very easily changed with the mouse wheel.



In Port_1 the parameters for the new measurement environment can be set. The VNWA can now calculate what the S-parameters would look like in this new environment, and put those new parameters into the Smith chart. With a port impedance of 1420 ohms and a capacitance of 49 pF, the measurements (at 20 MHz) would be optimally transformed (see picture). With "Matching Network Variant" you can choose between four matching circuits, which in a 50 ohm environment would achieve optimum matching. In this picture I have opted for no. 4. It must of course be specified for which frequency the matching is to be calculated. It can only ever apply to one frequency.

I use this matching tool very often - it is extremely practical.

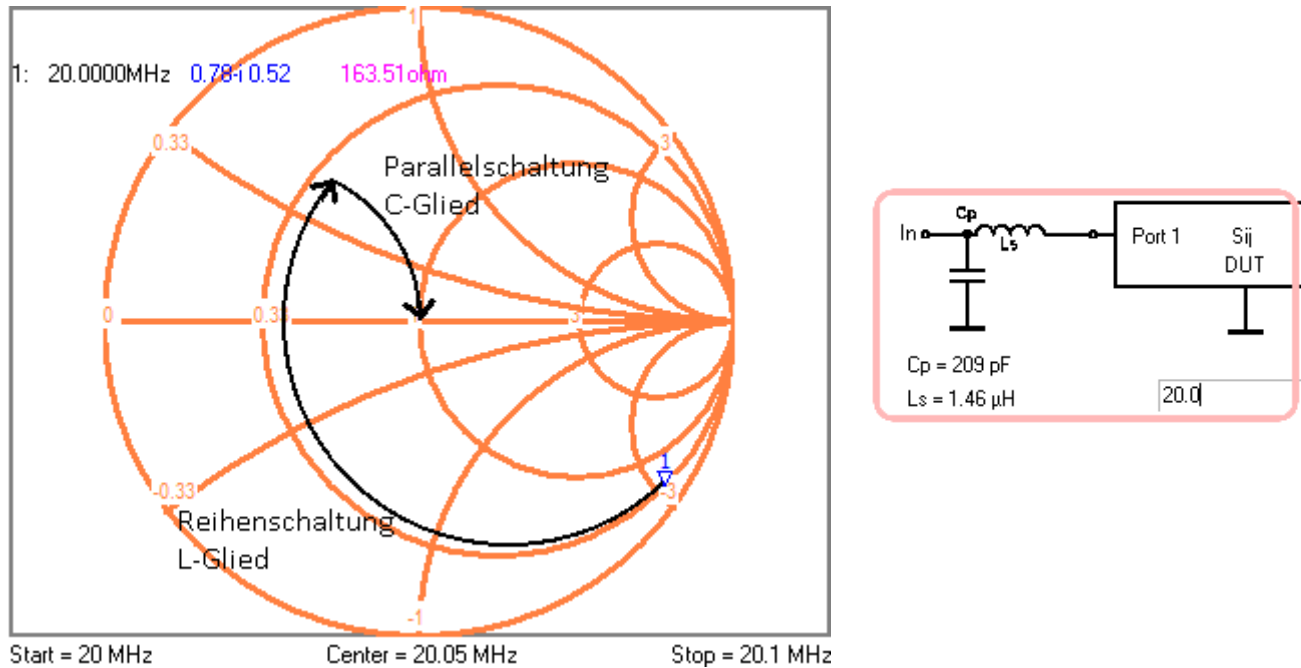
See also: Gerfried Palme DH8AG; "Measuring with the vector network analyzer VNWA2 / VNWA3 Book 2"; Chapter 3

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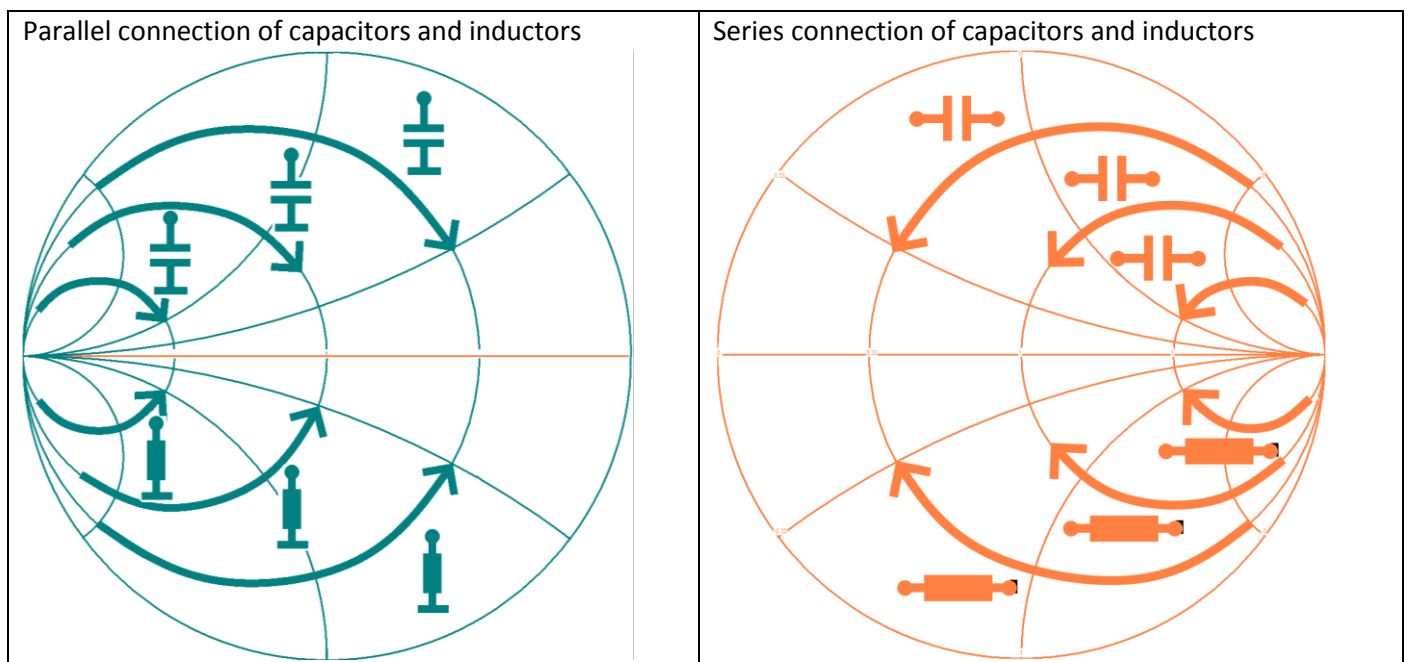
How does the proposed LC adapter transform?

In this example, the measurement object to be adapter to 50 ohms is from Chapter 3.9. The matching tool of VNWA provides a proposal for an LC matching network.

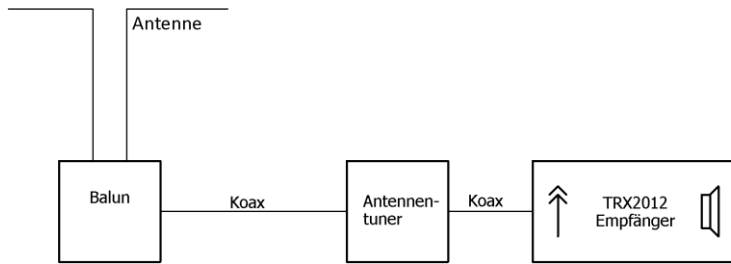
The measured object is adjusted by connecting an inductance in series and a capacitor to ground. As shown in the picture, in this way one can achieve an optimal adjustment to 50 ohms.



To help you here is the image of chapter 3.9 again

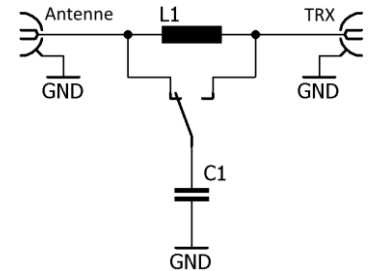


3.11 Impedance transformation example of an LC antenna tuner

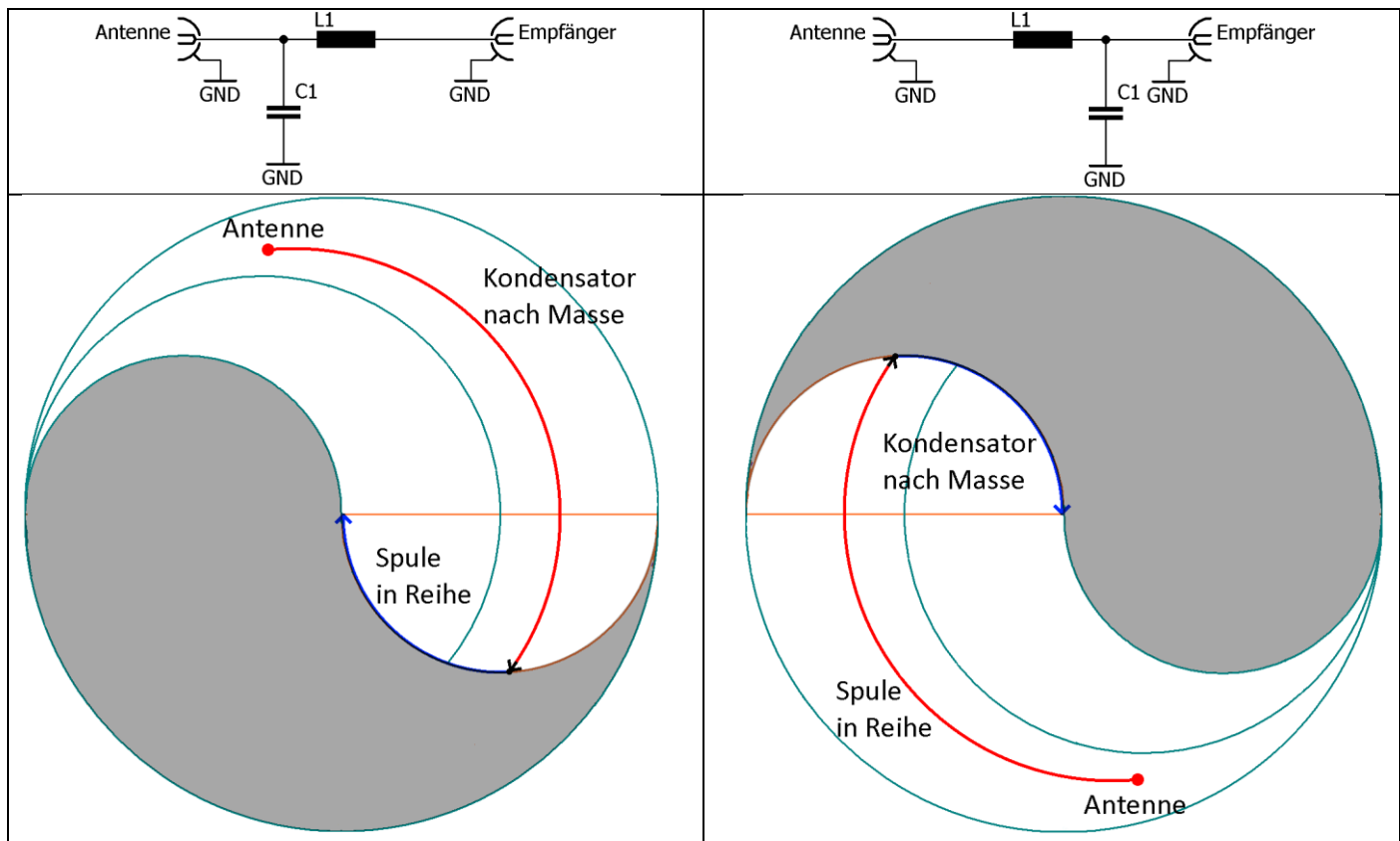


In this small chapter, I will explain how the LC antenna tuner from the Elecraft K2 works and how a dipole with random length can be matched as an antenna. The antenna is first balanced¹ with a balun for an unknown impedance² and then adjusted by the antenna tuner to 50 ohms.

The antenna tuner from K2 is a simple LC tuner. Depending on the switch position the capacitor is connected to ground either on the side of the antenna or on the side of the transceivers/receiver. With this simple circuit a very large range can be adjusted, usually with little loss.



The following figure shows the areas where the circuit can be matched. Areas where matching is not possible are grey. An example is drawn in each case:



1 For baluns I'm writing a craft diary. By the end of July 2019, it should be online. Just go to my website www.bartelsos.de and enter "baluns" in the search.

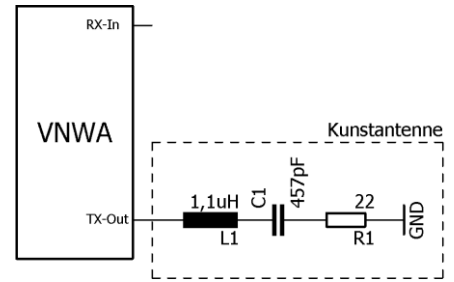
2 Link: www.dg0sa.de/balun1zu1undefklein.pdf

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Jörn DK7JB mail@dk7jb.de

3.12 Example: adjusting an antenna simulation:

In this chapter I use an artificial antenna simulation to describe how an antenna can be matched. The adjacent diagram shows my simple antenna simulation, consisting of a series resonant circuit in series with a resistor. I show how this "antenna" can be adjusted for 10 MHz, although it is actually resonant at 7.1 MHz.



The simulated antenna is measured. The markers 1 and 2 are fixed frequency markers and the marker 3 is a minimum marker. This "antenna" is resonant at the center of the 40m band, but not at 50 ohms.

With the matching tool of VNWA the antenna is matched to 10 MHz. We consider only one port and build the proposed LC match.

Recalculate to new source and load conditions

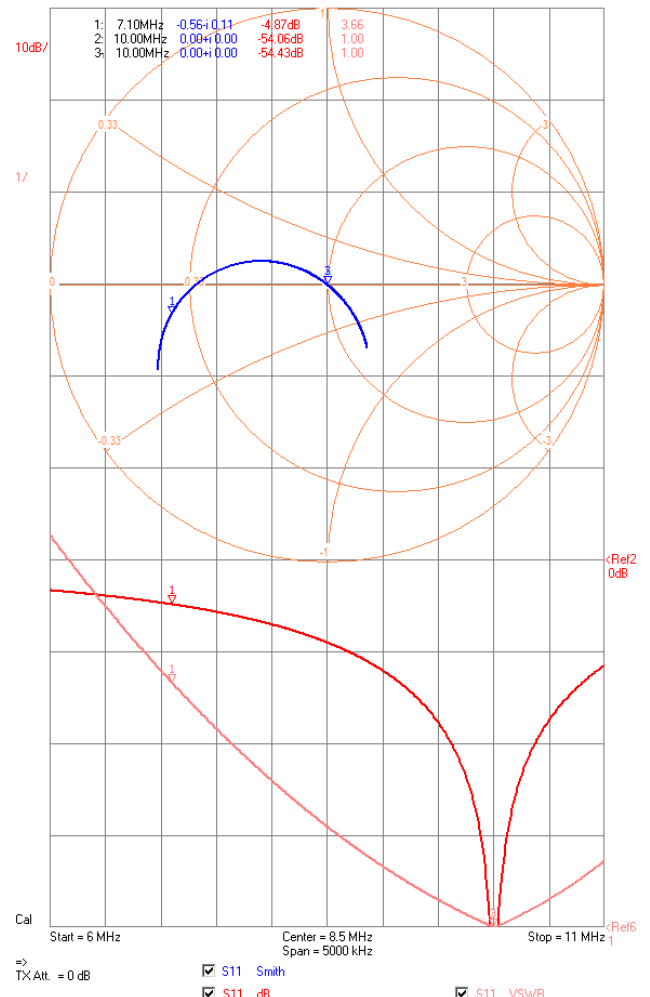
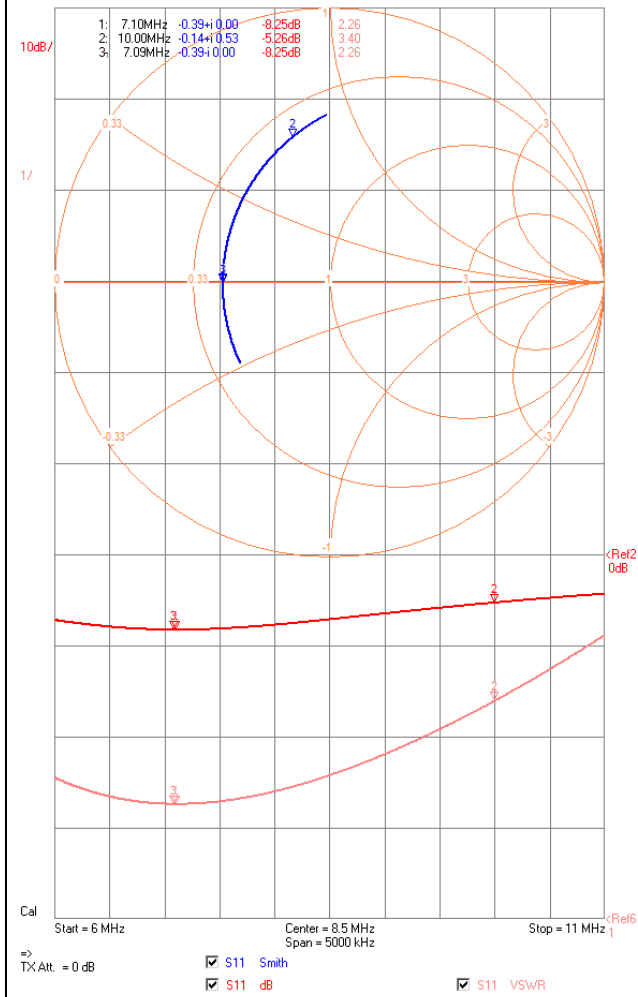
Port 1 Impedance	73 Ohm	Port 2 Impedance	50 Ohm
C parallel (neg. possible)	-327 pF	C parallel (neg. possible)	0 pF

Note, that the matching networks will transform to the conjugate Port1/2 impedances!

Matching Networks:

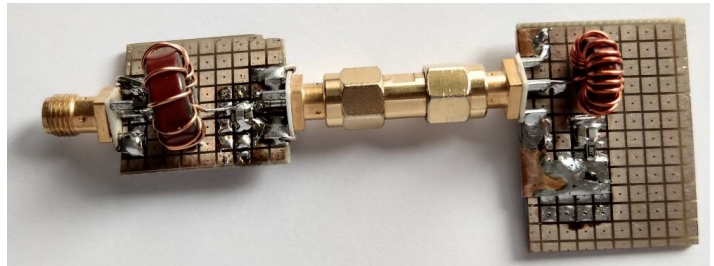
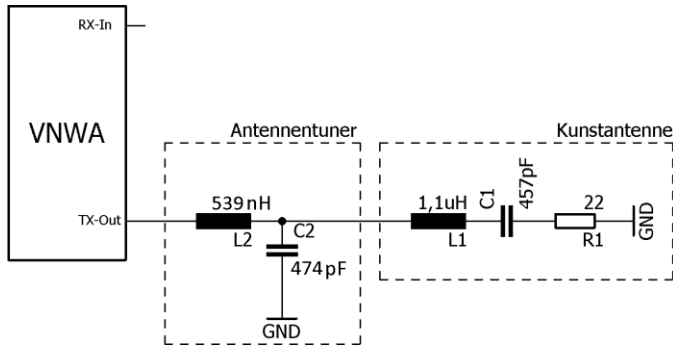
Input Impedance	50 Ohm	Output Impedance	50 Ohm
C parallel (neg. possible)	0 pF	C parallel (neg. possible)	0 pF
Matching Network Variant	2	Matching Network Variant	1

$C_p = 474 \text{ pF}$ $L_p = 79.5 \text{ }\mu\text{H}$
 $L_s = 539 \text{ nH}$ $C_s = 31.8 \text{ nF}$

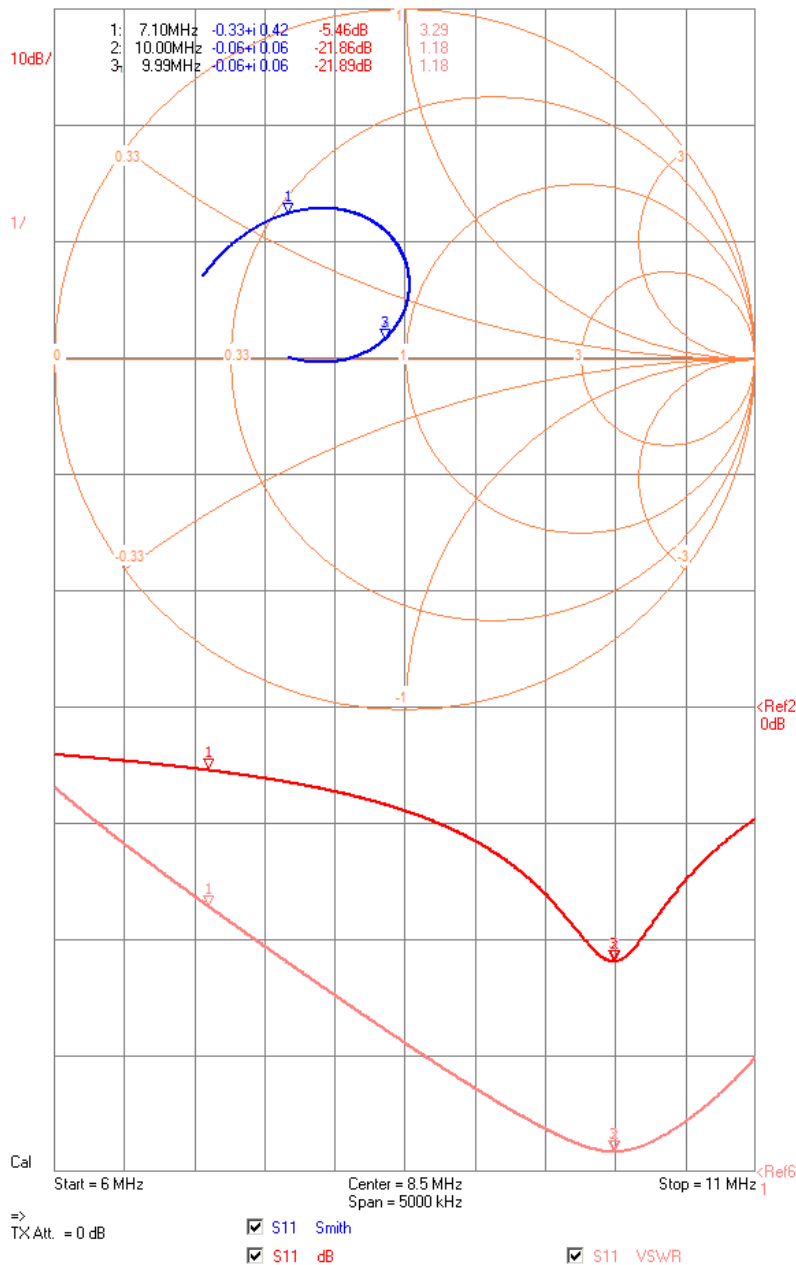


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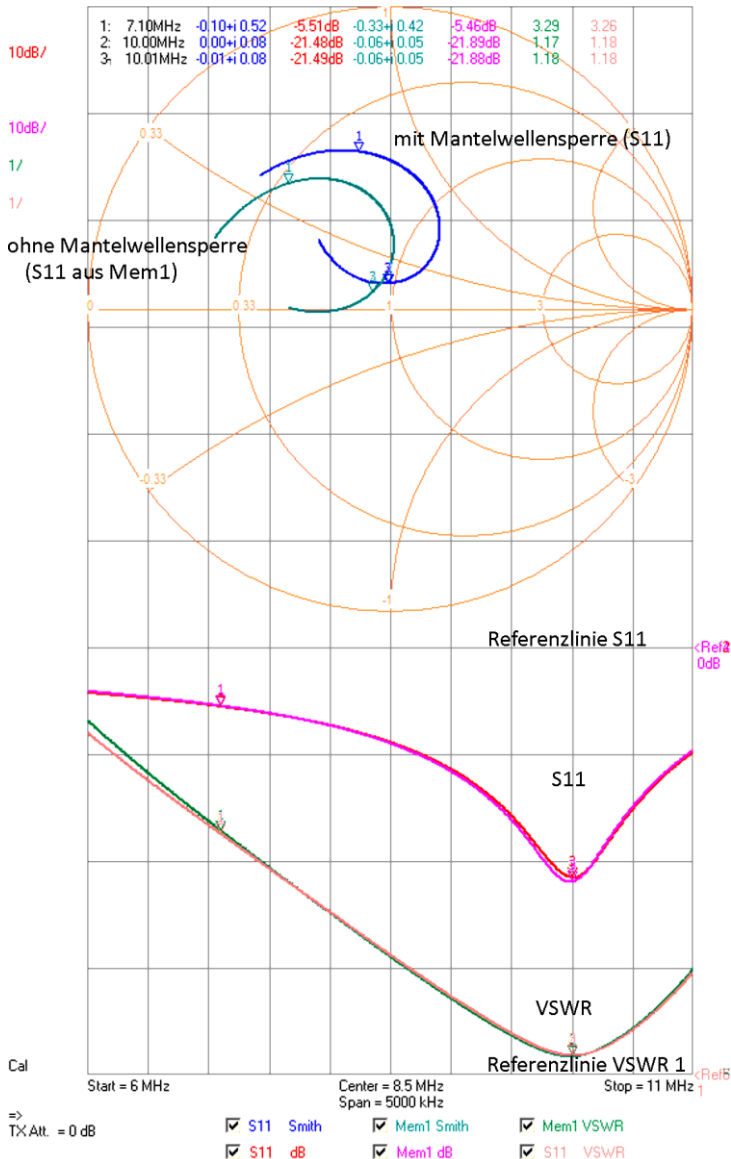
Jörn DK7JB mail@dk7jb.de



The proposed matching circuit was built and measured. The implementation has not been fully optimized. A VSWR of 1.2 was good enough to show me how an antenna coupler operates. At 10 MHz, it does not matter whether an antenna is matched with a VSWR of 1.0 or 1.2. In reality, one would have to consider the common mode trap. On the next page you will find this measurement.



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With braid current choke

In reality, you would still connect a current balun in series with the system to curb common mode currents. Since we are behind the matching circuit near the 50 ohm environment, the balun does not change the S11 and VSWR. In the Smith chart, however, the transformations are seen through the cable of the current choke.



More information on coaxial current baluns can be found in Chapter 5.3

For antennas one should ask the antenna experts. Here are some links to the highly recommended lecture slides by Max Rügger, HB9ACC (Section Bern) to his two lectures on antennas

https://www.hb9f.ch/bastelecke/pdf/Bern_Antennenpraesentation_Teil_1.pdf

https://www.hb9f.ch/bastelecke/pdf/Bern_Antennenpraesentation_Teil_2.pdf

Then there are detailed documents about the lectures of Max Rügger, HB9ACC

Part 1: General, Material, Accessories

https://www.hb9f.ch/bastelecke/pdf/HB9ACC_Antennen/hb9acc1.pdf

Part 2: Cables, SWR

https://www.hb9f.ch/bastelecke/pdf/HB9ACC_Antennen/hb9acc2.pdf

Part 3: Antenna couplers, SWR meters, measuring instruments, baluns

https://www.hb9f.ch/bastelecke/pdf/HB9ACC_Antennen/hb9acc3.pdf

Part 4: Antenna Theory, Antenna Simulation

https://www.hb9f.ch/bastelecke/pdf/HB9ACC_Antennen/hb9acc4.pdf

Part 5: Dipoles, Windom antennas, trap antennas, long wire antennas

https://www.hb9f.ch/bastelecke/pdf/HB9ACC_Antennen/hb9acc5.pdf

Part 6: Full-wave dipole, L-antennas, sloper, loop antennas, vertical antennas

https://www.hb9f.ch/bastelecke/pdf/HB9ACC_Antennen/hb9acc7.pdf

Part 7: Voltage-driven antennas, shortened antennas, special shapes

https://www.hb9f.ch/bastelecke/pdf/HB9ACC_Antennen/hb9acc7.pdf

Here are some thoughts on antenna construction:

www.dl2lto.de/dld/Antennenbau_Gedanken.pdf

4 Beginning with VNWA - from buying to first steps

In this little overview I want to introduce you to some hints and recommended reading to get you started with the VNWA.

Note: Commercial links should only serve as a starting point in the search.



(c) sdr-kits.net

4.1 What can you do with the VNWA of DG8SAQ?

Daten des VNWA3 [1]

Typ: Vektor-Netzwerkanalysator (Amplituden- und Phasenmessung)
Frequenzbereich: 1 kHz bis 1,3 GHz
Dynamikbereich: 90 dB @ <500 MHz, ≥ 50 dB sonst (mit eingeschränkter Genauigkeit)
S-Parameter-Messung: Zweitor-S-Parameter S_{11} , S_{21} , S_{12} , S_{22} ; Dreitor-S-Parameter (mit zwischengespeicherten Werten)
Messdurchlauf: linear, logarithmisch und nach individueller Frequenzliste; max. 65 000 Datenpunkte, Sampling-Zeit einstellbar 16 ms bis 100 ms; bei Ultrafast-Sweeping bis zu 6250 Datenpunkte/s
Kalibrierung: (normale) und Master-Kalibrierung
Antennenmessung: Fußpunktwiderstand, Stehwellenverhältnis, Rückflussdämpfung, Horizontal- und Vertikal-Strahlungsdiagramm, Anpasstopf
Komponentenmessung: Widerstand, Leitwert, Kapazität und Induktivität (mit Ersatzschaltbild), Gütefaktor
Schaltungsmessung: Verstärker, Dämpfungsglied, Leistungsteiler, Anpassschaltung, Quarz, Quarzfilter, Saugkreis, Sperrkreis, Bandpassfilter, Transformationsleitung, Balun
Koaxialkabelmessung: Längenbestimmung, Aufspüren von Stoßstellen, Wellenwiderstand
Spektrumanalysator-Modus unterhalb 100 MHz
Eingangspegel: ≤ 0 dBm
Signalgenerator: ohne Filter, max. Ausgangsleistung -12 dBm @ 1 MHz, mit steigender Frequenz abnehmend; einstellbares 50-dB-Dämpfungsglied in 0,1-dB-Schritten
Betriebssysteme: Windows7, Vista (64 Bit und 32 Bit); XP, ME, 2000, Windows 98
Sprache (Bedienung und Hilfedateien): Englisch
Spannungsversorgung: über USB 1.1, 2.0 oder extern 5 V / ≤ 500 mA
Anschlüsse: 2 x SMA, 1 x Mini USB-B, 1 x RJ-11

Quelle: FUNKAMATEUR; FA8/12; S.822ff

Here is an incomplete collection of possibilities.

If you browse the VNWA help file or leaf through the books by Gerfried DH8AG you can find many more ideas and suggestions. Even on my homepage www.bartellos.de you will find many examples of my work.

Here are some ways that have not been mentioned in the adjacent box:

- LCR meter with component quality measurement
- Quartz crystal analyzer
- Measurement of antennas
- Measuring antenna radiation
- Measuring line reflection (e.g. cable length and condition)

On his web site Hardy DL1GLH has compared the VNWA with a commercial unit of R & S: <http://www.dl1glh.de/vnwa/vnwa.html>

Here's a paper by Thomas DG8SAQ on the accuracy of VNWA for the advanced users among you: for the download you need to login to the VNWA-Yahoo Group and then you will find the file in the folder. Name: Measurement_Accuracy_Considerations.pdf
<https://groups.yahoo.com/neo/groups/VNWA/files/A1%20DG8SAQ/>

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4.2 Purchase one VNWA with some additional items

Should you still be unsure which VNWA model you should buy, I would always advise you personally to this version:

- DG8SAQ USB Controlled VNWA 3EC - (expansion board)
- VNWA Test Board Kit (Includes Test Components)
- SDR-kits Cal Kit of Rosenberger parts in Presentation Case 12 GHz
- 2 times: SMA Connector Flat tensioner 8, 6, 5.5, 5 mm and 5/16 inch (Low cost special SMA tool)

The "**Expansion Board**" "**EC**" is important so that the measurement time can be halved. When matching filters and amplifiers, this is very helpful.

The **Rosenberger Cal Kit** is very convenient to use! In the picture you can see the connector from the calibration elements kit marked by me with a paint pen. The mark protects against confusion with other connectors. The electrical characteristics can be found here:

https://sdr-kits.net/documents/Rosenberger_Female_Cal_Standards_rev5.pdf

We have had very good experiences with this calibration kit.

Then you still need **high-quality cable and SMA connectors and adapters**. I recommend you that you stock up at amateur radio flea markets. You will certainly find such items at stalls where GHz items are sold.

In this image, you will find a small collection of my cables, adapters, and home-built measurement tools. With these materials, we have experimented at the workshop



Please never use cheap plugs or cables. With those you risk destroying the VNWA or expensive adapters. Please dispose of faulty connectors or cables immediately.

Important note: If possible the measurement cables should not be removed from the VNWA to protect the VNWA's connectors. Calibration is always performed at the end of the measuring cable!

4.3 VNWA software and help files

The VNWA software and other information and help files can be found here:

<http://sdr-kits.net/DG8SAQ/VNWA-installer.exe>

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

On this page you will also find the Help file as a PDF in German. Please print it out and read it thoroughly! The help file is written as a tutorial with many examples, so it really pays to gradually work through the 500 pages of specific topics.

For more information on installation and the help file as a PDF in German language:

<http://www.sdr-kits.net/vnwasoftware/?21>

4.4 Recommended books, videos and other sources

These two books are highly recommended. They are to be understood as a workbook and should be thoroughly studied, at least in parts: "Measuring with the vector network analyzer VNWA2 / VNWA3" Volumes 1 and 2 by Gerfried Palme:

<http://darcverlag.de/Messen-mit-dem-Vektor-Netzwerkanalysator-VNWA2-VNWA3>

<http://darcverlag.de/Messen-mit-dem-Vektor-Netzwerkanalysator-VNWA2-VNWA3-Band-2>

The book "RF measurements for the radio amateur" by Hans Nussbaum, DJ1UGA, is very practical, even if it is not specifically tailored to the VNWA. Recommended.

http://www.box73.de/product_info.php?products_id=2939

Very good video presentations by Thomas DG8SAQ for the VNWA provide important background information and tutorials at: <http://www.dg8saq.darc.de/>. It is worth watching these videos without distractions. Strong recommendation !!!

Here are the direct links:

HAMRADIO 2012 DG8SAQ VNWA: <https://www.youtube.com/watch?v=SsbGAH9zdVM>

HAMRADIO 2013 with slides part 1 German version: <https://www.youtube.com/watch?v=bXfMaQBBHq4>

HAMRADIO 2013 with slides part 2 German version: <https://www.youtube.com/watch?v=nLYBcLtxpeQ>

HAMRADIO 2014 German as recorded: <https://www.youtube.com/watch?v=ed3ag1ToLBc>

There you will also find more recent films, but directed more to advanced users.

I strongly recommend the VNWA forum to you. Here questions can be asked and you will also find relevant software and PDF documents. You have to register for this forum. It is advisable to add an extra email address for this forum, since all messages are sent via email: <https://groups.yahoo.com/neo/groups/VNWA/info>

Mini Toroidal calculator to calculate inductances: <http://www.dl0hst.de/mini-ringkern-rechner.htm>

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4.5 Getting Started with the VNWA

The VNWA is a very powerful measurement tool. Therefore, it requires a certain amount of training. I would like to recommend you look at the videos and PDFs mentioned, and work through them.

To help you get started, Kurt Poulsen OZ7OU put a lot of effort into creating videos for beginners. These videos are all in English. Please watch the videos closely.

"Installing the VNWA software": <https://www.youtube.com/watch?v=TOMj4jaUSKs>

"First time with the VNWA software": <https://www.youtube.com/watch?v=cuLjsJYpODc>

"First time calibration of the VNWA": <https://www.youtube.com/watch?v=cuLjsJYpODc>

On the VNWA page of SDR-Kits you can find very good step by step instructions in German for the first installation and the first measurement:

https://www.sdr-kits.net/documents/VNWA3_Ans_Laufen_bringen-W10_W8_W7.pdf

On the homepage of Gunthard Kraus DG8GB (www.gunthard-kraus.de) you will also find an introduction to the VNWA: <http://www.gunthard-kraus.de/VNWA3/VNWA3-Tutorial.pdf>

Everything is explained step by step. You should also work through this tutorial.

"Vector network analysis explained using the example of VNWA 3" Episode 1 and 2. Radio Amateur FA 8/12 p 822ff and FA 9 / 12 p 926ff

If you have installed on the software as shown in the videos, started the software for the first time, and performed a calibration, it's time for a first measurement. Take a high-pass or low-pass filter from your collection and perform a measurement as we practiced together in the workshop. The tutorial of Gunthard will help you.

4.6 Advice to VNWA beginners when the first hurdles have been overcome

So you can get an idea of what you can do with the VNWA, I have listed projects in this sub-section, which you can find on my website.

All about band filters and quartz filters: <http://www.bartellos.de/dk7jb.php/projekte/quarzfilter-und-bandfilter/>

Here you will find many measurements can be carried out on a receiver with a VNWA:

<http://www.bartellos.de/dk7jb.php/experimente-am-k2-mit-baumapfe>

<http://www.bartellos.de/dk7jb.php/selbstbau-trx-2012>

<http://www.bartellos.de/dk7jb.php/der-kubik-verstaerker>

A low noise amplifier with transformer negative feedback and high linearity. The "panacea" for the short wave region:

<http://www.bartellos.de/dk7jb.php/der-kubik-verstaerker>

5 Measurements for beginners - useful information

5.1 VNWA: how to create a Master Calibration

Here is the procedure to create a "Master Calibration":

First of all, with a normal calibration every time you change the sweep start or stop frequencies or the number of points, the calibration is invalid and thus must be recalibrated. To avoid this cumbersome procedure, the Master Cal was invented.

- 1) Calibrate with the maximum count of 8192 points and with the maximum permissible sweep time.
- 2) Select the maximum width frequency range of 1 kHz to 1300MHz
- 3) Perform a SOLT calibration (SOLT means short, open, load, through). Crosstalk cal (crosstalk) should really only be used if you have to avoid crosstalk, otherwise you can simply omit that item.
- 4) After SOLT calibration press the button "save cal as master cal", the calibration data will then be saved under a name which you enter. I recommend you use a descriptive name, such as MC_sw_coax_1KHz-1300_8192pnts_8_Aug_12.
Indicating: MC: master cal, sw_coax: the short black coaxial cables used for measurement, frequency range, number of measurement points, date. This information helps in retrieving the correct calibration.
- 5) NOTE: if you see a red M in the green display points then there is a single MC (Master Cal), and as soon as the Master Cal has been loaded, the red M disappears.
- 6) Note: if the number of points or the frequency range are changed now from the master cal, new calibration data is interpolated. This is indicated by a green M in red display points (in the Cal menu).
- 7) Note: you can create more than one Master Cal file, but with different names.
- 8) You can restore a saved Master Cal again at any time via File-> Retrieve-> Master-Cal.

But I also like Master calibrations of 1-200 MHz with 600 points and maximum sweep time selected. That's my main measuring range. Here the focus is on the reduction of noise.

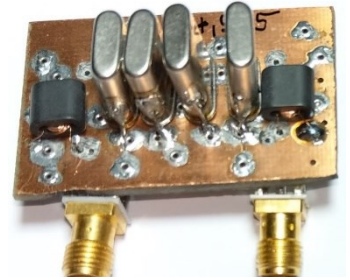
More information on calibration can be found in the book by Gerfried "Measuring with the Vector Network VNWA2 / VNWA3 Volume 1" in Chapter 3. Throughout the book Gerfried goes into great detail on the basics of calibration and also specific aspects that should be considered in detail.

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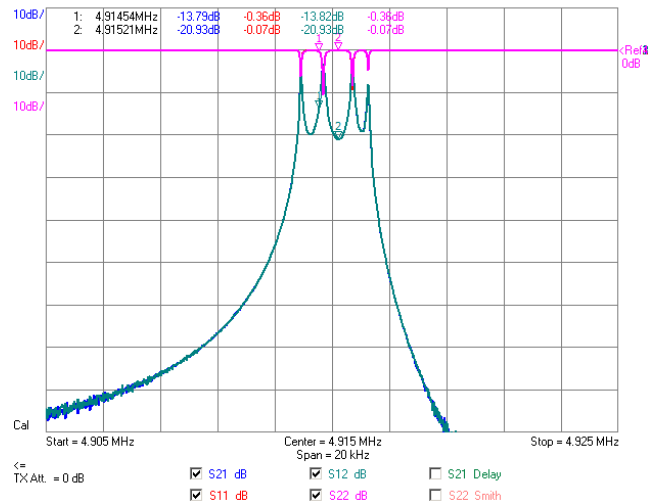
Jörn DK7JB mail@dk7jb.de

5.2 4.915 MHz Quartz filter measured and adjusted correctly

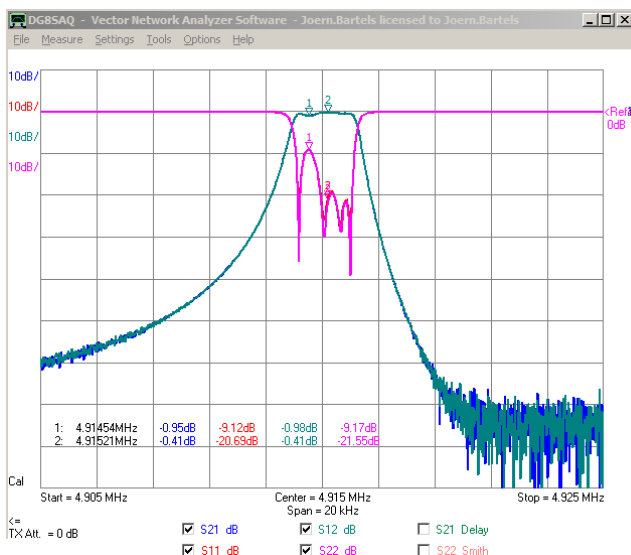
Here, a quartz filter is re-measured and provided with new transformers for impedance matching.



The first measurement shows the crystal filter after the two transformers have been removed and the filter circuit is directly soldered to the SMA connectors. The direct measurement shows extremely poor matching, as you would expect. For the measurement first S11 and S21 are measured. Then the filter is reversed at the measuring cables of the VNWA, so the filter input and filter output are swapped. The measurement direction at the VNWA is changed by selecting the return direction under the VNWA-Measure Direction. Before the measurement, you have to have all four S-parameters displayed – as in the picture. Then the return direction can be measured.



Now the matching tool performs a virtual adjustment - see picture below. The best curves for the four S-parameters are obtained with a filter impedance of 1030 ohms.



Recalculate to new source and load conditions

Port 1 Impedance: 1030 Ohm
 Port 2 Impedance: 1030 Ohm
 C parallel (neg. possible): 0 pF
 C parallel (neg. possible): 1 pF

Note, that the matching networks will transform to the conjugate Port1/2 impedances!

Matching Networks:
 Input Impedance: 50 Ohm
 Output Impedance: 50 Ohm
 C parallel (neg. possible): 0 pF
 C parallel (neg. possible): 0 pF
 Matching Network Variant: 1
 Matching Network Variant: 1

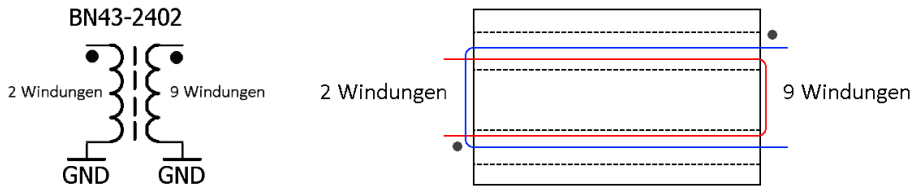
Lp = 7.53 µH
 Cs = 146 pF
 4.915 MHz
 Lp = 7.47 µH
 Cs = 146 pF

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Jörn DK7JB mail@dk7jb.de

Since it is usually too cumbersome to match with LC elements, I mostly use double hole cores. To speed up the calculation I have written a small Excel spreadsheet. You can find it on my website: <https://www.bartelsos.de/dk7jb.php/uebertrager-mit-doppellochkernen>

For the shortwave region I always wind on the double-hole core BN43-2402. For the primary winding always 2-4 turns and the secondary winding not more than 15 turns. In our case two turns were wound for the 50 ohm side and then 9 turns on the secondary side for 1030 ohms



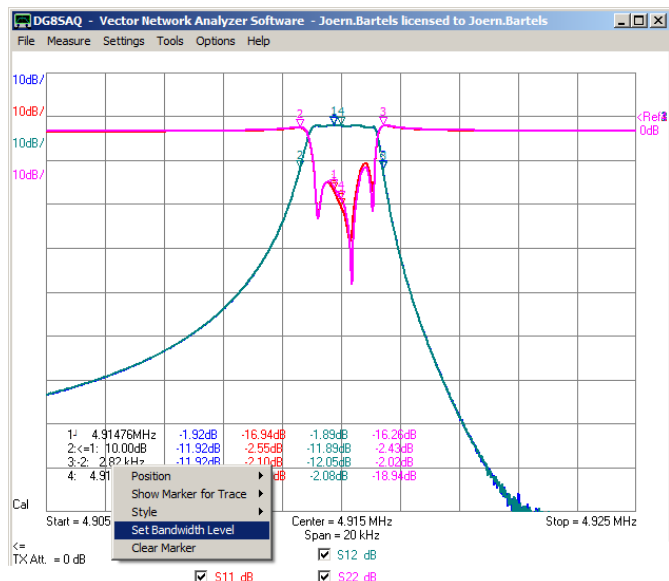
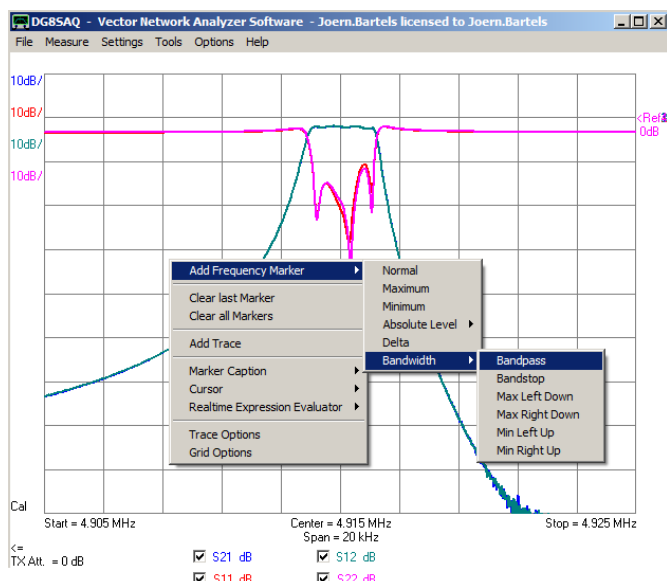
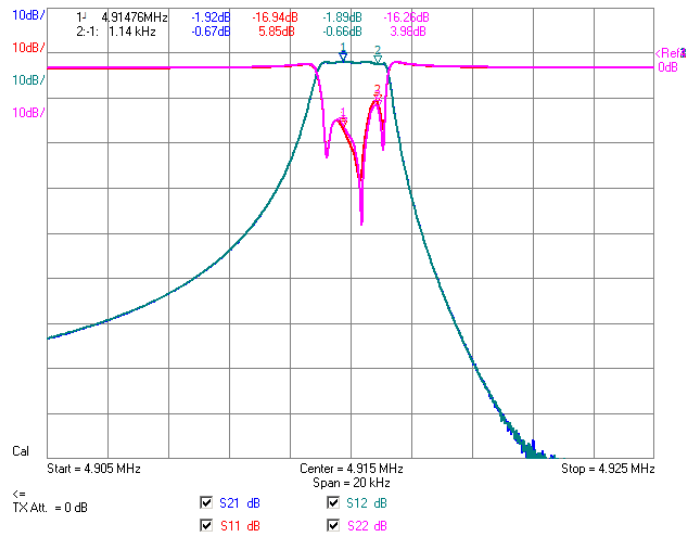
The "hot" end of the transformer is marked with a dot.

Übertrager	
Quellimpedanz:	50 Ohm
Zielimpedanz:	1030 Ohm

Anzahl an Windungen	
Primär	Sekundär
1	4,5
2	9,1
3	13,6
4	18,2
5	22,7
6	27,2
7	31,8

The following figure shows the measurement of the quartz filter matched with the transformers.

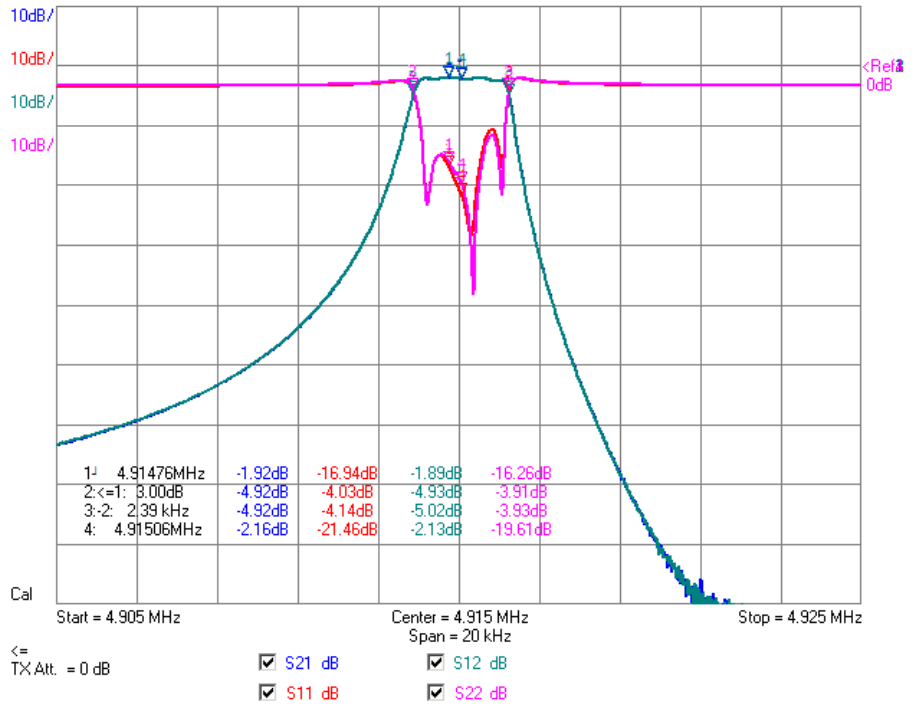
The tabular display of measured values can be moved with the mouse if the table is "touched" with the left mouse button in the region of the frequency data. When the right mouse button is clicked in this area, a context menu is opened which allows the width of the bandwidth markers to be changed. The picture below shows a bandwidth of BW = 3 kHz. The quartz filter then has a 3dB bandwidth of 2.39 kHz.



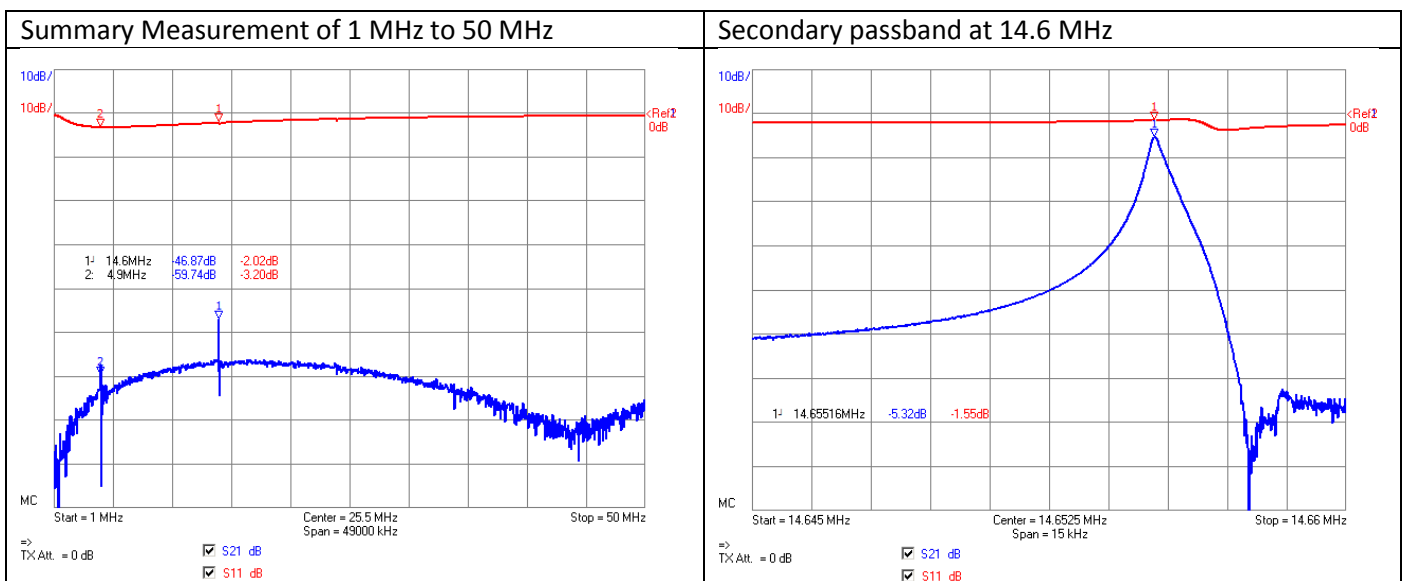
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Here are the final measurement for the passband. For a quick set-up for a workshop, the values are good and we can be satisfied.



Here are two more measurements. The first measurement shows a wide frequency range from 1 MHz to 50 MHz with 1300 points. The stop band attenuation is roughly 55dB, which would not be enough. The passband of 4.9 MHz cannot be displayed completely because the measurement points of the VNWA are too far apart with this large frequency interval. The S21 transmission measurement shows two points in the measurement curve (marker 1 and marker 2). In addition to the pass band there is also a disturbance in the stop band at around 14.6 MHz. That should be the subject of a more detailed investigation. The right image now shows a measurement with a small frequency interval at 14.6525 MHz. This shows a common feature of crystal filters, that the secondary resonances of the quartz crystals can also form a second passband. That's something no one wants. The remedy would be to create a diplexer or an adaptation with LC elements sections in a low-pass configuration. The only drawback with LC elements would be exact tuning. The stop-band attenuation could only be improved by a quartz filter with more crystals.



5.3 Baluns, UnUns and braid current chokes

In the course of preparation for the workshop in 2019 several participants asked us questions about Baluns, Ununs and Braid Breakers. This, rather longer chapter, serves as preparation and follow-up for the workshop.

I would particularly like to mention a presentation by Günter DL4ZAO about baluns. Thank you for letting me use the images and text freely: https://dl4zao.de/downloads/Balun_dl4zao.pdf

Wolfgang Wippermann (+) DG0SA has put together an impressive website that deals mainly with baluns and suppression devices. I was also allowed to take content from him: <http://www.wolfgang-wippermann.de/>

At the end of the chapter you will find more links.

As space is limited in this document, I will deal only with the current balun case - with experiments. For the other balun types I refer to the two previously-mentioned sources.

5.3.1 Difference: current balun - voltage balun - unun

For the term balun, two variants are usually distinguished. An Unun must be separately considered again:

- The "current balun" forces symmetrical currents.
A current balun is used as a common mode choke (standing wave trap, common mode choke).
The task of a current balun is to generate at the output terminals equal and opposite currents. As a consequence, the voltage present at the output terminals with respect to ground will take whatever value is necessary to produce current symmetry.
- The "voltage balun" forces symmetrical voltages.
It frequently serves as an impedance transformer for broadband matching of antenna and cable.
A voltage balun generates at its output terminals equal voltages relative to ground potential. A voltage balun is often wound with a transmission ratio, so that it transforms different impedances between input and output.
- An UnUn transforms only impedances. An Unun is a simple transformer, usually in the form of an autotransformer circuit. Nothing is balanced or suppressed.

A current balun suppresses braid currents. A voltage balun is not designed to suppress braid currents effectively!

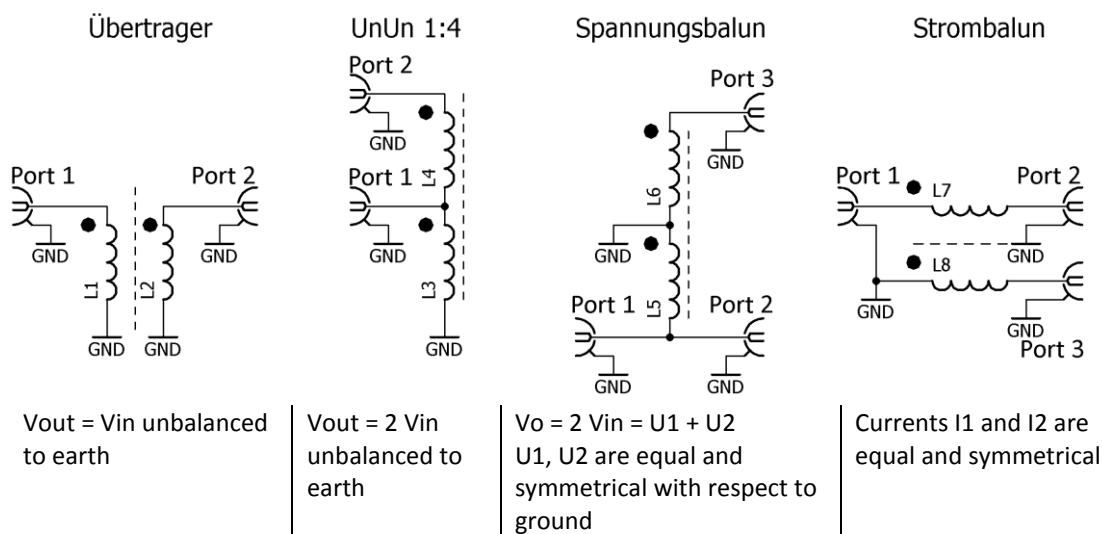
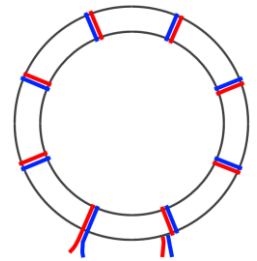
However, a voltage balun can be combined with a 1:1 current balun for this purpose (a Hybrid balun).

On the next page I'll show you an example of how a current balun, a voltage balun and an UnUn can be built with a wound toroid.

Gerfried also deals with baluns and 3-port measurements in his book "Measuring with the vector network analyzer VNWA2 / VNWA3 Book 2" in Chapter 10.

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Same winding - different result



This figure shows clearly how a toroid with two windings can be configured as an UnUn, a voltage balun, or a current balun. The picture also shows the possibility of switching the two windings of a 1:1 transformer - so actually four ways.

Attention! Exchanged connections quickly make a current balun into a voltage balun or UnUn.

Note: In chapter 5.3.5 I will wind and build baluns and transformers on four toroids exactly as described here, and then measure them

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5.3.2 the current balun

In this chapter I first explain the formation of standing waves, then the operation of current baluns, followed by two examples.

5.3.2.1 Energy transport on coaxial cable

Due to skin effect, a coaxial cable effectively has three conductors:

- inner conductor
- the screen inside
- the screen outside

The transport of energy takes place as a TEM wave in an electromagnetic field between the inner conductor and the inside of the shield. In a "Transverse Electromagnetic Mode" (TEM for short) the magnetic and electric fields only occur in planes perpendicular (transverse) to the direction of propagation. In a coaxial cable, such a wave is formed as a guided wave.³ For such a TEM propagation in the coaxial cable two ideal conductors must exist, their arrangement is uniform in the propagation direction, and it is located in a homogeneous space. The current on the inner conductor and the current on the inner side of the screen are equal in magnitude but opposite in direction. On the outside of the screen no current flow takes place in the ideal case. But if a current flows on the outside of the screen due to disturbance (e.g. asymmetry), it is referred to as standing waves. I go into this more below.

Due to the skin effect, the outside of the screen acts as a separate single-wire line for HF, it has a slightly smaller loss than the coaxial cable inside.

Skin-Effect

Due to the high conductivity of the material of a conductor, the electric field of an alternating current cannot completely penetrate the material. With alternating currents, the electric fields serve as carriers of energy and not electricity. The interior of the conductor almost no longer contributes to the power transfer. The effective conductor cross-section for electron flow is reduced. The effective resistance of the conductor increases. The skin effect decreases the penetration depth of the alternating current in a conductor with increasing frequency

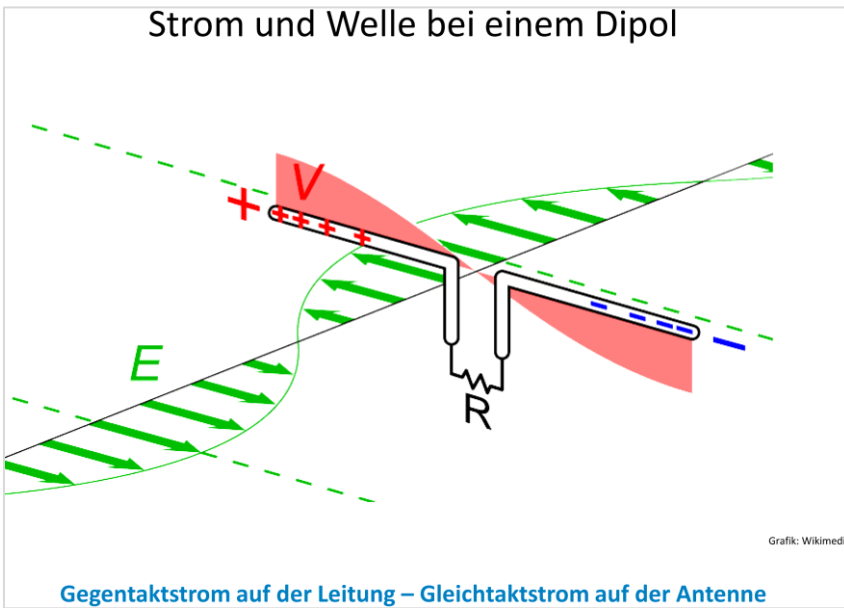
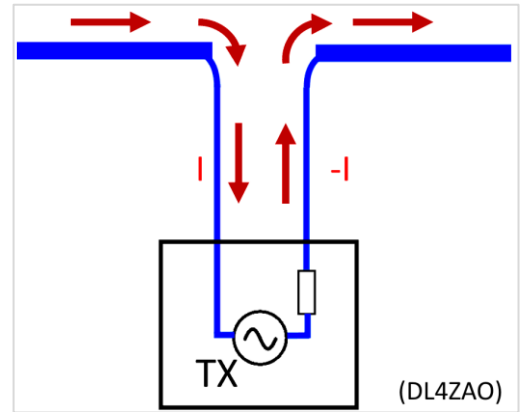
Frequency	Penetration depth
50 Hz	9 mm
500 kHz	0,1 mm
5 MHz	30 µm
500 MHz	3 µm

³ https://de.wikipedia.org/wiki/Transversalelektromagnetische_Welle

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5.3.2.2 Differential mode current and common mode current

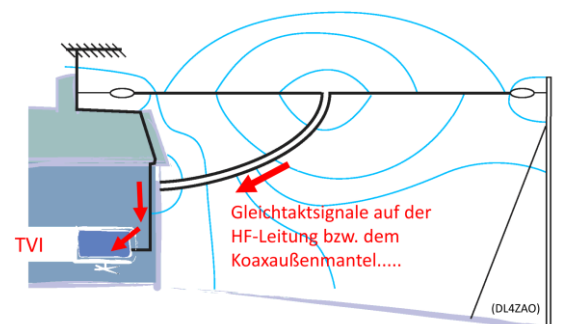
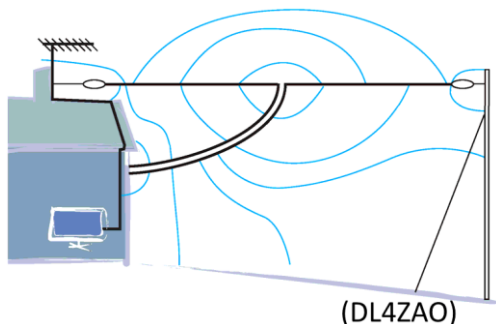
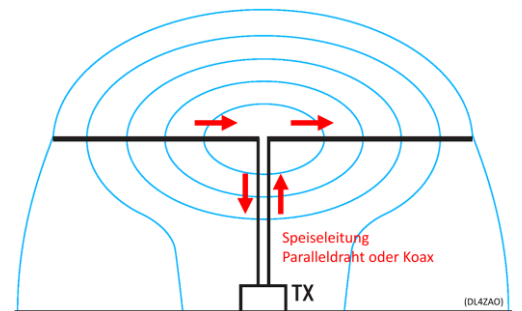
The energy transfer takes place between source and load on the line as a transverse electromagnetic wave (TEM wave). On two conductors of the line equal but oppositely directed currents flow. This is called "push-pull power". The push-pull fields in the line cancel each other. The line does not radiate energy to the environment. Also, no interference occurs on the line. At the feed point of a dipole the push-pull current on the line becomes a common mode current on the radiator. Accelerated charges of common mode currents on the antenna lead to wave separation (radiation, electromagnetic wave) - the line / antenna radiates.

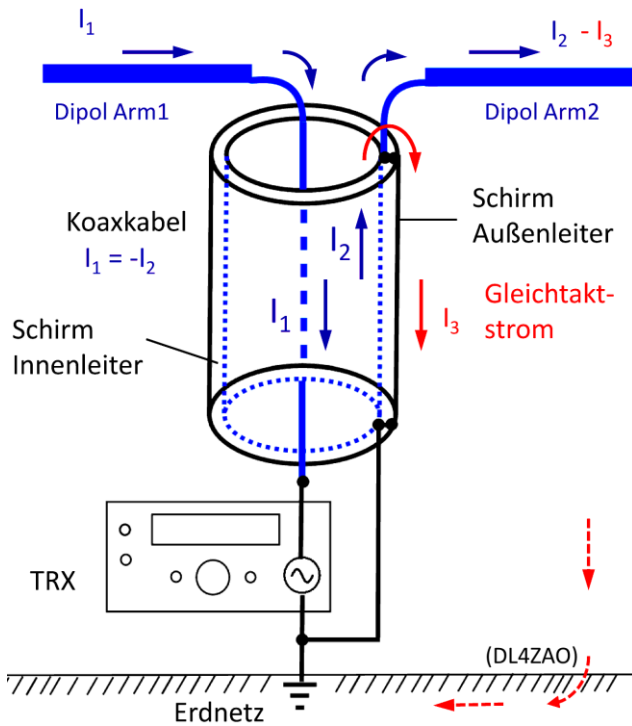


5.3.2.3 braid currents

The adjacent image shows the fields which result for an ideal symmetrical dipole in the ideal case.

In reality, very few antennas are symmetrical. Different impedances of the dipoles mean differences in potential to ground. The consequence of this imbalance are common mode equalising currents on the feed line. They cause TVI (interference to radio and television reception) and receive interference from domestic noise.





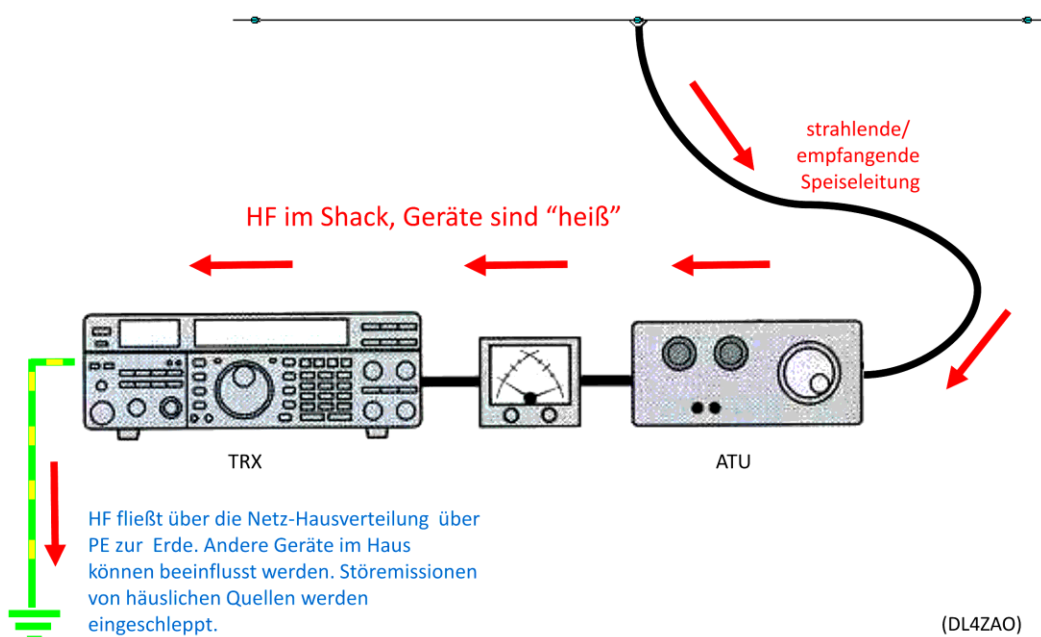
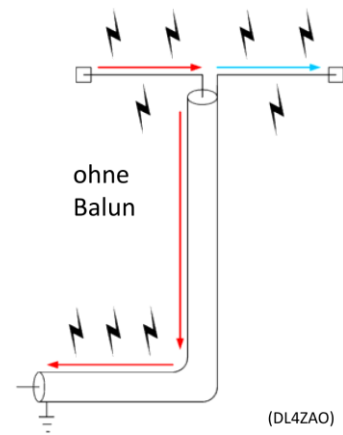
Energy flows as the current I_1 on the inner conductor and as a current I_2 on the inside of coax screen to the antenna. Here, I_1 and I_2 are equal and opposite in magnitude. The outer casing of the screen now acts as a separate conductor between dipole arm 2 and earth. Asymmetry in the antenna results in a potential difference to earth. As a result, high-frequency common mode current (I_3) flows through the coax screen outer surface to earth. Now the line radiates and acts as an antenna!

Common mode currents are equalising currents which are provoked by different potentials between balanced and unbalanced systems.

Common mode currents are undesirable because the screen acts unintentionally as part of the antenna. Screen and dipole act as an additional Inverted L antenna - with all the unwanted effects when sending and receiving.

The push-pull currents are responsible for the desired energy transport in the line and thus desirable.

We need a component that allows differential currents to flow freely and effectively reduce common mode currents. It must ensure that symmetrical current flows at balanced / unbalanced transitions



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5.3.2.4 the current balun

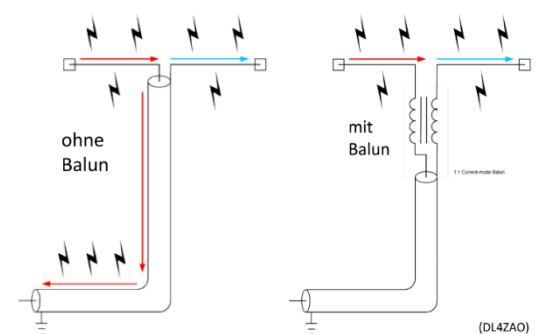
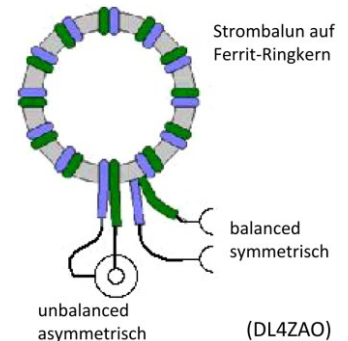
A current balun acts as a common mode choke or standing wave barrier and enables the transition of an unbalanced line to a symmetrical load.

Standing wave trap

It allows push-pull currents through unhindered. The flow of energy through equal but opposite currents from the antenna to the TRX, and from the TRX to the antenna, is not affected.

At the same time, the standing wave trap (also called current balun) presents common mode currents with the highest possible resistance since it acts as a choke and hence represents an impedance with high inductive resistance at the installation point (common mode choke). Screen currents are effectively reduced or ideally suppressed. The impedance of the coil is determined by its inductive resistance, the choke effect, which will oppose the common mode components. The balun is most effective when it is inserted in the current maximum of the common mode current. There, the common-mode rejection is highest. The energy transport from push-pull signals inside the coax is not affected, however.

The current balun consists of a transmission line that is wound on a core. The cable is either a parallel wire or a coaxial cable (air wound coils are also possible sometimes).



Looking at the partial currents on the two conductors of the line, they are equal in magnitude but are oppositely directed - they push-pull. The magnetic field of the currents is canceled in the ideal case, so that no magnetic flux occurs in the core.

The impedance of the line should correspond to the geometric mean between the input and output impedance.

$$Z_{Leitung} = \sqrt{Z_{Ein} * Z_{Aus}}$$

Transition of an unbalanced line to a symmetrical load

A current balun (balanced to unbalanced) also allows the transition of an unbalanced line (such as coaxial cable) to a symmetrical load (for example, a dipole antenna) or a balanced line (for example, parallel wire-feeder line) to an unbalanced load such as antennas with unbalanced properties (for example ground plane or off-center fed or unbalanced dipole).

A current balun (common mode choke) interrupts braid currents and forces symmetrical currents on the line

Not everywhere where you see Balun written on it, is there actually a Balun in it! The term balun (artificial word from: Balanced-Unbalanced) is often used improperly. Other forms of impedance transformers are also wrongly called balun, even if they have no symmetrizing properties and should therefore be called UnUn.

5.3.2.5 How should a current balun ideally be built?

High impedance to common mode currents - a multiple of the common mode impedance to be choked. (This also depends on the coax length and the insertion point of the balun: in the current maximum - low impedance, in the voltage maximum - high impedance). A well-functioning balun is always a compromise

- Goal: high impedance with few turns and short winding length
- Wide range = common mode impedance with resistive content (low coil quality)
- Characteristic impedance of the wound line = geometric mean between the input and output impedance. (Difficult for the balun behind an ATU as Z is undefined there)
- Dielectric strength of the winding (eg Teflon insulation)
- Low insertion loss for wanted push-pull signals
- Adequately sized core - can cope with the max. occurring magnetic flux.

5.3.2.6 Example, current balun constructed from coax 1:1, 50 Ohm

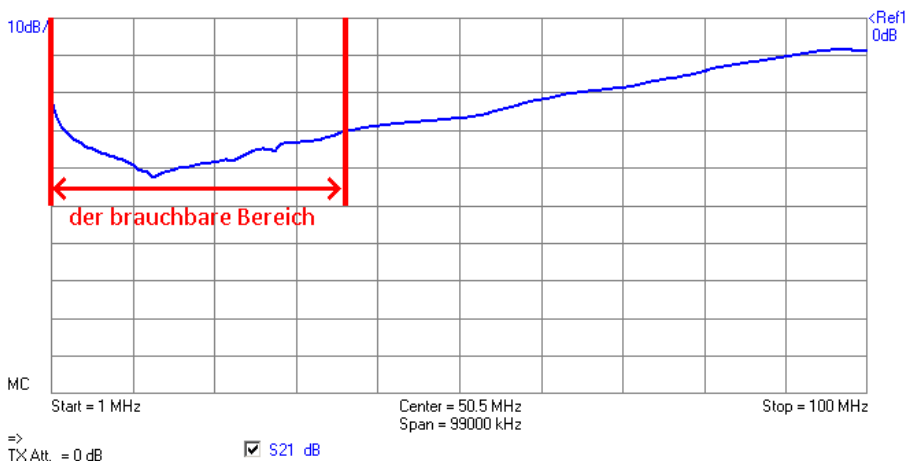
Current baluns can be easily made with a toroidal core and a coaxial cable. In the shortwave band the winding method described by Reiser is not absolutely necessary.



DL4ZAO



Here's my test setup with coax cable. The toroidal core is similar to the toroid RK1 from DARC.



The measurement shows blocking attenuation in the range up to 100 MHz. About 30 dB should be sufficient in most cases.

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5.3.2.7 Example, current balun 1:1, 50 Ohm

A 1:1 current balun (50 Ω to 50 Ω) was built from a design by Wolfgang DG0SA (+). The winding instructions can be found here:

<http://www.wolfgang-wippermann.de/balun1zu1kleinptfe.pdf>

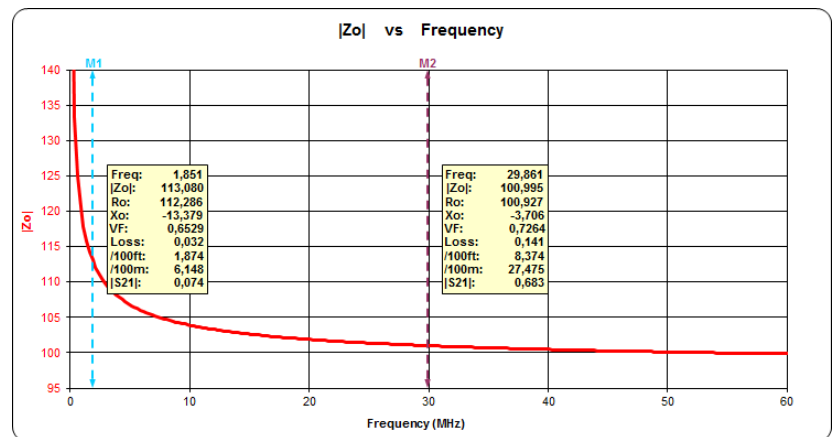
Since I did not have the recommended Teflon litz wire available, an existing solid wire was used to demonstrate the principle.

First, the wire used is measured with the VNWA and analyzed with the supplementary program Zplots. This measurement is described in chapter **Fehler! Verweisquelle konnte nicht gefunden werden..** So I am not going to talk further on the matter at this point.

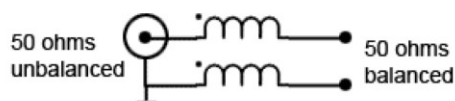
As a cable I use an existing wire with Teflon insulation (wire diameter: 0.62 mm and 0.98 mm outer diameter of the sheath). For the measurement, the DUT consists of two 515mm long wires.



If I measure the two wires with Zplots, I get the results shown in the adjacent picture. In the shortwave region significant deviations from 100 ohms can be observed.



Da es sich bei einem Balun um einen Leitungstransformator handelt, muss die verwendete Leitung entsprechend auch einen Wellenwiderstand von 50 Ohm aufweisen um ein gutes SWR zu erreichen.



Strombalun 1:1

Bild: DG0SA



Wicklung nach DG0SA (oben) Es werden einmal 12 Wdg 100 Ω Zweidraht-Leitung auf die eine Kernhälfte und 12 Wdg auf die andere Kernhälfte gewickelt. Das Parallelschalten der 100 Ω Leitungen ergibt 50 Ohm Wellenwiderstand. Wickelsinn beachten!

Baluns are devices with 3 ports. The VNWA can perform a 3-port measurement by always connecting two ports to the VNWA and terminating the third port with a good 50 ohm terminator. Subsequently, all combinations are measured. The 3-Port Analyzer can be found in the VNWA software at: VNWA – Measure - S-Parameters - 3-Port. Now, just follow the on-screen instructions.

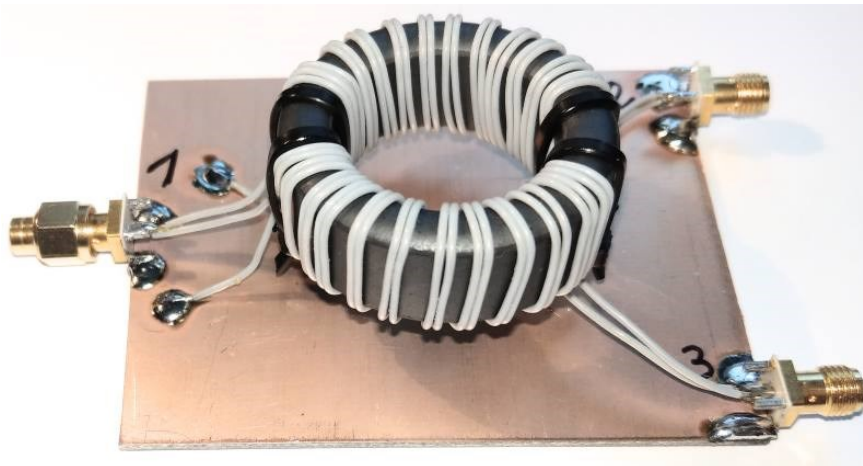
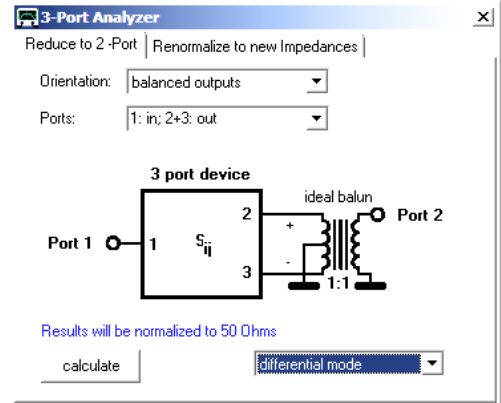
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Jörn DK7JB mail@dk7jb.de

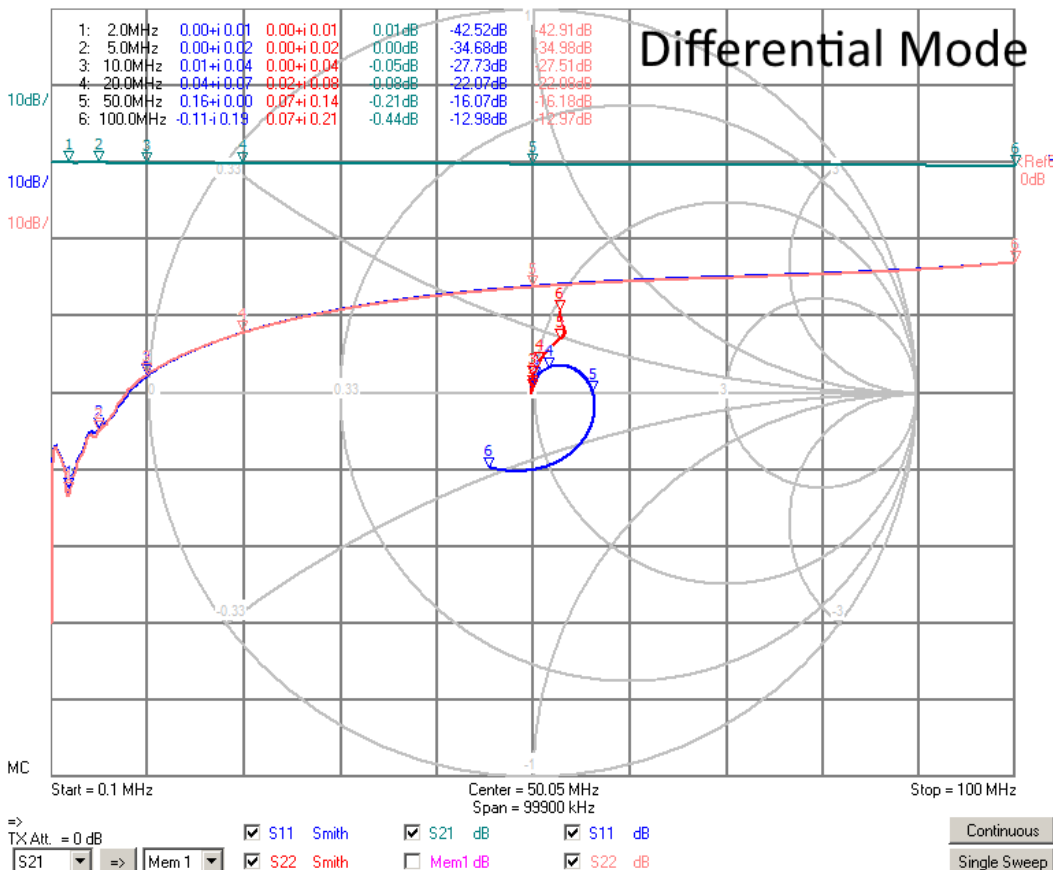
We cannot do much with the measured 3-port S-parameters because they have to be converted into the familiar 2-port S-parameters first. This conversion is performed by a tool, the "3-Port Analyzer". You can find it at: VNWA - Tools – 3-Port Analyzer.

The results are stored in S11, S21, S12, S22. A push-pull or common mode analysis is possible by selecting either "differential mode" or "common mode" in the 3-Port Analyzer.

Since we are staying in a 50 ohm environment, no adjustment with the matching tool is necessary.



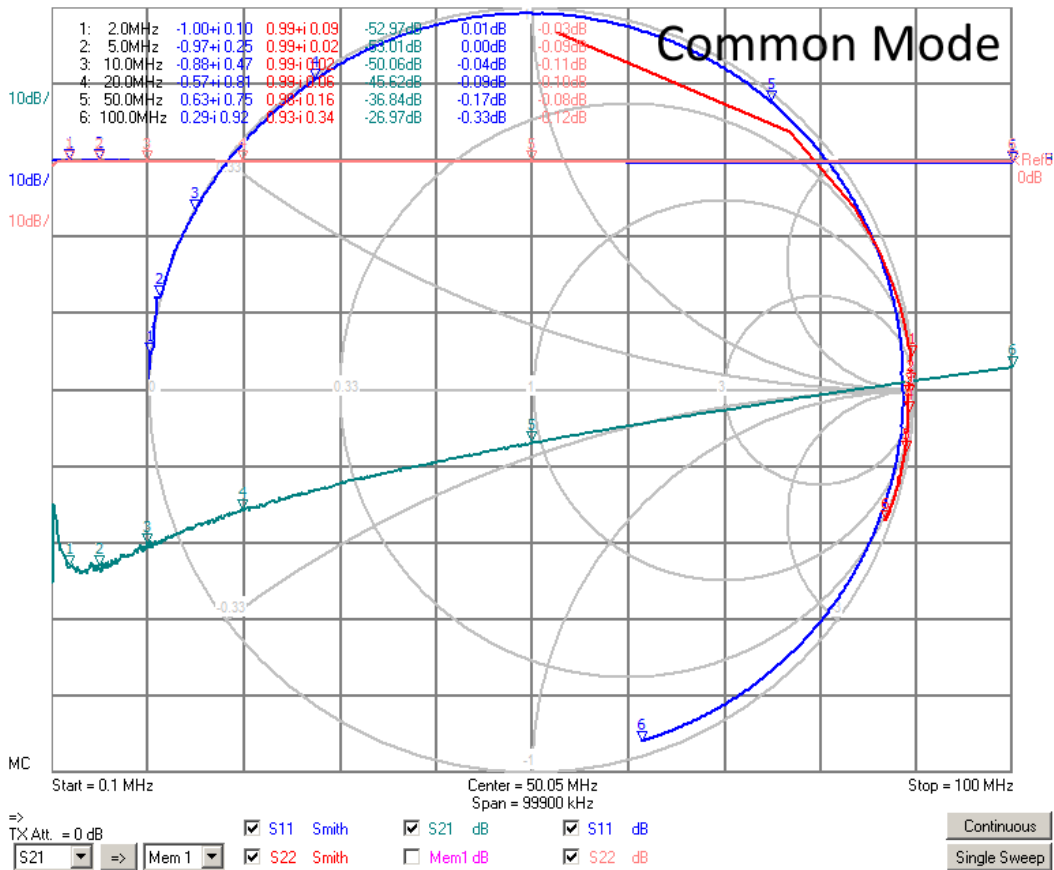
The analysis in differential mode shows that the S21 is very low and therefore negligible to 30 MHz. The S11 match is good up to 30 MHz and then gets worse at higher frequencies.



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Measurements in common mode show that the stop-band attenuation is really good when we are in a $50\ \Omega : 50\ \Omega$ environment.

The reader can even build the balun himself and investigate with the matching tool how such a balun behaves when the terminal impedances are changed.



5.3.3 Voltage balun

See literature, for example the book by Gerfried "Measuring with the Vector Network VNWA2 / VNWA3 Volume 2" in Chapter 10.

Also see the next page.

5.3.4 Unun

see literature

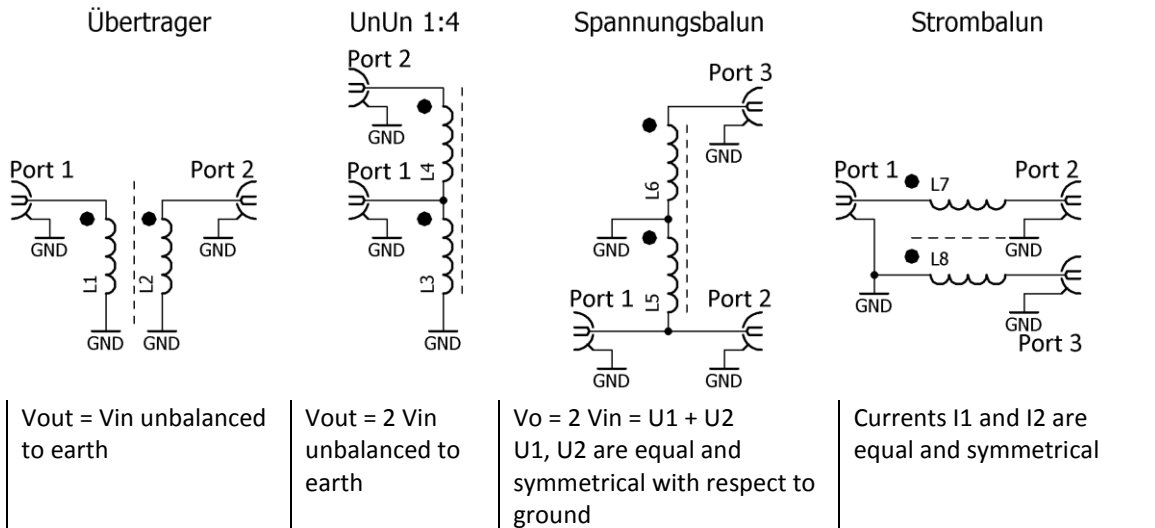
Also see next page.

5.3.5 Same winding - different result

At the beginning of Chapter Fehler! Verweisquelle konnte nicht gefunden werden. I pointed out that with the same windings on a toroidal core the circuitry determines whether one has a transformer, UnUn, voltage balun or current balun.

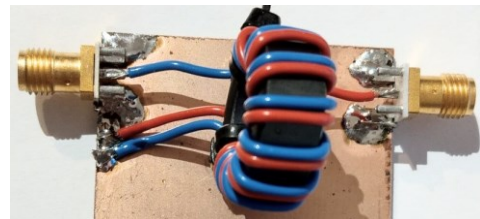
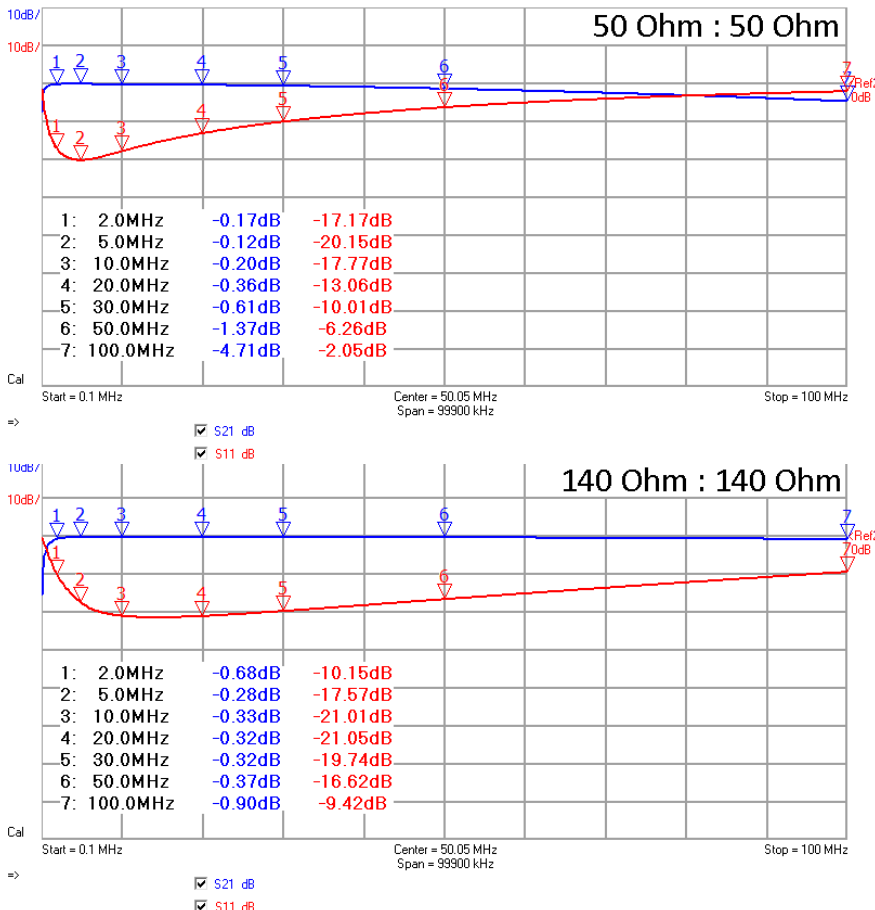
To demonstrate, I wound 8 turns on each of four small toroidal cores and then wired them differently as in the picture. Then they were measured. This is not about the best possible baluns - they are and remain demonstrators for the workshop.

I will not explain at this point how the 3-port measurement is carried out. You can read about this in the book by Gerfried (Volume 2, Chapter 10).



In the following sections, the four variants will be set up, measured and the results interpreted.

5.3.5.1 transformers



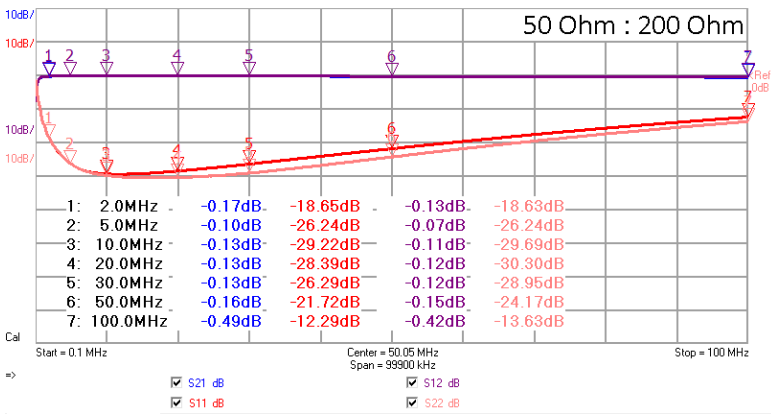
In a 50 ohm environment, only the match at 5MHz is good enough (i.e. $S_{11} < -20$ dB).

Better transformers can be wound for example with double hole cores. For low power applications you can use the BN43-2402 very effectively in the shortwave band.

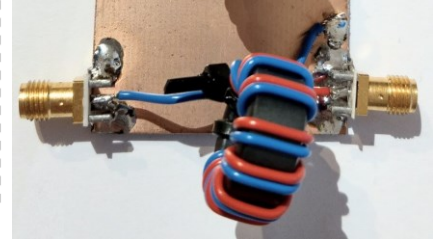
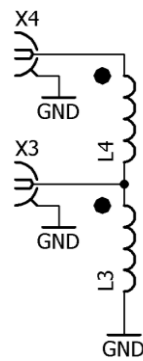
The second measurement shows the transformer in a 140 ohms environment with a significantly wider match. The reason is the winding technology. The two parallel windings have a line impedance of about 100 ohms.

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5.3.5.2 UnUn

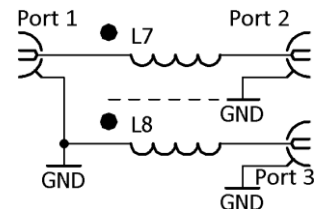
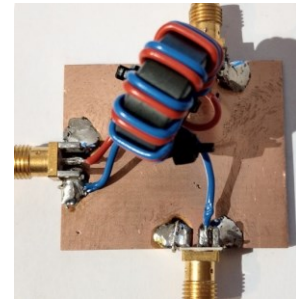
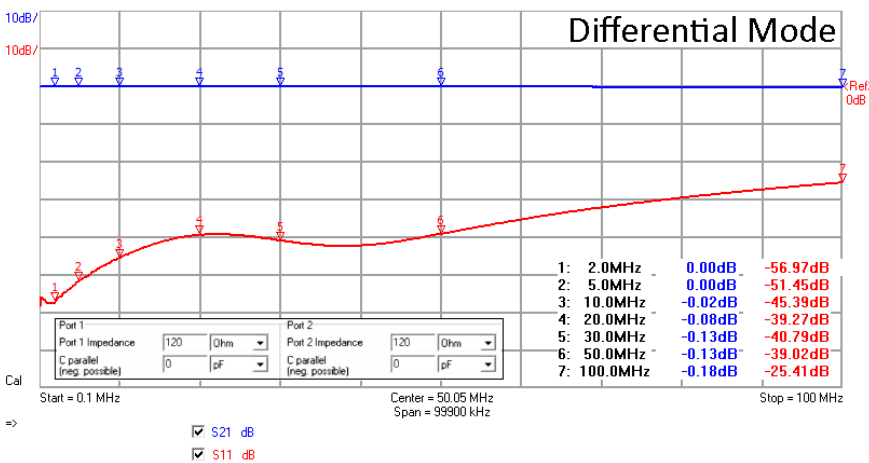


UnUn 1:4

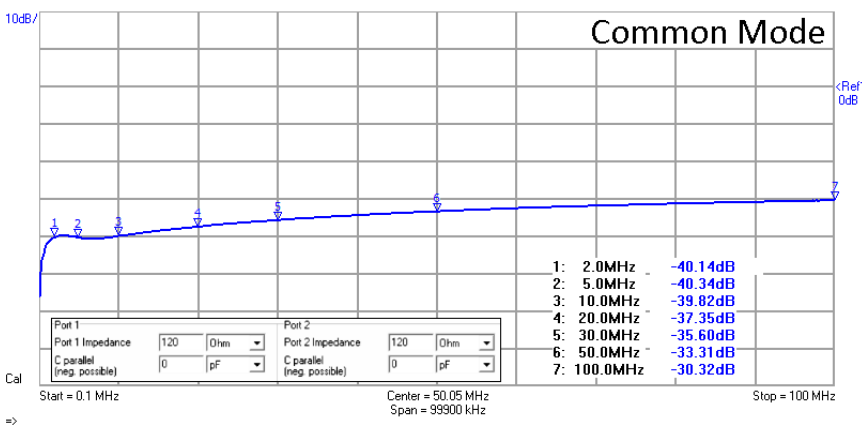


A UnUn is nothing more than a normal transformer. This type of winding is also called an autotransformer. In a translation of 50 ohms to 200 ohms, the through-attenuation S21 is very small in the range of approximately 3 MHz to 60 MHz and matching is good to very good.

5.3.5.3 current balun



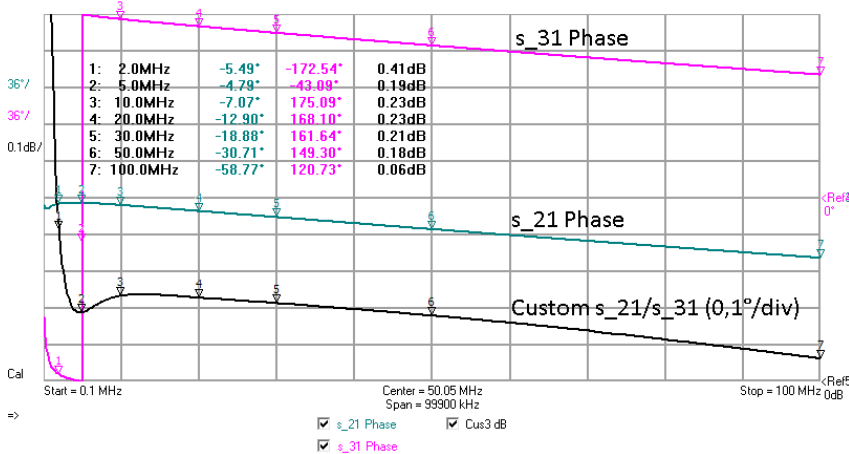
The current balun was measured as described with a 3-Port measurement and then evaluated with the VNWA tool "3-Port Analyzer". The picture shows the transmission loss and the match for the desired signal, which is a push-pull signal. The best fit is found, when everything is considered in the 120 ohm environment. Over the entire frequency range, the transmission loss S21 and S11 match are very good.



To investigate how common mode signals are suppressed, we set the "3-Port Analyzer" of VNWA to "common mode". The suppression of common mode signals is then stored in S21. Over the entire frequency range the common mode signal is suppressed by 30 dB to 40 dB - in a 120Ω-environment..

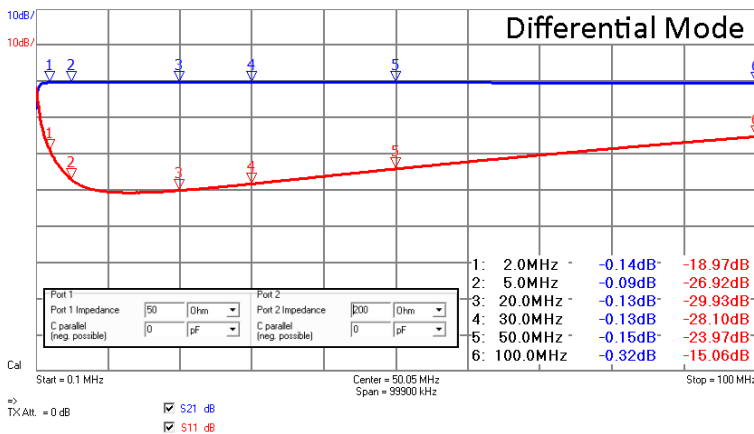
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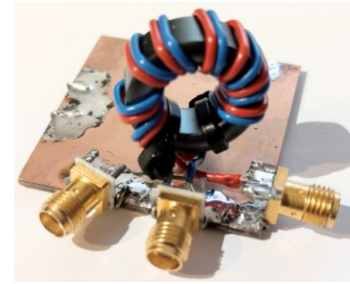
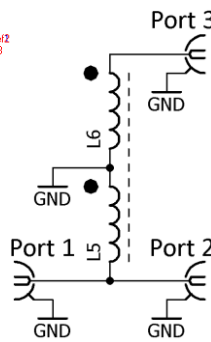


This image shows the phase of S21 and S31 and the custom trace shows the differences between these two signals. The phase difference is very small over almost the whole range.

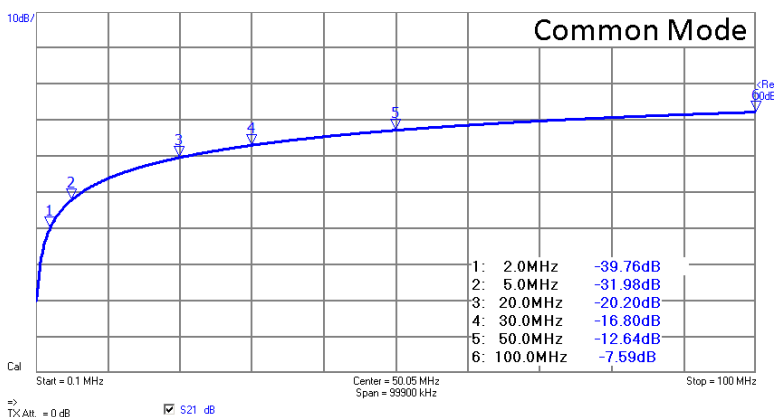
5.3.5.4 Voltage balun



Spannungsbalun



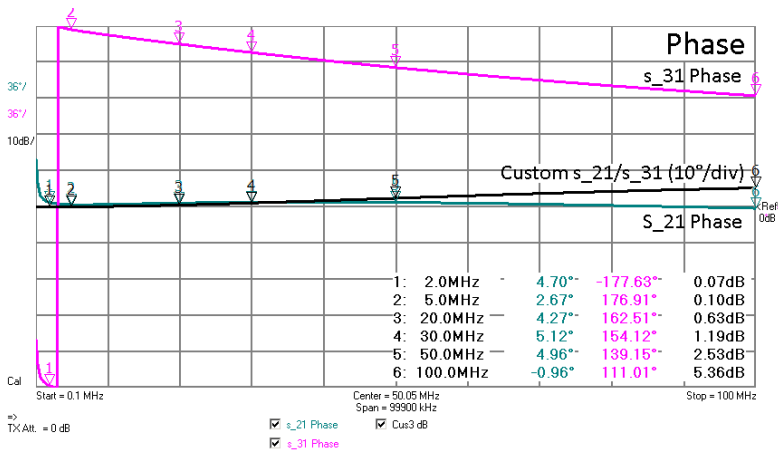
The voltage balun was also measured with a 3-port measurement, as described, and then evaluated with the VNWA tool "3 Port Analyzer". The image shows the transmission loss and the match for the desired signal, which is a push-pull signal. The best match is found when translating from 50 ohms to 200 ohms. In the frequency range of about 3 MHz to 70 MHz, the insertion loss S21 and the matching S11 are very good to good.



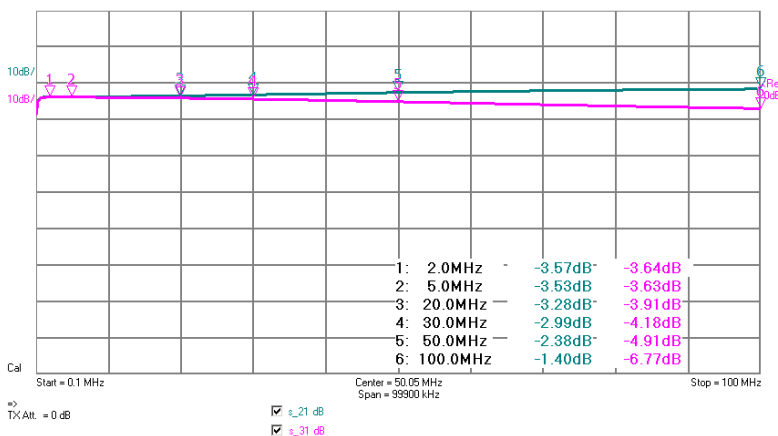
To investigate how common mode signals are suppressed, the "3 Port Analyzer" of VNWA is set to "common mode". The suppression of common mode signals is then stored in S21..

It can be clearly seen that the common mode signals are attenuated worse with increasing frequency, which is not surprising, since the focus is on balancing the voltage.

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In the short wave region, the phase differences between port 2 and port 3 are still quite small.



This diagram shows the equality of output amplitudes (s_21 and s_31).

5.3.6 Other measuring methods

When taking a closer look at baluns, you should also take control measurements. The late Wolfgang Wippermann describes on his website measuring methods under the link "balune". Some pages about measuring baluns are also found in the presentation by Günter DL4ZAO. I cannot go into any further alternative measuring methods for space reasons.

5.3.7 Links to baluns

https://dl4zao.de/downloads/Balun_dl4zao.pdf

<http://www.wolfgang-wippermann.de/>

<http://www.wolfgang-wippermann.de/balun1zu1kleinptfe.pdf>

<http://www.wolfgang-wippermann.de/balun1zu1undefklein.pdf>

<https://darcverlag.de/media/pdf/datenblattkerne.pdf>

<http://www.baekerei-heitmann.de/DF1BT/> Click on "Mantelwellen"

6 Measurements with the VNWA Test Board Kit

Thomas DG8SAQ and Jan have developed a small test platform to try out small circuits quickly.

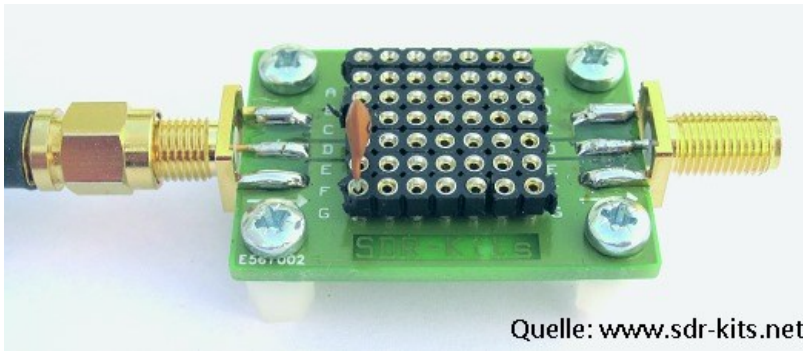
Hints and small and large experiments can be found here::

<https://www.sdr-kits.net/DG8SAQ-VNWA-Testboard-kit>

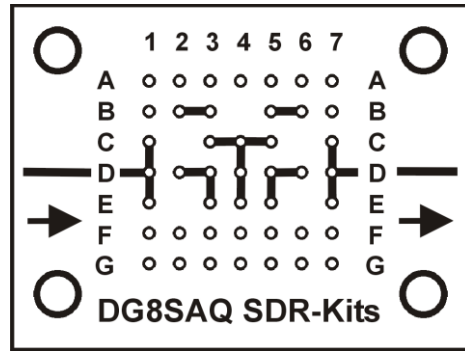
http://sdr-kits.net/documents/Testboard_kit.pdf

http://hamcom.dk/VNWA/DG8SAQ_Testadaptor%20Multi%20Label.zip

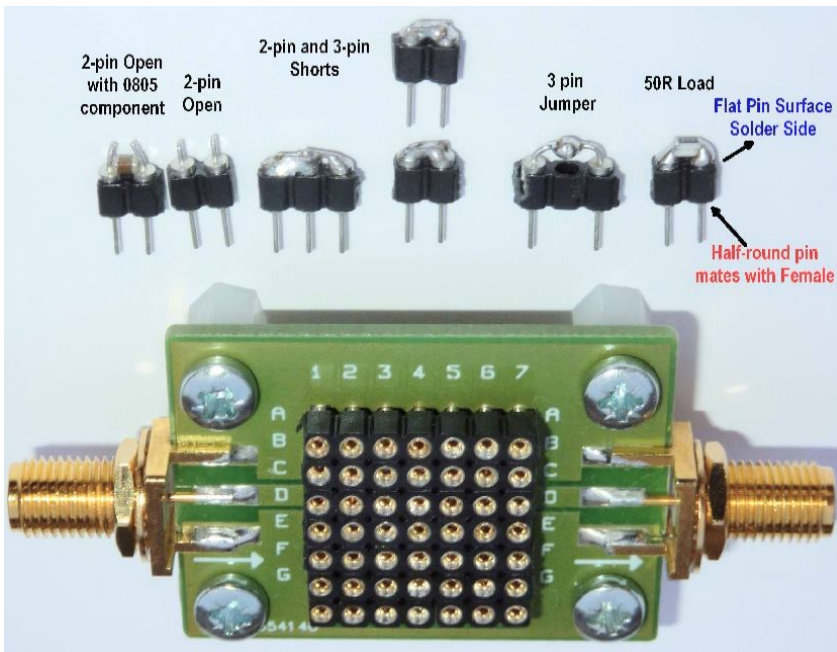
www.sdr-kits.net/DG8SAQ/VNWA/VNWA_Experiments.pdf



Quelle: www.sdr-kits.net



In the autumn I will fill this chapter with further examples 😊.



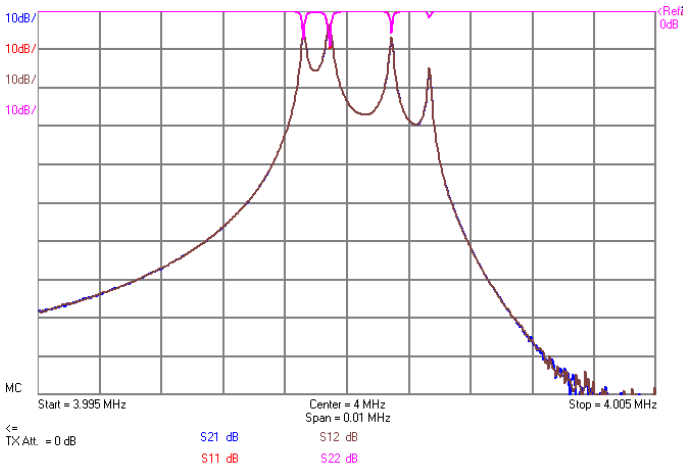
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Jörn DK7JB mail@dk7jb.de

7 Measurements for advanced users

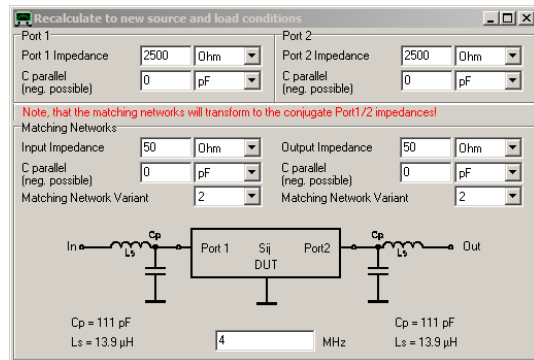
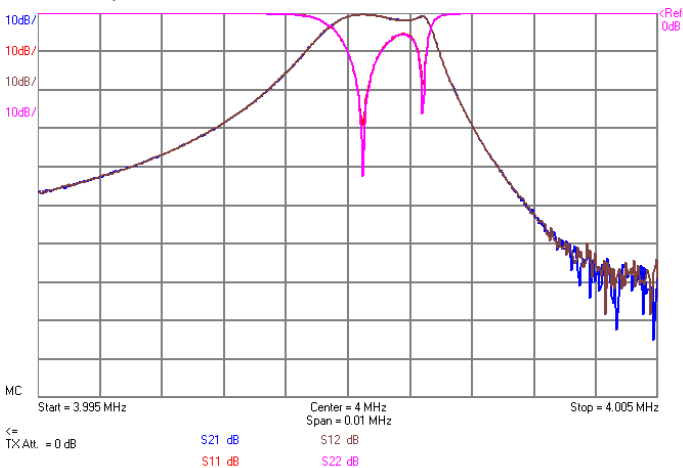
7.1 4 MHz crystal filter measured with matching tool

Here is how to measure a newly-built quartz filter that has not yet been matched. The first measurement is an S-Parameter measurement without adjustment (S21, S11, S12, S22).

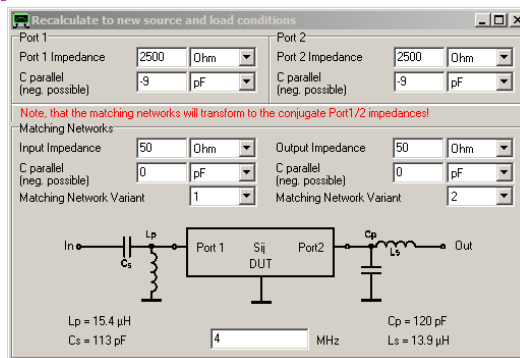
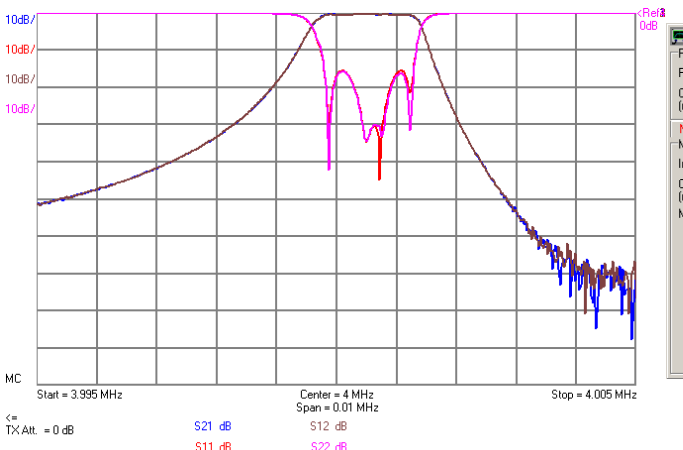


It can be seen very clearly that in a 50 ohm environment, the filter shape is very bad. But the VNWA gives us the ability to match the impedance virtually, which is very convenient and fast. Only the four S-parameters have to be measured beforehand.

If you select the matching tool, under Tools, the following adjustment with 1800-2500 ohms leads to a pretty good filter shape.



An even better curve is obtained when one plays with the C and applies a negative impedance in parallel (corresponding to an inductance). In the lower half of the window different matching circuits and their values can be selected or read. Personally I almost always fit quartz filters with transformers (double hole cores).



7.2 calibrating out plugs and adapters

In this chapter, I show how the measurement effects of a connector can be calibrated out.

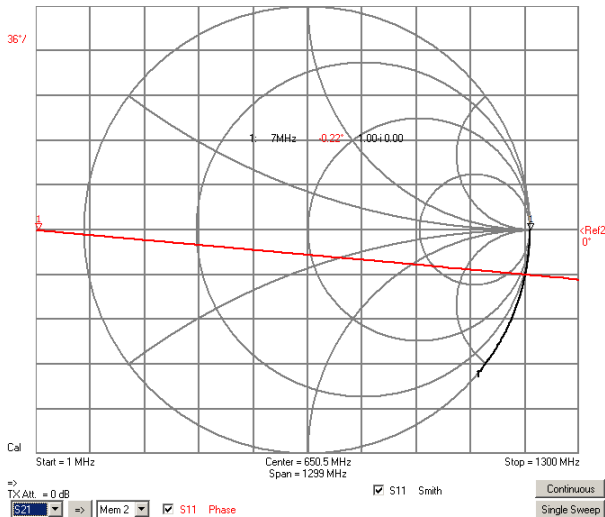
The VNWA is provided with good SMA cables to protect the connectors of the VNWA.

VNWA settings:

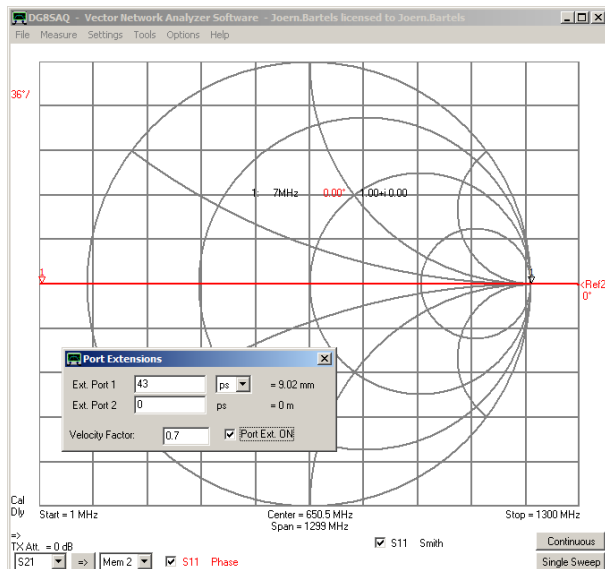
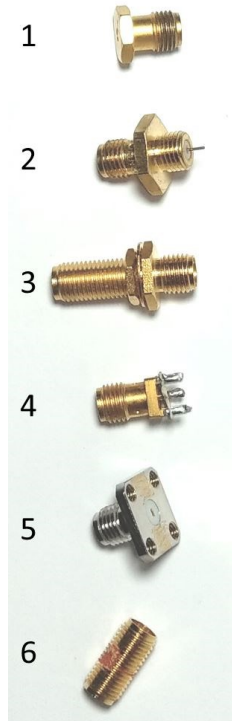
1-1300 MHz; 200 data points; 20s Time per sweep

Measured "S11 phase" and "S11 Smith"

A normal "Reflect Calibration" is performed.



As an example, the connector number 6 from my calibration set is measured. This results in the adjacent image



Under "Measure – Port Extensions" the calibration plane can then be moved by entering the signal propagation time. I say this 'calibrates out' the plug.

Using the mouse wheel, the phase position can then be set to 0°. For connector no. 6, this yields 43ps.

plug	Through time delay
1 (short)	24 ps
2	61 ps
3	89 ps
4	50 ps
5	39 ps
6	43 ps

For the advanced readers:

In the first sentence of this page I wrote: "In this chapter, I show how the measurement effects of a connector can be calibrated out." If you take it exactly, you also have to differentiate between the calibration and measurement reference planes. Gerfried describes this in detail in his books. It would be more correct to write here: ... how the measurement reference plane is moved. Please forgive me for the small inaccuracy - in this document I focus on the "first understanding".

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7.3 Measuring a cable

This section shows how to measure a 39cm long cable with SMA connectors using the VNWA. The ZPlots program is used. The installation is as described in the VNWA-Help file. On the TX and RX ports good SMA cables are permanently attached to protect the VNWA SMA connectors.

In this chapter, Eric helped me a lot.

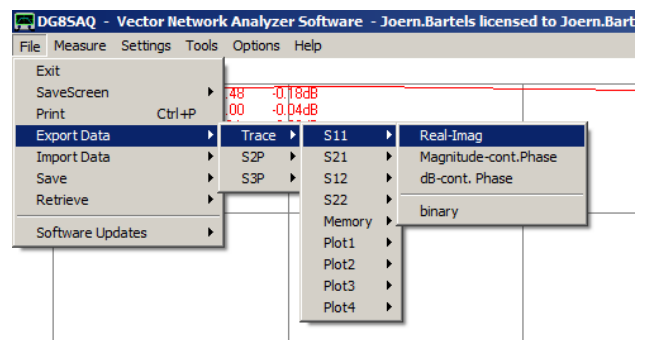
This chapter will be even easier to read in a later revision:
The green line can be partially removed from the images.

VNWA settings: 0,1-1300MHz, 801 points, Time per sweep 10.15s

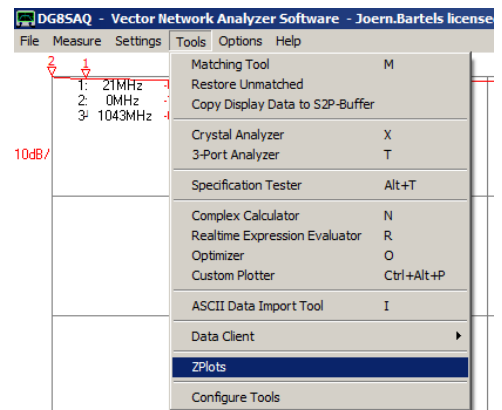
Without the cable to be measured, perform a Reflection Calibration with short, open and load.

Measurement:

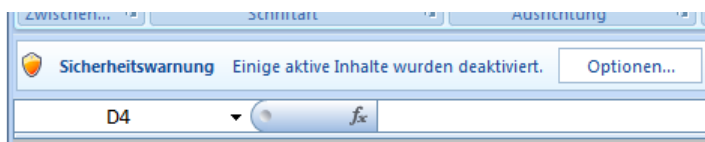
- The cable to be measured is connected to the TX port adapter with an SMA to SMA adapter (the calibration plane), and an S11-Open measurement is performed.
- The data is stored. In my case, the file is named "S11 open 39cm.s1p" (see picture)
- The cable is terminated at the free end with a short and then an S11 measurement is performed again. The measurement is then saved under the name "S11 short 39cm.s1p". The frequency range should be chosen such that at least one "turn" was drawn on the Smith Chart



- The Zplots program is started by VNWA-Tools- ZPlots. Alternatively, it can of course be opened directly.
- Depending on the Windows version, Excel document processing must be allowed (allow macros). See also the VNWA-Help File

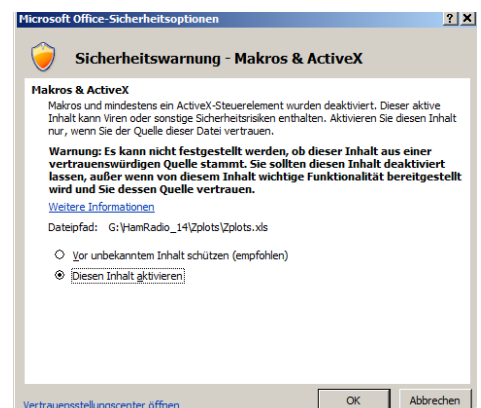


Eric sees this:



Enable content: select the corresponding item (Activate Content), press OK

From here ZPlots can be used as desired.

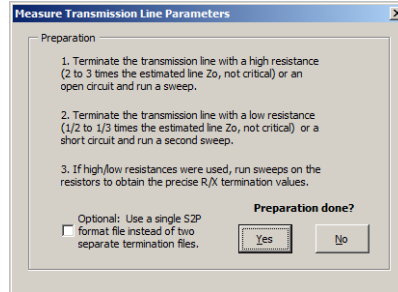


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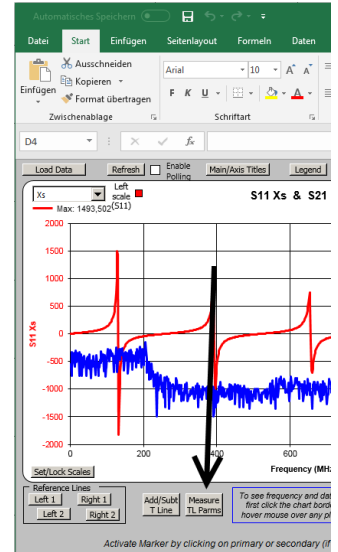
Jörn DK7JB mail@dk7jb.de

Reading of the data is prepared with the following settings:

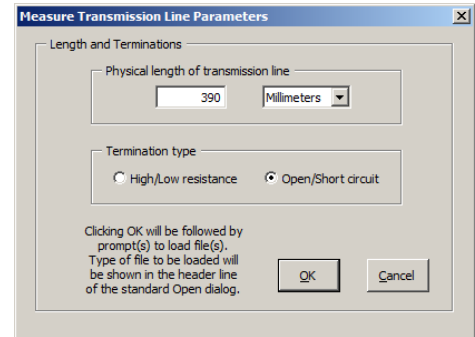
- Click button "Measure TL parms". (see image)



- Confirm the following window with "Yes".

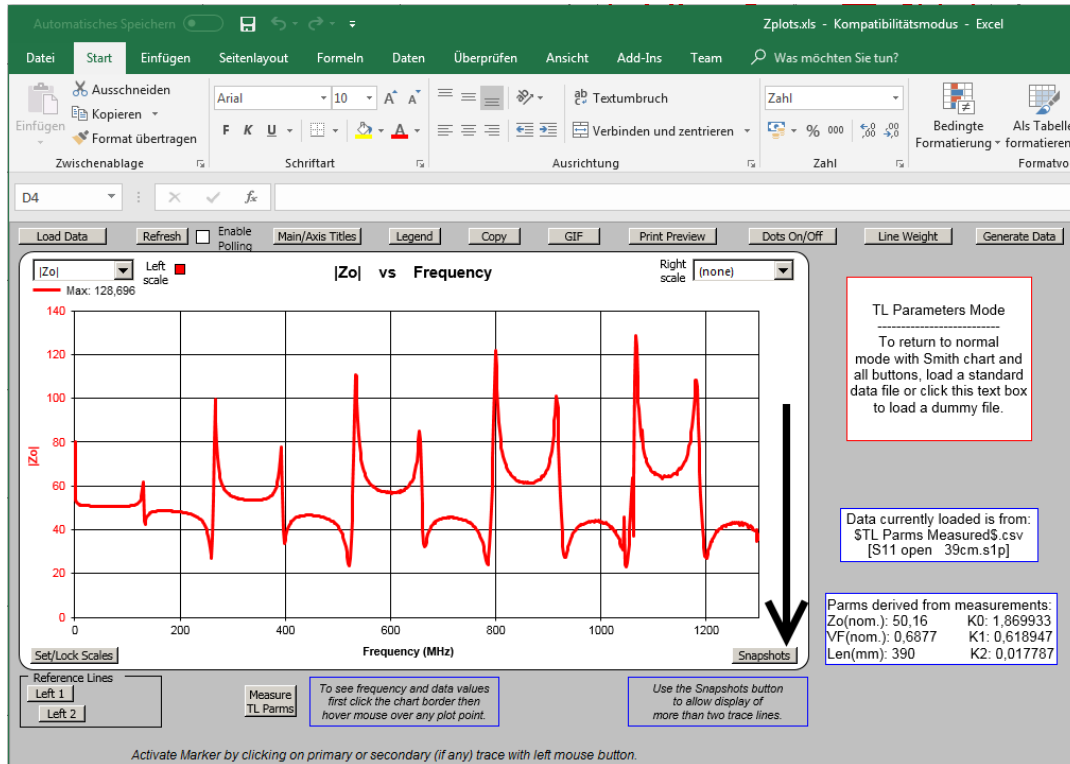


- In the following window the mechanical length and the type of termination must be specified (the electrical length is determined by the program based on the $\lambda / 2$ resonances). In our case, 390 mm, and the open / short termination. Note, all entries with a comma, not a point!



- Now the measurement data (open and short measurement) are read in succession with "Load data". The window that opens clearly shows the order.

The window will look as follows.

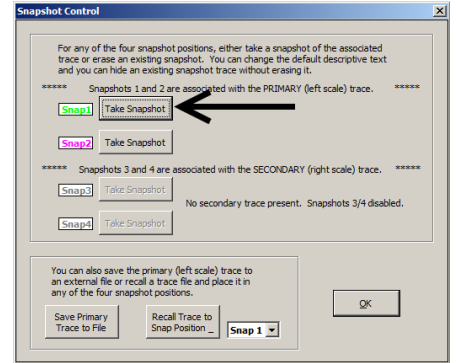


You can see the $\lambda / 2$ resonances very well, and also see why it is not easy to accurately determine $|Z_0|$ because the resonances confuse the image (but one can roughly estimate Z_0 of course).

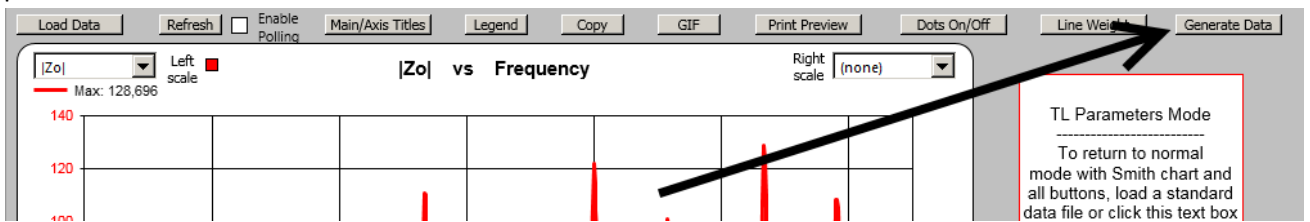
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- The next step is to allow Zplots to determine the line parameters exactly (in the program higher mathematics with Bessel functions are applied to accurately solve the line differential equations). First save the original image with snapshots and then press Generate Data. Now an additional line will appear. As shown in the previous picture the snapshots button is pressed. Then the window on the right is displayed and the question is answered with OK.

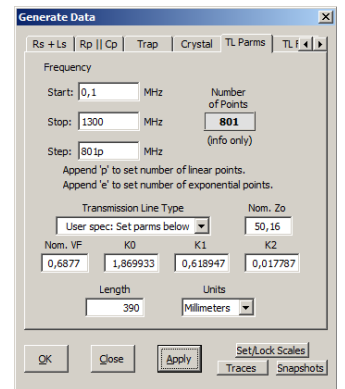


- Now the green curve is populated with the cable impedance data. For this, press the "Generate Data" button and select the "TL Parm" tab. Press the button "Apply" and "OK" in this window. This window shows all cable parameters.

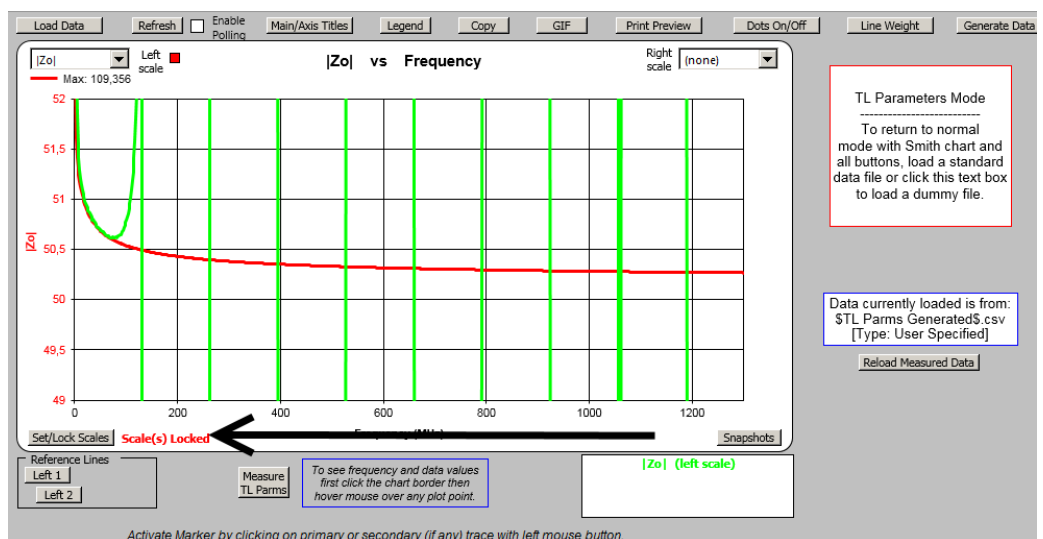


You can now already read the nominal values for Z0, VF, etc. If you press Apply the line is shown without the resonances. At the end press OK.

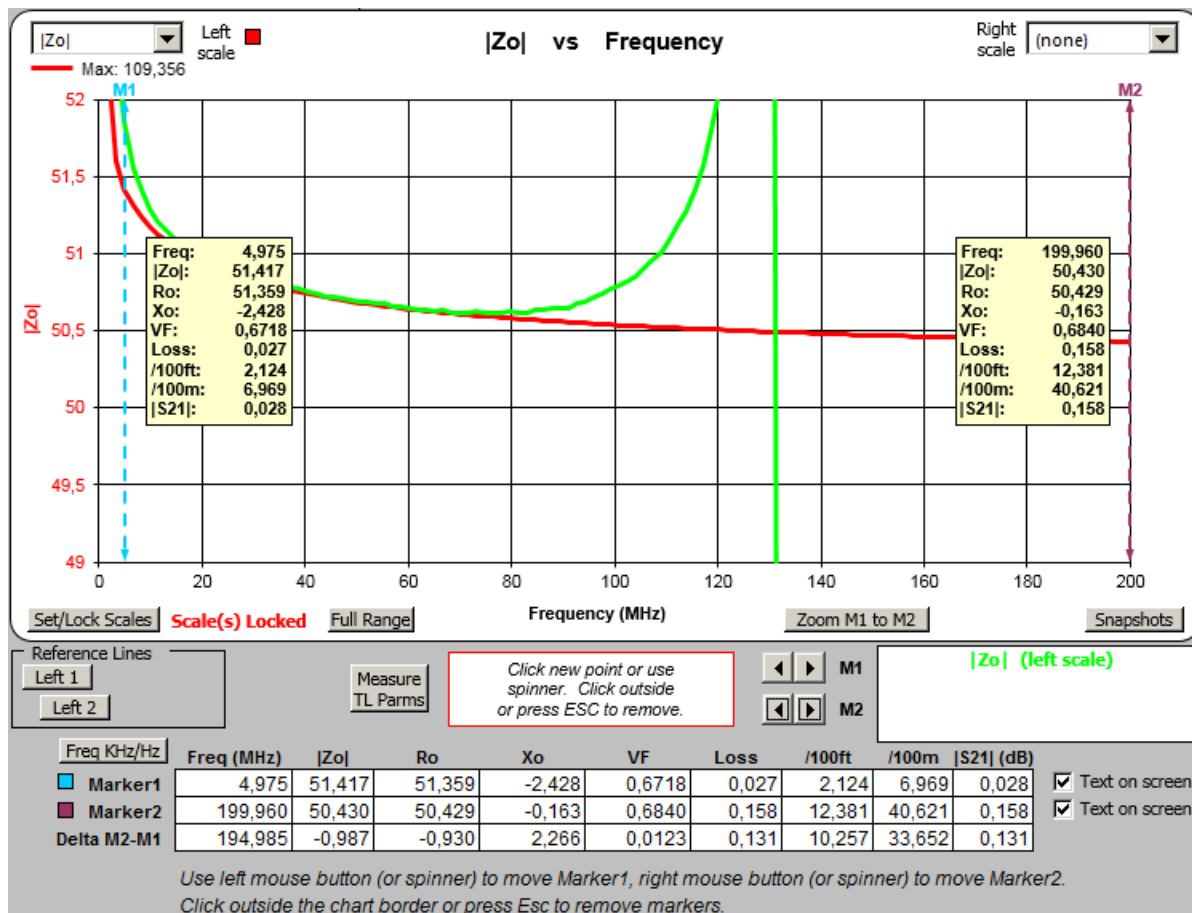
For analysis purposes, you work on the diagram, you also choose the correct scale. Left-clicking on the curve places a marker at a specific frequency (where the mouse cursor was) and opens a marker window.



For better representation, the division of the X or Y axis can be changed with "Set / Lock Scales".



Markers can be set if you click with the left or right mouse button on the red curve:



This marker information can then be displayed for further evaluation. You can then choose the desired parameter at the left or right scale. Incidentally, the marker is moved by the arrow keys on M1!

If you are measuring circuit board material, you can calculate the dielectric constant from the equation dielectric constant = $1 / (VF)^2$.

By the way, you can see very nicely that all parameters have a frequency dependency. In coaxial cables this effect is much more pronounced than in the line selected here.

Do not save when closing the Excel program, this makes re-starting easier.

I hope this example makes the process understandable.

Generate Data

Rs + Ls | Rp | Cp | Trap | Crystal | TL Params | TL f

Frequency

Start: 0,1 MHz

Stop: 1300 MHz

Step: 801p MHz

Number of Points: 801 (info only)

Append 'p' to set number of linear points.
Append 'e' to set number of exponential points.

Transmission Line Type: User spec: Set parms below

Nom. Zo: 50,16

Nom. VF: 0,6877 | K0: 1,869933 | K1: 0,618947 | K2: 0,017787

Length: 390

Units: Millimeters

OK | Close | Apply | Set/Lock Scales | Traces | Snapshots

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7.4 Power Sweep - The 1 dB compression point of an amplifier

The 1 dB compression point of an amplifier can be measured with the VNWA by slowly changing the power at a fixed frequency while taking S21 measurements.

The TX level of the VNWA is too small at -17 dBm to drive an amplifier to be measured into compression. Therefore, a pre-amplifier (booster amplifier) is needed, which raises the VNWA-TX level. To suppress Spurs and other spurious signals a bandpass filter must be connected behind the preamplifier.

In this example, the 1-dB compression point at 7.1 MHz is measured for the Mini Circuits amplifier ZFL-500. The amplifier is operated at 12V.

7.4.1 Measurement of the preamplifier

As a preamplifier I use the Kubic # 06⁴ amplifier. When measuring, make sure that the TX level is lowered by 10 dB to avoid overloading the VNWA. Furthermore, one can also avoid compression effects this way.

At 7.1 MHz, the gain S21 is 9.8 dB.

7.4.2 Measurement of the bandpass filter

Here are the measurement results of the bandpass filter used to get an initial overview.

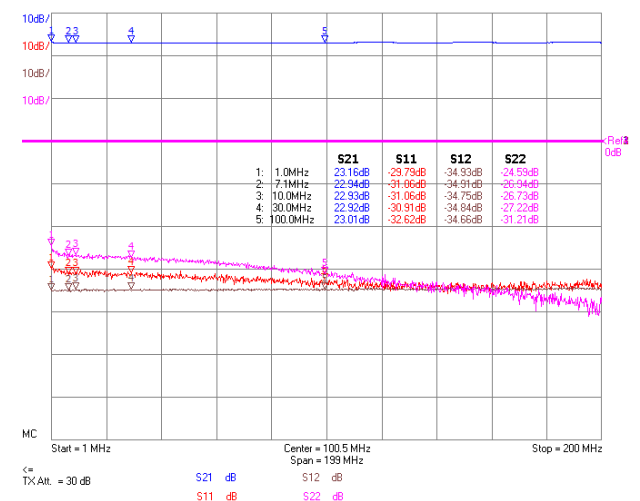
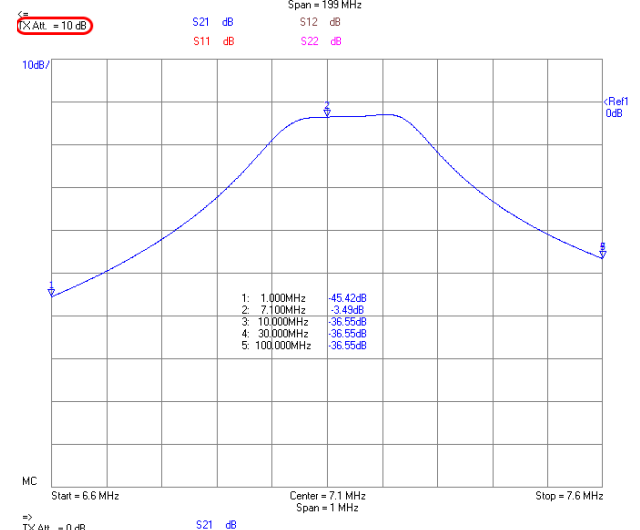
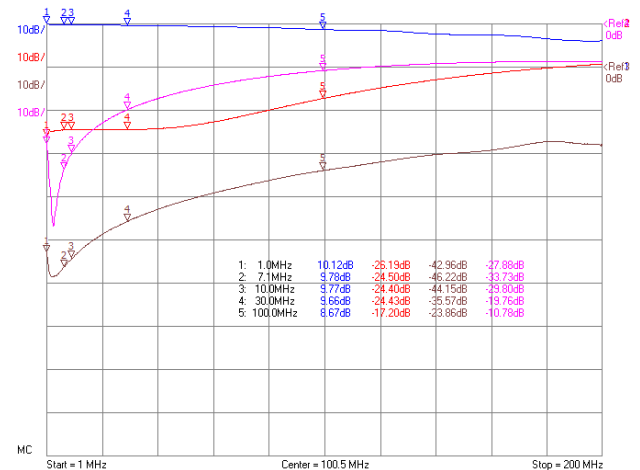
The band-pass filter has an attenuation at 7.1 MHz of 3.5 dB.

Note: At these low frequencies a low-pass filter would have been enough. Maybe I could have managed completely without a filter. I was just too lazy to check the output spectrum on the spectrum analyzer.

7.4.3 The measurement object - a first overview

To obtain a first overview, all four S-parameters of the amplifier are measured. In order not to overload the VNWA the TX level is lowered by 30 dB. Caution: do not forget to undo this level reduction afterwards.

Here's the (DUT - device under test) Mini Circuits ZFL-500.



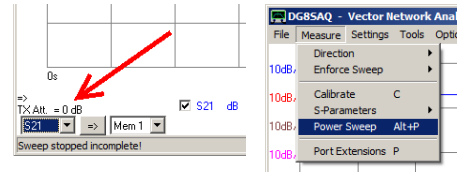
⁴ <https://www.bartelsos.de/dk7jb.php/der-kubic-verstaerker>

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Jörn DK7JB mail@dk7jb.de

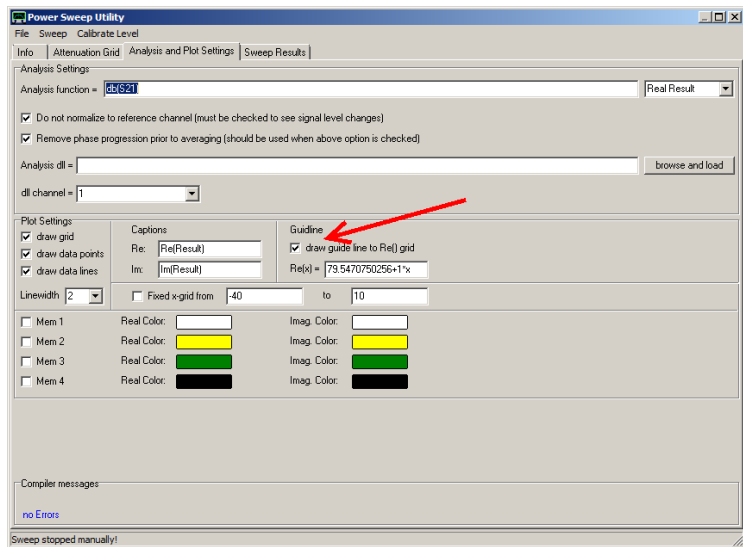
7.4.4 Power Sweep Utility

Before starting the Power Sweep Utility check whether the TX level has been lowered for any amplifier measurements. Please set to 0dB. The instrument state should also be backed up, otherwise some settings may no longer be correct after the measurement.

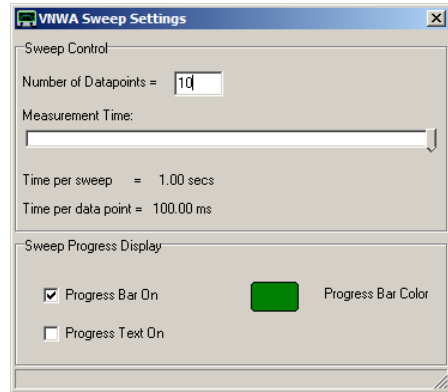


After the power sweep Utility has been invoked, adjustments to the measurement settings still have to be made.

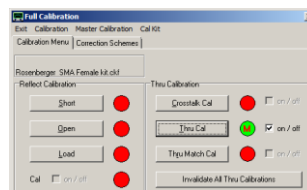
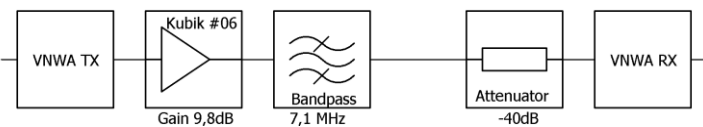
More settings



#	Attenuation Grid	Actual Attenuation/dB
1	0	0
2	1	1
3	2	2
4	3	3
5	4	4
6	5	5
7	6	6
8	7	7
9	8	8
10	9	9
11	10	10
12	15	15.001
13	20	20.002
14	25	25.003
15	30	30.001

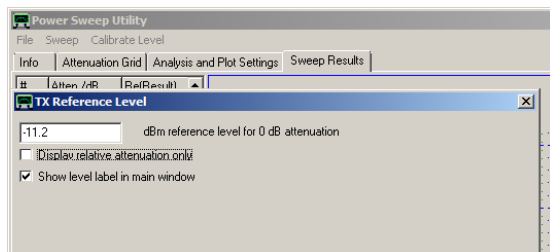


Thru-calibration = continuity calibration

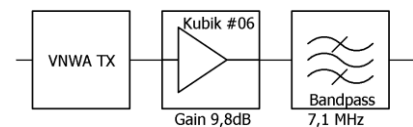


Then a normal Thru calibration needs to be performed.

Measure level

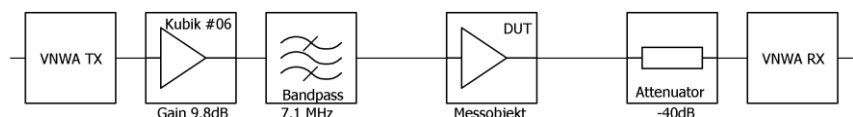


Under "Calibrate Level" the real level must now be specified after the preamplifier and bandpass filter. With an HP436A power meter (with HP8482A measuring head) -11.20 dBm was measured.



The measurement

Now the amplifier can finally be measured.



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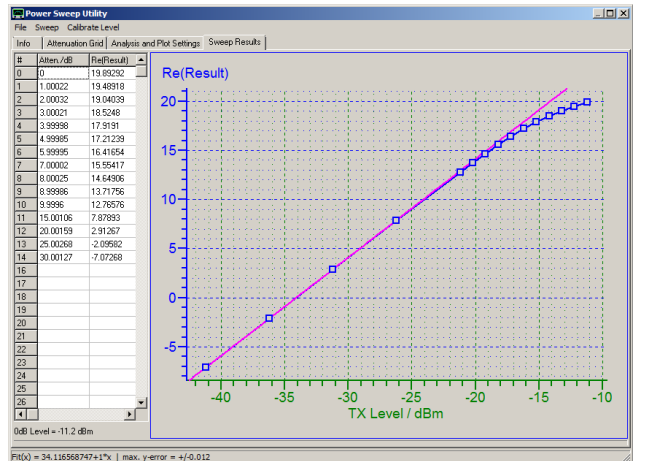
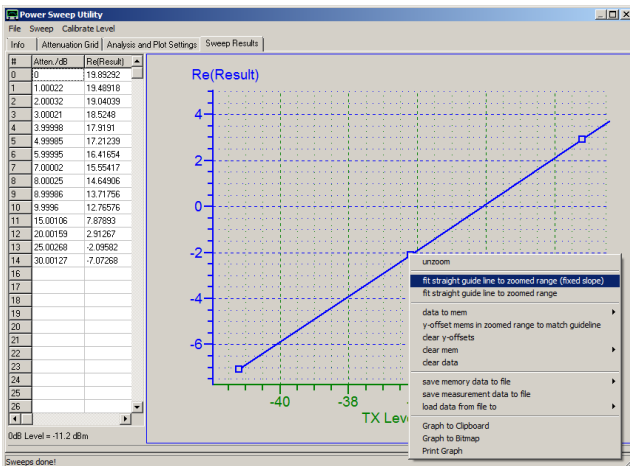
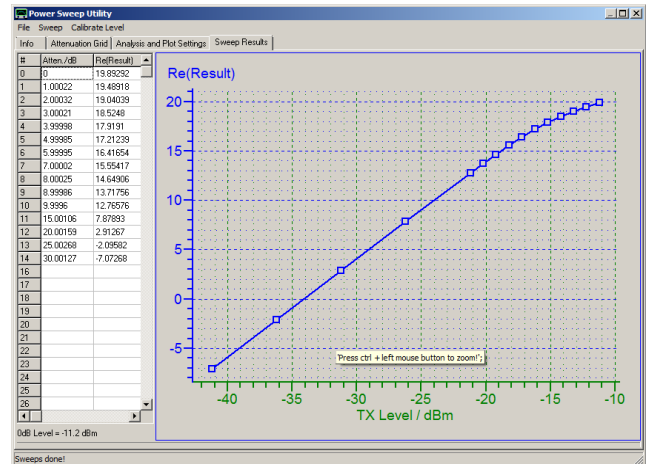
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#	Target Attenuation/dB	Actual Attenuation/dB
1	0	0
2	1	
3	2	

By selecting "sweep" the measurement is started, which lasts a few seconds.

The following image should then be shown. It is good to see that with increasing level at some point compression is clearly visible.

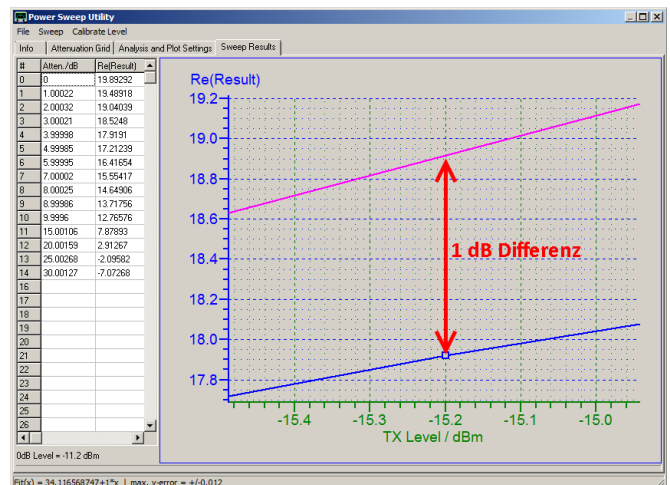
The following pictures show how to precisely generate a line from the linear section of the trace. The Ctrl key (Ctrl) and the left mouse button can be used to zoom into the first three readings. Then the line can be created with the left mouse button (see picture). With unzoom the original image can then be seen again.



Now just zoom to find the 1 dB compression point. In this amplifier a compression of 1 dB can be seen at a TX level of -15.2 dBm. Here the real measurement result deviates from the linear straight line by 1 dB.

Based on the input of the amplifier the 1 dB compression point at -15.2 dBm.

Since the 1 dB compression point is usually related to the output level of the amplifier, we have to add the gain of $22.9 \text{ dB} - 1 \text{ dB} = 21.9 \text{ dB}$. Thus we obtain a 1 dB compression point of $-15.2 \text{ dBm} + 21.9 \text{ dB} = 6,8 \text{ dBm}$ at the output of the amplifier,



The data sheet specifies a 1 dB compression point of + 8dBm with a supply voltage of 15V. Since we have lowered the supply voltage to 12V and have measured a slightly smaller value, the result is plausible.

A very good summary with many other hints can be found here:

http://www.hamcom.dk/VNWA/How to use the new VNWA power sweep Utility_rev1.pdf

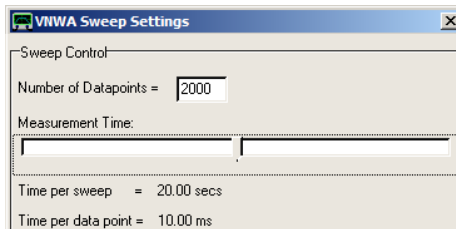
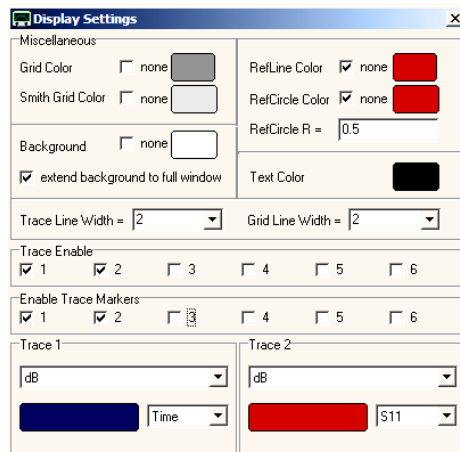
7.5 Cable Measurements

7.5.1 The measuring method - Time Domain Reflectometry and Frequency Domain Reflectometry

Cables can be measured using Time Domain Reflectometry (TDR) or Frequency Domain Reflectometry (FDR).

In time domain reflectometry (TDR), a short voltage pulse is applied to a cable. Defects reflect a portion of the signal. This reflection is analysed. Since the VNWA cannot emit an impulse, the second method is employed by the VNWA. In frequency domain reflectometry (FDR) sine waves are emitted in a wide frequency range and the reflection of the signals analyzed. The VNWA is able to perform Frequency Domain Reflectometry. Mathematically, each method can be converted into the other and they are therefore largely equivalent. Using Time Domain Reflectometry or Frequency Domain Reflectometry, the lengths of cables can be determined; joints or velocity factors can be measured. More detailed explanations can be found in the VNWA help file⁵ under "TDR" or in the book by Gerfried (Volume 1, chapters 12 to 15). In this chapter, the investigations on cables are only briefly outlined – think of them as "appetizers".

7.5.1.1 Velocity factor of a coaxial cable

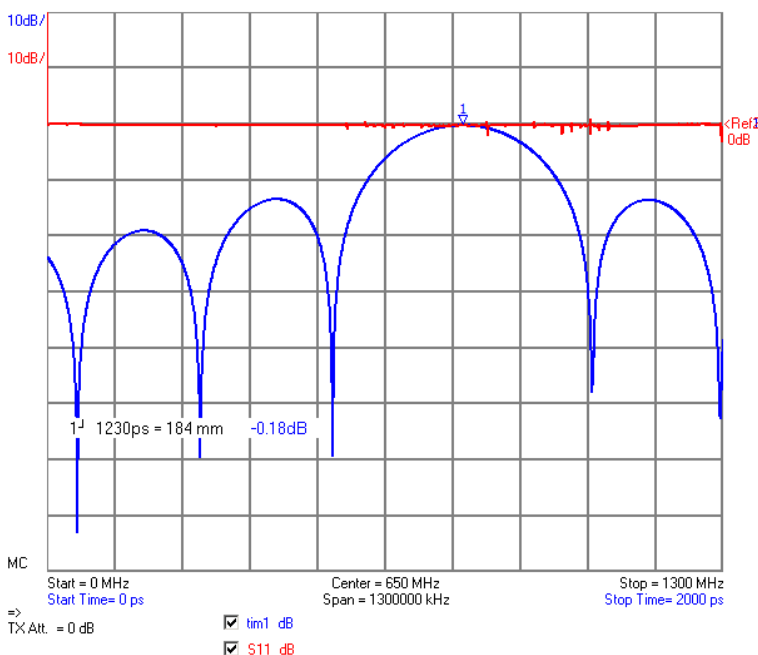
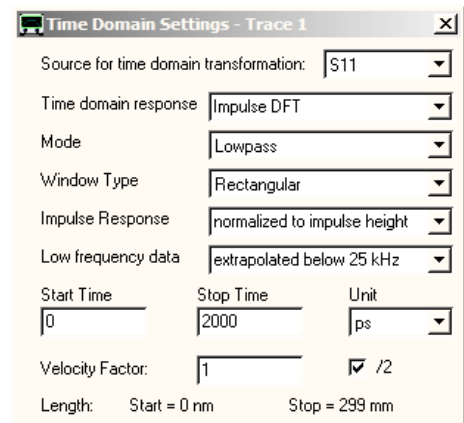


Here is just a very brief guide:

Sweep Settings: 2000 points; Time per sweep 20 secs

Display Settings: Trace 1 Time

Then in the main window double-click on "tim1" (below in the trace selection) and this opens another selection window.



Since we want to calculate the Velocity Factor, it must first be set to 1. Now a measurement can be started. The marker "Add Maximum Time Marker" then gives the length. The measurement gives 184mm for an ideal cable. The real cable has only a length of 130mm (measured with a vernier caliper). The calculation $130 \text{ mm} / 184 \text{ mm} = 0.71$ then gives the velocity factor

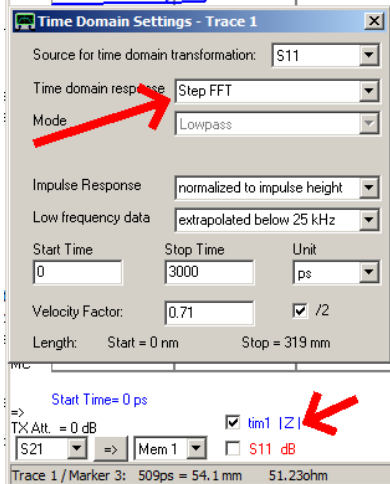
⁵ http://sdr-kits.net/documents/VNWA_HELP_36-7-6_%20deutsch.pdf

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7.5.1.2 determine length of coaxial cable

After the measurements from the previous sub-section have been performed, the length of a cable of previously unknown length can now be measured. With the measured and calculated velocity factor, the length of a long cable of the same type can now be determined. The measurements become more accurate when the cable to be measured is terminated with a short.

7.5.1.3 Measuring the characteristic impedance

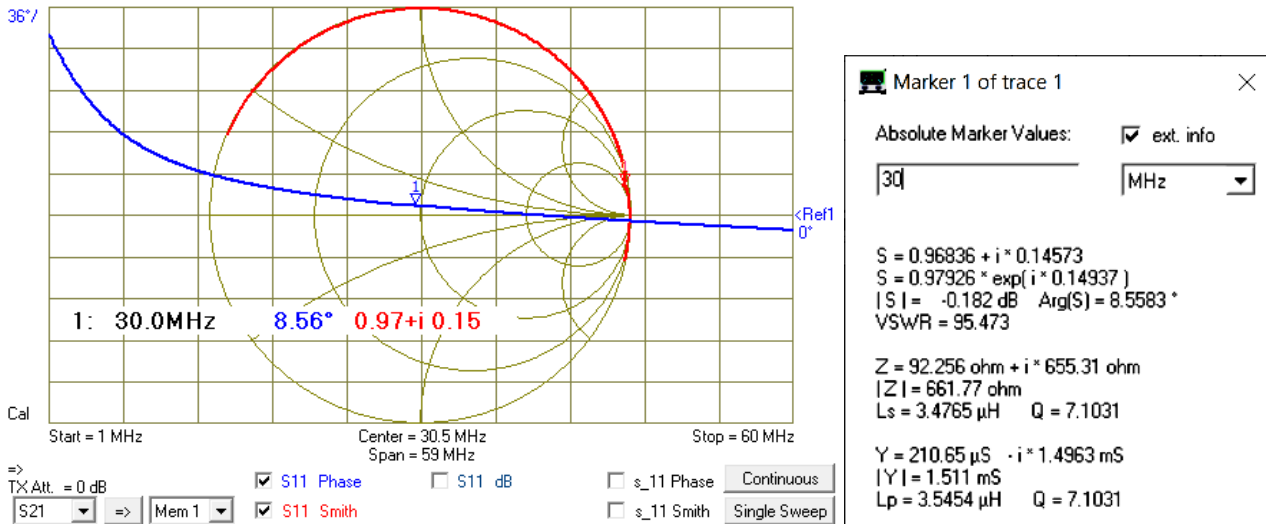


The settings for the measurement of characteristic impedance.

7.6 The optimizer using the example of a measurement of a loop antenna

In the German translation of the VNWA help file⁶ (Version 36.7.6 German translation) you will find on page 237 a detailed description of how to measure a small loop antenna, and then the equivalent circuit is formed with the optimizer.

I present this chapter as an "appetizer" and not as a guide. All necessary additional explanations can be found in the help file.



An S11 measurement is taken. The picture shows S11 in a Smith chart and also the phase. The marker information for 30 MHz can be found in the picture on the right.

Under tools the "Optimizer" is called up and the inputs are taken over as in the picture. A coil, and the antenna is nothing more, can be very well described by the equivalent circuit in the diagram. After the formulas and other inputs have been accepted, click "Optimize" to start the optimization process. The data of the optimized equivalent circuit are written to s_11 (The memory for S11 of the 3-port measurement, which is not needed here and serves only as a placeholder). If the case arises that the optimizer should not find reasonable values, start values for the search can be specified.

Optimizer - Model Fitting Tool

File Load Save Model Settings Optimize

Optimizer | Splines | Distance |

Expression to be globally fitted to: S11 Simulation stored to: s_11

in restricted frequency range: 0 MHz to 1300 MHz

Expression: $y2s(1/ZL+YC)$

Name Alias Subexpression (available in main expression, subexpressions may use other subexpressions from below)

Sub1 = ZL = $j\omega L + R$

Sub2 = YC = $j\omega C$

Variable	Alias	Real Value	Delta	Optimize
x1	R	2.938628803164E-001	1.0E-001	<input checked="" type="checkbox"/>
x2	L	1.595587573559E-006	1.0E-007	<input checked="" type="checkbox"/>
x3	C	1.003348332380E-011	1.0E-013	<input checked="" type="checkbox"/>
x4		1.000000000000E+000	0.0E+000	<input type="checkbox"/>
x5		1.000000000000E+000	0.0E+000	<input type="checkbox"/>
x6		1.000000000000E+000	0.0E+000	<input type="checkbox"/>
x7		1.000000000000E+000	0.0E+000	<input type="checkbox"/>

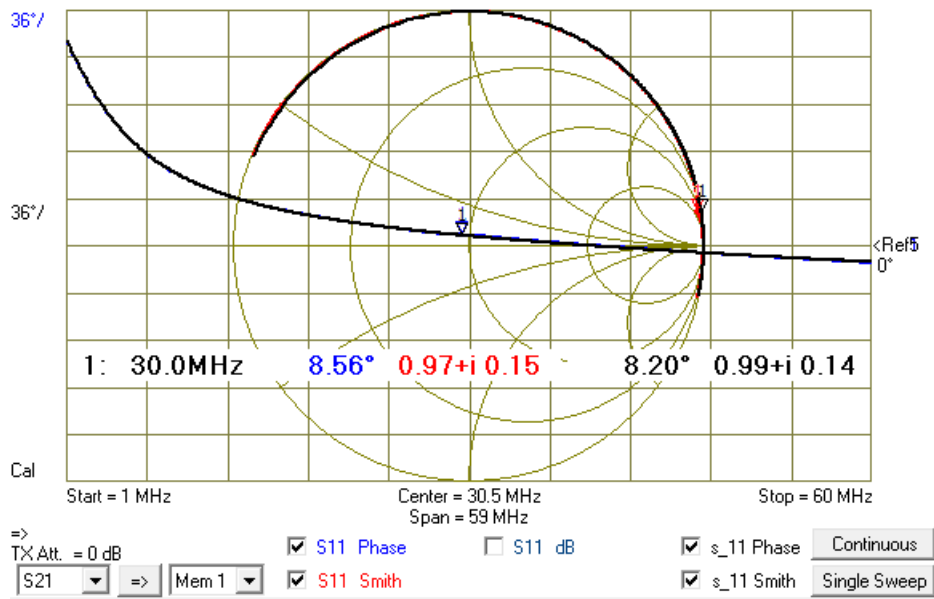
Figure of Merit = 0.0278 (should be as small as possible)

Inductor Model

21:58:53 : Model loaded from D:\Programme\VNWA\Spule.mod

⁶ http://sdr-kits.net/documents/VNWA_HELP_36-7-6_%20deutsch.pdf

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The optimized curve of the equivalent circuit perfectly describes the real measurement.

The data can be found in the image:

$$L = 1.596 \text{ uH}$$

$$C = 10.03 \text{ pF}$$

$$R = 0.294 \text{ ohms}$$

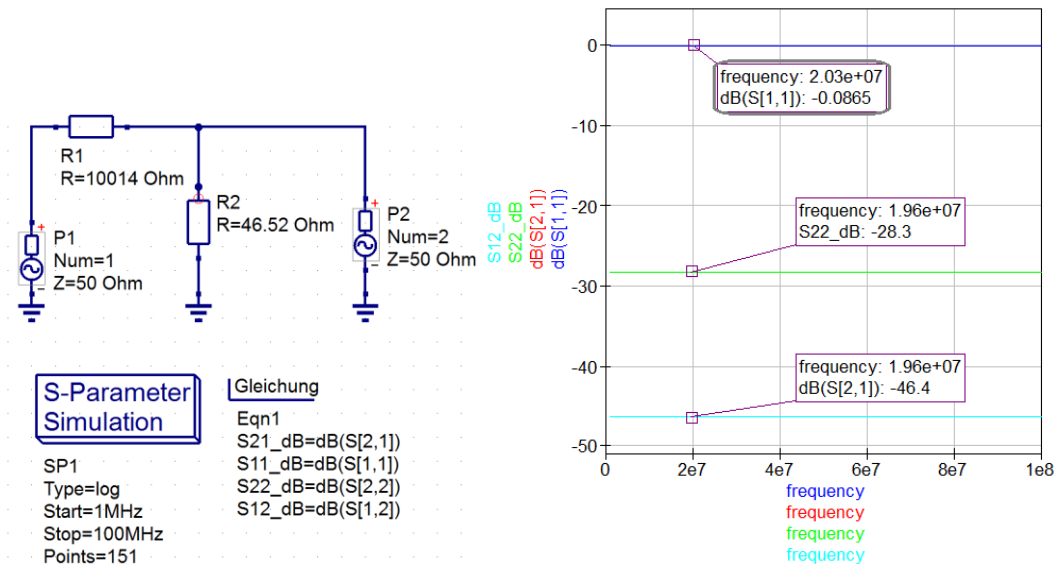
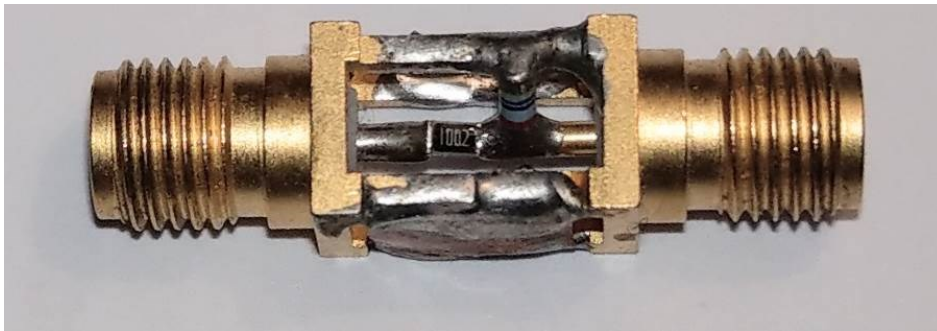
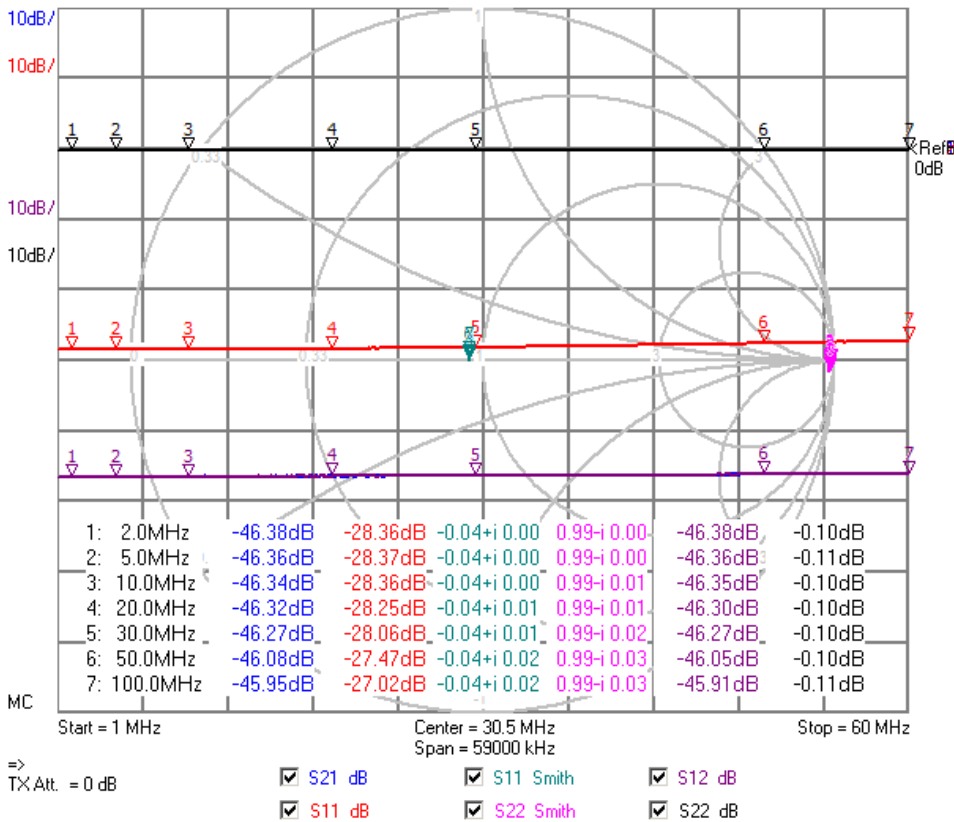
The data of the equivalent circuit obtained with the help of the optimizer can be reused in a simulation.

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Jörn DK7JB mail@dk7jb.de

7.7 Check the calibration

For a quick check of a calibration, I built a test DUT out of two resistors (switched as L-element). By quickly comparing the current measured values with an old measurement, you can quickly check that everything is OK. So you can quickly find gross errors..



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8 miscellaneous

8.1 dB scale

Whenever working with quantities that extend over a scale of many powers of ten, the choice of a logarithmic scale makes sense.

The power ratio and voltage ratios from the output signal to the input signal are shown in the figure below (numbers rounded).

	Power ratio	Voltage ratio
40 dB	10000	100
20 dB	100	10
10 dB	10	3.16
6 dB	4	2
3 dB	2	1.41
1 dB	1.26	1.12
0 dB	1	1
-1 dB	0.79	0.89
-3 dB	0.5	0.71
-6 dB	0.25	0.5
-10 dB	0.1	0.32
-20 dB	0.01	0.1
-40 dB	0.0001	0.01
-100 dB	0.0000000001	

For more detailed information, I recommend the following source:

https://dokumente.unibw.de/pub/bscw.cgi/d351120/dB1_new.pdf

Here is another very good source:

https://www.rohde-schwarz.com/de/applikationen/db-oder-nicht-db-educational-note_230850-15534.html