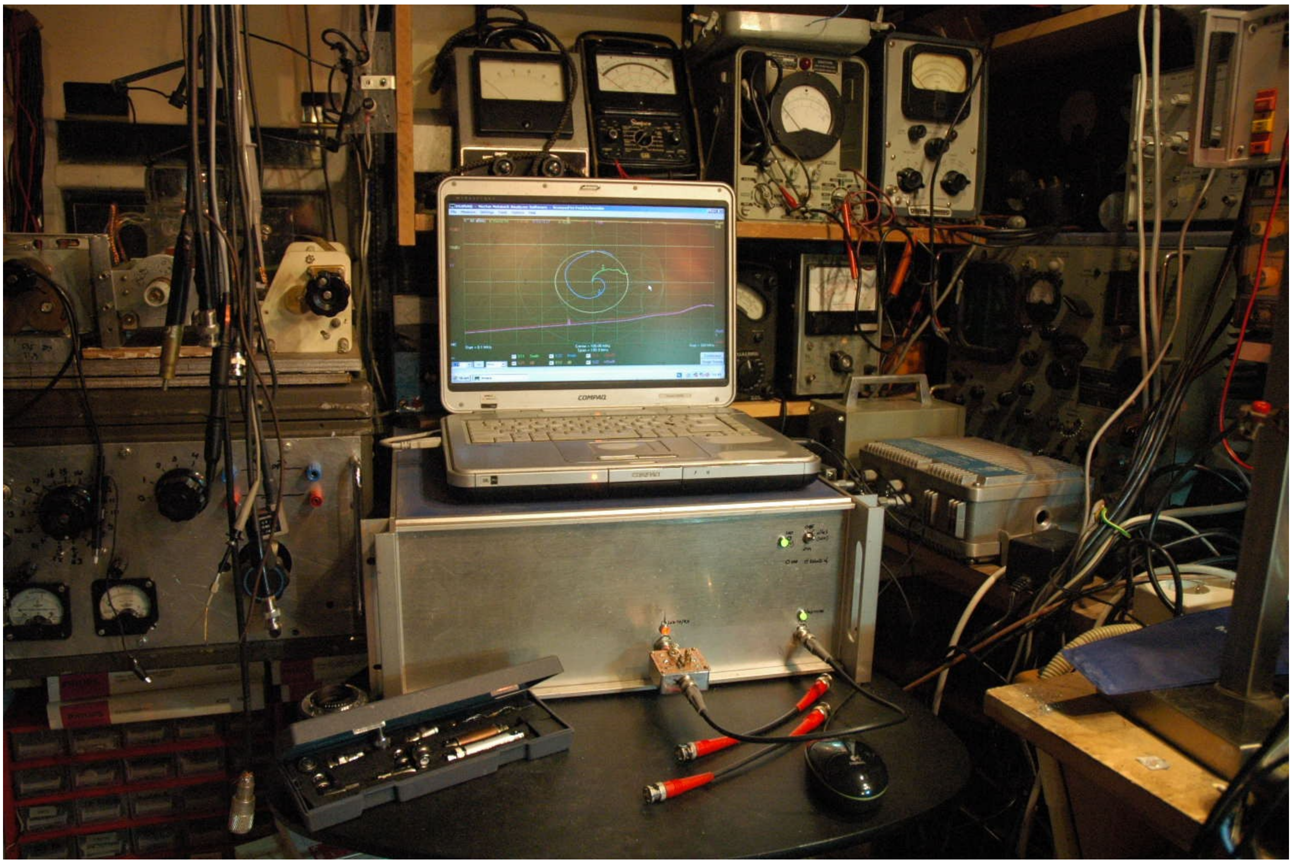
The beginning:

You now have your analyser, you followed the set up from the help-files and now you want to start using it. If you are not a trained network analyser or math-geek but just an average radio amateur it can be a bit overwhelming. So this is not about math or concepts, this is a practical journey through the wonderful world of VNA's. Let us look at it the way, a Dancing Wu li master would do it, or better become a dancing VNA master . This may seem a lot of text but I if you want to learn it the proper way just read it and try to understand. Looking at the pictures alone will leave you with questions.

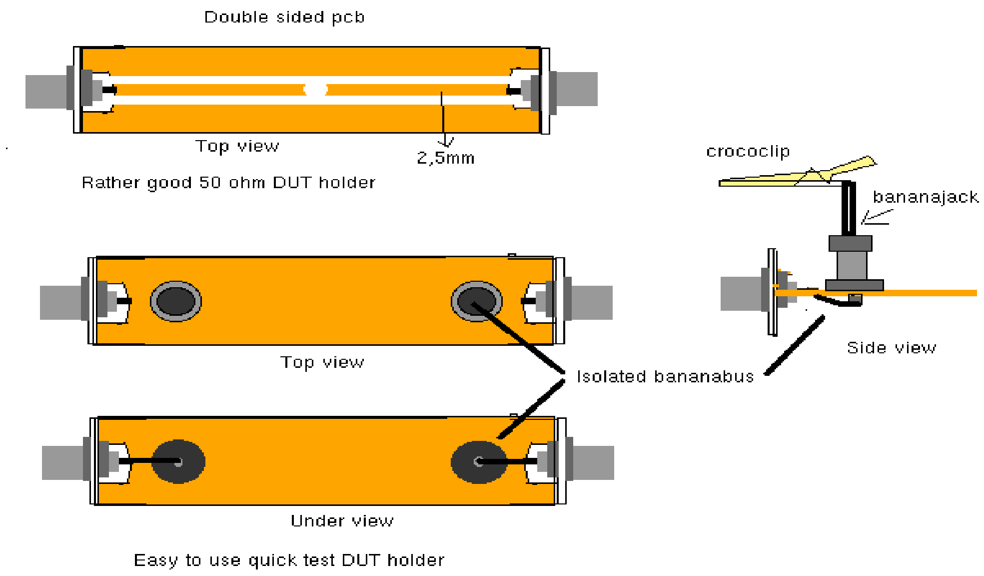


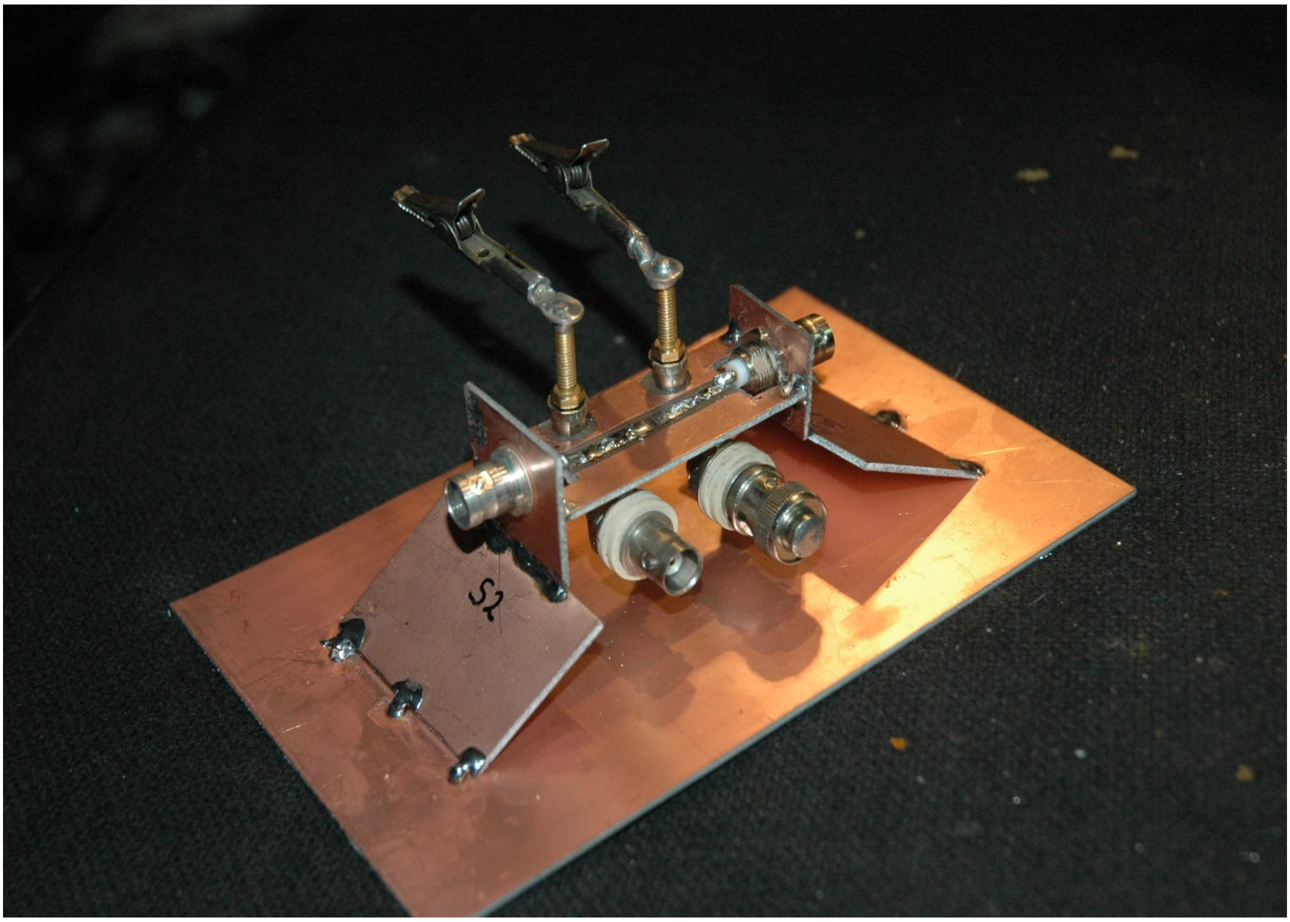
Important
To see what our VNA can do lets start with something simple, OK, you will say after reading the next part, that is simple, I believe that. Do not believe, you read my words and have a vision about what I write, but I can see it in an other way. When I say AM, a radio amateur thinks about amplitude modulation, a linguist about "being" and an audio freak thinks about acoustic-magnetic. So do the little experiments your self, think about what you see and be sure it is clear. Then do a similar experiment to check if you had it right. Change a value and think about what you expect to see before you sweep. But to do this you need a DUT holder. Our VNA has just two connectors and it is not recommend to jam a resistor or coil you want to measure in those tiny connectors. We will build a decent DUT holder to solder on or to quickly clamp something in.

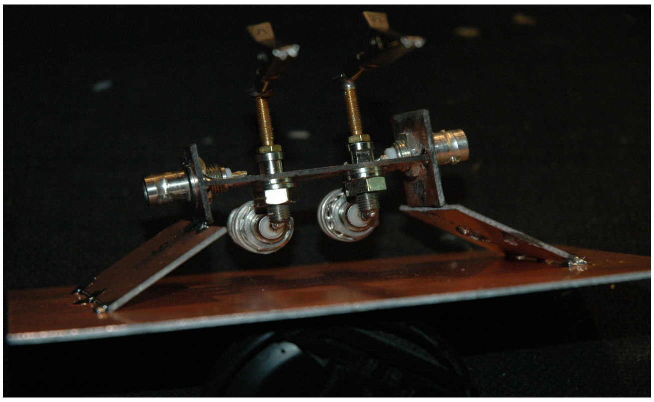
Say we want to test a resistor, that is a thing made of a material that makes it possible for AC and DC current to flow through it. So if we send a signal through it, it will be attenuated. The flow of current will be limited and the voltage drop over the resistor will be higher.

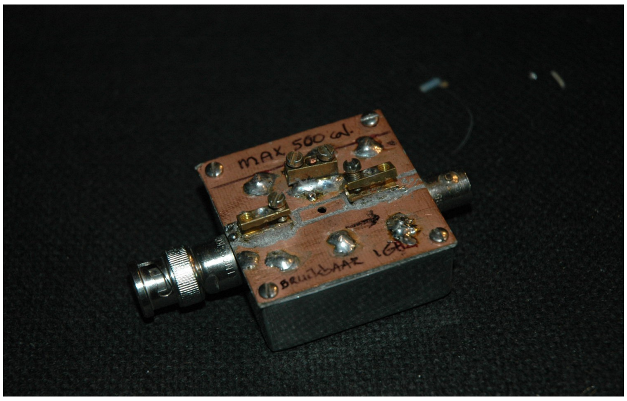
First we have to make something to measure that resistor and of course, use an "ideal" resistor.
We take a carbon or metal film one, with long legs and we are going to measure that.
The problem is we have to have something to connect it to the VNA. Lets do it the easy way. We

take a little piece of PCB and mount two connectors to it. We also mount two banana buses on the same plane and connect them to the SMA or BNC jacks we made at the PCB. See the picture, We also make two banana jacks and solder a crococlip to it. The second one is a piece of double sided PCB where we make a strip about 2,5mm between the connectors. Just use a Dremel or so. You split that strip in two so you can solder a part over it. With this little set up we can make several tests and also see the **faults** we introduce ourselves and experience the **DUT set up** and **calibration** which is almost as important as the VNA itself.





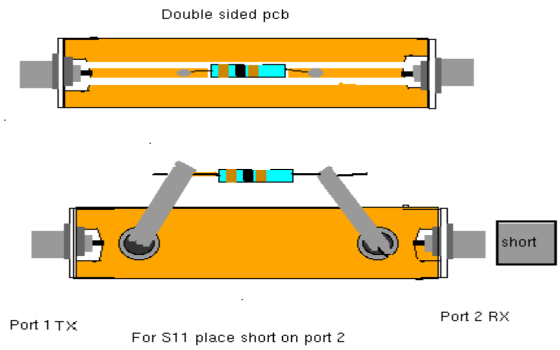




I made it like above, a sort of two in one. Below the details from the other side and an other form I also often use.

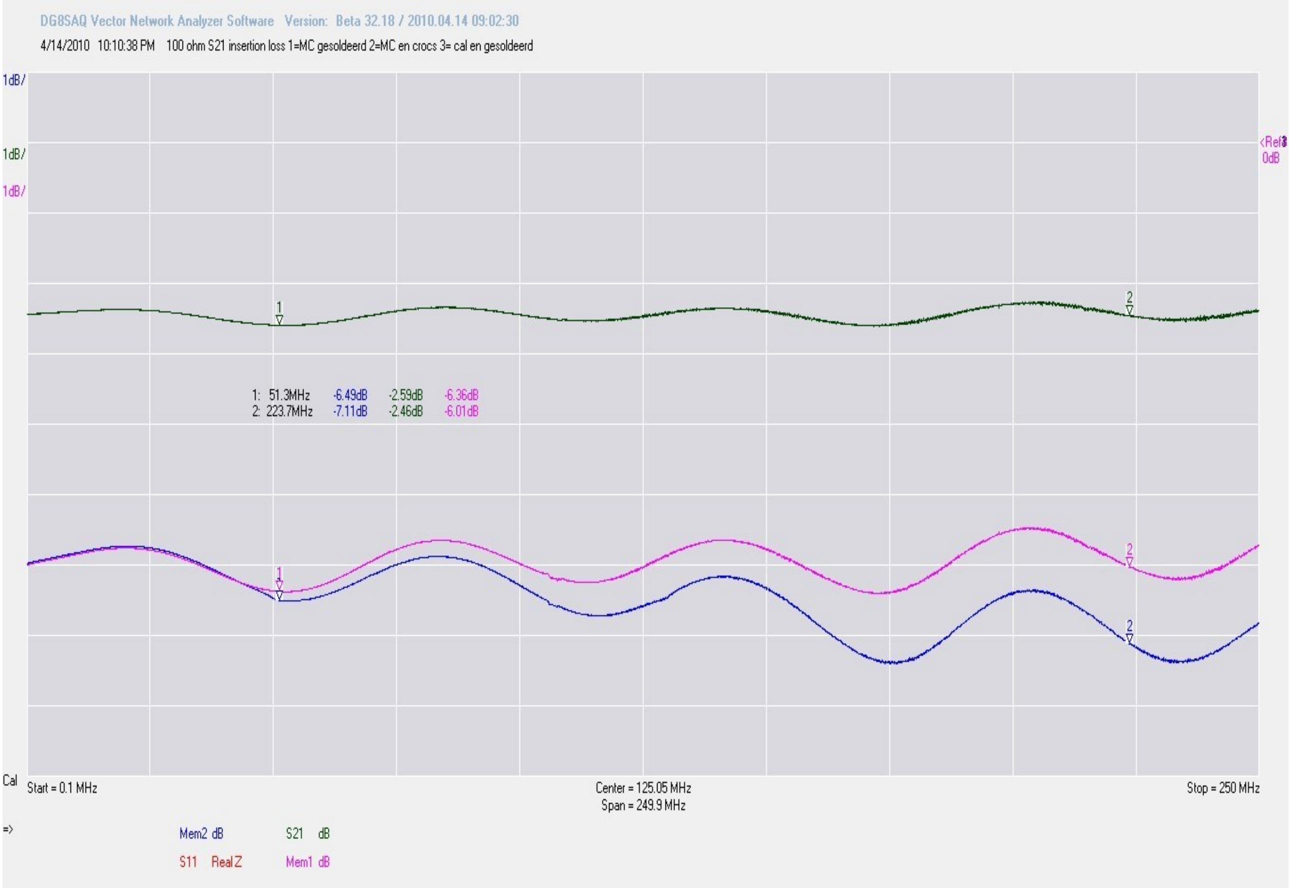
Our first measurement:

Not by accident I told you we take a ideal resistor. An ideal resistor only has resistance, no capacitance and no inductance. A carbon resistor is pretty ideal, is it ? Lets find out.



We first do it the lazy way. We have calibrated our VNA the correct way with our perfect(ed) Calibration kit and use this as a master cal. We connect the cables we used for calibration to our DUT holder and plug the two banana jacks with crococlips in. See the lowest drawing above this text. We clip them on the end of the 100 ohm resistor wires and set our sweep from 0.1MHz to 250MHz. We chose S21 in dB. This means we are going to send a signal from the TX port, toward the resistor. The “in” wire from the resistor is port 1. That signal goes through the resistor towards its “out” wire, port 2, from there it goes through our cable toward the RX port. So that is what S21 stands for: looking at port 2 at what it is receiving from port 1.

What you should see if the resistor was ideal ? A flat lined attenuation from the signal, the green one called S11. How much the VNA tells you in dB, we call that negative gain or just loss. A resistor has no induction, no capacitance so we see a straight line with an attenuation that is the same at every part of the trace. But hey, you see something like the purple one. Damned, this is bad.



The purple trace mem1 gives the sweep using the master cal and the resistor between the crocs, mem2,

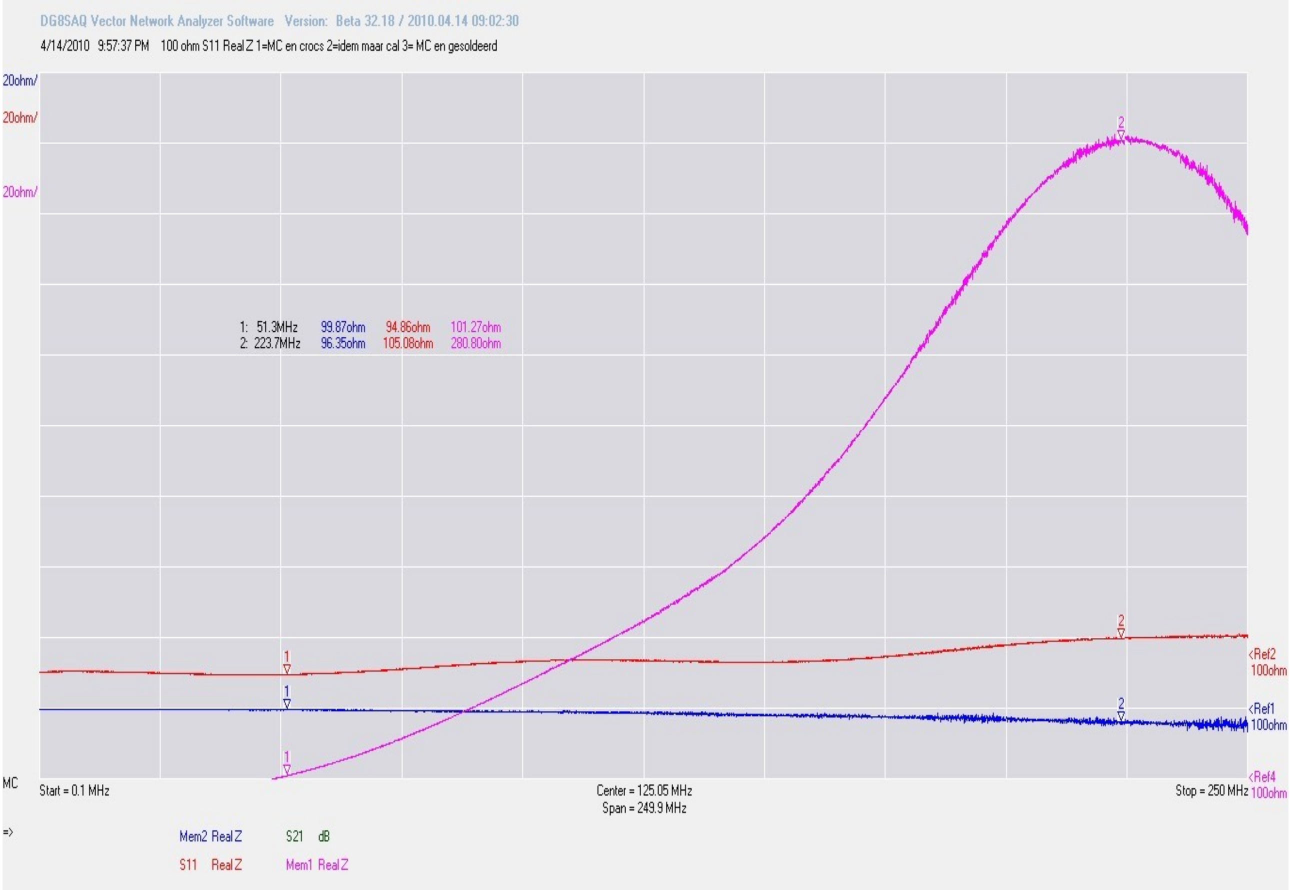
We go on. We now solder the resistor straight at the PCB with the shortest wire we can. See the picture at the beginning.

We sweep again, this should be much better you think. We used a piece of 50 ohm transmission line, the 2.5 mm strip, but this is hardly better. Strange, it is still the same resistor. Could it be wire wound ? We first removed two coils, eh, I mean the two wires but still it is not perfect. Now you see see the effects from the wires but also all that is between the end of the cables that was not there while calibrating. That is the entire DUT holder. Soldering the resistor to the pcb is as good as you can get it without to much work.

But we can calibrate. We can tell the VNA all the stuff we added is to be ignored or better compensated. Then we get the green trace and that is what we want. A nice flat line. And now we can use the data we see.

How do we get that line? First we replace the resistor by a piece of wire. Then we open the calibration field and do a tru and tru match calibration. After that we solder the resistor in its place and make a sweep. This is the way to do it. You can also use the crocs and do the calibration thing but that will not be as good as this way. Just a little moving the crocs will be seen at the higher frequencies.

But we want to know more about this resistor so we are going to disconnect the RX cable and connect a short from our cal kit to the now open DUT connector. We have the resistor soldered again and we sweep with the result below. Choose “S11” and “real Z”



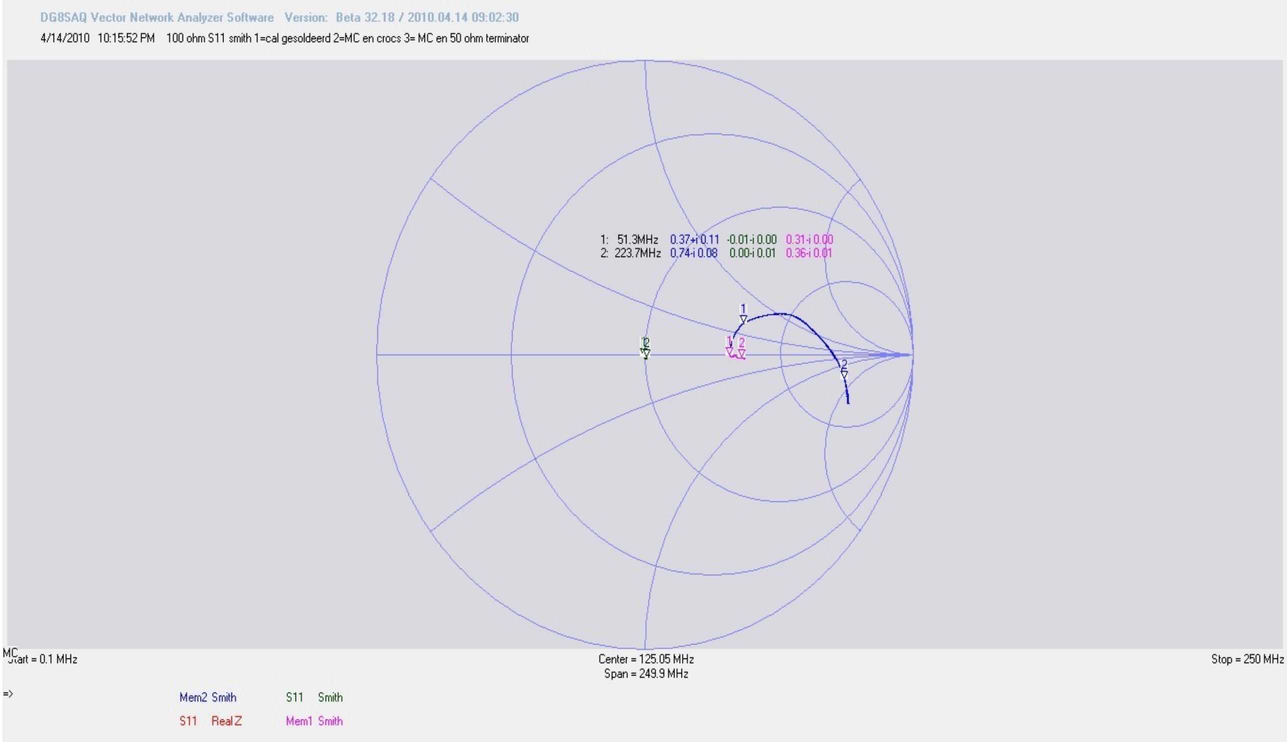
I sweep several times and place the sweep in a memoryspace so you can see three sweeps.

We see the real Z. The R part of R+xj, S11, the red one in our picture. Not bad. A resistor that is somewhere between 94 and 105 ohms. Now do a calibration. Place a second 100 ohm resistor in parallel so together they make 50 ohms and calibrate “load”. Remove them both and do “open”. Solder a straight wire over it and do the “short” calibration.

Now solder the 100 ohm back and sweep. We now have the blue line, mem2. A 96,35 ohm resistor at 51MHz. The wires are still a bit different from the calibration but now we have a useful result and if you have to know more exactly, just calibrate better.

The reason calibration works better is we told the VNA there is a lot of stuff it has to ignore. But we also know now that if we place this resistor with its wires above a ground plane that we add capacitance and inductance by crocs or a DUT-holder. That doesn't always have to be a problem as long as you are aware of those facts and know what to do to make it right.

Some theory:
I talked about reactance, introduced by the DUT, and the DUT holder. Our VNA can tell you, not only the total value of Z, but also the components of it. The smith card is a handy tool for that. Everything under the horizontal centre line means the major part of the impedance is a capacitance. Above that line it's biggest part is inductive. If it stays just on the centre line it is pure resistive. A pure reactance without resistance moves around the most outer circle. If it comes inwards or the pure resistor goes towards the outer circle we know we have a resistance with some reactance or a reactance with some resistance (losses). In both cases we have an impedance.



The **blue** line is our resistor with the long wires in the crococlips You see at 52MHz the wires and poiles of the crocs form a inductance. Remember, this is the sum. There is also a capacitance involved from the two crocs next to each other but the inductance is much bigger. You see that as the frequency goes up. The line passes the centre line, there the capacitance is as big as the inductance, the sum is zero. We call this resonance. (+20j + -20j= zero)
Then the capacitance gets the overhand and the trace leaves the +xj zone , passes the R line and goes in the -xj zone. The small purple trace is the calibrated and soldered resistor and to make things clear I swept the 50 ohm terminator too. That is the green spot in the middle, that is the 50 ohms point. Furthest left on the resistance line is zero ohm or a short, far right is an open, a resistance so high you can not measure. Now you also see a limitation. The distance from 0-50 ohms is as big as 50 ohms – open. That tells you the measurements from 0-50 ohms are much more precise than those from 50 ohms up. 50 -100 ohm is a equal span but it can do better, much better but do not expect it to measure 100K accurate. A very small calibration fault becomes very big at these values.

The whole picture:
Now you are used to some more traces , I make it a bit more complex. This is the “bad” set up from the resistor with crocs. I now added The R +jx traces. Green is the real part, R, purple is the imaginary or xj part. S11 is the return loss in dB, if you know the phase angle and the return loss you can calculate all other values. But we are lucky, the VNA does that for us. Just double click the marker and you get a box with all parameters. The red trace is the VSWR.

Just to make it complete, sweep the same traces, but this time from our calibration load.
This you **must see** after a good calibration. **Always** do a check. Just sweep your load, open and short. Just smith is enough. The load gives a spot in the centre, the open a spot far right on the centreline/outer circle and a short a spot on the far left site/outer circle. If not there is something wrong with your calibration. The picture down here is done with the master cal so it can been done much better.

In the next part we are going to look and play with inductance. You always thought a coil was just a coil and you can measure it's inductance with a LCR meter and then use it at every frequency ? Yeah, sure, dream on......

To be continued.

Fred PA4TIM