Chapter 6 Tuners

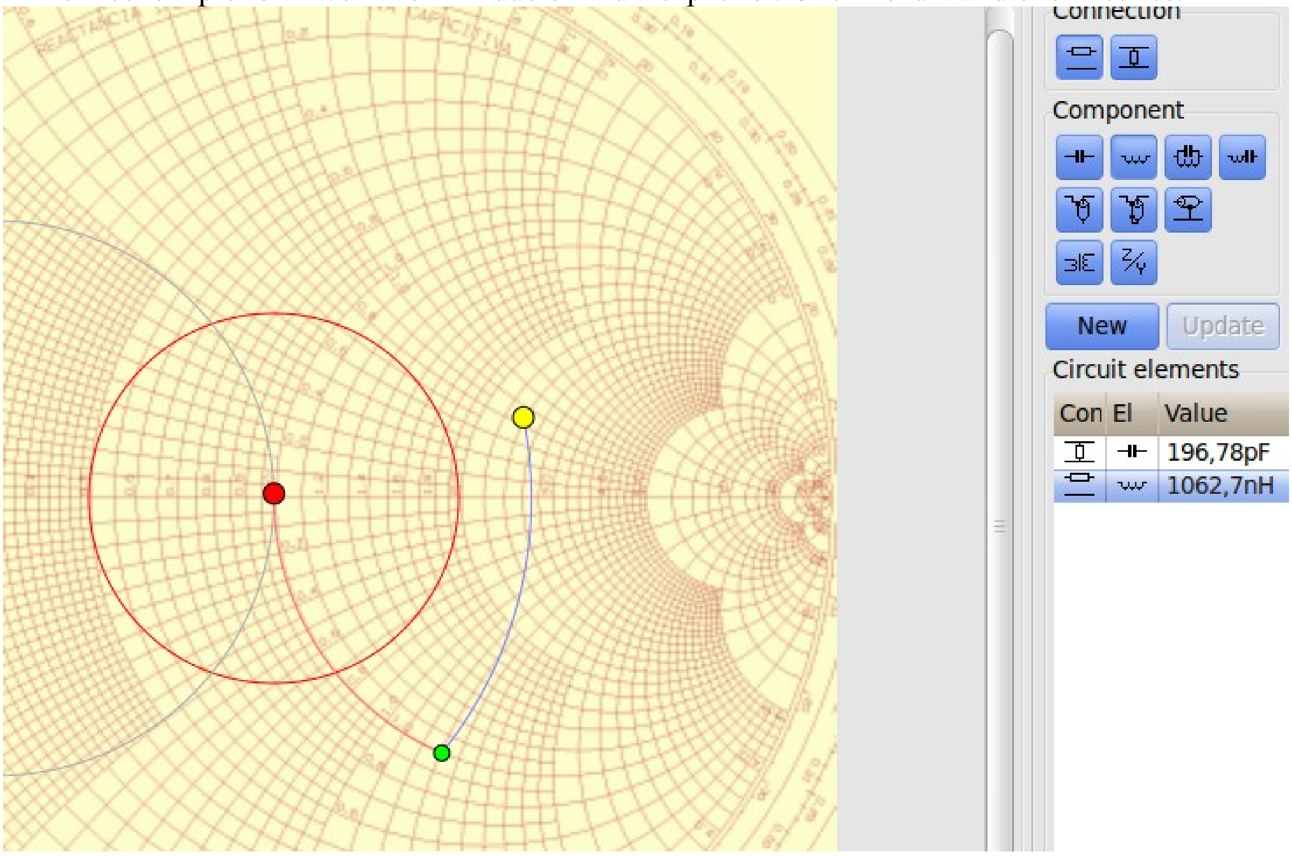
Because most users on the VWNA group are also HAM, I will do some chapters on HAM related gear. But not to worry, a tuner is something you use in most RF designs. A tuner is just a device for impedance matching. If you use an inductor and a capacitor between a filter and a mixer to match them, you also could say you use a tuner.

What do we want from a tuner ?

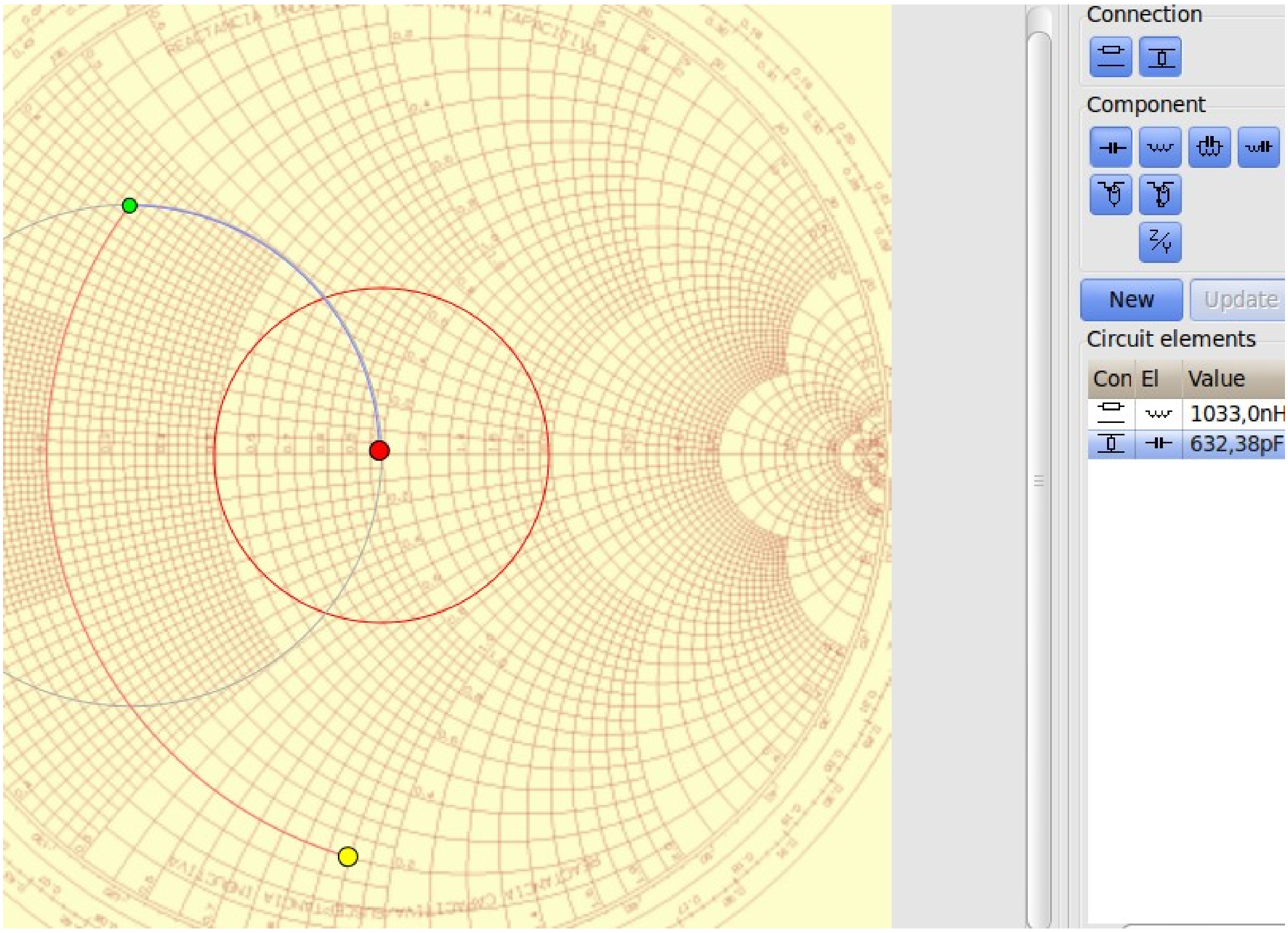
- impedance matching, sometimes as broadband as possible, sometimes for one frequency
- not to much transmission loss, you do not want to lose power in the tuner
- sometimes also some form of filtering, like being a low pass filter at the same time.

How is a tuner build:

In it's most simple form we have an inductor and a capacitor. One in shunt and one in series.

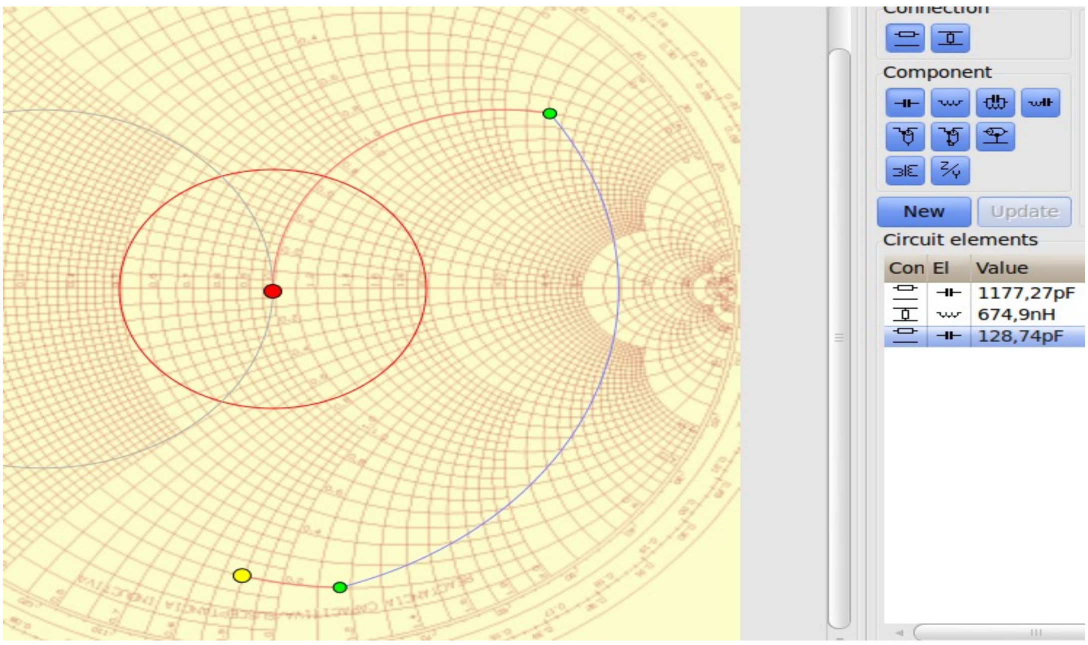


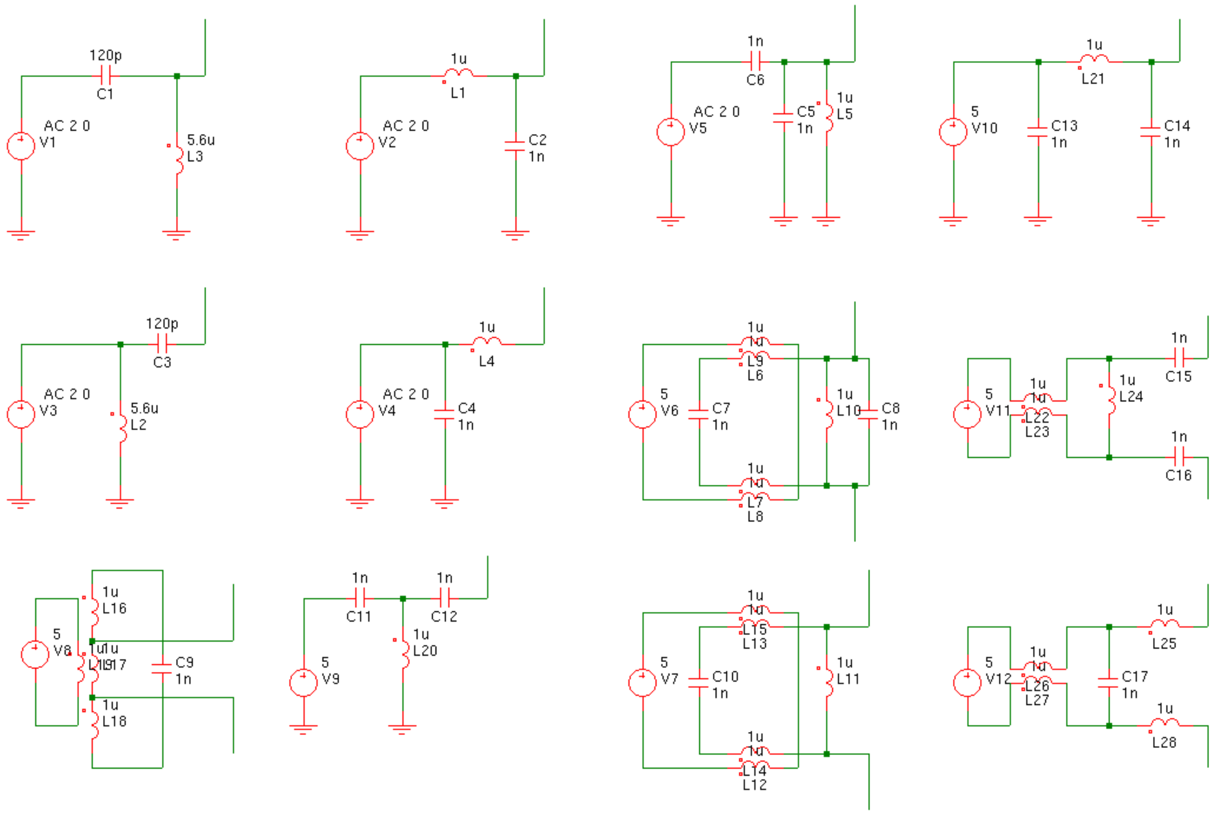
This is a smith chard view of a LC tuner. The yellow dot is the load. This can be an antenna. It is 120+j45 ohm in this picture at 10MHz. The Red dot is the generator at 50+j0 ohm. The series inductor travels over a circle of constant impedance, the shunt capacitor travels over an admittance circle towards the load. This is if we look from the generator towards the load. This is a simple L-tuner. Named L because the physical place of the two components form the letter L. The capacitor is at the site of the load because the load is high. If we take a load that is, lets say, 10-j45 we need to place the capacitor at the generator site, because now the generator is the high impedance. We get the following picture:



Yellow is again the load. The blue line the shunt capacitor, again travelling over an admittance circle, the red line is the inductor travelling over an impedance circle. The inductor has almost the same value, this is because the inductor only changes the imaginary part. It does not change impedance. The shunt capacitor changes the impedance. That's why it changes in value and in location.

In the HAM world most used tuners are T-tuners. (not because they are the best) Two series capacitors with a shunt inductor in the middle. There are numerous other ways to combine the elements to transform impedance. The following picture is a T-tuner.

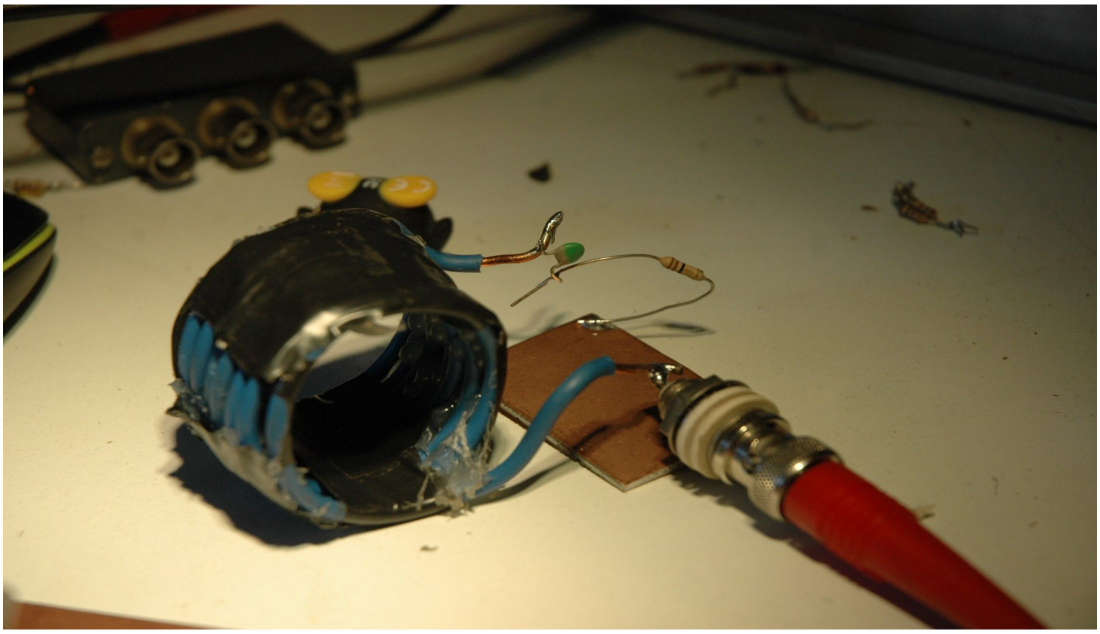




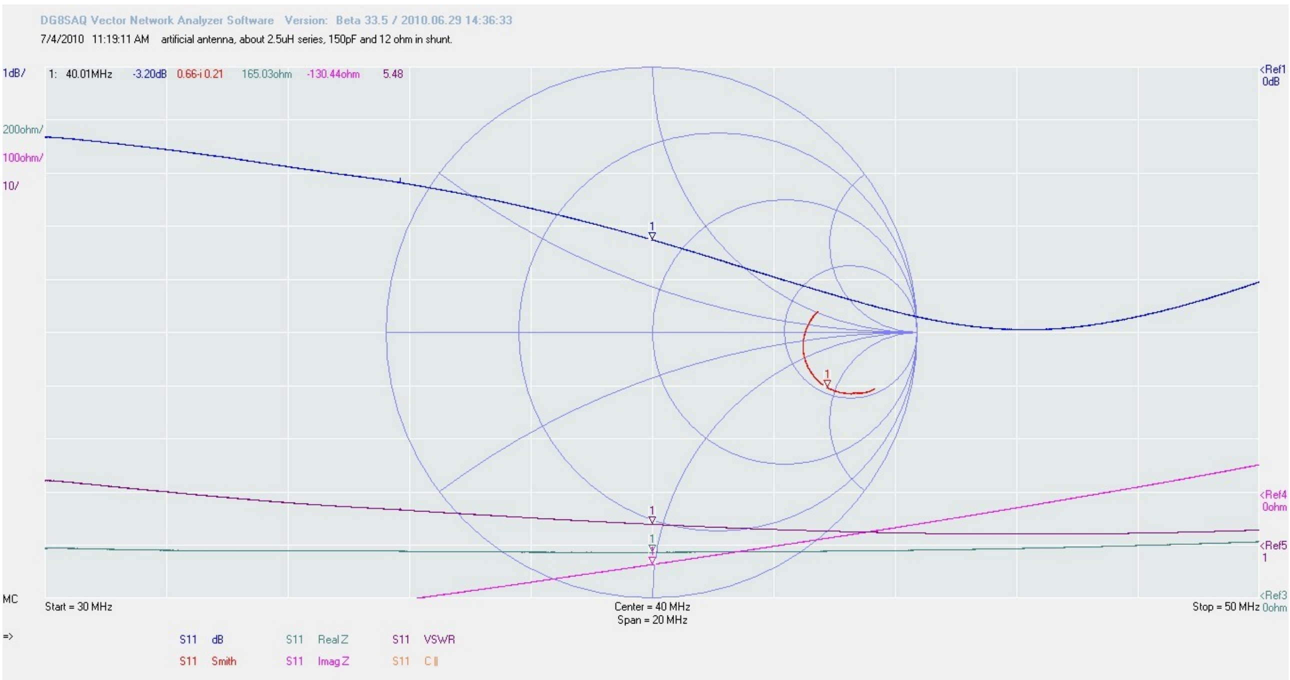
Here you see all sorts of tuner.

But how to choose the one that fit's our needs and test it. There are many, many lores about tuners so find out the truth and lets get practical. First we are going to look at the tuner action. This is something that is hard to show at pictures. The pictures above are made at a constant frequency and a changing component values. Our VNA changes frequency and we can manual change values, so you have to do the measurement to see the effect.

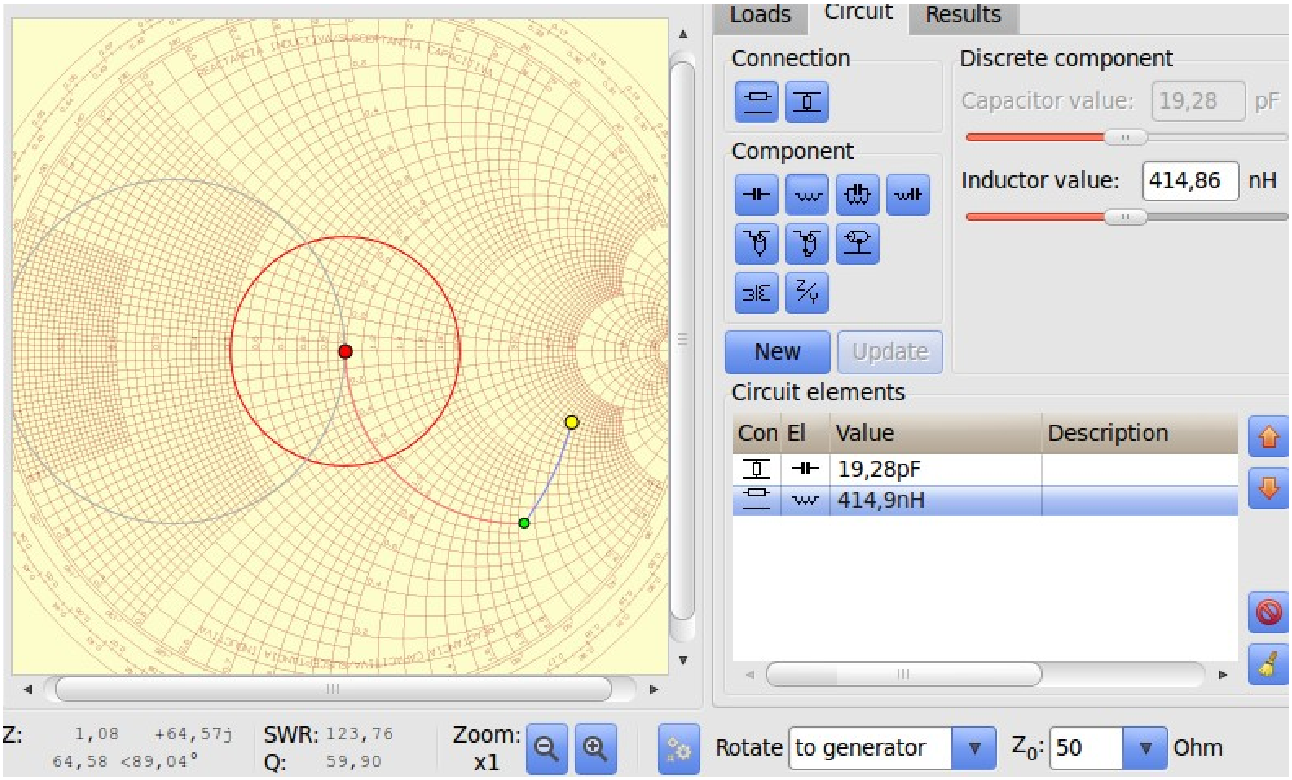
We first make a (complex impedance) load (an artificial antenna) . Take a small piece of PCB and solder a series inductor (our antenna wire) followed by shunt capacitor (the capacitance of the antenna towards earth) on top of a resistor (the earth resistance of a monopole) Do not worry about strays, the tuner will handle that. I used 3,7uH, 150pF and 12 ohms. Take what you got. Measure the parts, use a smith chard program or your (t)rusty calculator and you can make an educated guess about the values you need.



We will make a tuner for this, but this is a bit tricky. We need a coil which we can vary in value and we need a variable capacitor. The first is most times a variometer or roller-inductor, something not every one has in his junkbox. But we can make one from a small coil with a adjustable ferrite core. Not usable for transmitting power but great for our test. The value will depend on the AL value of your ferrite, the size of the coil holder and the amount of turns. How much inductance you need depends on the values of your "antenna" So first we will measure them.

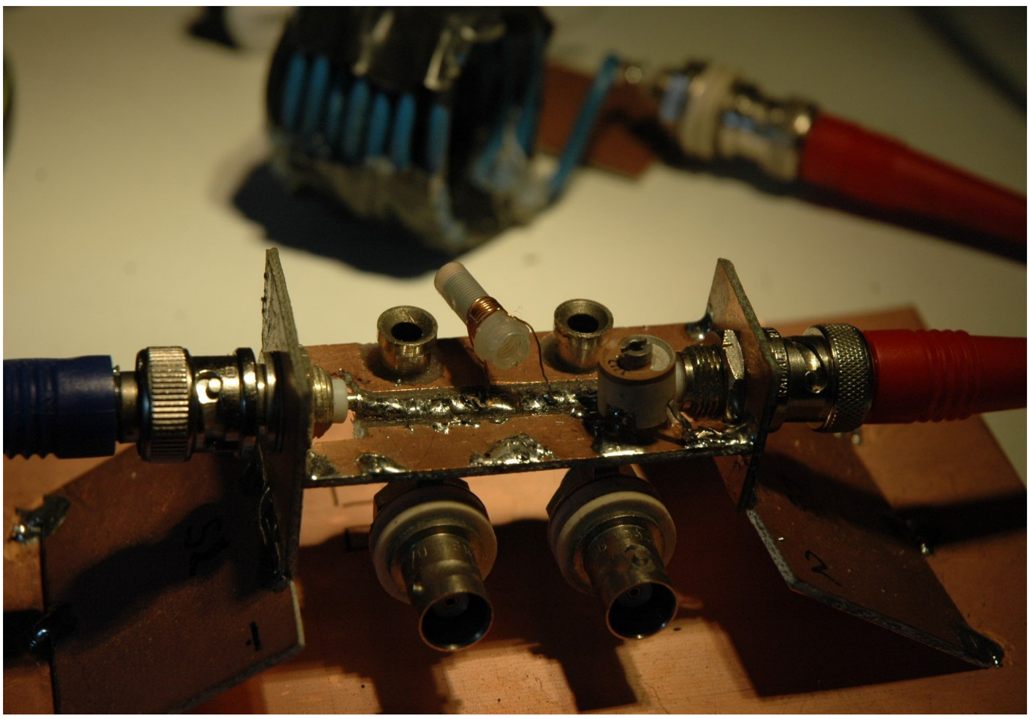


I random took a part of the spectrum where already was a little notch, in this case 30 to 50 MHz. This keeps component values small. The "antenna" has an swr of 5.48 so our tuners has to do an easy job. The antenna is 165-j130 ohm at 40MHz. So our tuner must have a small series inductance and a shunt capacitor at the antenna side. Lets simulate first:



So we need about 20pF and 400nH. But our tuner adds some strays in the construction so probably we need less capacitance and inductance. I just used the mastercall for this test. If you really must know parameters, better calibrate for use at 30-50MHz. The reference plane will be the end of your cable because the DUT holder itself is not important. Your real tuner will also be mounted at a pcb or other construction.

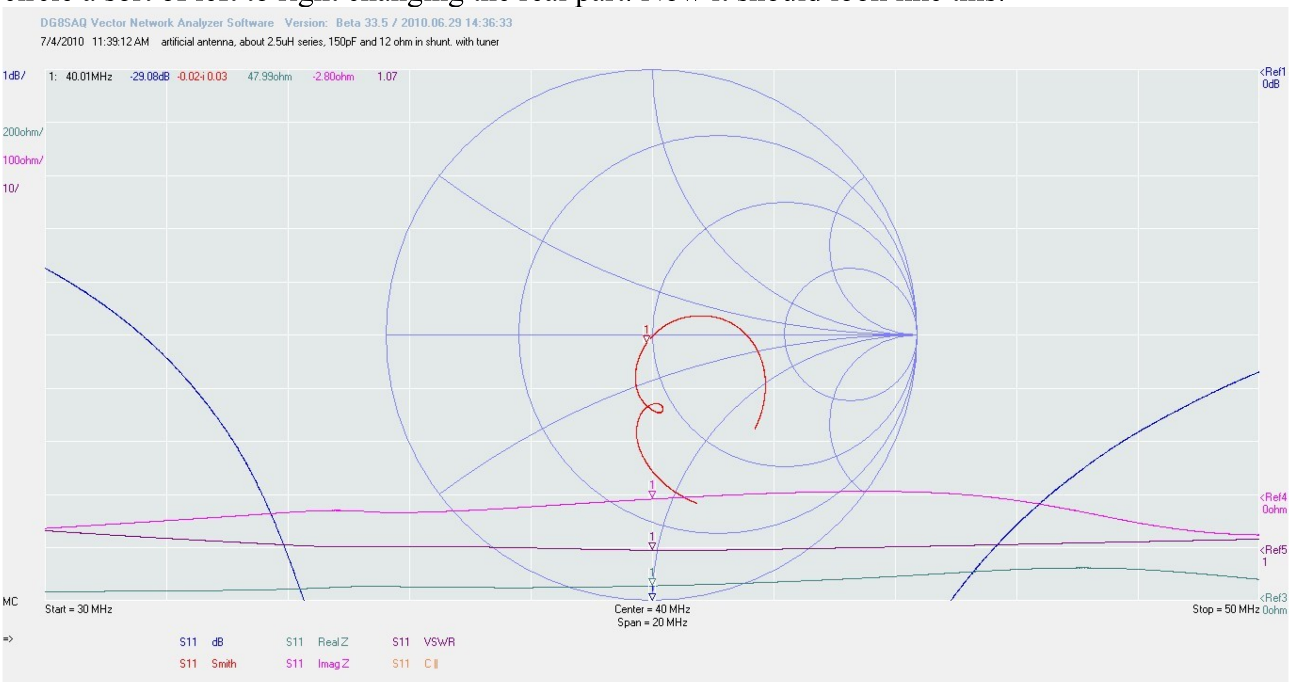
This is how mine looks like:



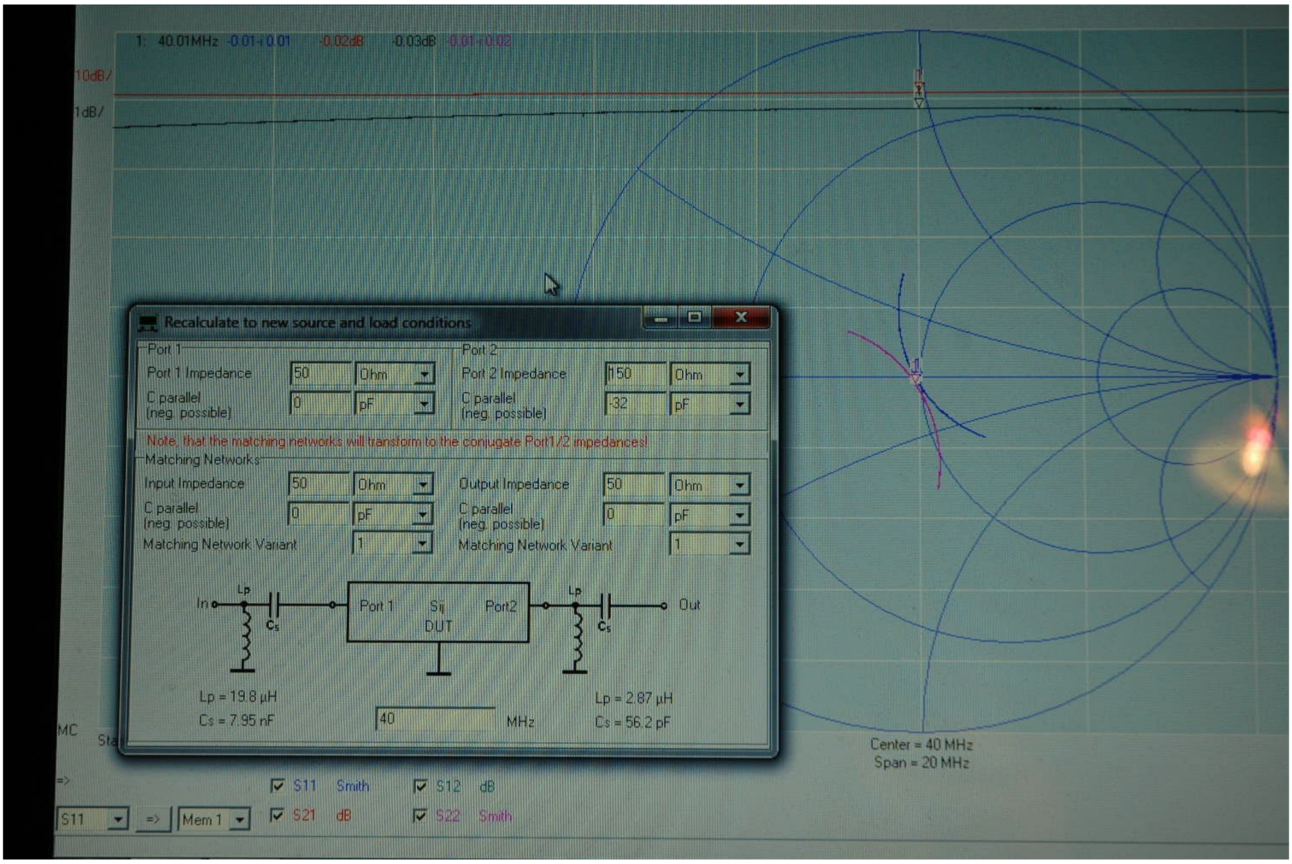
You see a small inductor body with 6 or 7 turns and a ferrite insert. It bridges the gap of the DUT holder.
The VNA is connected to the right, the Antenna to the left. Remember, the little cable between the Dutholder and antenna changes the impedance a bit. Just try different lengths, you will see.

This is something to take in account if you use long cables between antenna and tuner . So measuring at the foot of the antenna, making a tuner based on that data and then connect it after 20 meter of cable will give you a different result.

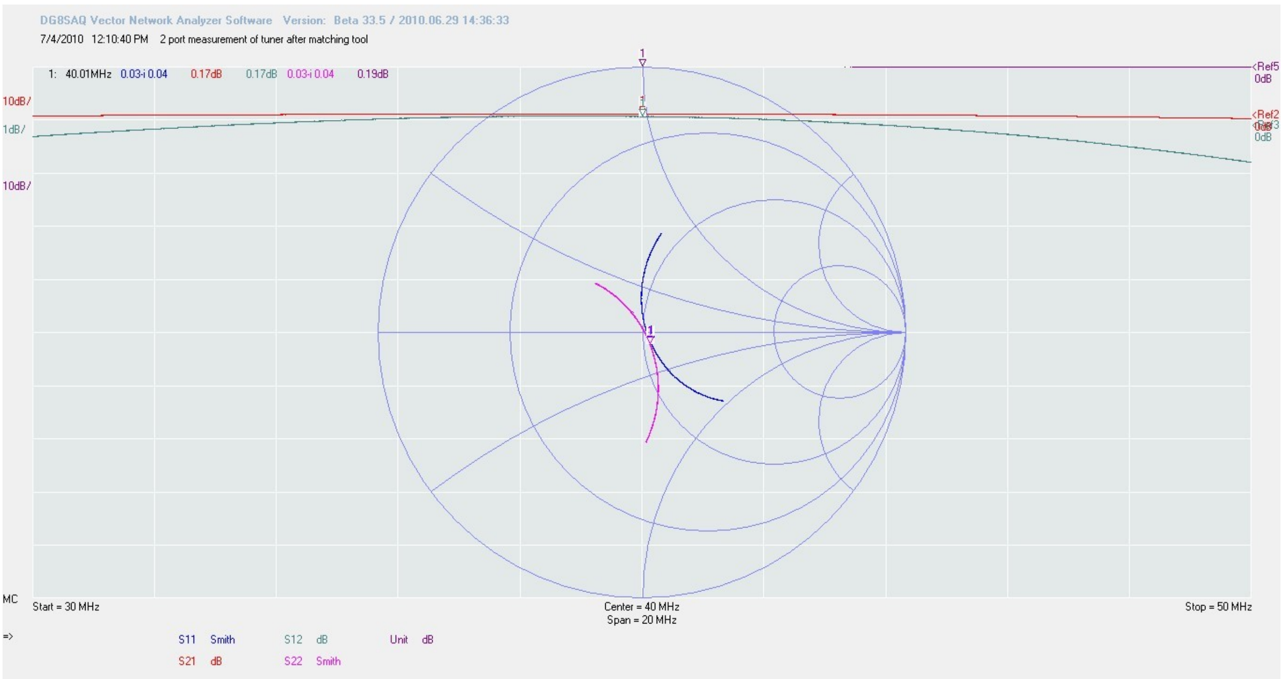
Set the VNA on sweeping with a not to slow sweep and tweak the parts until you get a VSWR of 1. Put a marker at 40Mhz so you see in the smith chard where you are going to. You have done it ? Cool isn't it. You see the smith trace circling towards the centre and you see the coil making that circle go up and down to correct the imaginary part and the capacitor shifting the marker over the circle a sort of left to right changing the real part. Now it should look like this:



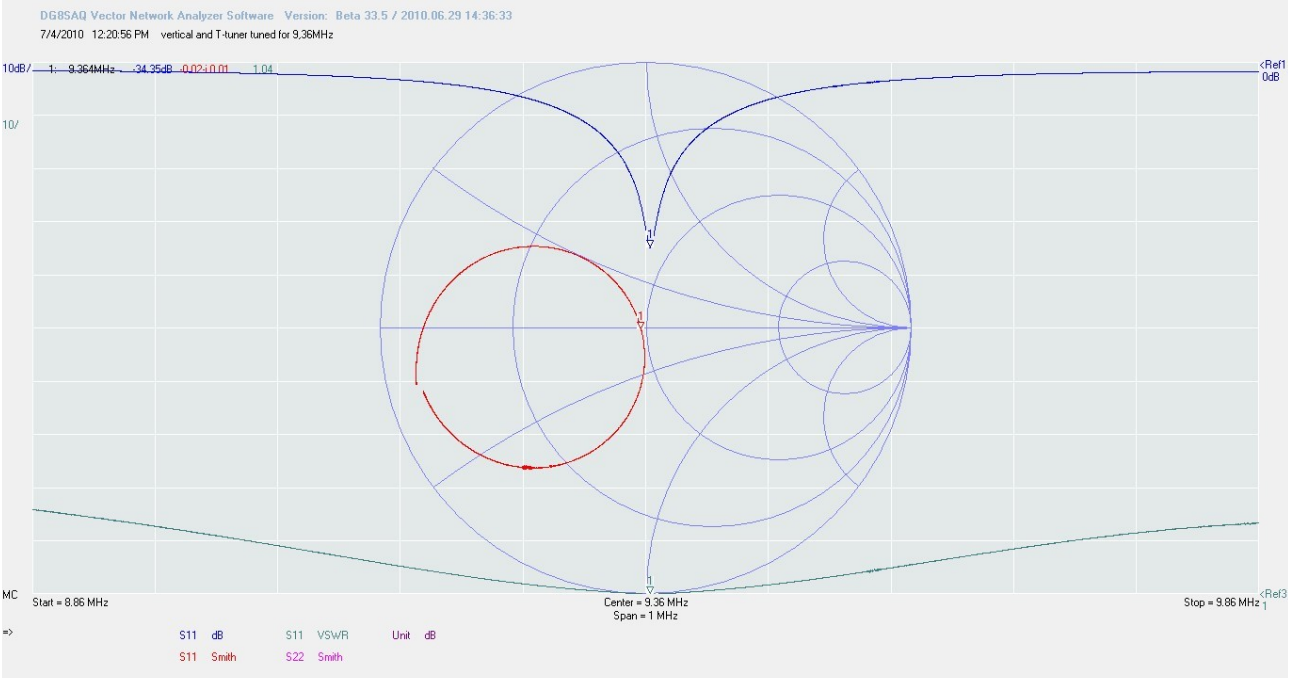
We have a return loss of -29dB that gives a VSWR of 1.07 so we have a good match. But is there some catch here ? You always here stories of tuners consuming all the available power...
No problem we just measure the losses. We connect the VNA to the in and output of the tuner and sweep. The results you get are useless. We now miss our load so there is a severe miss match. But our VNA has a very handy function we played with before, The matching tool. We first make a two port measurement. Then we open the matching tool menu and insert the values of our load. In my case 150 ohm and -32pF because the cable between tuner and load is not there any more. I forgot this because I made this picture later. If you use that cable you will see you use the same values as measured before. You see the two smith traces meet in the middle to show there is a match.



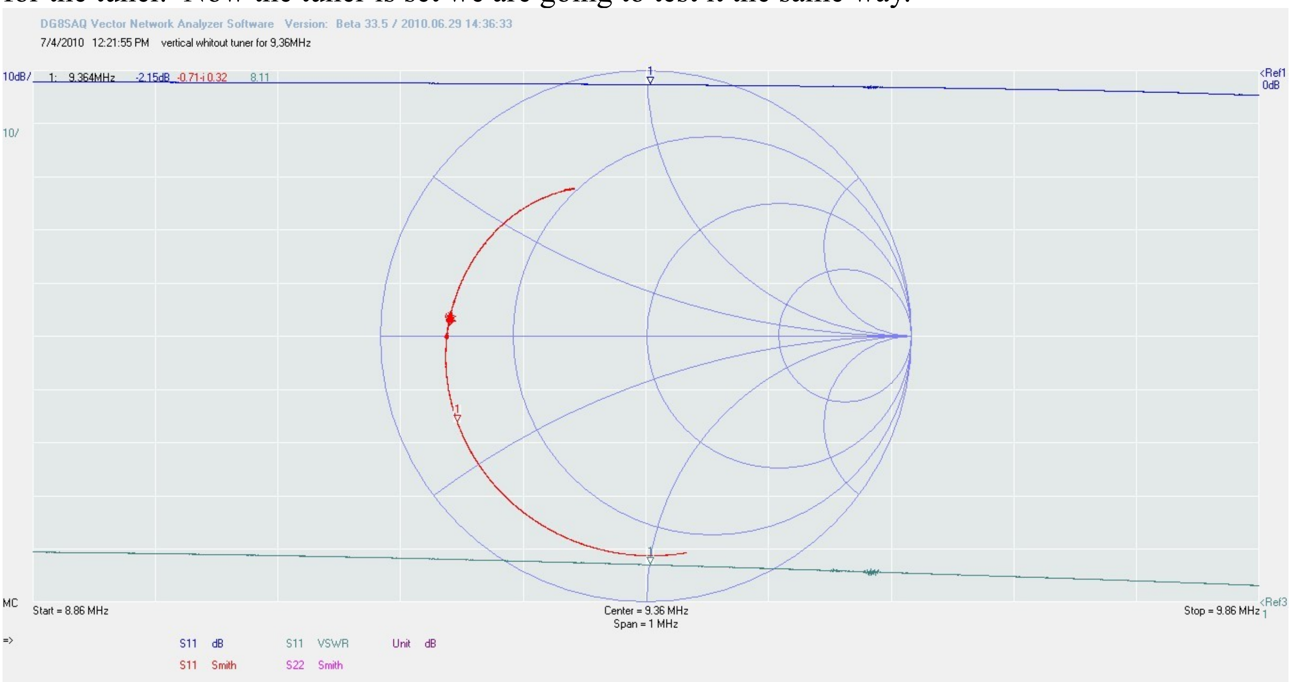
You can read the value of S21 in next screendump. This one is made the right way (the picture was done later to show the matching tool) and you see the tuner has a 0.17dB transmission loss. You can make a check by connecting the cables without the tuner and do a S21 sweep. The loss must be almost 0dB. In this case, if we would transmit 100W, the loss in the tuner would be around 4W. I bat you lose more in the cable towards your antenna.



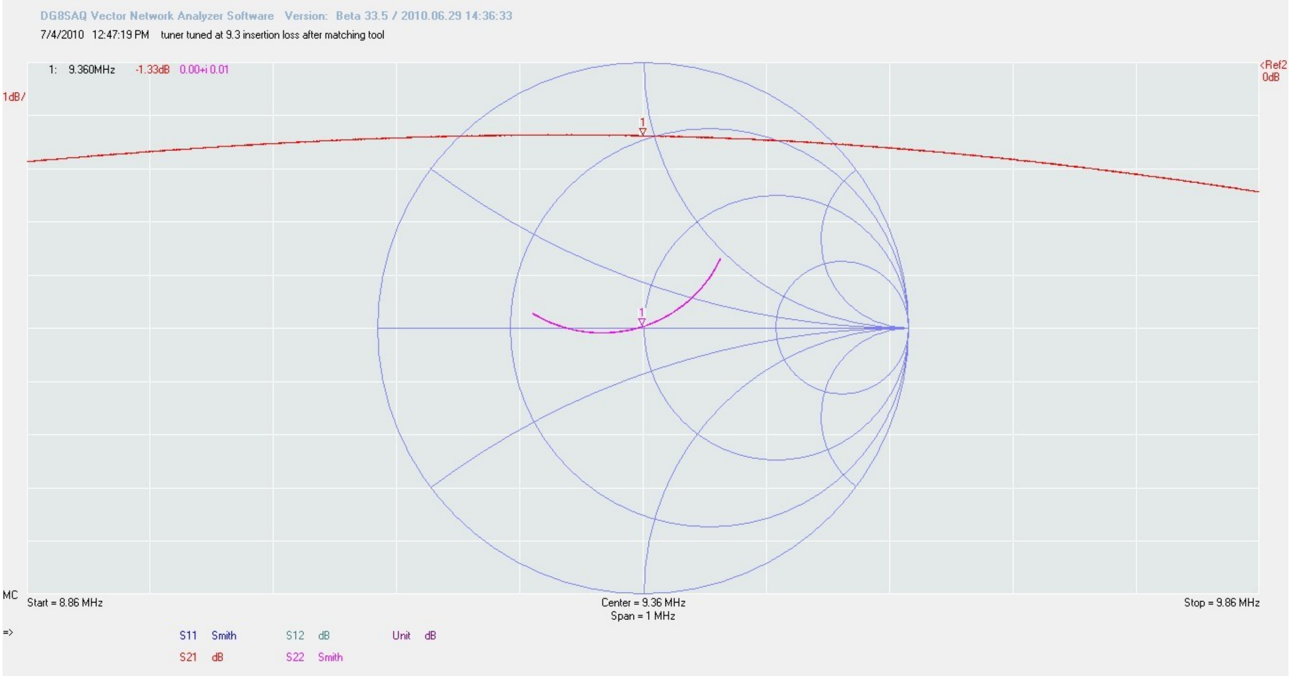
This way you also can test a commercial or home build “big” tuner. Next experiment is done on a MFJ T-tuner. It is coupled to my vertical and tuned for 9,36MHz. Why this frequency, why not ? :-)



It was hot and I'm lazy, so a random tuning gave this resonance. But also because the vertical is resonant at almost all higher HAM bands above 40m so I needed an impedance that was hard work for the tuner. Now the tuner is set we are going to test it the same way.

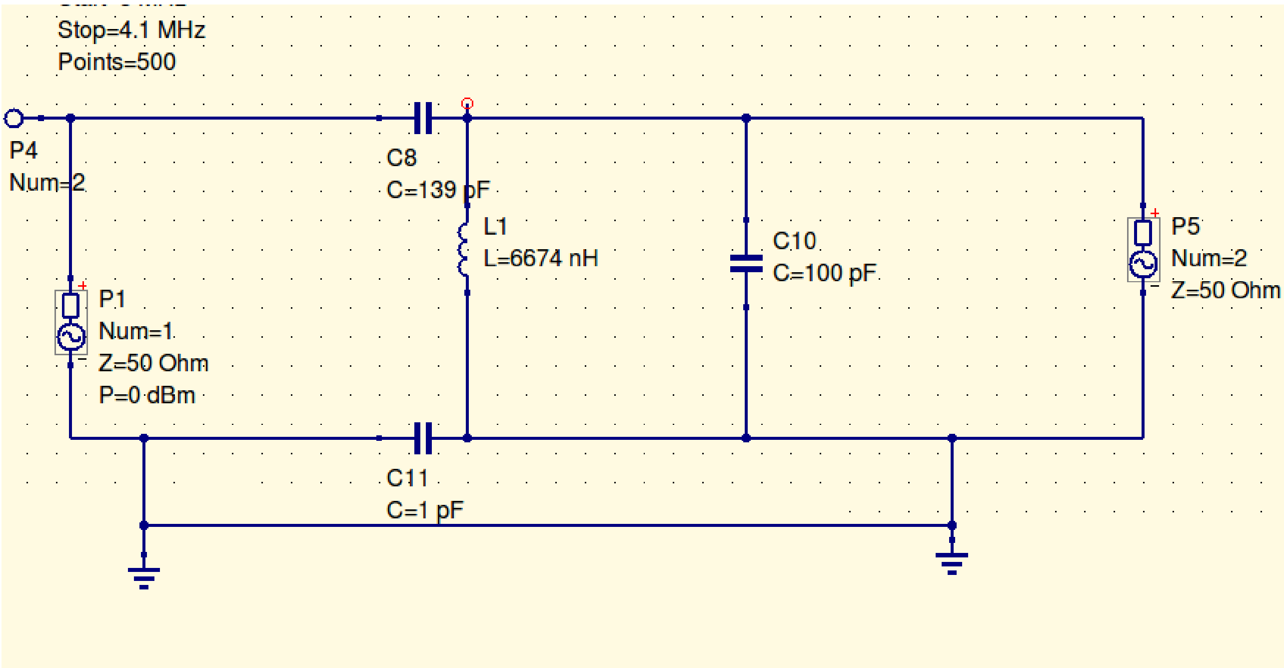


This is how the vertical looked without the tuner. A VSWR of 8. So not extreme but more then an internal tuner is capable for.



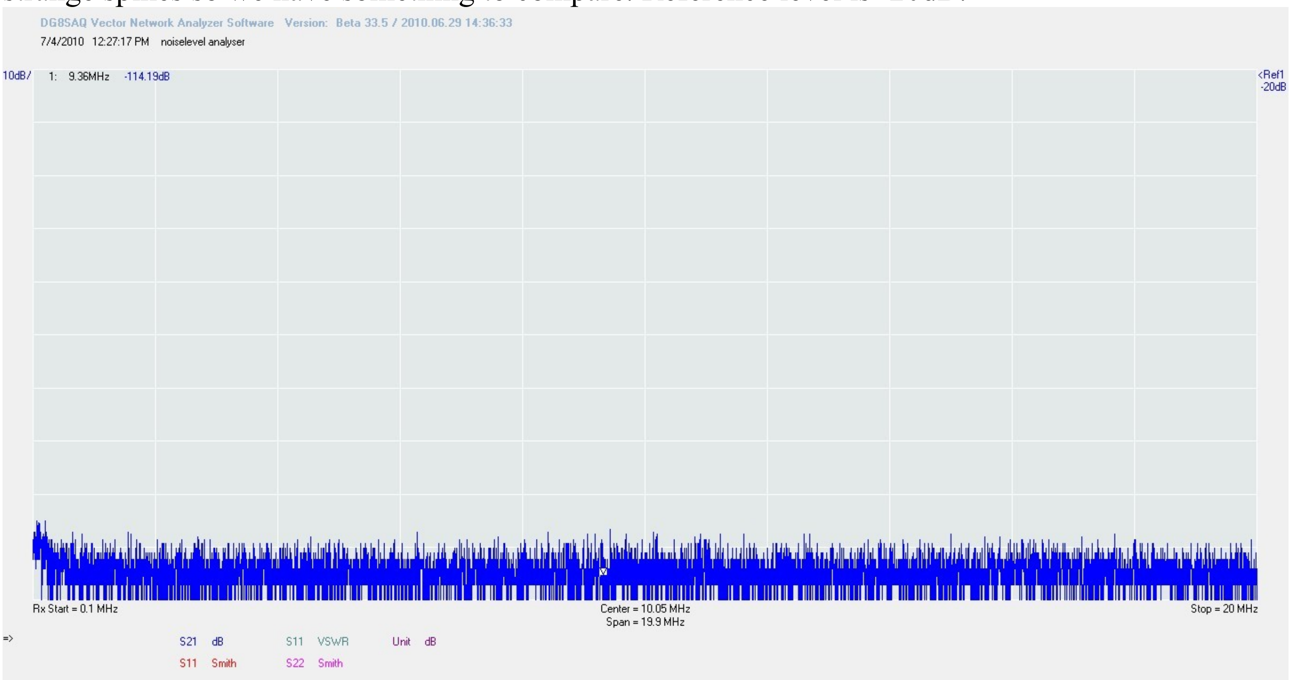
The tuner measured like before (VNA on in and output) and using the matching tool gives us a loss of 1.33dB.
This way you can measure the efficiency of any tuner. This will not say the MFJ has always a loss by this amount. It only tells you the loss is 1.33dB at this frequency and this antenna. For those interested I wrote an article about how a tuner works. It is on my site:
http://www.hamforum.nl/viewforum.php?f=48 At the bottom near the VNA chapters.

One word about symmetrical tuners. This is much more complex but can be done too. The problem is you have the grounds of the two connectors at the same ground level so the signal does a bypasses the “ground” part of your tuner. I made a drawing of this to make it more clear. A normal tuner is single ended. A symmetrical one is not but our VNA is single ended. A balun is not an option. But a 3 port measurement is the way to go. You measure it as a three-port device against a common ground. During measurements the unused port must be terminated with 50 ohms to the common ground. The tuner has 3 hot-pins. 1 input to the TRX and two outputs to the open line of the dipole. The input, being single ended, has a ground. The outputs have no ground. So the input ground will be your common ground for all three ports. Connect the unused port with 50 ohms to the common ground during the three port measurement. I will not go in to this right now. There is a good tutorial about this rather advanced method in the helpfile and the traces you get and the way to evaluate are no different as with a single ended (unbalanced) tuner.

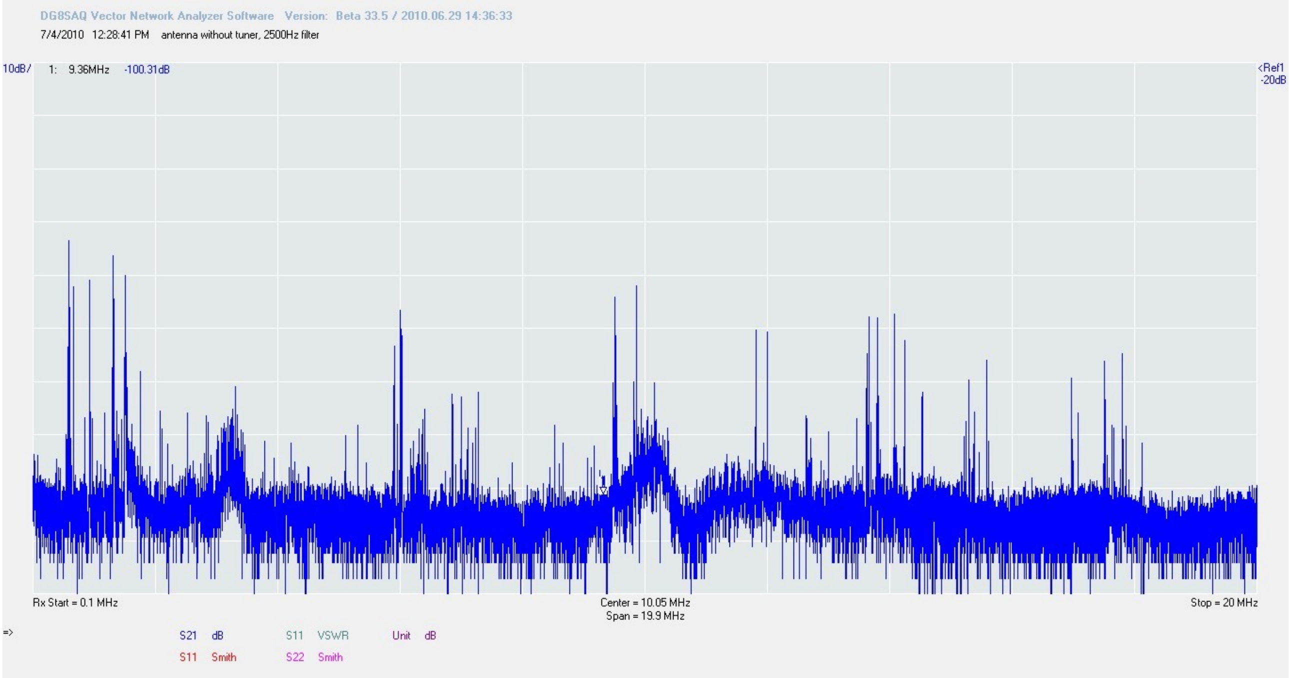


This is what you get if you try a 2 port measurement for a balanced (symmetrical) tuner.
You bypass the C11.

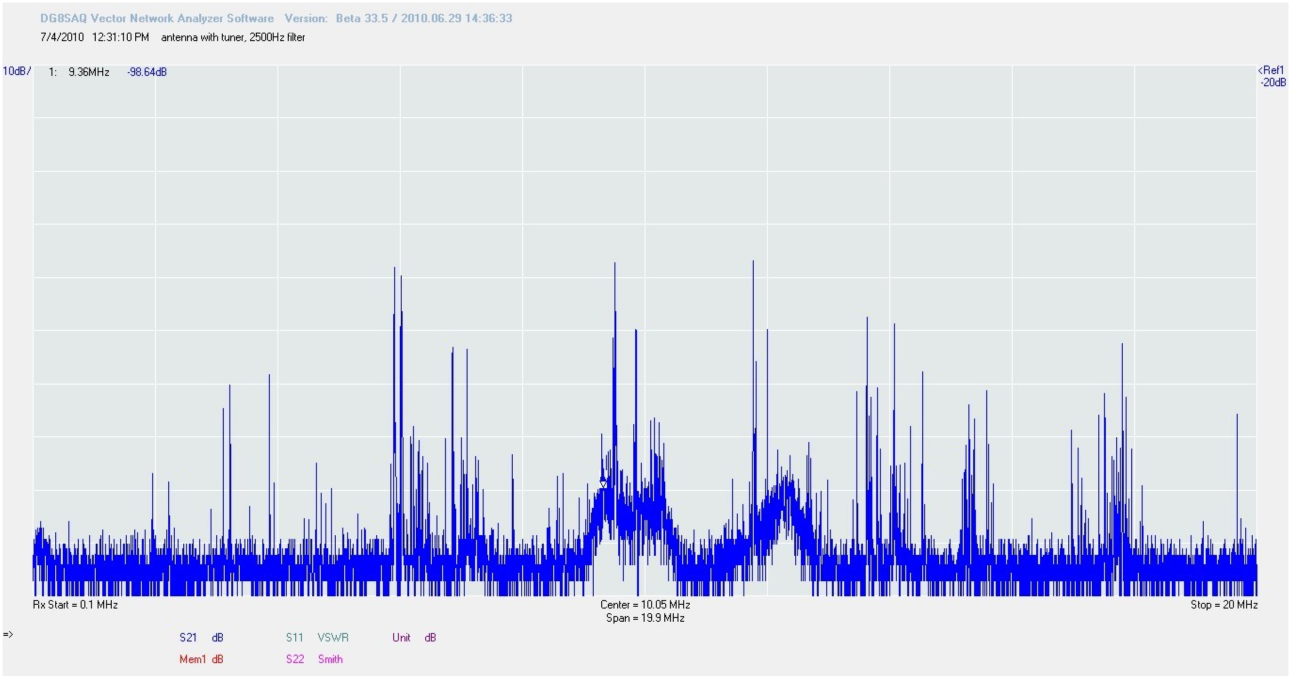
Some people argue about the use for a tuner while receiving. With our VNA this is easy to test. I used the MFJ tuner for this like it was tuned for 9.3MHz. The Spectrum analyser function is perfect for this. I connected the vertical to the SA (port 2, trace S21), selected a sweep and the 2500Hz filter bandwidth (of the 33.3 Beta version) First a check for the noise level: Better then -100dB, no strange spikes so we have something to compare. Reference level is -20dB.



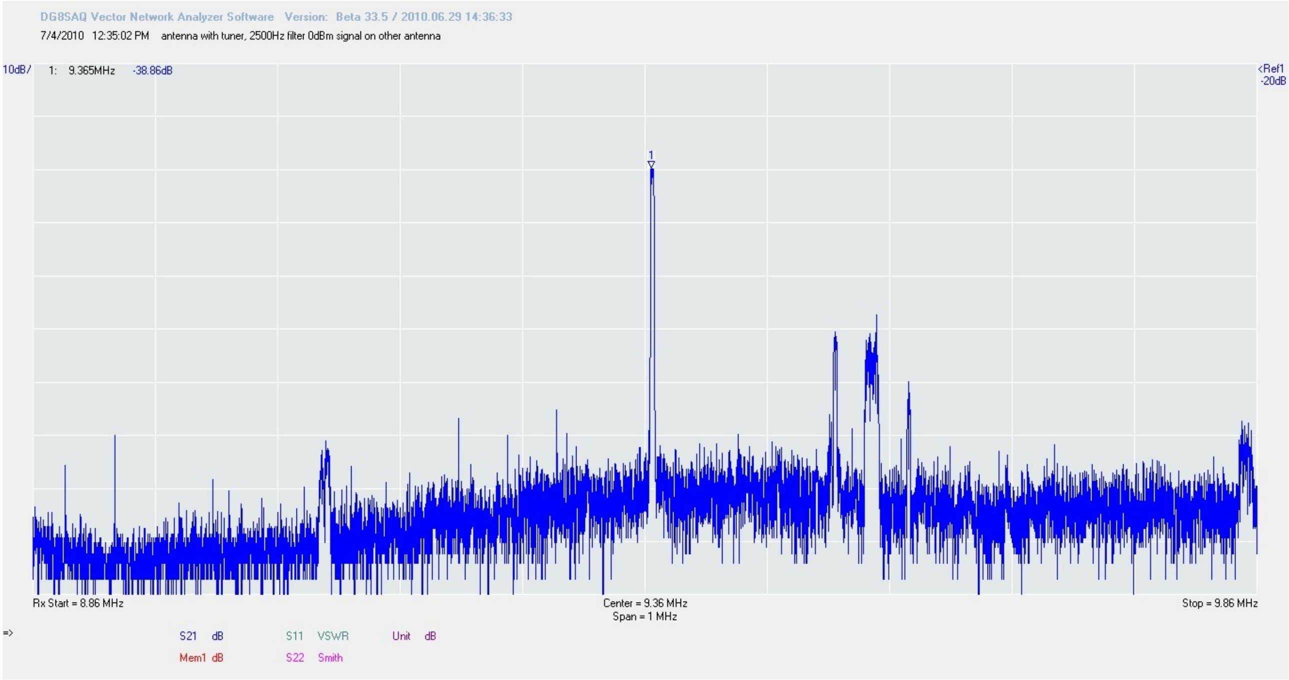
VERY IMPORTANT: coupling your VNA direct to an antenna, like I did for you guys this time, is not a very save thing. On large antenna's there can be a high static level and it is not a very good thing to discharge that into your VNA. So first discharge (short) your antenna to ground. Use a coupler or attenuator. The next chapter will be about antenna's and I will tell more about save measurements in there.



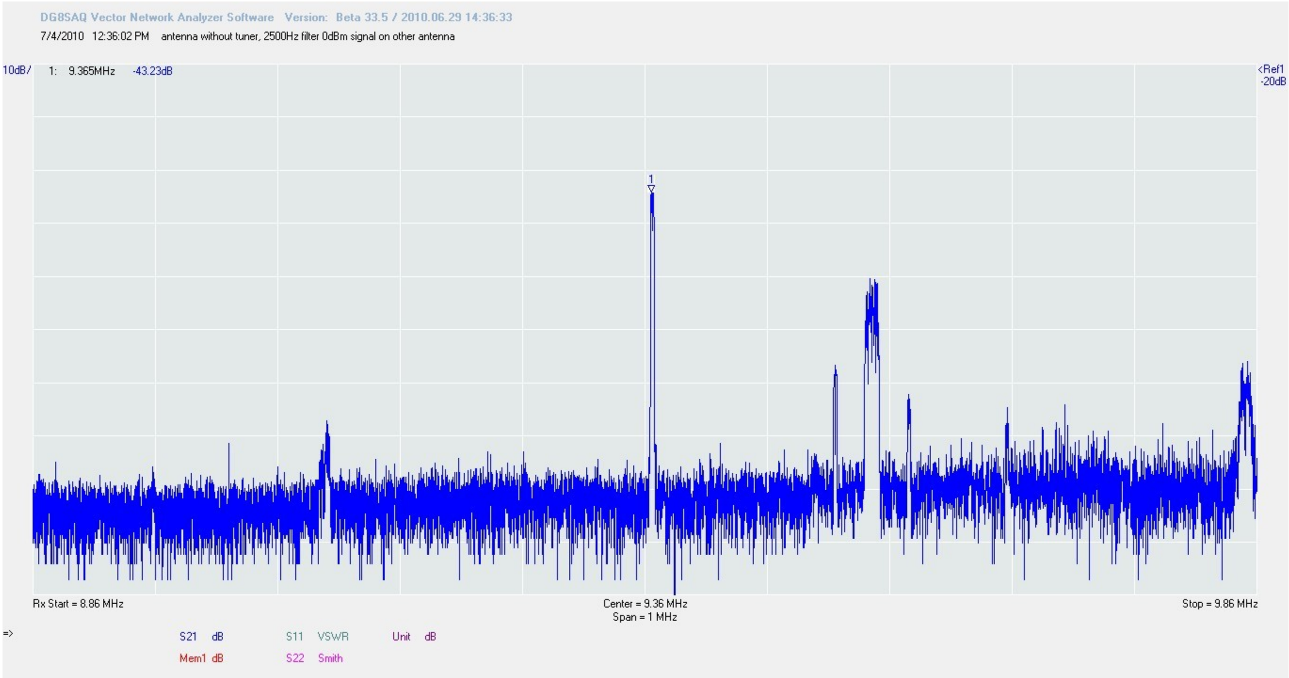
This is the first sweep. I did not use the tuner here. You see signals over the whole sweep. Noise level is raised to -100dB. Lets look at the effect of the tuner.



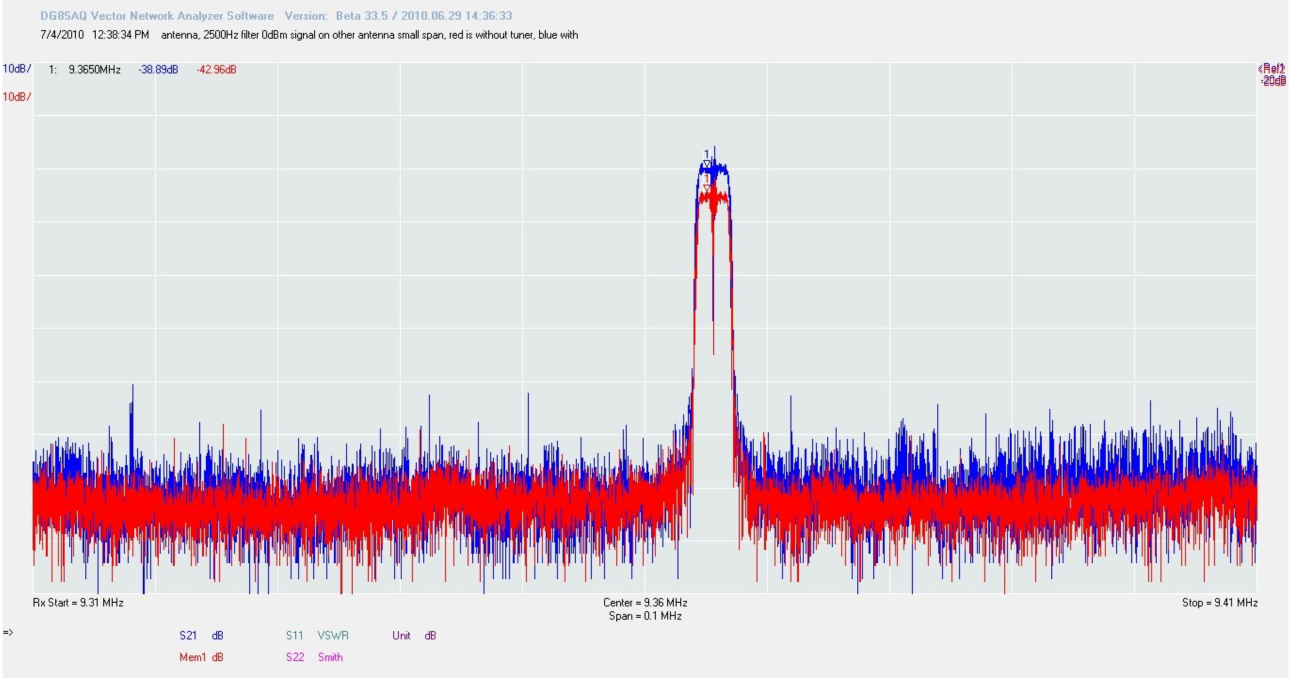
First thing you notice, the noise level is now at -110dB. That is 10dB better but the noise floor of the SA is at that level too. This means the real profit can be bigger. If you look at the first part of the sweep you see all AM broadcast stations are now gone. The strength of the other peaks are difficult to evaluate by a static picture. The AM and SSB signals vary in magnitude so I tested this an other way. But you can see the noise level at the marker is at almost the same level as without a tuner. So the wanted signals are not attenuated.



To test the attenuation of a wanted signal I put a 0 dBm signal on my second antenna, a dipole.
I changed the span to 1MHz to better see the signal. This is with the tuner in between. -38.86dB



This is how it looks without the tuner. The wanted signal is -43.23dB. That is over 4dB loss.
Remember, 3dB is half the power !!!



Here the span is 100KHz. The blue trace is with a tuner, the red one in memory is without the tuner. So you see, a tuned antenna for receiving is not a bad choice. This sort of things are very good. Instead of discussing endlessly over these things, most time based on thing like, “I worked DX-rare with this antenna, so it must work like this for every one”, all though it is still better then the “it is true because I already was a licensed HAM before you were born”, you now can actually measure it. You will find out, many HAM's then still not believe you, but who cares, as long as you know.

Have Fun,

Fred, PA4TIM
5 juli 2010