MEASUREMENTS WITH THE NANOVNA

Part 2: Measurement of high Impedances

By Arie Kleingeld PA3A

Preface.

There are many discussions about sheath current chokes (also called common mode chokes). They should have a high impedance (5 kohms or more). In this article, I test whether you can measure such high impedances sufficiently well with the nanoVNA. I can already tell you that it stands its ground. In episode 3 we will then measure different chokes from practice so that you can test your own chokes with the nanoVNA. But first a description of the measuring method that can be used and the results of the test measurements.

The nanoVNA measures S11 and S21

S11:

S11 is a measure of the reflection from port 1 back to port 1. Hence the name S11. This is also called the reflection coefficient. With this we calculate, for example, the SWR known to us or the other (more sexy) expression of reflection, the "return loss" in dB. Within the domain of the S11 you can also calculate which impedance appears on the measuring port CH0 of the nanoVNA. This is expressed in R + jX, so resistance plus reactance. The program nanoSAVER has that and then puts it in an easily readable graph.

S21:

S21 indicates how much signal is coming into port 2 (CH1) from port 1 (CH0), hence the name S21. With this we can e.g. measure the transmission characteristic of a filter. Not only the amplitude of the transmitted signal is measured and thus the degree of damping in dB is determined, but also the phase so that capacitive or inductive behavior becomes visible.

Export measurements in a file

NanoSAVER can export the measurement values of a sweep to a file so that you can save or import them into another program. These are the S1P file for 1 port (in our case values of S11) and the S2P file for 2 ports (in our case for the values of S21, among others). We will actually use and process the S2P export later with Excel.
The file format that nanoSAVER uses is fixed and contains a number of columns as follows:

S1P file (3 col): Stim (ulus) Re (S11) Im (S11)

S2P file (9 col): Stim (ulus) Re (S11) Im (S11) Re (S21) Im (S21) Re (S12) Im (S12) Re (S22) Im (S22)

Stimulus is the frequency used and further we see the different transmissions. Each time there is a split into "Re" and "Im". Here "Re" again stands for the real part and "Im" for the imaginary part so that we not only know the amplitude of the measured signals, but also the angle of rotation. The nanoVNA does not measure S12 and S22, because it requires a signal source in port 2 (CH1), which is not the case. NanoSAVER will therefore export a zero in the S2P file in those places. Imported into Excel it looks like this:

	A	B	C	D	E	F	G	H	I
1	#	Hz	S	RI	R	50			
2	500000	0,317827	-5,33E-05	0,680673	-0,00019	0	0	0	0
3	795000	0,317765	0,000451	0,680574	-0,0002	0	0	0	0
4	1090000	0,317748	0,000244	0,680465	-0,00021	0	0	0	0

Please note: the first line does not give the header names of the columns but tells something about the file:

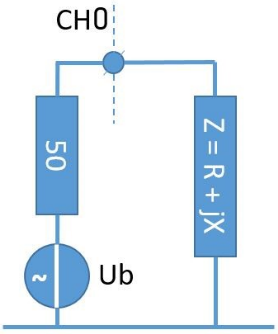
- Hz: frequency is expressed in Hz
- S: These are S parameters
- RI: file is in Re (Sxx) Im (Sxx) format so split into real and imaginary part
- 50: characteristic (measurement) impedance is 50 ohms.

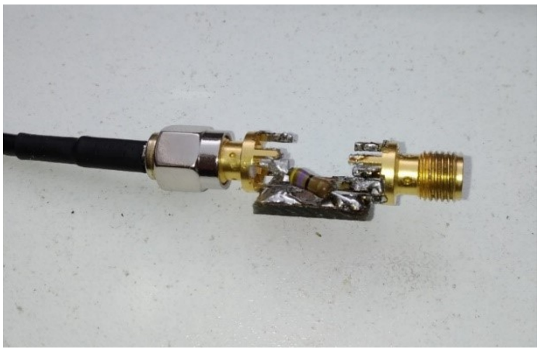
For the numbers below, the format mentioned earlier is valid: frequency (Hz), Re (S11), Im (S11), Re (S21), Im (S21) and the aforementioned four zeros, since S12 and S22 are not measured.

Some programs generate the total value of Sxx, expressed as | Sxx |, plus the angular displacement in radians or degrees associated with it. This can cause confusion if you want to do something with this file. So if you use a program other than nanoSAVER to export the values, pay attention to what's in the file.

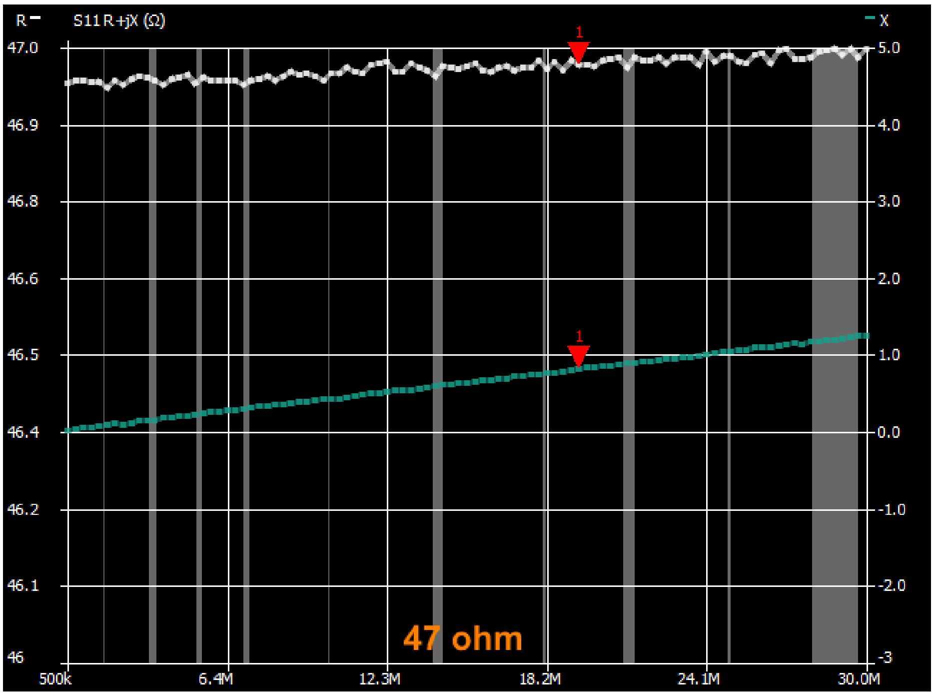
Measure the value of a number of resistors by means of S11:

To test the performance of the nanoVNA we will measure 4 resistors: 47, 470, 4700 and 10,000 ohms over a range from 500 kHz to 30 MHz. Once we understand how the nanoVNA performs (or fails), we can later estimate the value of the measurements on an HF sheath current choke. The intention is to measure practically. So measuring is not the goal here, it is only a means to find out something. All measurements below were made with nanoVNA type H3.2 linked to the nanoSAVER program. The connected resistor in the diagram below has impedance Z, consisting of R + jX.



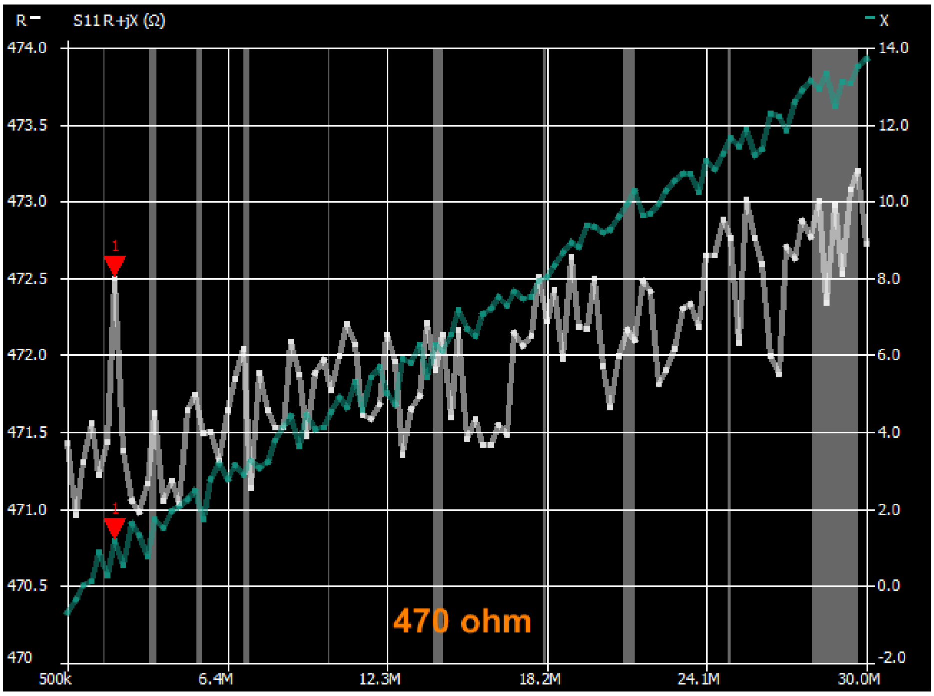


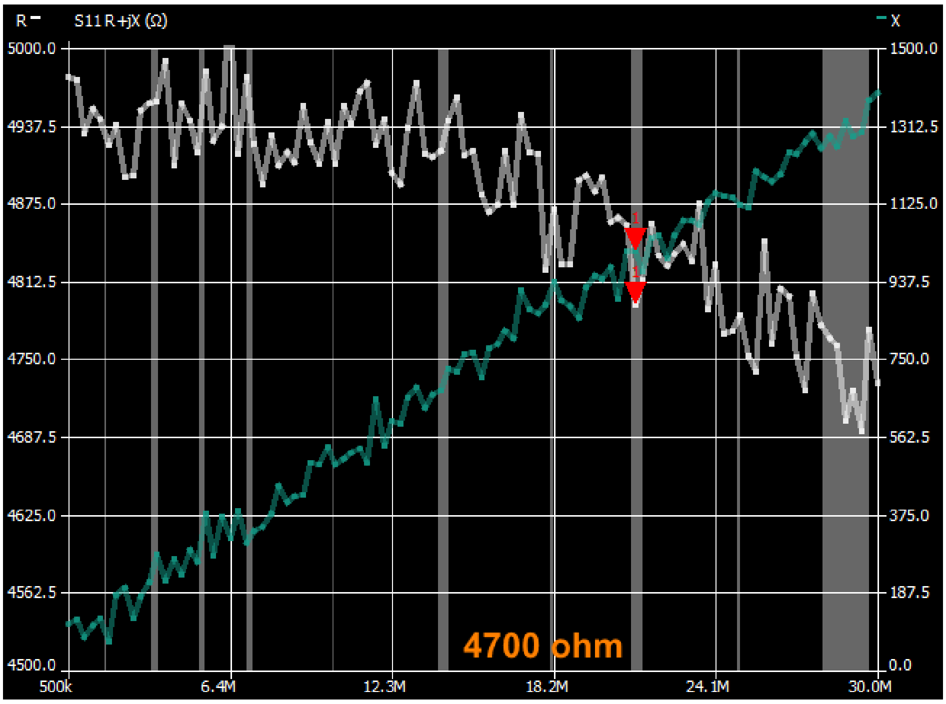
First, a 47 ohm resistor is connected to CH0 and the S11 is measured.

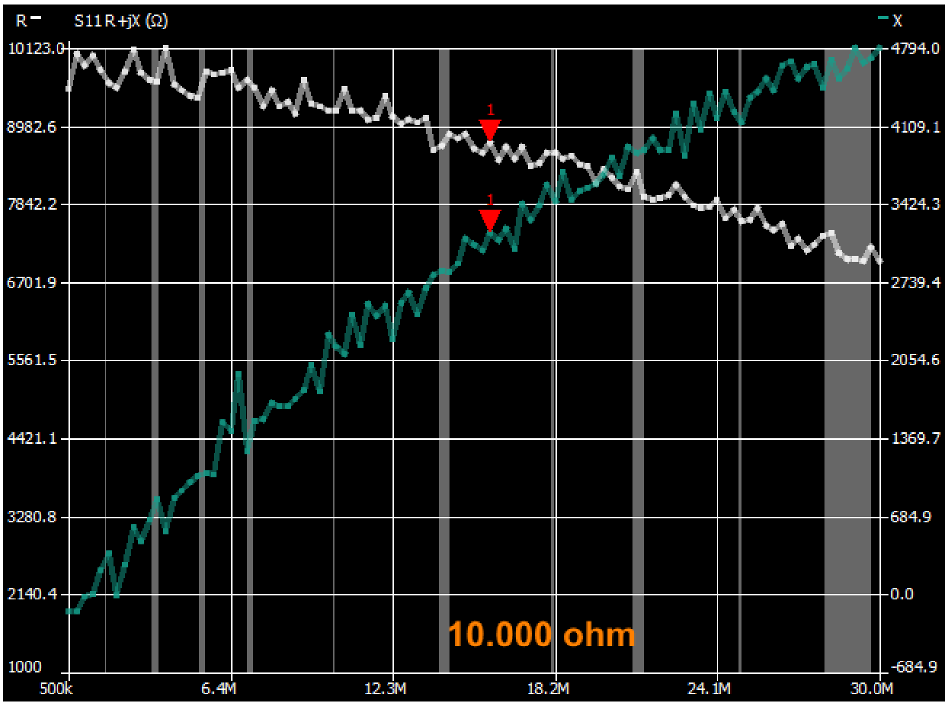


NanoSAVER reports from the nanoVNA, among other things, an S11 graph for R + jX. We see that the resistance value is almost 47 ohms (white line, left scale) and also has some inductive reactance (the green line with the right scale). We see that the X goes up almost linearly to about 1 ohm and that's not much. This corresponds to a coil value of approximately 5 nH. This is in line with expectations when you see how it is measured. There is a small loop in the signal path [see photo of the resistor].

The other resistances 470, 4k7 and 10k have also been measured in this way with the following result curves for S11 R + jX.







Overview of measured values by means of S11, read from the graphs.

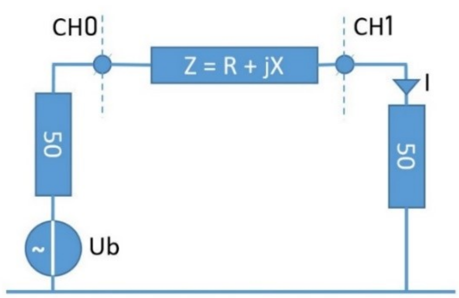
Resistance	S11 repport R + jX (see graphs above)		Series L-value
	R	X	
47 ohm	R: 47	X: 0 – 1	5 nH
470 ohm	R: 470	X: 0 - 14	70 nH
4700 ohm	R: 4k9 – 4k7	X: 0 – 1k4	8 µH
10.000 ohm	R: 10k – 7k	X: 0 – 5k	about 30 µH

Observation: 47 and 470 ohms are well measured. For 4k7 and 10k we see some deviations and unexpectedly high inductance values. The measurement of high resistance values also appears to be very sensitive. Influences include recent calibration of the nanoVNA, heating of the nanoVNA and is a connector tight enough or not. Please note, we are in a ham shack so we are doing "best effort" here.

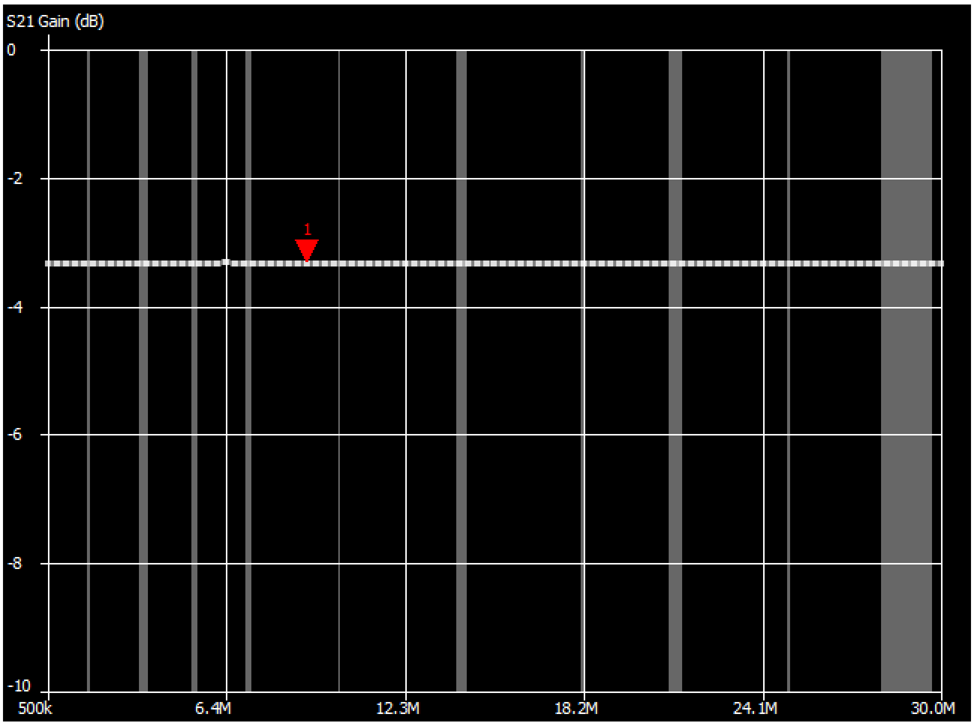
In summary: measuring 47 ohms and 470 ohms is not a problem, but if we end up in kohms, the combination nano(VNA + SAVER) gives a less reliable measurement via S11 R + jX.

Measure these resistances again based on the S21

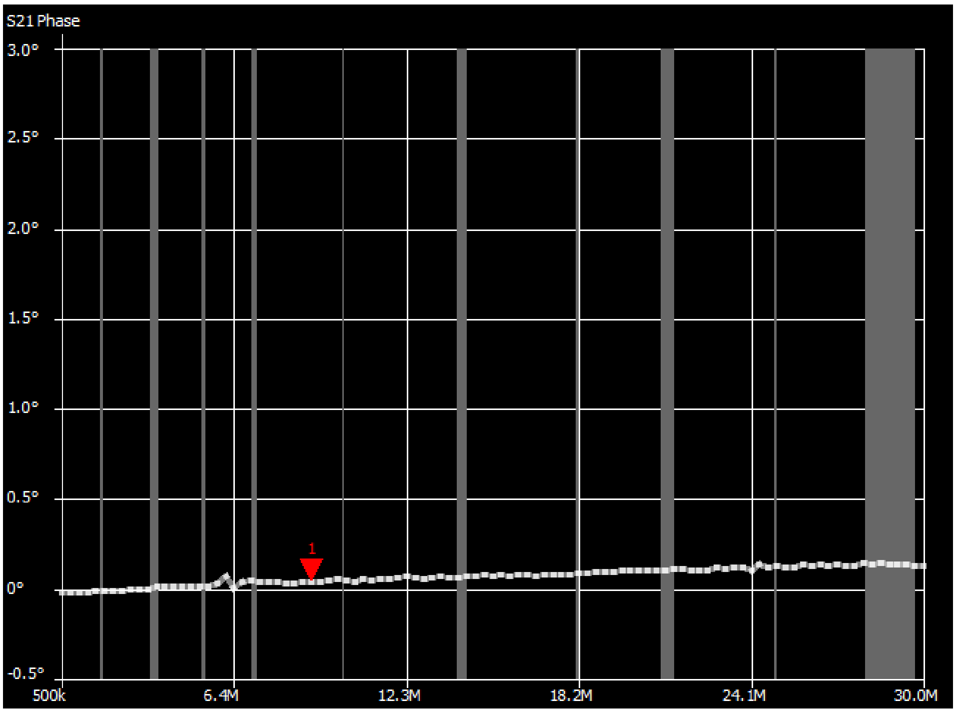
We will now see how well the measurement of the resistors goes by placing them between the two nanoVNA ports. This in itself is not an unknown method. G3TXQ wrote about this before (see reference) testing a number of common mode chokes with different core materials. However, he uses a more expensive VNA.



We start with 47 ohms and see the following graphs in nanoSAVER: S21 Gain and S21 Phase.



S21 Gain



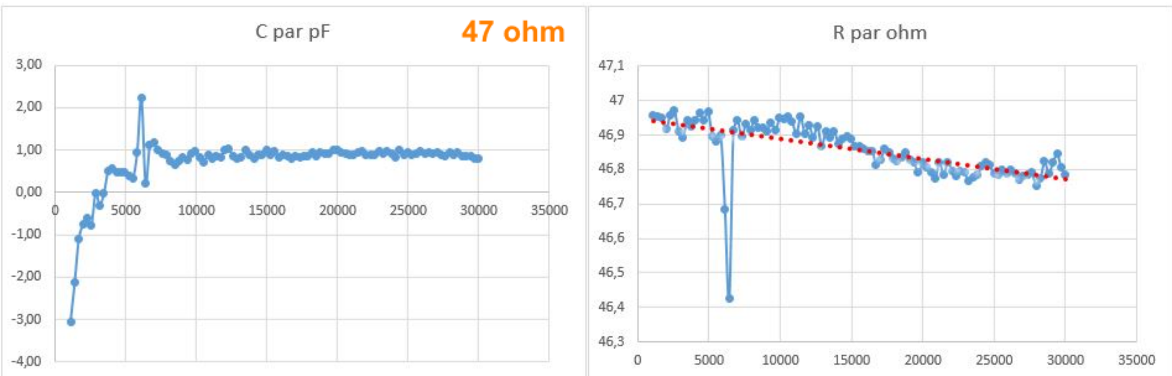
S21 Phase

There appears to be a constant and expected damping of 3.3 dB (calculation see box 1) and a slight increasing angular displacement positive, which indicates slightly capacitive behaviour that increases with frequency. This means that there must be a (parasitic) capacitor parallel to the resistor. We see that with the other three resistors also, the expected damping (e.g. 40dB at the 10k resistor) with increasing phase angle.

Unfortunately, nanoSAVER does not have an algorithm that converts the S21 values to a parallel connection of Rp and jXp, nor to a series connection of Rs + jXs.

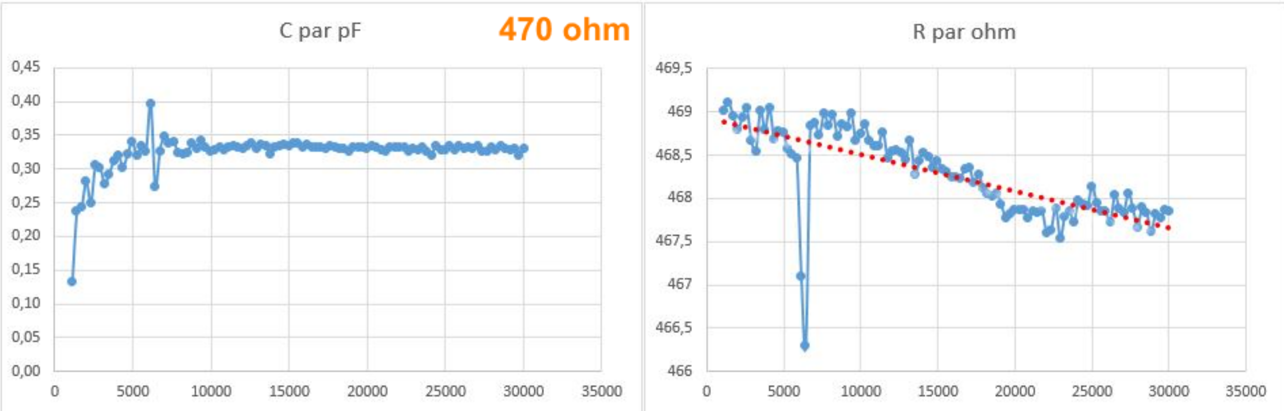
The solution is a manual conversion of the S21 values from the S2P file. The formulas from the previously quoted article of G3TXQ do not work with the nanoSAVER export, so new formulas have been derived. Box 2 shows the outcome for conversion from S21 to series connection Rs + jXs. Box 3 shows the conversion of series values Rs and Xs to parallel values Rp and Xp. The derivation of all used formulas can be found at:
https://pa3a.nl/wp-content/uploads/2021/07/Math-for-nanoVNA-S2Z-and-Z2S-Jul-2021.pdf

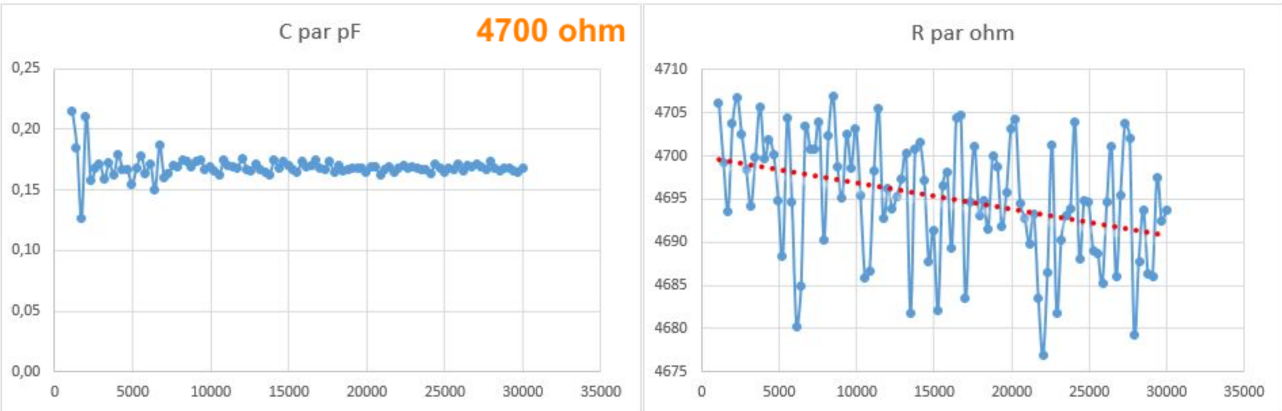
Converting the S21 file for the measurement of 47 ohms yields the following picture (Xp has already been converted to capacitance in pF):

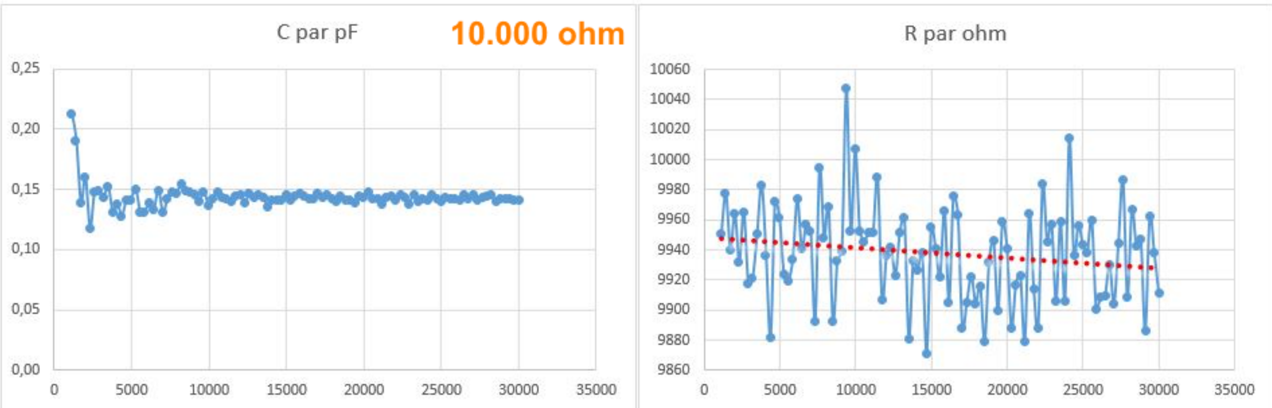


A few points are striking:
There are a few deviating values around 6 MHz. This is a minor glitch in the nanoVNA. At a low frequency, the capacitance is negative. This indicates that some inductance is still seen before the parallel C takes over in the current. For the big picture, it doesn't matter. You can actually measure that 47 ohm resistance faster with the S11 R + jX.

For the set of 470, 4k7 and 10k resistors, we immediately convert the damping to Rp and jXp with the conversion from jXp to a capacitance value. All in all, we get a completely different picture with the S21 measurement, compared to the previous S11 measurement.







Overview of measured values by means of S21, read from the above graphs.

Resistor	S21 report → Rp + jXp	from Xp: C-value
47 ohm	Rp: 46,9 ± 0,1	1 pF
470 ohm	Rp: 468 ± 1	0,33 pF
4700 ohm	Rp: 4,69 k ± 0,01 k	0,17 pF
10.000 ohm	Rp: 9,94 k ± 0,05 k	0,14 pF

These are actually incredibly good and stable outcomes. Considering that the nanoVNA 3.2 doesn't exactly have a 50 ohm input resistance on CH1. Apparently the calibration is doing well and PA3A might also be lucky with his measurements.

Conclusion

With the help of the nanoVNA and some calculations you can measure resistances with fairly high values using the S21 method. An unambiguous calibration is required.

In part 3 of this series we will measure impedance of Common Mode Chokes found in the field. Expectation is that the S21 measurement will produce reliable values of R + jXs.

Box 1.

We could have expected the 3.3 dB. In case of a short circuit between the two ports (see the circuit diagram):

$$I_0 = \frac{Ub}{100}$$

With a 47 ohm resistance inserted it is:

$$I_{47} = \frac{Ub}{147}$$

The ratio of the currents is then

$$\frac{I_{47}}{I_0} = \frac{100}{147}$$

With that, the gain is:

$$Gain = 20 * \log\left(\frac{100}{147}\right) = -3{,}3 \text{ dB}$$

Box 2.

Convert S21 (damping D) to Rs+jXs

$$Re(S21) = Dr \;\; and \;\; Im(S21) = Di$$

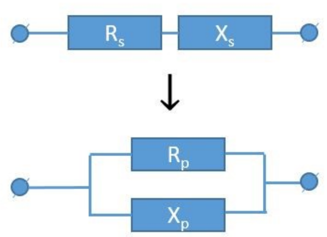
$$Rs = \frac{100\left(\mathrm{Dr} - (\mathrm{Di}^2 + \mathrm{Dr}^2)\right)}{\mathrm{Di}^2 + \mathrm{Dr}^2}$$

$$Xs = \frac{-100\, Di}{Dr^2 + Di^2}$$

In Excel these formulas are easy to use.

Box 3.

Converting series Rs and Xs to a parallel circuit consisting of Rp and Xp.



$$Rp = \frac{Xs^2}{Rs} + Rs$$

$$Xp = \frac{Rs^2}{Xs} + Xs$$

73,

Arie Kleingeld PA3A

Reference:
Amateur Radio (G3TXQ) - Common-mode chokes:
http://www.karinya.net/g3txq/chokes/#measurement