MEASUREMENTS WITH THE NANOVNA

Part 7: Measuring the Q of a coil

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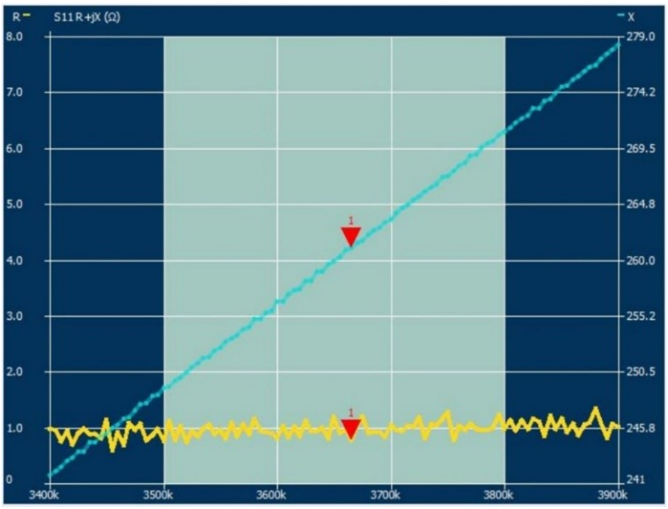
Introduction

Recently, a radio amateur friend asked me how he could measure the quality factor Q of a coil. After discussing it, of course I said with conviction: “You do that with a nanoVNA in combination with the PC program nanoSAVER”. NanoSAVER contains this function, namely 'S11 Quality Factor'. Hang the coil on the S11 port (CH0), measure and read it. Because I‘m working on a small project to design and build a good preselector for my receivers, it is good to know the Q of the coils that you use. We can measure that quickly. But... sometimes you underestimate a task; and turned out to be a bit more difficult than first proposed. Enough reason to share that in this story.

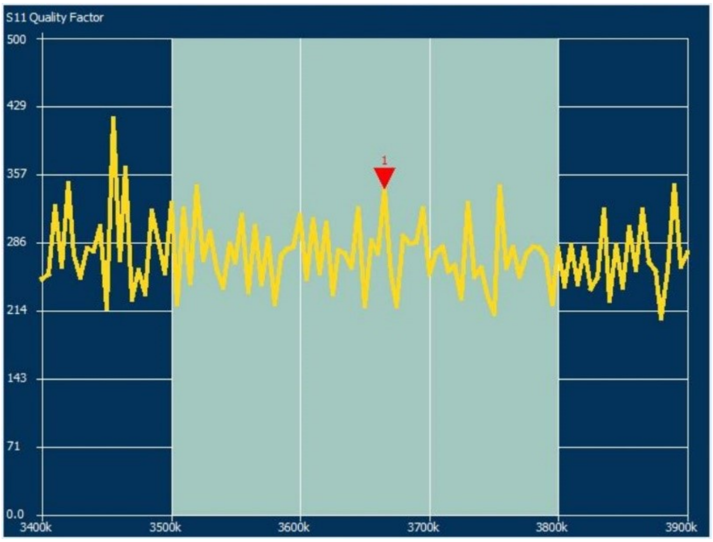
The S11 R+jX measurement and translation to the Q

As a test object in this article, I use a purple 4C65 core, approx. 23mm diameter. A nice workable size with relatively few windings valued at about 11 uH. For comparison, next to it a red T200-2 core that also works out to about 11 uH. The difference in windings is clear and can be explained immediately by the relative permeability μ_i of the two materials. For the 4C65 material that is approx. 125 and for the 2-material it is approx. 10.



Before taking a measurement, the nanoVNA is first calibrated for the desired frequency range where I plan to use the core: 3.4–3.9 MHz. Then the core is measured. The result is shown in the figure next to it that shows S11 R+jX. From this nanoSAVER calculates, among other things, the L-value.

The next graph (S11 Quality Factor) shows the calculated quality factor Q based on the same data. This is calculated by dividing X_L by R.



It's not as straightforward as I had hoped. The Q sometimes goes from 211 to 345 within 5 kHz and of course that is not the case. The reason for this is that we measure a value of XL that is around 260 ohms and a resistance value R near 1 ohm. The XL runs nicely in a tight line according to $X_L = 2\pi fL$.
The value of R jumps up and down at 0.5 ohms and as a result you can't really read the Q. In this combination, the nanoVNA is apparently not able to measure the resistance component noise-free.

In short, this is not the correct method. In addition to the noise on the measurement, another complication arises, evident from the following. Of course, you never do only one measurement if you get a diverse result such as this. You connect everything again, tighten the connectors, and then measure again. The results (especially the R-values) varied from around 1 ohm to around 1.3 ohms with the same amount of noise. With that variation we obtained different values of the calculated quality factor Q.

The shifting of the average R-value arises from variations in the nanoVNA itself. If my nanoVNA (type H3.2) has just been turned on and is calibrated, you can measure something perfectly. An hour later with the same calibration you get very different values in the Q-measurement. Apparently, the nano heats up when it is on, with an undesirable side effect. Now it doesn't matter so much for a simple SWR measurement, but it does matter in the Q measurement. Therefore, for the next measurements we will turn the nanoVNA on for an hour before calibrating and measuring. We'll also move away from measuring only the coil.

Measurement using an LC circuit

To get a better ratio between measured X and R we are going to measure with an LC series circuit using a good quality capacitor of just over 50 pF. This value was chosen because I want to measure the Q in the 80m band.

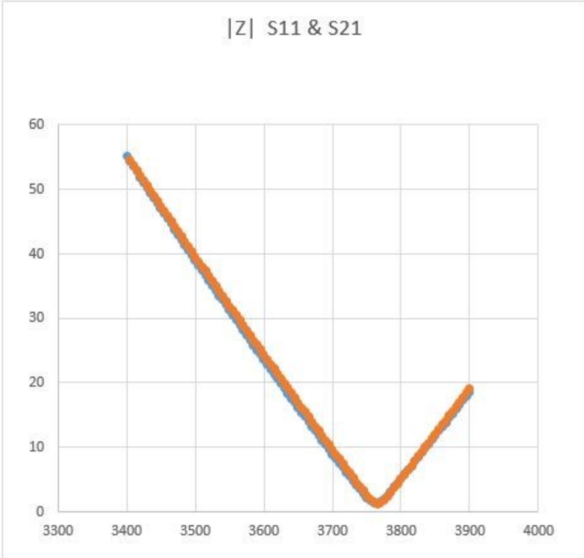
With a series resonance there will be a small resistance and hardly any reactance to measure. Previous measurement tests showed that a resistance of 1 ohm could still be measured fairly well with the S11 R+jX method and with the S21 shunt method. Measuring a 0.2 ohm resistance was also feasible (see part 5 of this series on measuring low impedances). Therefore, I used both methods side by side to somewhat verify the results obtained.

For the new measurements, the nanoVNA was first turned on for an hour, and then calibrated for the two methods: the S11 R+jX measurement (circuit to CH0) and the S21 shunt measurement (CH0 directly connected to CH1 in parallel). To clarify, both connection methods are shown next to each other in the boxes [next page].

The results were astonishingly good. The two measurements S11 and S21 were exported in S1P and S2P files respectively and then calculated with Excel to Z = R+jX. (For the formulas used see the two boxes below).

A resonance frequency of 3763 ±1 kHz was found for both setups (where X≈0) and the value for R also corresponded: 1.27 ± 0.005 ohms. The two calculated |Z|-graphs therefore correspond in the adjacent figure. It seems almost too good to be true, but apparently, I did something right.

With the XL value of 267 ohms measured at the same frequency, and found R=1.27 ohms, you end up with Q = X_L/R at a Q of 210. A great toroid coil!



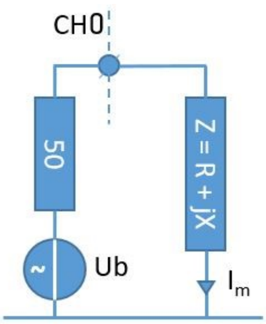
Conclusion

It is quite possible to measure the Q of a coil using the nanoVNA. The series resistance of the coil appears to be easily measurable with series resonance of the coil in a series circuit. It's as if it comes right out of a schoolbook, and the nanoVNA makes it measurable. If the measured resistance is below 1 ohm, choose the S21 method as described in box 2 because measurement with S11 then becomes too inaccurate.

Box 1.

S11 = Sr + j Si .
Dr and Di values are exported by nanoSAVER by means of an **S1P** file. R+jX can be calculated using below formulas. The principle of this is explained in part 2 of this series.

$R = 50\frac{1-(Si^2+Sr^2)}{(1-Sr)^2+Si^2}$	$X = \frac{100Si}{(1-Sr)^2+Si^2}$



Box 2.

S21 = Dr + j Di .
Dr and Di values are exported from nanoSaver by means of an **S2P** file.
R+jX can be calculated using the formulas below.

$R = -\frac{Di^2(Dr+25)}{(1-Dr)^2}+\frac{25Dr}{1-Dr}$	$X = \frac{Di(Dr+25)}{1-Dr}$