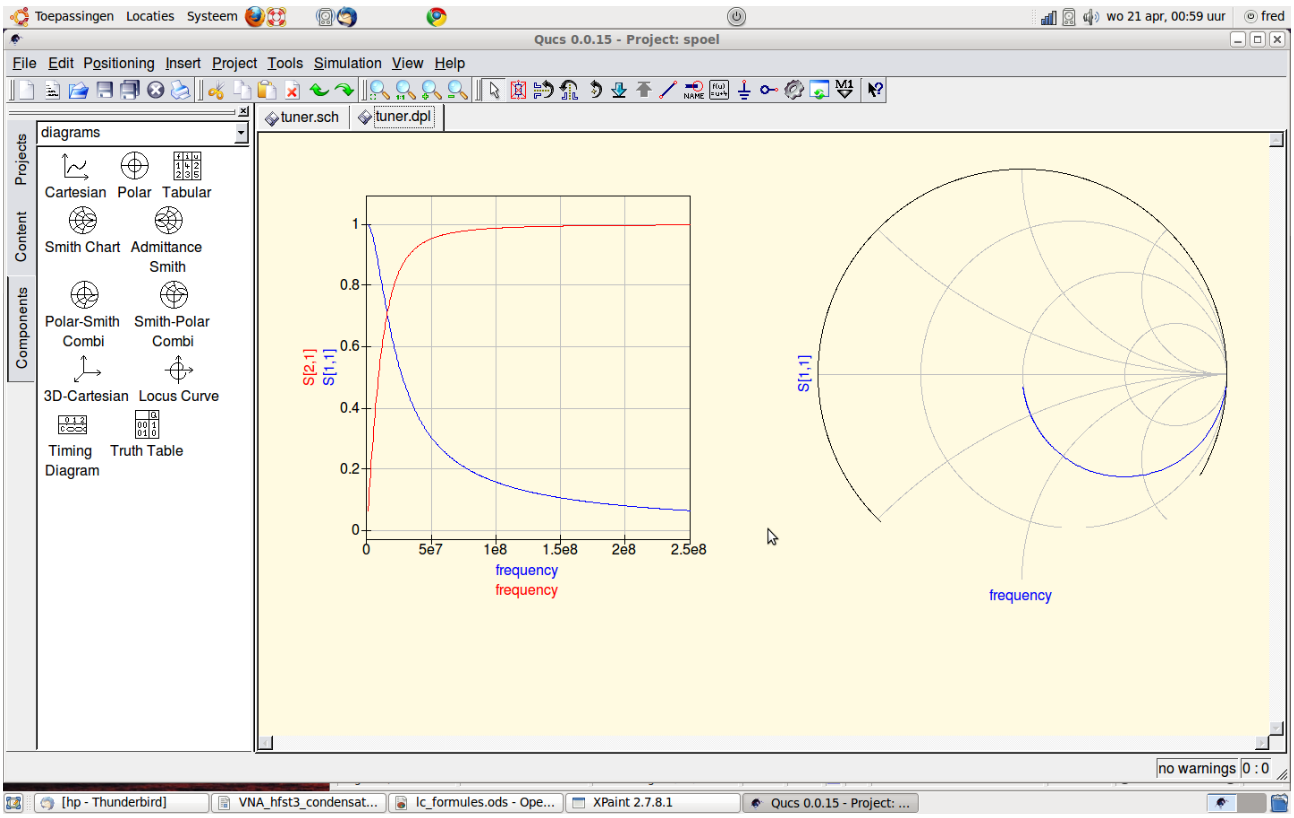
Chapter 3 Capacitors

In Radio technique there is a pair of twins. In a way they are opposite but also the same. When you see this one, his “evil” twin will most times be near by. This evil twin, the inductor we already investigated. So now we are going to look at the better behaving brother. As usual we are more interested in his dark side....

There are more interesting things to measure on capacitors. First there is reactance, the “resistance” for AC. Here our VNA will be the boss. Then there is ESR, equivalent series resistance. This is mainly a thing that is important in power supplies. It tells us about the internal resistance that is the cause a capacitor does not start de-charging at once. It causes a delay when the current changes from positive to negative. Our VNA can not measure that, your square wave generator and oscilloscope can. Then there is, again mainly with elco's, DC leakage. How much DC current is leaking through the capacitor at it's working voltage. Not a job for our VNA but a power supply and simple ampere meter will do that job for you. Then there is a not so known last parameter that is important to us, the ESL, Equivalent Series Inductance. You seldom read about that. That is because you need a VNA to see it.
The leads from the capacitor and sometimes parts of that inside form an inductor. This is something you will only see with the VNA and the most important reason a capacitor at high frequency is not always so ideal as we think.

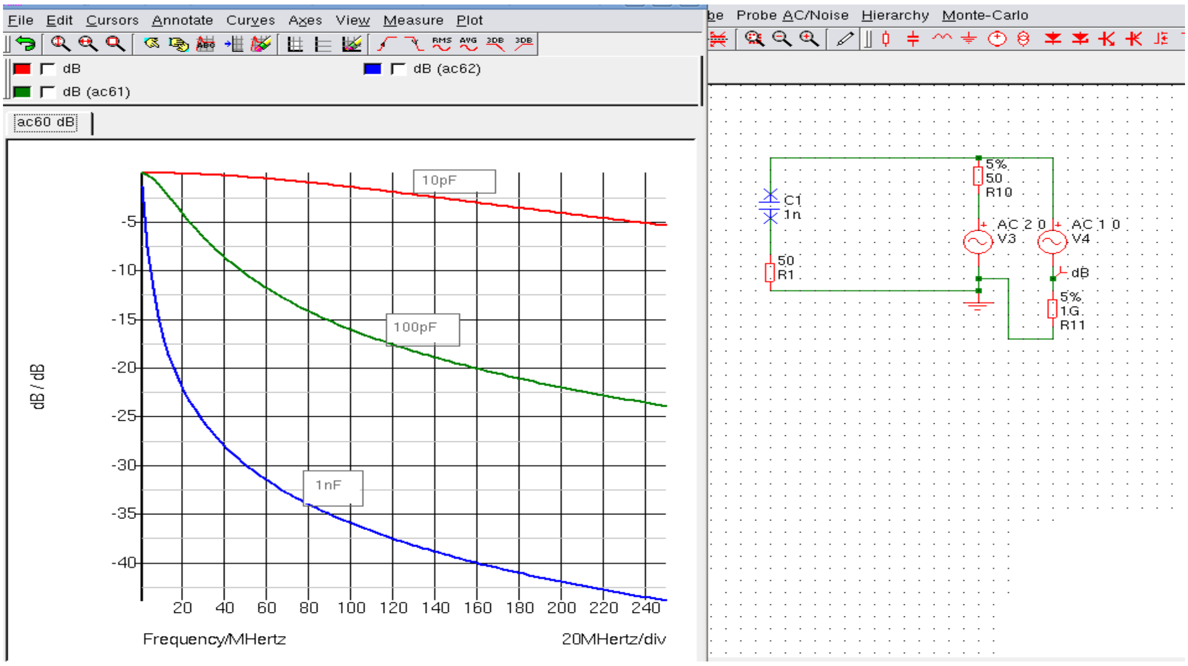
Set up

Before we set up our DUT-holder like in our previous experiments, we are going to search for some capacitors in our junkbox. There are many flavours in capacitors and many values. We need value's that shows us what we want to know, but not all will be available in every value. So this is the right moment to tell you about a very powerfull tool. Simulation software. I use Simetrix and Qucs for this.

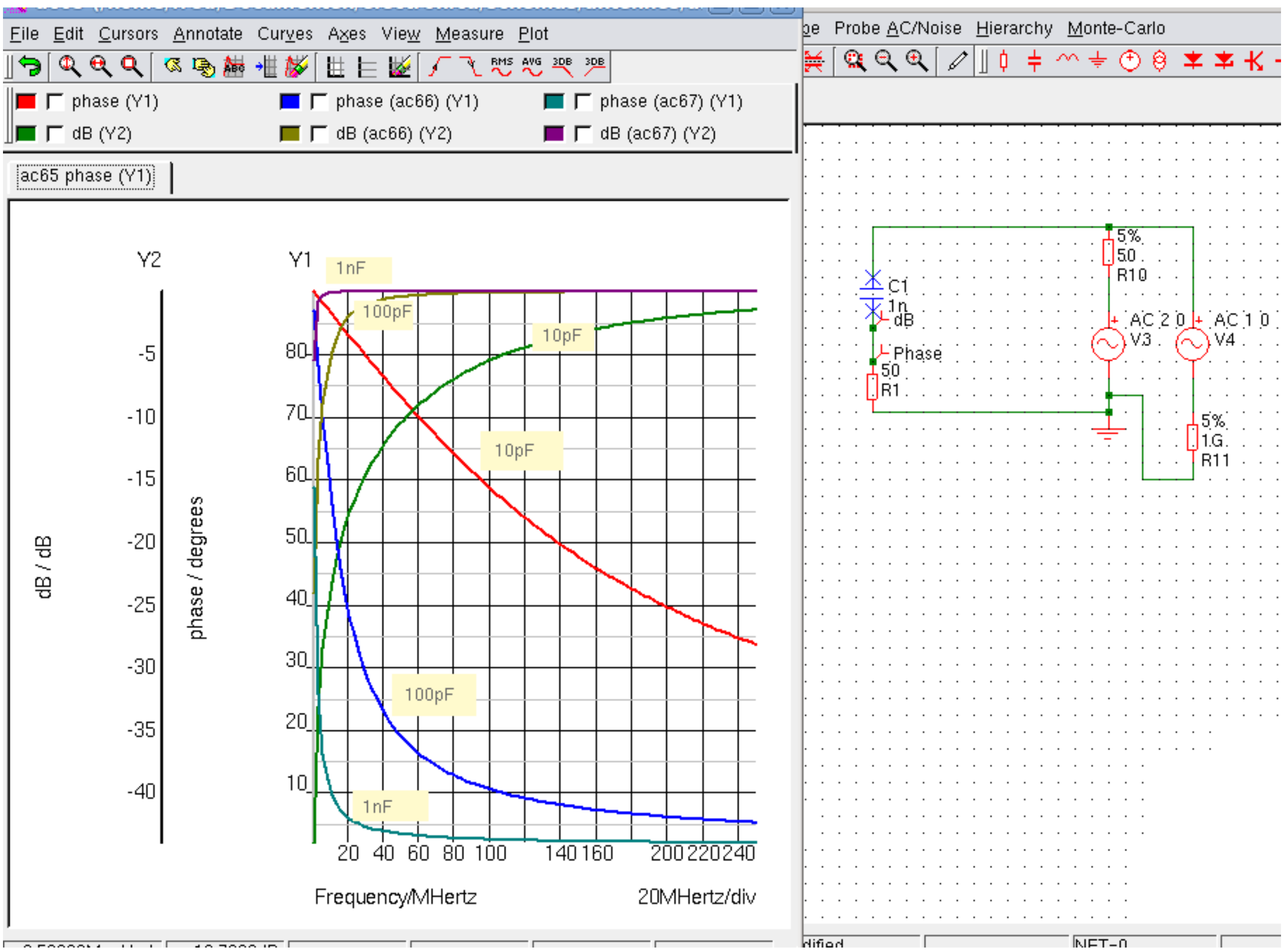


This is Qucs. It shows a plot from a 100pF capacitor. Left is S11 and S21 and right is smith S11.

The blue one in smith is in the resistance area because it is S21. There is a 50 ohms resistor there invloved to simulate. The trace we want is white in that picture so you do not see it very good.

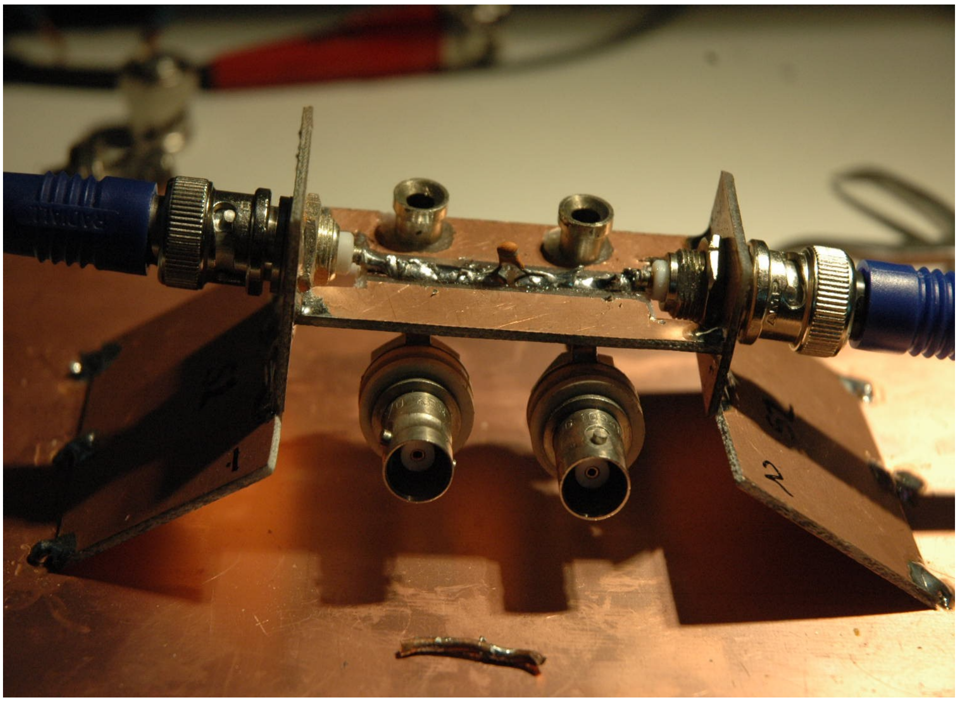


The same trick we can do in Simetrix. Here you see how to simulate a VNA. Above is a picture from a S11 set up. Following you see a picture from S21. Both cases show you an ideal capacitor. But we do not live in an ideal world....

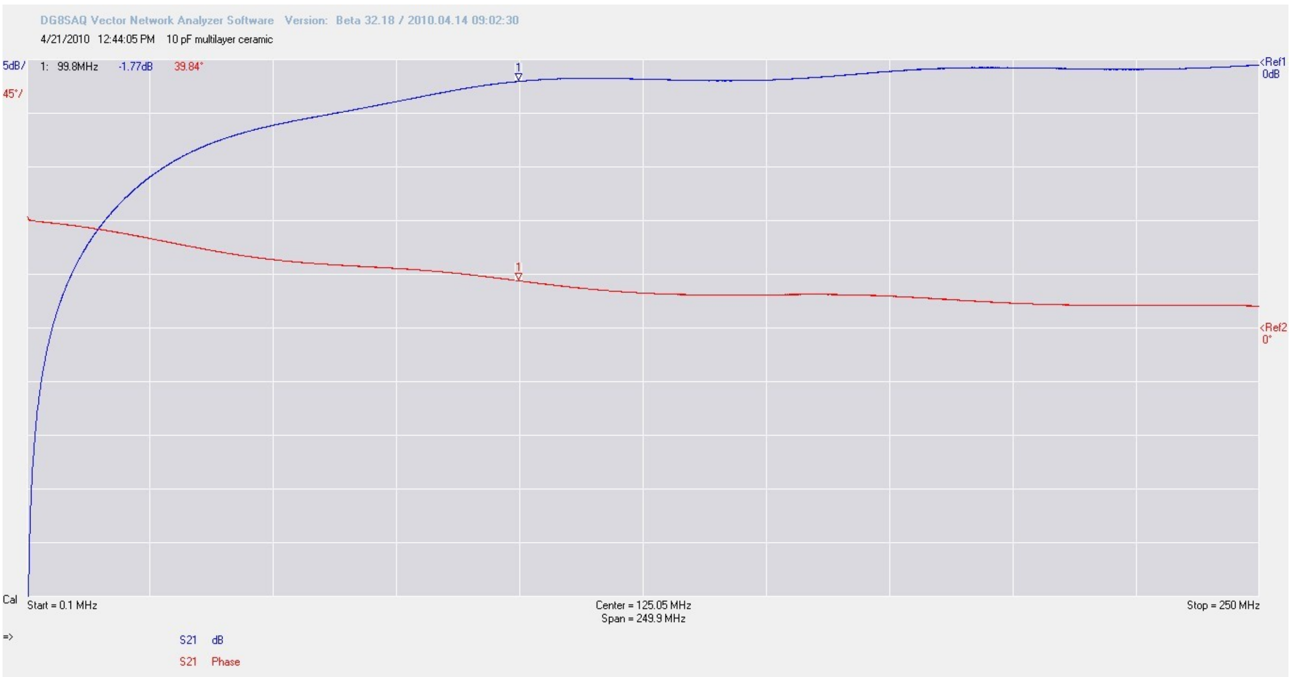


Ceramic

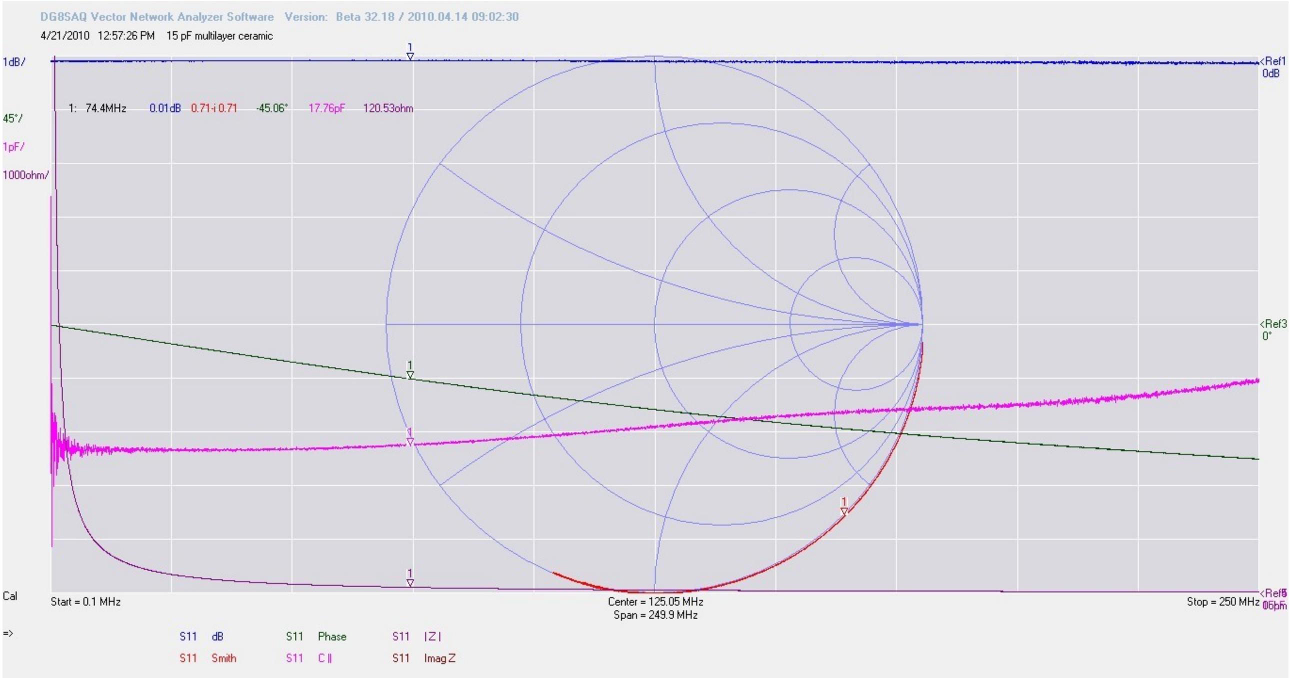
The first capacitor will be a 15pF ceramic disk capacitor. We solder it on our DUT holder and retrieve the DUT-holder calibration we saved in chapter two. So now everything is ready to do a S21 measurement. Like you see in the simulations. We should see a high attenuation at low frequency. 15PF is a huge impedance at 1Mhz. The attenuation should be become a lot less at 250Mhz. The green line (with 10pF) in the picture above shows what we can expect. It is always wise to first short the DUT holder, so use a short wire instead of the capacitor to see there is no attenuation (or how much it is) but more important if there is no reactance or even worse resonance. You see that as dips in the S21 trace. The wire I use is in front on this picture.



You see the leads are still rather long compared to the capacitor itself but the results show an almost perfect behaviour.

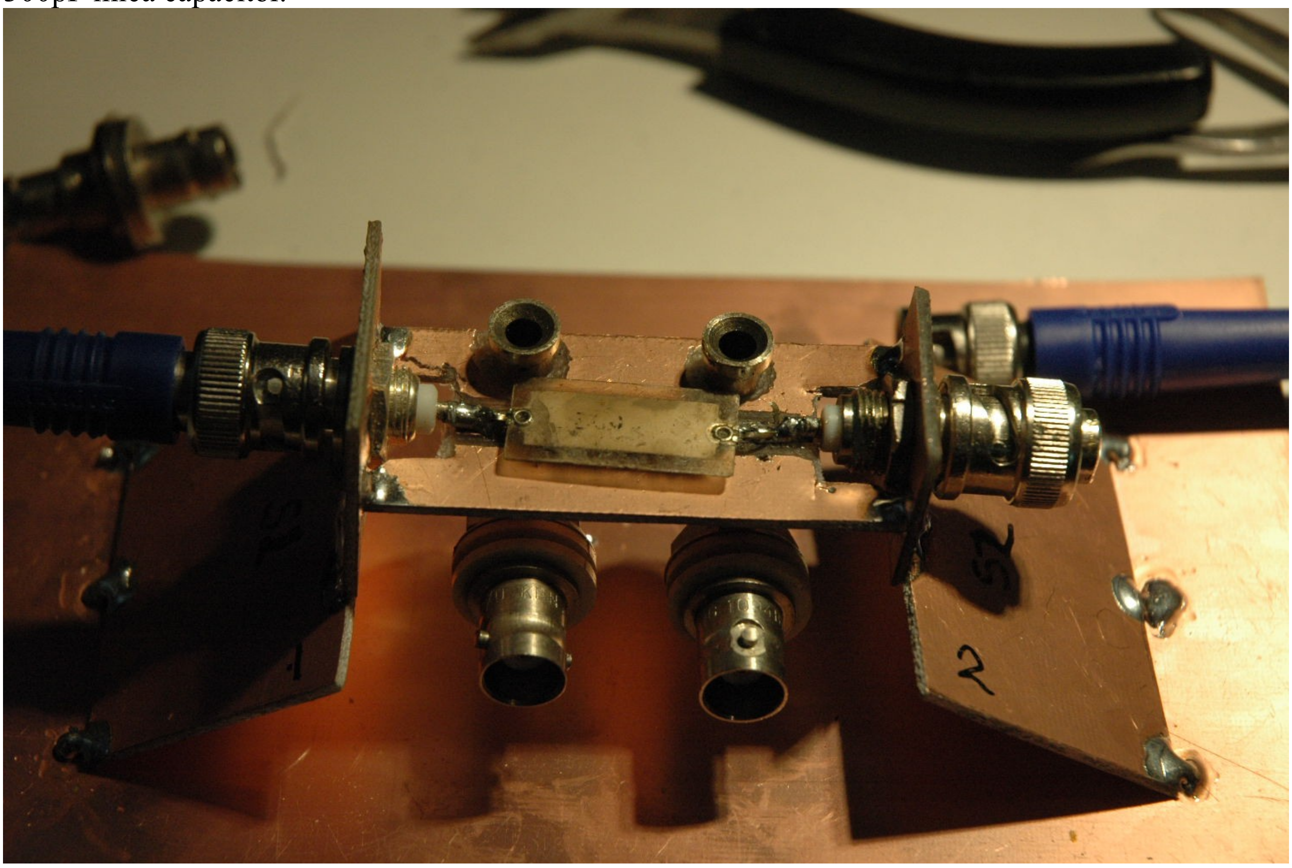


You see the phase stays above zero degree and the attenuation is almost like the simulation. But are there hidden things in this little good guy.

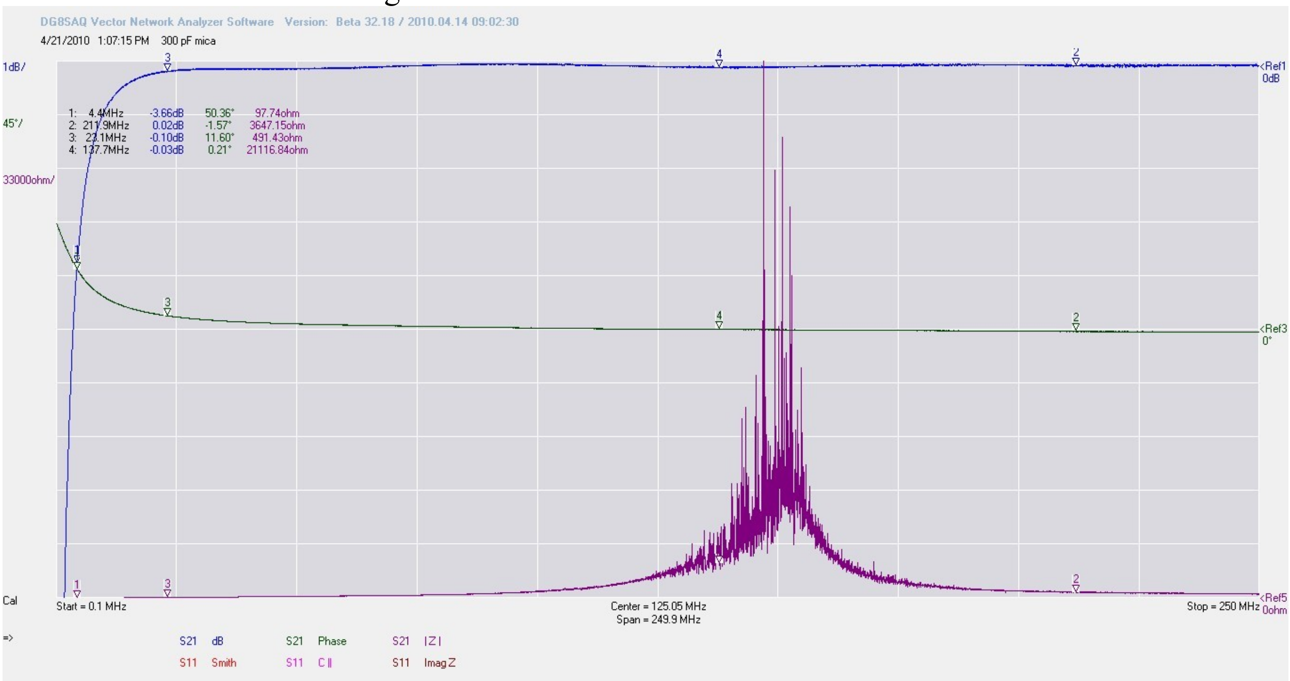


For that, we do a S11 measurement. I added some traces this time. Important is the green one, Phase. Do not forget to remove the RX cable and place the short instead.
Again we choose a point around 45 degrees to measure capacitance. You see it is 17,76pF. The pink trace shows it too and you see it stays within 1pF over the whole sweep. In the smith chard you see the trace follows the outer circle like it should. So no losses. But are they all that good ? You wish they were.....

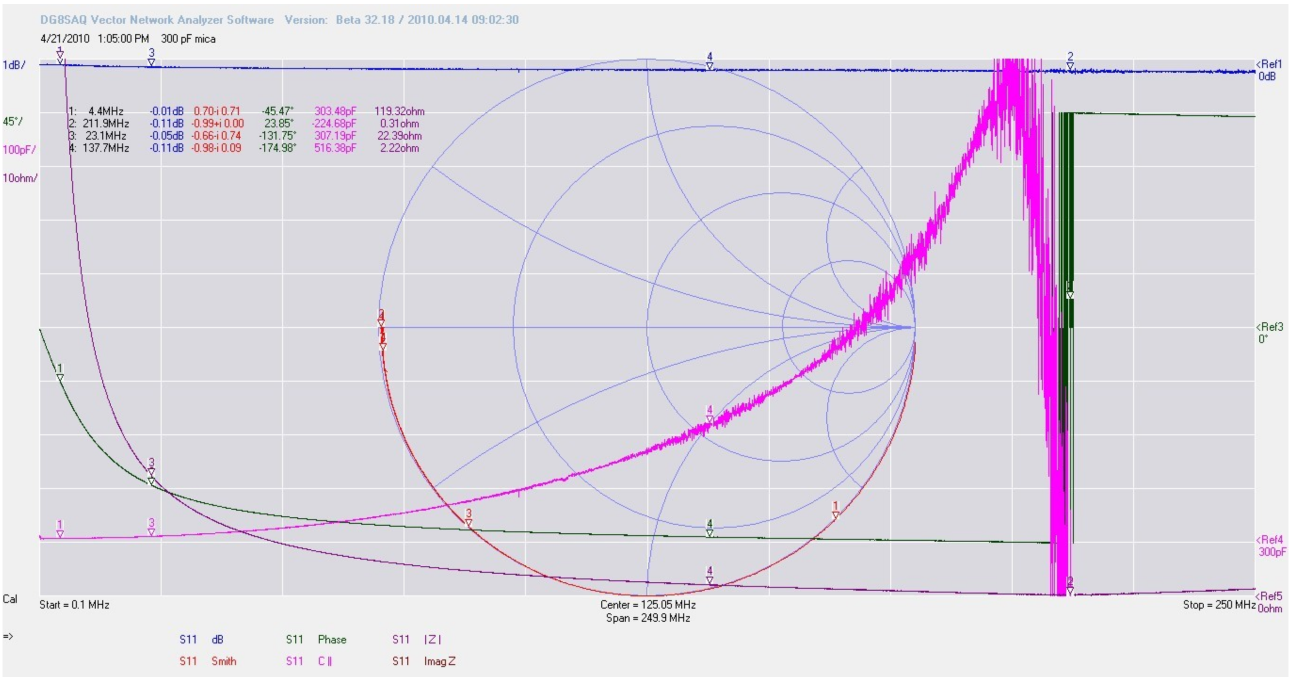
Silver-Mica
300pF mica capacitor.



Before WW2 the most used capacitor in HF was silver-mica. In WW2 there was the problem that these things came from the USA. So the Germans developed a ceramic alternative. The company set up to produce them was R&S. So after our test with the ceramic one it is now time for it's grandfather. The problem with the mica's is that they are huge compared to most ceramics. The one I used has flat leads to reduce inductance. The leads I used are almost as short in this case as with the first test. But there are longer internal leads here.



The S21 trace looks good. The phase tells us there could be an issue above 130 MHz.
I added a |Z| trace here. This shows we indeed can expect some bad things to happen. Let's examine after an S11 measurement.

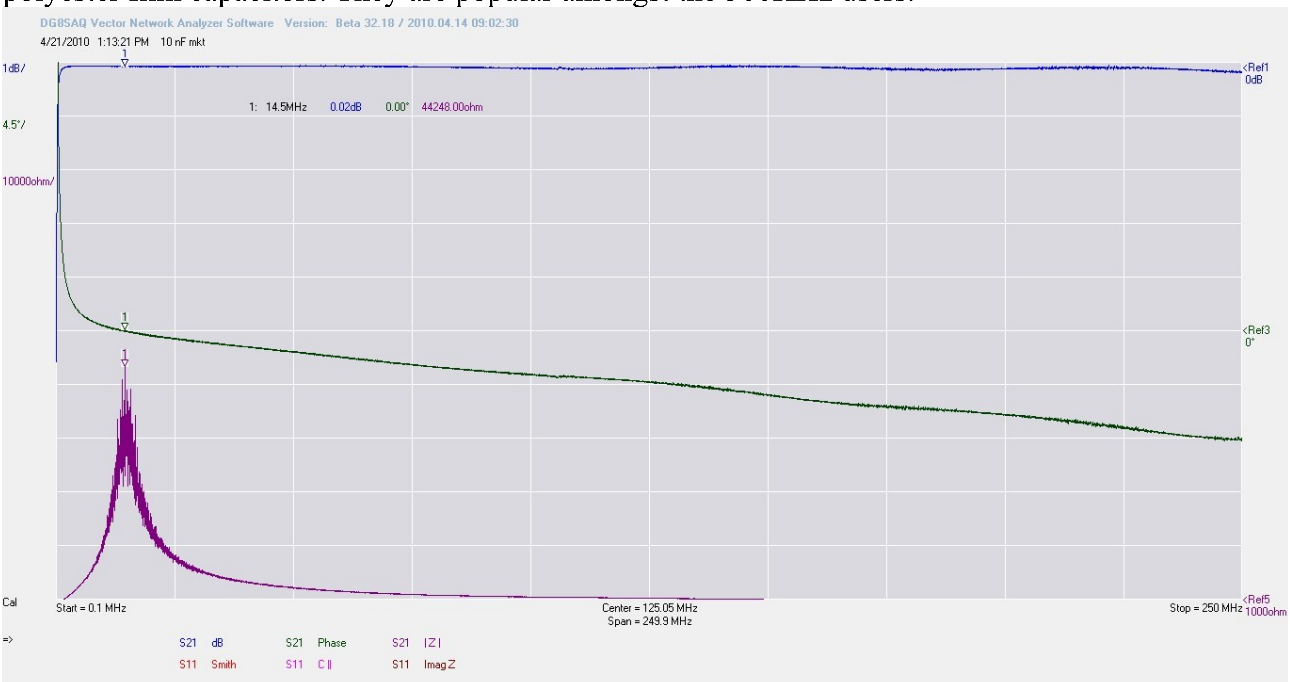


After this picture we have no question marks any more. But here we see another interesting thing. We measure capacitance at 45 degrees , 303pF in this case, but if we look about 90 degrees up streams we see 307pF. Between marker 1 and 3 the capacitance is almost the same. In smith that is a huge area, a quart of the circle, but in the sweep it is only 20MHz. Around 200MHz it goes serious wrong. First we see a rise in capacitance that goes much faster then |Z| lowers. So there must be something compensating the capacitance. That something is the inductance. You see around 210MHz a self-resonance. The smith trace also goes a bit inward so there are also losses. But it still follows the contour of the outer circle while going into the inductive area. So there is some parasitic inductance. For HF this still is a perfect capacitor but at 2 meters you do not want to use it.

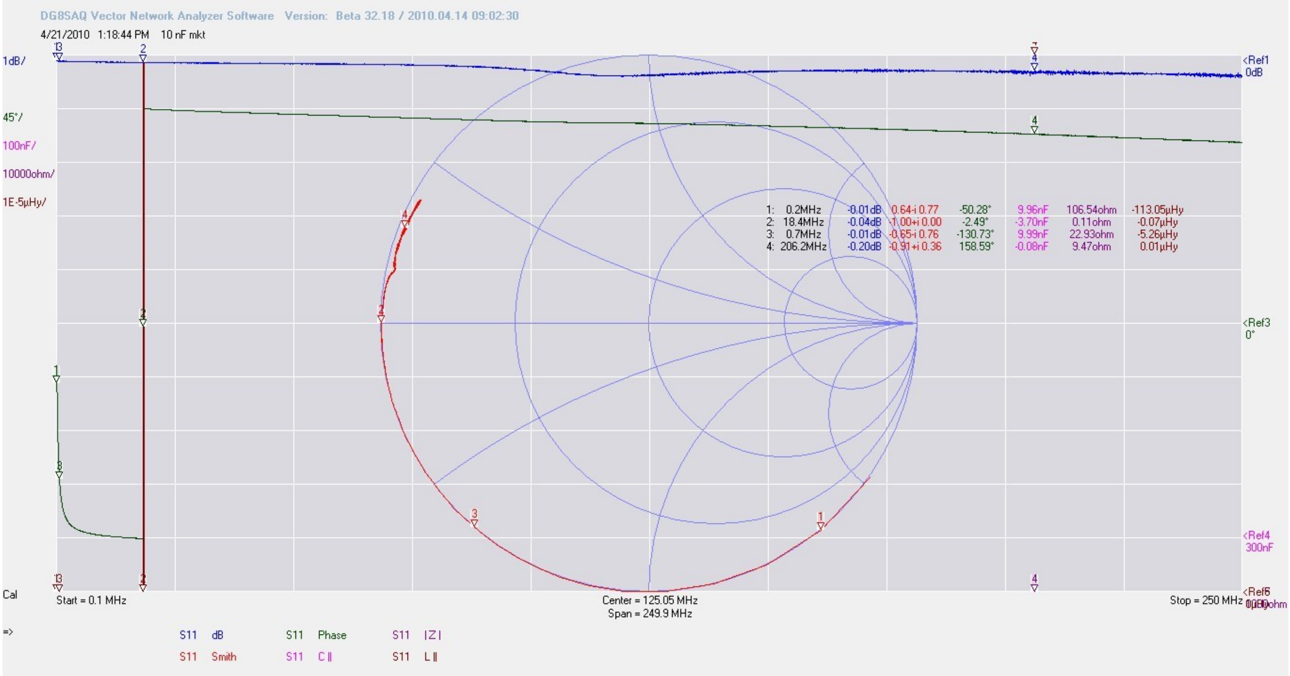
You would become paranoid from this sort of measurement but it is often a cause for strange things happening. Just consider the PA from an old tube transceiver like a Yaesu FT200 or FT101. Open the cabinet and look at the length of the wires used. There are mica capacitors inside with wires that are so long, there is almost no need to use inductors. There are fantastic stories about parasitic chokes. They must be made from exotic materials to lower the Q (yes, they worry about the Q of an inductor parallel with a resistor) or it has to be plain silver to lower losses and all possibilities in between. Resistors should be inside the choke or just besides it or the choke should have some magical shape that will work in all PA's. Welcome to the wonderful ferry-tale world called HAM radio. But take a look at the long wires before and after the choke, the wires towards switches, and ask your self the question, what is it's purpose and for all, what hidden dark forces are here at work. Then make a solution that works in **your** case as a result of good measurements and good interpretation of the data.

MKT capacitor

The next I show you in detail is a 10nF MKT, the well known square colourful plastics, metallized polyester film capacitors. They are popular amongst the 500KHz users.

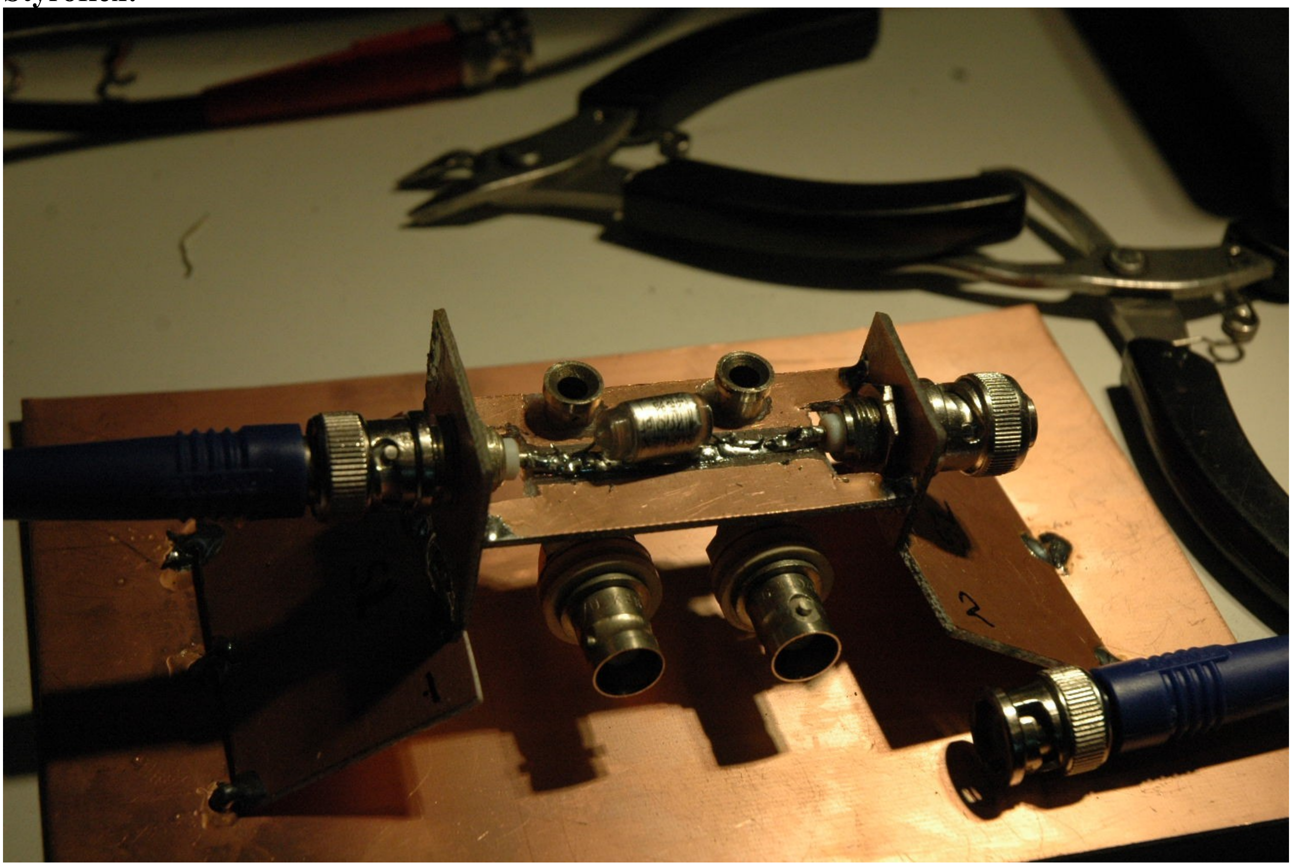


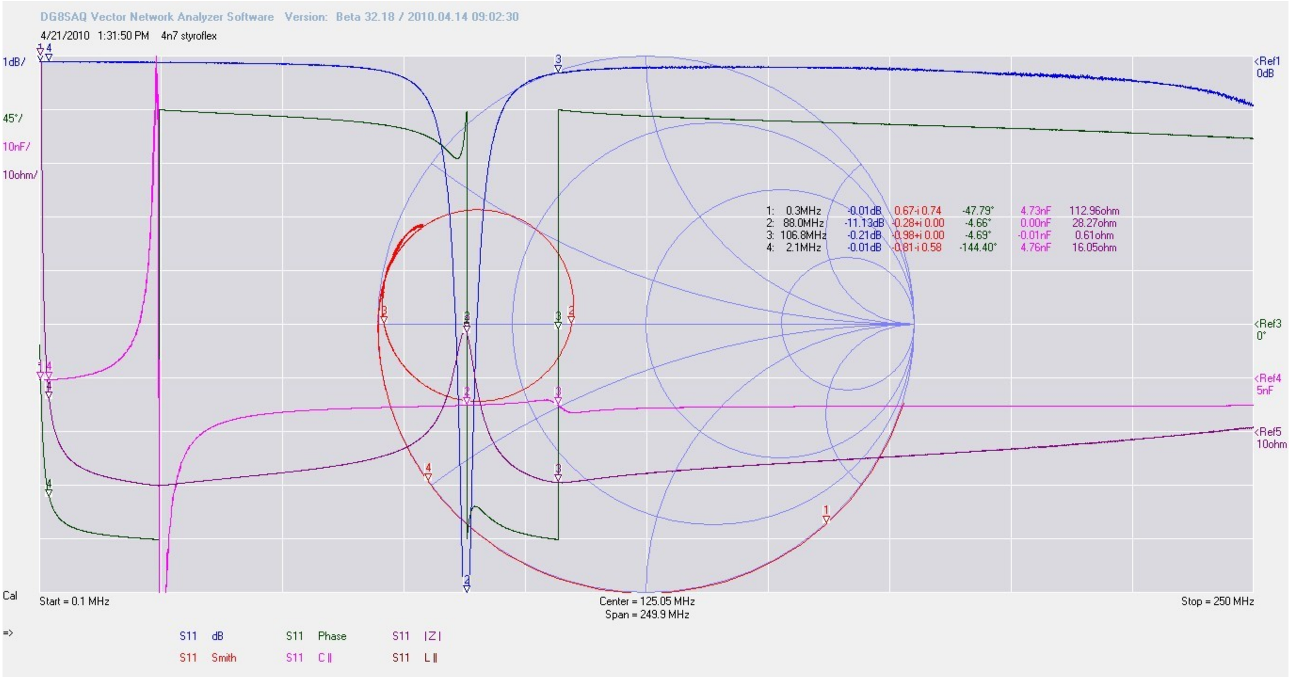
The S21 traces I show every time are just to get the feeling. Normally they are not always interesting. But if you use a capacitor as DC blocker or a coil as RF choke this is good info. The only thing that is important there is that it blocks DC and does not attenuate the signal more than should be according to their reactance. Suppose you use this one above for a PA, working at 20 meter. DC will be blocked perfect, no doubt about it but the AC will see a |Z| around 44Kohm. Wow, nothing will comes by that any more. But wait, in that case the loss must be shown by S21. Damn there goes theory. The attenuation is only 0.02dB. But look at the phase. It goes through zero degrees, So there is resonance. In this case a capacitor in series with some inductors. Let examine it by the S11 measurement.



First look at Smith. Marker 1 (and 3) show an almost perfect 10nF at -50 degrees. No losses, just perfect following the outer circle. But at 18MHz it is over. A big resonance jump and our capacitor becomes a lossy inductor. Just for the fun. Look at marker 4. The |Z| is here 9,47 ohms at 206MHz. If it was an ideal capacitor its Xc should have been 0,08 ohm. It shows an inductance that is 0,01uH. At this frequency this is an Xl of 13 ohm. The trace is also inside the smith diagram so this proves there is also a resistive loss too. Together they are 9,57 ohm. You can use the marker function (double click on the S11 blue trace marker to open the info box or ad some traces and look at real Z and imaginary Z to find out how much R and how much xj are involved.

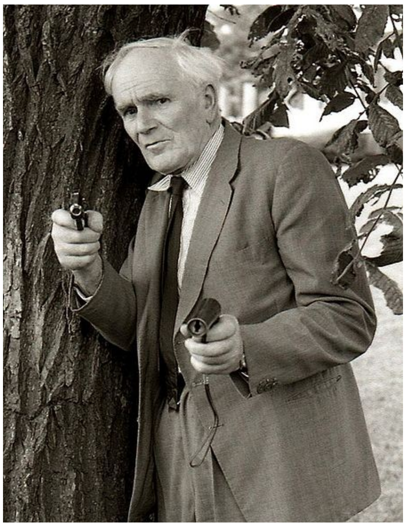
Styroflex:





To close this chapter I added a S11 sweep from a 4n7 styroflex. Here you see multiple resonances. And two resonances next to each other. But look at marker 2. Here it is pure ohms. A perfect induction free resistor with a value of 28,27Ohm. But on HF it is still a very usable capacitor.

So now you know (almost) everything about resistance, inductance and capacitance. Time to combine some elements. Up to the wonderful world of resonant networks. Here we will take a better look at the mysterious Q, eddy currents and other magical effects.



picture: from the wiki

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