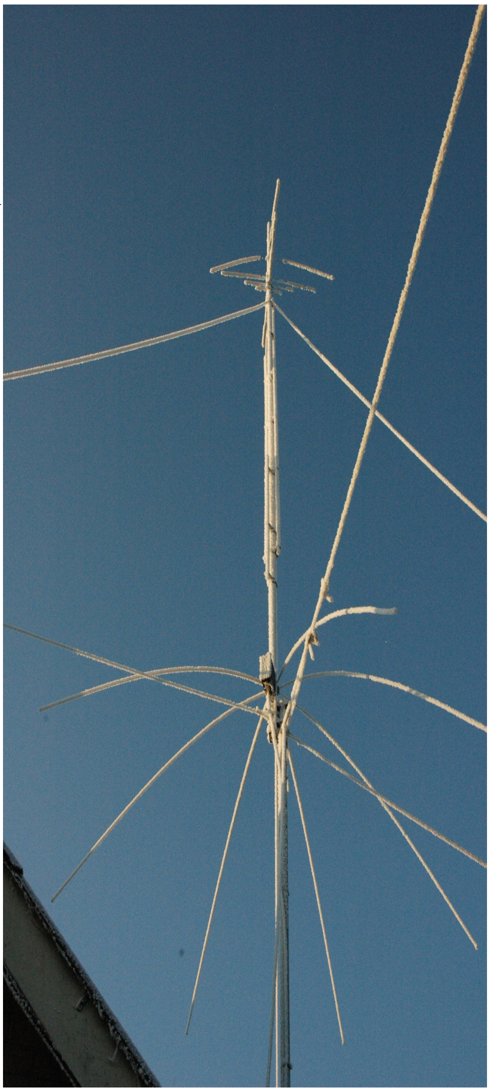
Chapter 7 Antenna measurements.

This is the reason I think the most HAM's have bought the VNWA. I must say, it is indeed a handy little device for this. But let I warn you. This takes a lot of the magic (or voodoo if you want) out the whole of building and testing antennas.
So if you love to run around an antenna, naked, under the full moon after ritual sacrificing a virgin (deep-frozen ones or fresh), while cutting pieces of wire and looking at strange mechanic devises (like things with a moving meter) and doing you magic hoping you get it right then do not read what comes next. I'm not responsible for mental damage after the shock. It can cost you some friends too. Most times oldtimers and experts in antenna voodoo that contradicts the laws of physics.

You will see antennas are just simple things with known parameters that do follow the laws of physics. You sweep, look at your screen and you see why it is not working. Sounds a little boring :-)

Warning
But serious, first a real warning (not only for the lawyers in the USA) Your VNWA is a very delicate device, antennas can be dangerous because they can have a big static field or pick this up at any moment from the atmosphere. This risk is proportional to the size of the antenna. On my dipole (51 meters) I have seen sparks jumping between the feeders of my antenna. Most times before a thunderstorm but also once under a blue sky with one little cloud. I was working at my tuner and the feeders were hanging to my arm. I got a shock. It scared the hell out of me. I hung them away next to a grounded cabinet. Then I did see a spark jumping over (about 2 inch). A few minutes later a thunder-strike and that was all. But that could be just enough to kill your VWNA... or you !!!

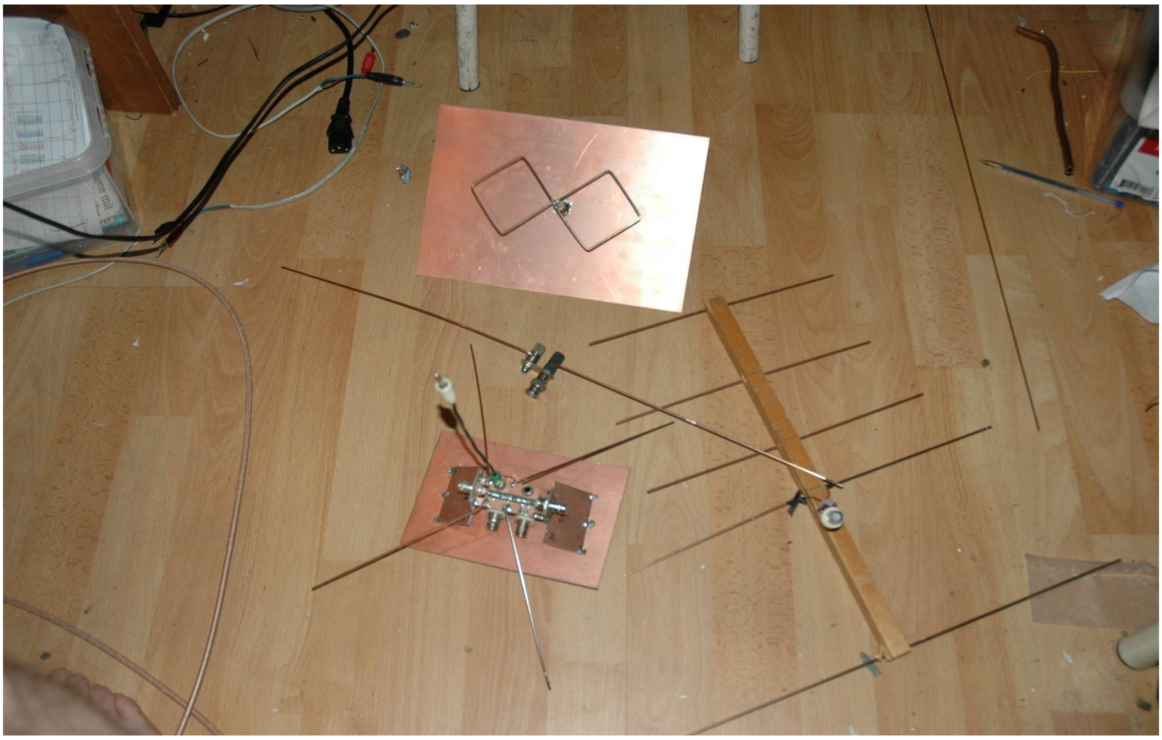
So be sure you know the weather forecast if the antenna is big and outside (they usually are if their big)



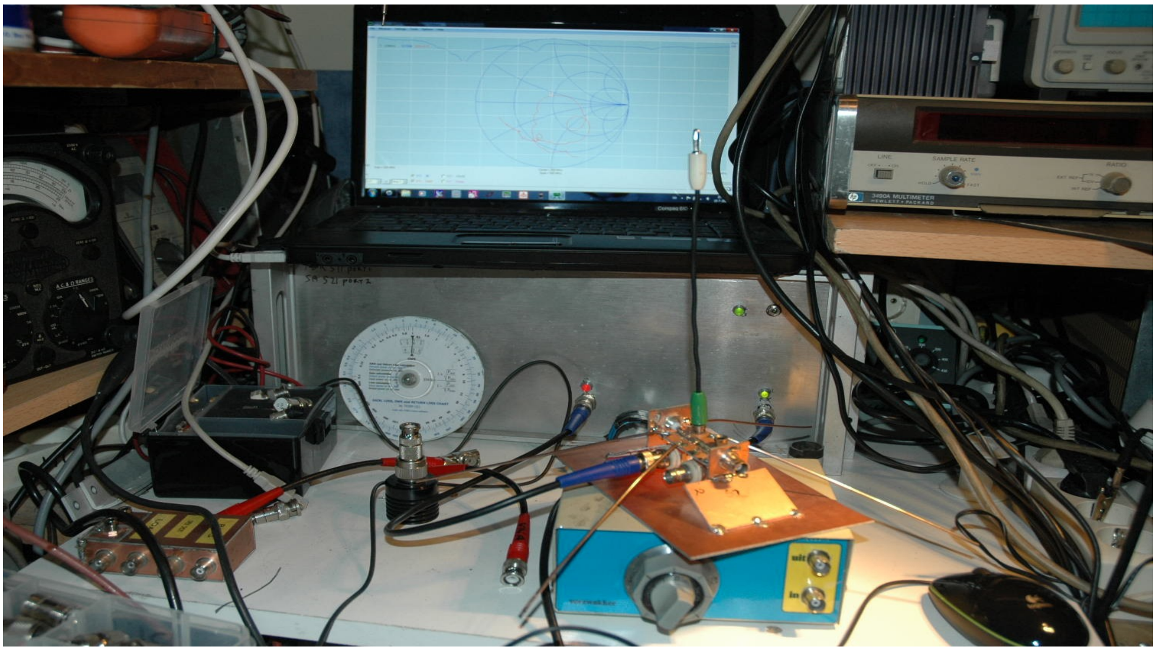
This is not a tutorial about making an antenna or what is the best antenna. I do not care about that. There are plenty books and every situation is different. You will soon be able to sort that out yourself (I hope)
But enough serious stuff, lets play.

A first simple measurement.

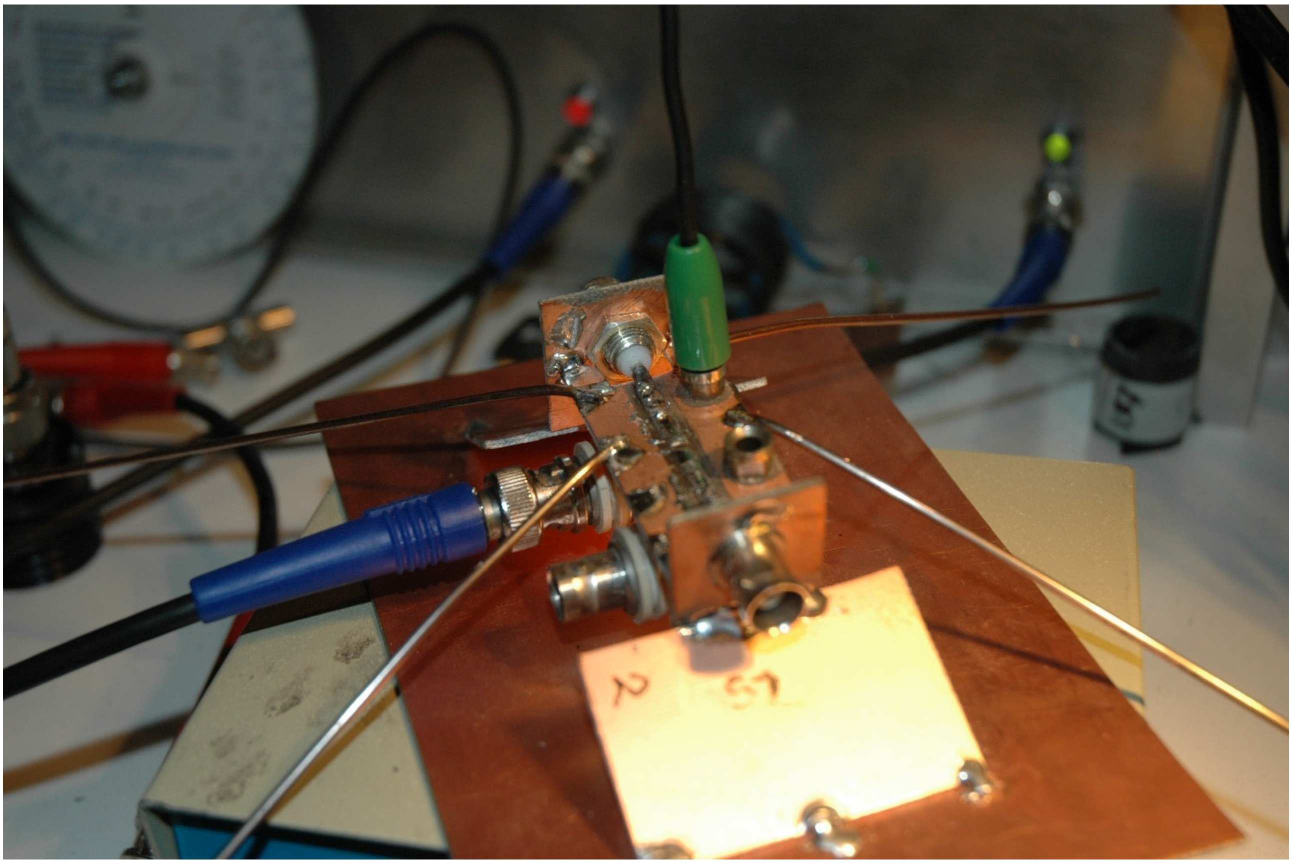
First we need an antenna. Make a small one, you can use indoors. I you do not have an antenna. Do not worry. Just make a simple dipole from a banana-bnc adapter or solder it straight to a connector. It does not matter. Do not worry about resonance and VSWR, a perfect antenna is no fun measuring. You can also make a small vertical groundplane. Just from copperwire and your trusty dutholder. Here you see some examples:



Make them short for, lets say 300 MHz or so. We use the cable that is part of our calibration so the antenna is at the reference level.



I did this experiments on this nice little DUT⁻plane antenna.
You see, the antenna is just a jump cable with bananas and 4 radials soldered to the DUT holder

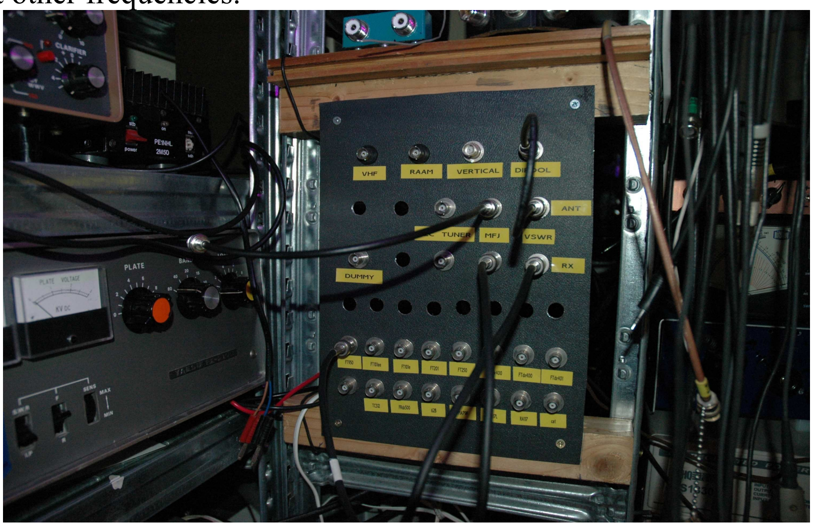


Some details.

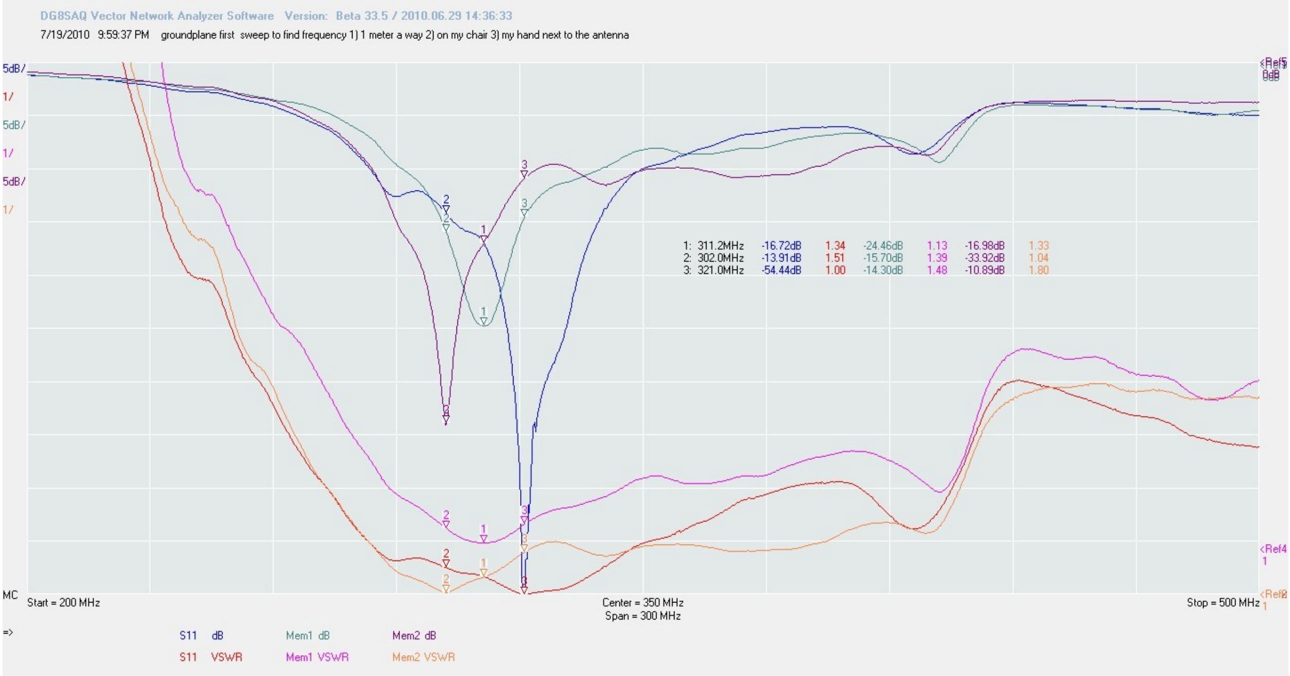
It does not matter what size. I just hooked up some material and made it look like an antenna. There is one thing you should remember; **the most difficult antenna to make, is an antenna that does not radiate**.

But now you say, but Fred, that radials are not 45 degrees down and they are not the right size and how could a jumpwire stuck on such a strange device act like an antenna. And to make it worse it is on a metal box, next to a metal cabinet. All true, this is not the way to test a real antenna but the principle is the same and now you can do funny experiments.

First I swept the antenna using the mastercall to see where it is useful. Normally you do this always. If you designed it for 145MHz then still sweep it broad first, so you see if it has strange resonances at other frequencies.



Just to fill up space. My patch panel. Every tranceiver has it's own bnc connector. So have the antennas and tuners. When I'm not arround all antennas are disconnected in a second.



I integrated three measurements in one picture with the handy mem function.
The first sweep is made while I was not on my chair and standing 1 meter away from the antenna. This is still to close by, not to influence the antenna but that does not matter in this case. We are curious about this effects.

So we look at the trace made bij mem1 and marker 1. We see the green trace dipping at -24.46 dB. So the Return loss is 24.46dB (not -24.46 , that is because it is a loss and a negative loss is gain) This is not bad, the VSWR is 1.13 (purple trace). We can hook it up without doing much more work to a 311MHz transmitter.

But I just told, I was one meter away, what if I had sit there on my chair, or like you see often, with an antenna analyser at the foot of the antenna because that is the place you want to measure. OK, lets try shall we !

Trace mem2 at your service. Here I sat in my chair lazy and satisfied with this superb antenna pushing the mouse button and enjoying the fruits of my hard labor, after sweating hours on building it (duh). But good grieves, what happened, it must be full moon, or did I sacrifice to much virgins ? The VSWR is now 1.04 at 301MHz. I must have superpowers.

No just kidding (am I ?), in real live I placed a big conductive mass next to my antenna. That influences the impedance. So if you are sitting there with your MFJ at the foot of your antenna and cutting pieces of it, remember this effect. It is hard to cut your antenna longer again. Also this is a 300MHz antenna. 1 meter is already one wavelenght. An antenna has about three zones. The reactive field, the radiating near field and the radiating far field. The first is about a half wavelength. This antenna is 300MHz so that is a 1 meter wavelength. The first sweep I was outside the reactive field. I was in the near field. But the second brought me almost in the reactive field. The antenna has a huge impedance at the top. It forms a capacitor with the ground, (or my body) so that top has a reactance. The voltage there is high. If impedance is high, current must be low. But at the base of the antenna it is almost 50 ohms so current is high there and voltage low. We know that a current through a conductor makes a magnetic filed around that conductor.

We also know a voltage causes an electrical field (like in a capacitor). So we have an electrical field that is max at the top and min at the bottom and a magnetic field that behaves just opposite. These two fields will become a radio wave in time but in the reactive field they are just the forces made by the reactances of the antenna. They are not yet in time-phase. They do not reach their top and lowest value at the same time (cos Phi is low so the field is reactive) And if we are in that field we become part of the antenna.

In this case I would say, stay there and use it. To bad this will not work. Although VSWR is perfect, do not forget electrons are lazy. They do not want to leave there friends and they are desperate searching for a quick way back to the set. While they return they are in such a hurry they throw away the package of energy (quanta) they transport and form the magnetic field and electric field and these two are needed to form our precious radiowave.

If I sit in front of the antenna the electrons jump through me, a nice conducting surface and take the easy way home, but their energy will be lost because I do not radiate that well. I absorb the waves. So this is not a good idea. To show the effect better , at sweep 3 (S11, marker 3) I hold my hand at 10cm from the antenna (that is about 4 inch for the monolingual) and you see what happens. The influence is even bigger. Do not think, oh, it gets better because the SWR improves at the marker position. Normally you make an antenna for a certain frequency and now it is moved up about 10 MHz so VSWR at the wanted frequency is become worse.

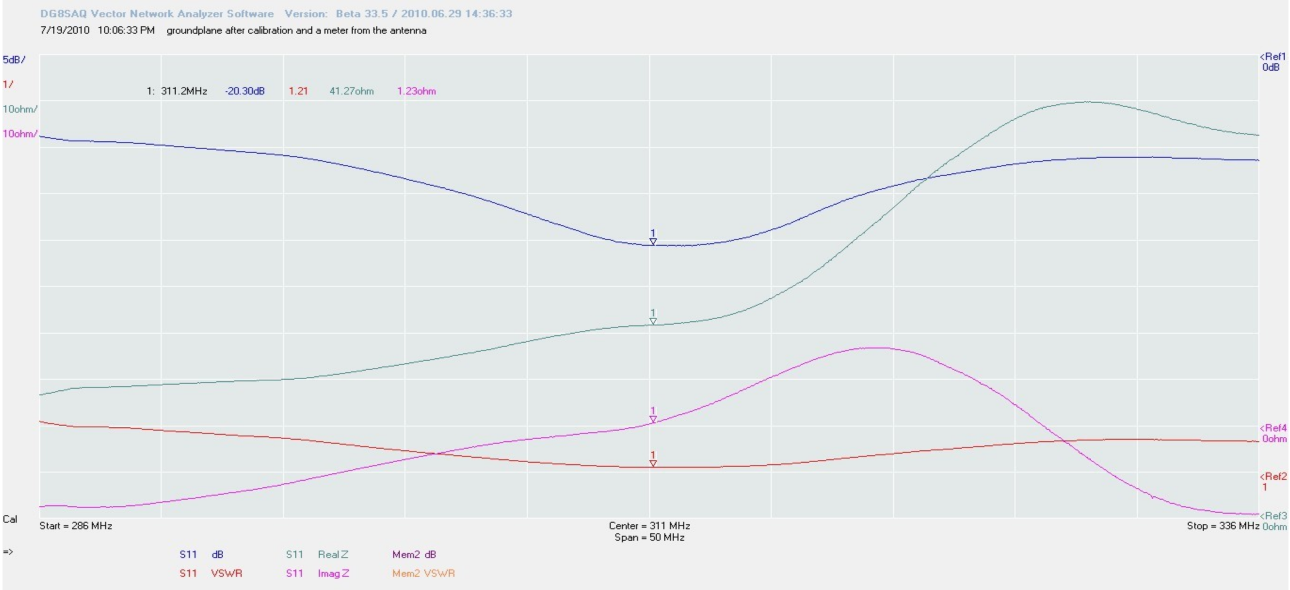
To be complete. The near field is the place the electric and magnetic field meet each other and become friends. But you can imagine that near the top the electric field is stronger and at the bottom the magnetic field is. But radiated energy is E times H already. However they have to find a balance to keep moving through space. This balance, where they are true radiowaves is in the far field. This starts somewhere between half a wave length (some antenna's do not really have a near field) and ten times a wave length. Formula : Far field starts between $2D^2/\lambda$ and 10λ. But a dipole has almost no near field. D is the largest dimension of the antenna

The next step:

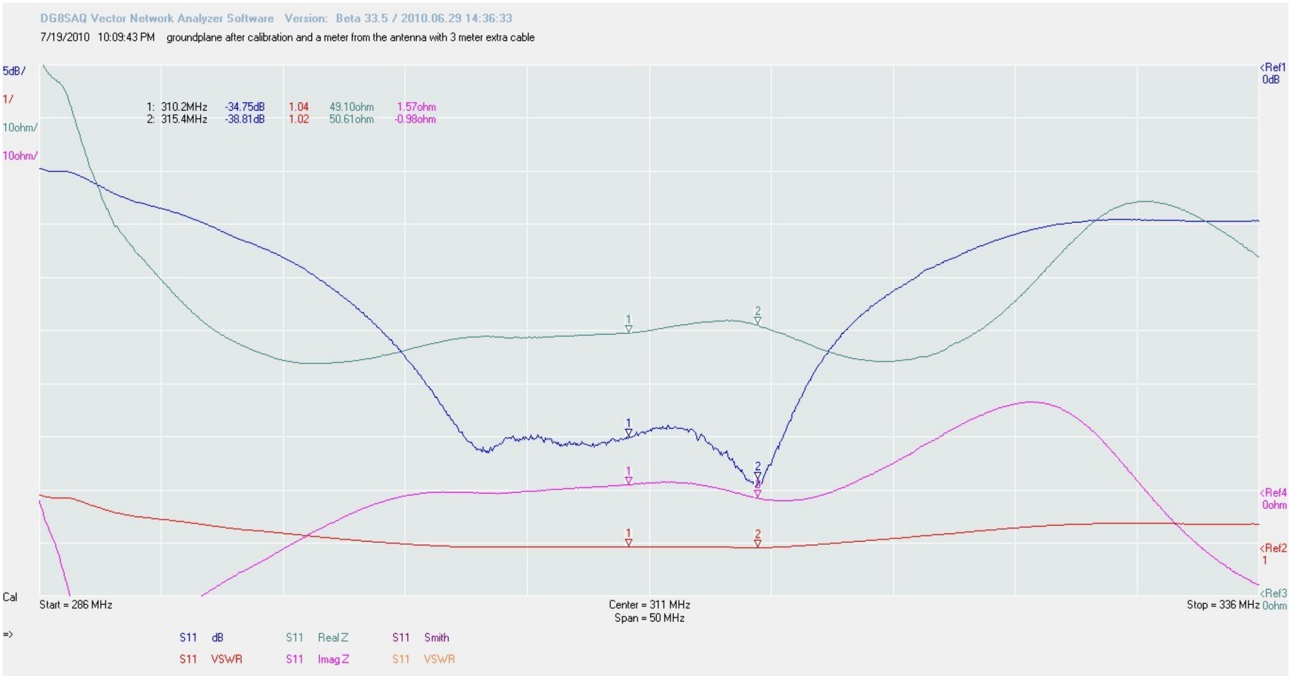
Now set the VNA on permanent sweep and move around the antenna. Look what happens if you move around it, hold your hand above or next to it, make the radiator a bit longer, touch it, bow the radials up and down ect.

For all try to understand what is happening. So now we know the antenna we builded is not bad for 311MHz. But what if we want to use it at 350 or so. We have to tweak it and look at the VNA if the results go in the right direction. Now lets optimize it.

First we make a calibration for a more narrow span, and with the cable we use, to be sure it is free standing. I have done this all just in front of me because I'm a bit lazy and you do not see it in the pictures. But if you build a real one, you want to measure it at the place it should be used. We have the luxury to calibrate our VNA after 10 meters of coax or use port extentions.

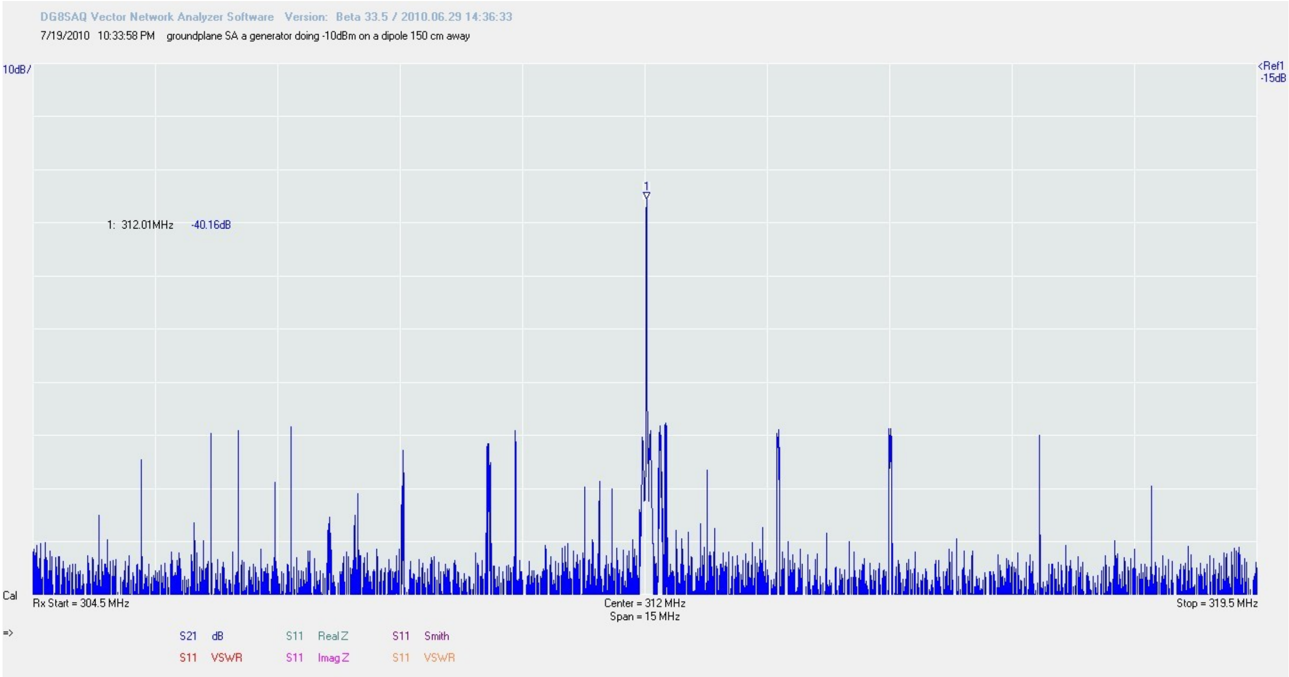


This is the same antenna, again at 311MHz but now swept with a span of 50Mhz after calibration. You see the antenna has a Return loss of 20dB and that is a 1.2 VSWR. Not bad but not good enough. Here you also see Real Z and imaginary Z being 41.3+j1.23 This tells us the antenna is almost in resonance but needs a bit more real resistance. If you want to see what to do, you now can just change a parameter and check. Making the radiator a bit longer gives more R but also more jx and moves the resonance point. The VWNA makes that simple, just try something and see the result. If you are clever you make notes about how it reacts on changes. That is handy for other experiments.

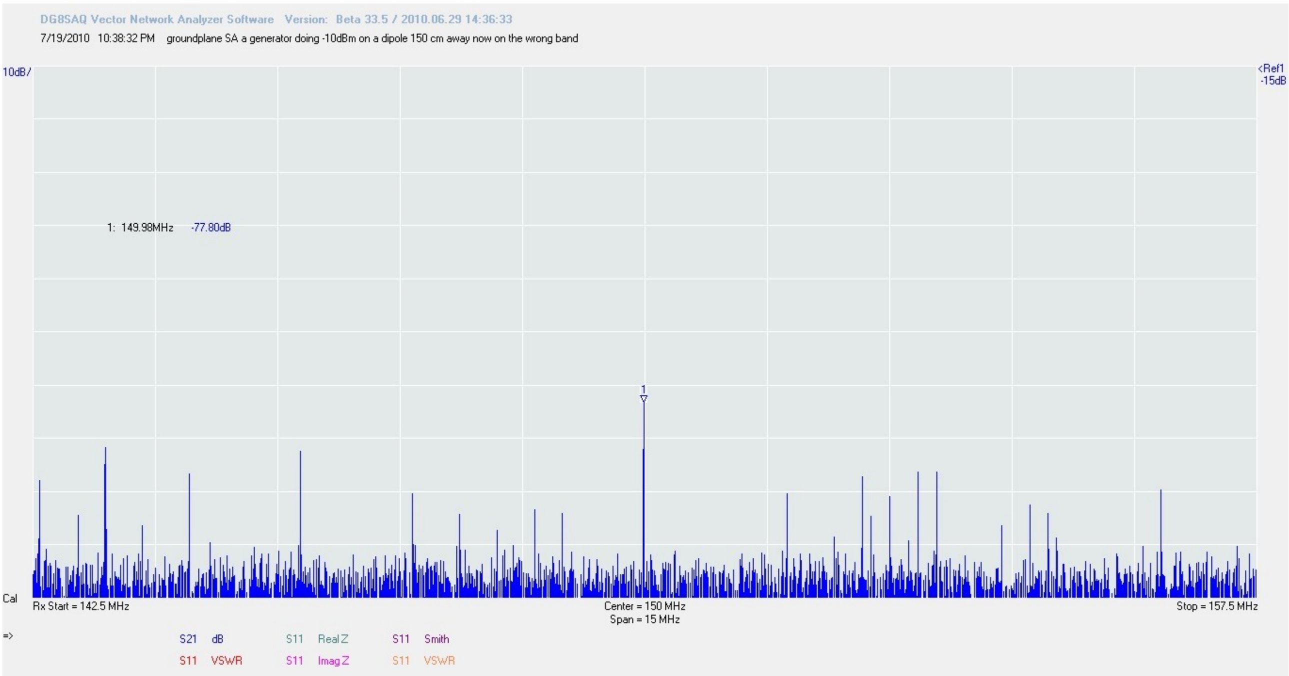


About cable. After the calibration and sweep before I removed the cable and inserted 3 meter extra teflon mil specs RG58. We learned before a 50 ohm cable transforms values that are not 50 ohm. But it can never become 50 ohm. You see that here very nice. At 311MHz the antenna is still good. There is a small transformation more towards 50 ohms but that is more caused by the heavy metal BNC and cable then transformation. We added some capacitance. But look at 315MHz. The impedance changed a lot there to a Return loss of almost 40dB. It has become a nice wide band antenna this way. But with 6 meters or 10 meters of cable things also can come worse. But just connect, sweep and you know.

Now some other cool stuff you can do with the VNWA and antennas. We connect it to port 2 (RX) and choose Spectrum Analyser mode. Trace S21 and choose the right sweep and bandwidth. I coupled my signal generator to a small dipole and transmitted a signal of -10dBm to that dipole that was 150 cm away.

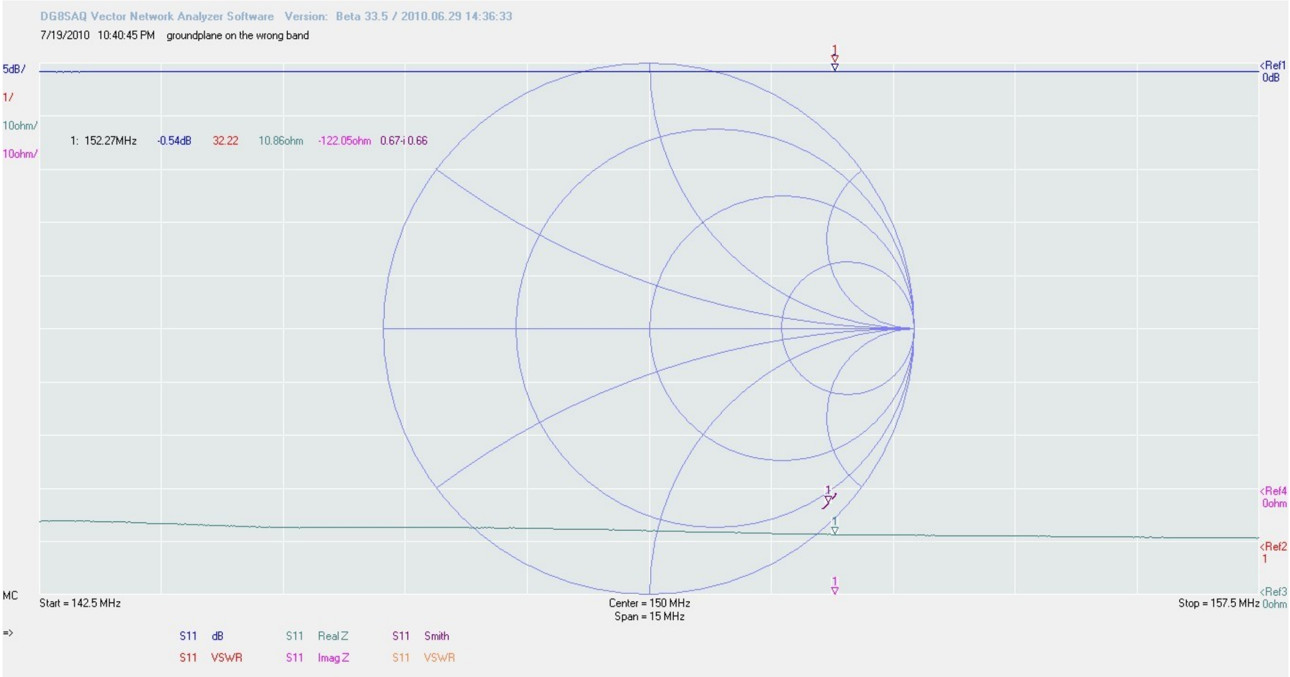


We see the antenna picks up the signal at -40dB. So we lost 30dB between antenna and transmitter. Do not take this values to serious. The VNA can be calibrated to a known source but we are still in the near field and the antenna may have a nice VSWR, but it is not on a good place. Lots of metal around, reflections, me absorbing ect. The function of this picture is to show you the advantage of the SA function.



This is the same setup but now I transmit at 150MHz. The signal is now only -77.8dB so you see it works better around the frequency where the return loss is good and a short antenna is rather deaf. It's length is now half of what it should be, the signal received too....

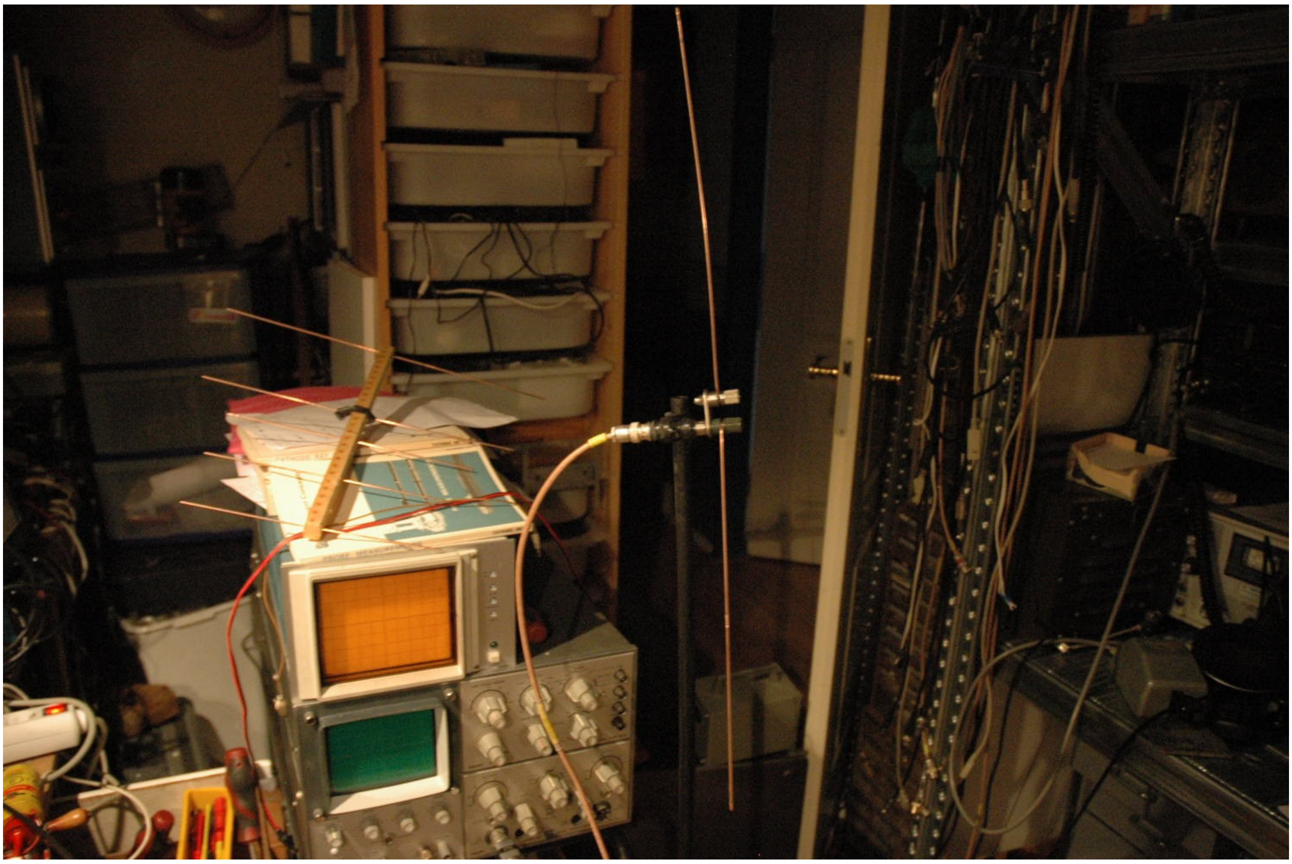
So now you know what to to if you want to hear more, just make it longer. Size does count, not only for the ladies.



To be complete, this is how the antenna looks at 150Mhz. 10.9-j122 ohm. So if you want to transmit with it. The radiation resistants is very small and it is very capacitive. But this does not mean it is always capacitive as people often think. And inductive if to long. See down here if we invite mister Smith.

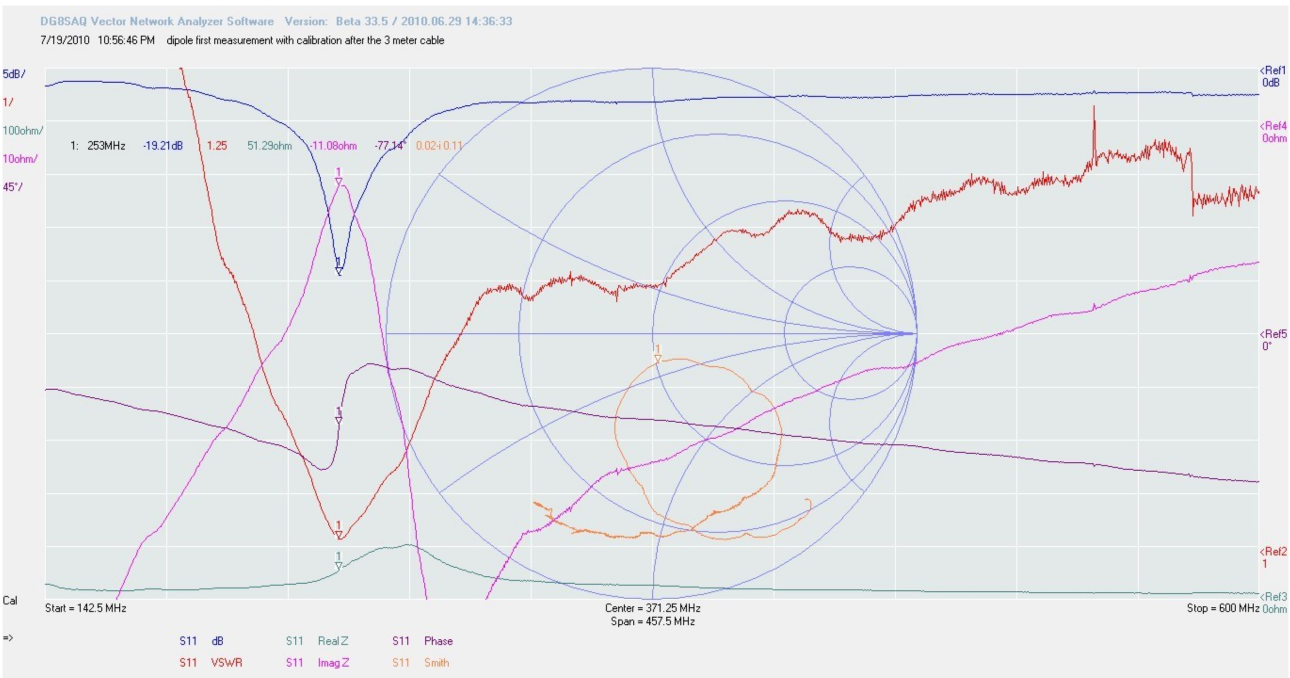
We talked before about the circle of constant impedance. By making the cable 6 meters we get more transformation. Smith is the best way to see it. You see a constant circle. When we look at the chard we see that the antenna is first inductive, then becomes ohms but at the high R part. It then becomes capacitive until it passes the middle to become resonant again but this time having a low impedance. (remember VSWR has two values for Z, a low and high impedance) BUT I have not calibrated after this six meters. So now you add a trace. Add Phase. You will see the resonant jump is not at the same frequency as in smith. Now calibrate after the 6 meters and sweep again. Alway remember. Cables transform if not terminated with their Zo.

A Dipole on test:

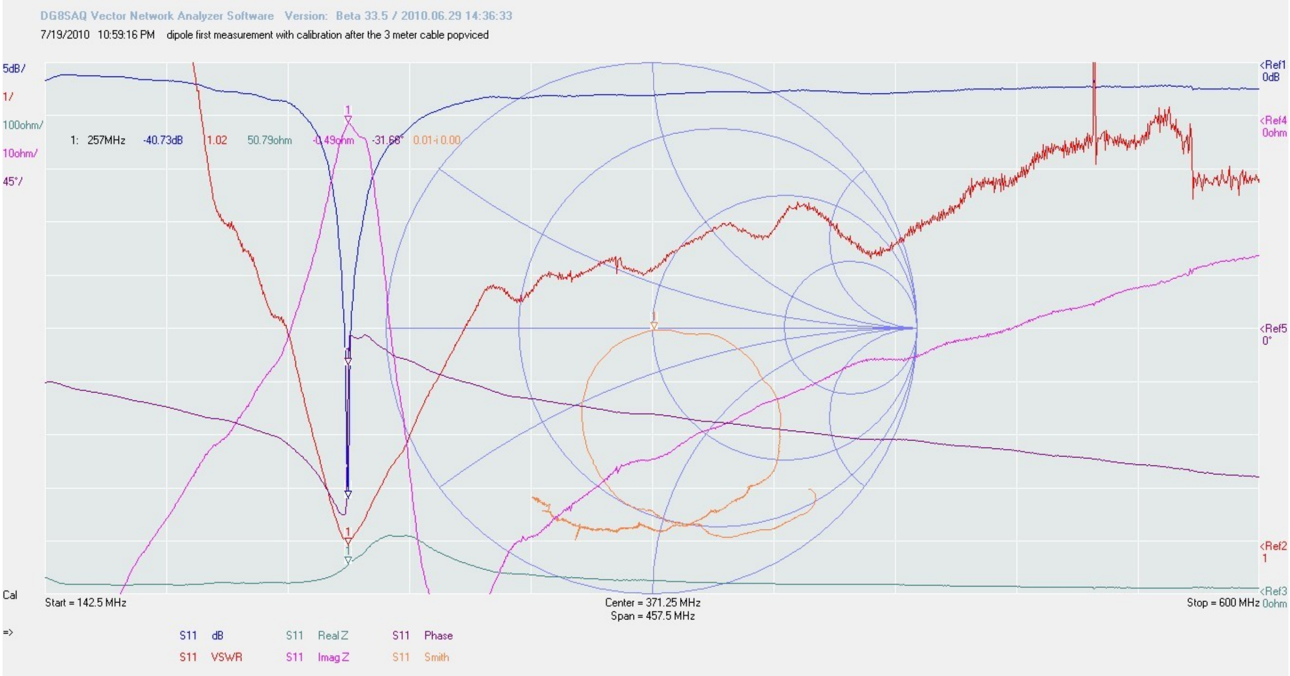


Do not look at the battlefield around it. This dipole is connected on a plastic pole on a small rotor made from a magnetron motor. So I can rotate it.

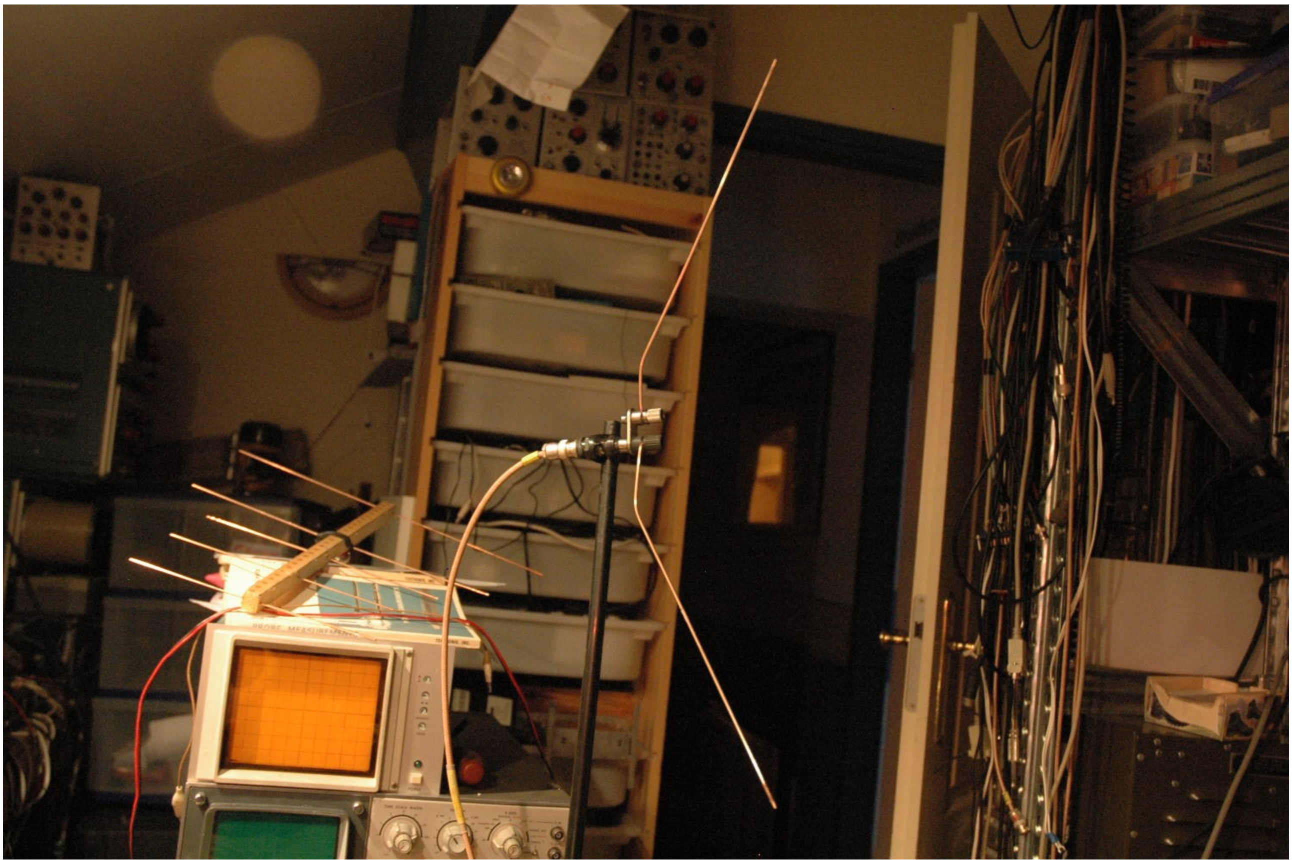
I hooked it up through 3 meter cable and first swept to look where it is at and after that did a calibration.



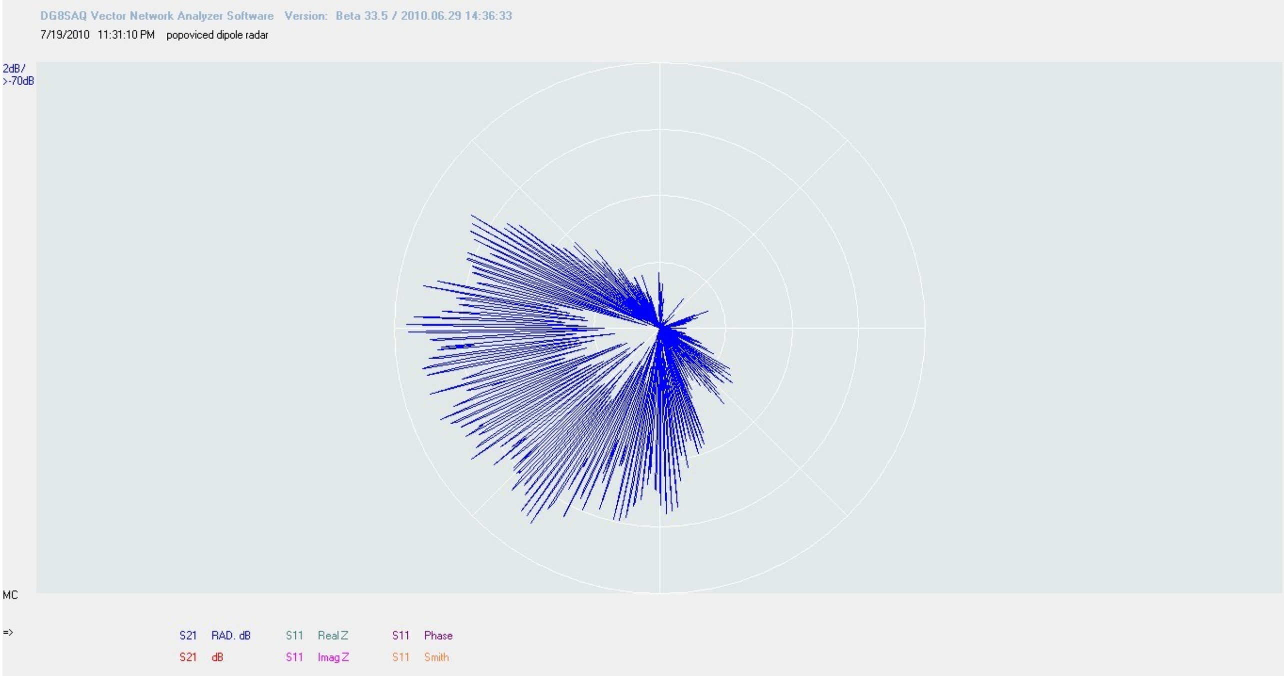
The dipole is now around 250MHz and has a VSWR of 1.25 and that is an impedance of 51-j11 ohm. Lets make that better.



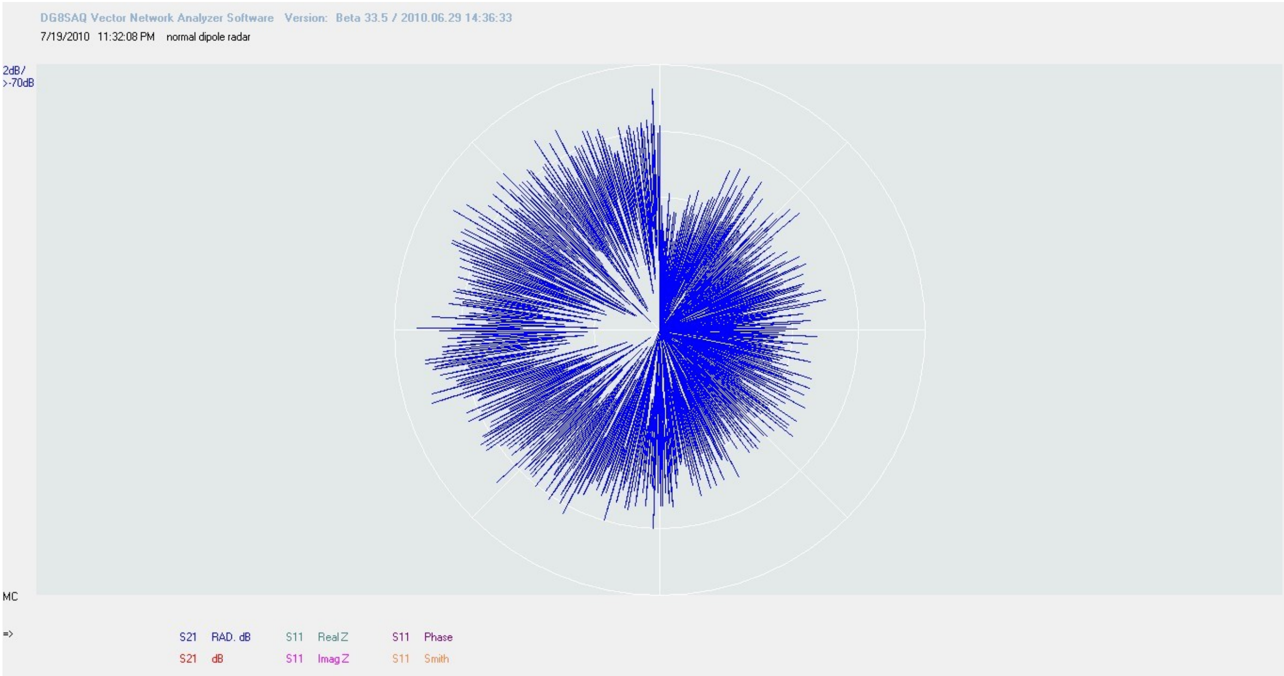
What I did was form it into a sort of popovic antenna. A very simple and easy to make dipole with some directional working. You see VSWR is perfect now. Here you see what I meant with the phase. This is now exact at the resonance frequency in smith, return loss and phase. But you also see the top of the R trace is not resonance. So not always assume a peaking trace is the place to be.



This is how it lookes now. But Fred, what about this direction thing. Is that true.... lets find out.



We have a radar plot function for this. I connected the dipole to the generator at a fixed frequency and the VNA had a directional antenna at the RX port. I measured the time the rotor needs to go round one turn and set the sweep the same time. This is the result. You see the received signal at the right top being very weak. This is the back of the dipole. So there you have the proof. Oh you are no believer, what about the straight dipole, you are lucky, I have a suspicious mind too. So here is the dipole. This radiates nice round the clock. It has a little back/front difference because of the cable that runs behind it.

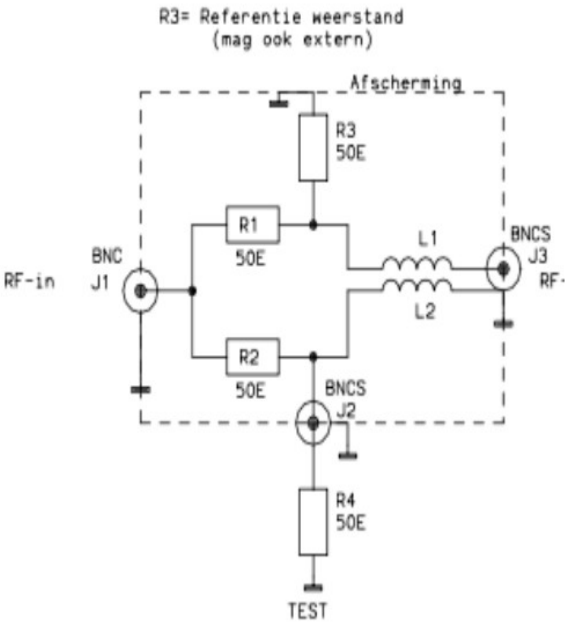


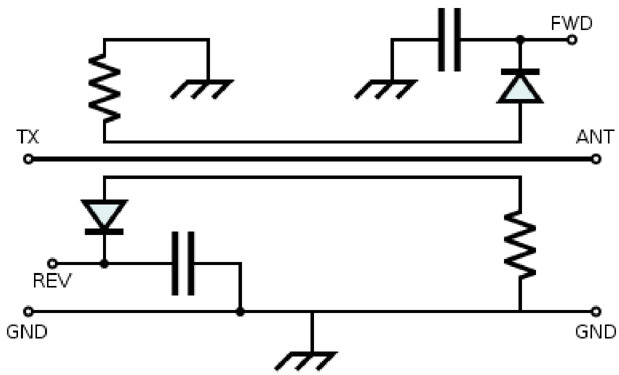
Directional couplers and bridges:

As told before, when we measure at full size antenna's it is safer to use a different way. For this there are two options. The first is a directional bridge. This is a well known design. Also known as 6dB hybride bridge. It is a resistive bridge with a current balun. The 6dB is the loss of the outgoing signal. The other option is a directional coupler. This is a construction like in a SWR meter. You have a loss-free path for the generator but the receiver is coupled by a conductor parallel at the transmission line conductor. The distance gives already a damping so most times is is called a XXdB directional coupler.
So if you insert this device between TX and RX and attach a DUT you see the return loss attenuated XXdB. This means you have to calibrate it first. After that it gives you the same results as doing a normal S11 measurement using the internal bridge.
The only problem is the bridge/coupler takes away 6 to 40dB of your dynamic range.

This is a directional coupler from HP. It is to be used between 1.9 and 4GHz but it works good from about 3MHz. I also have one from Ericson that is made for 800 MHz but that does not work well at lower frequencies. The HP is a very robust and well made coupler. The Ericson is more "mass" production.

Left you see a bridge, right a coupler:

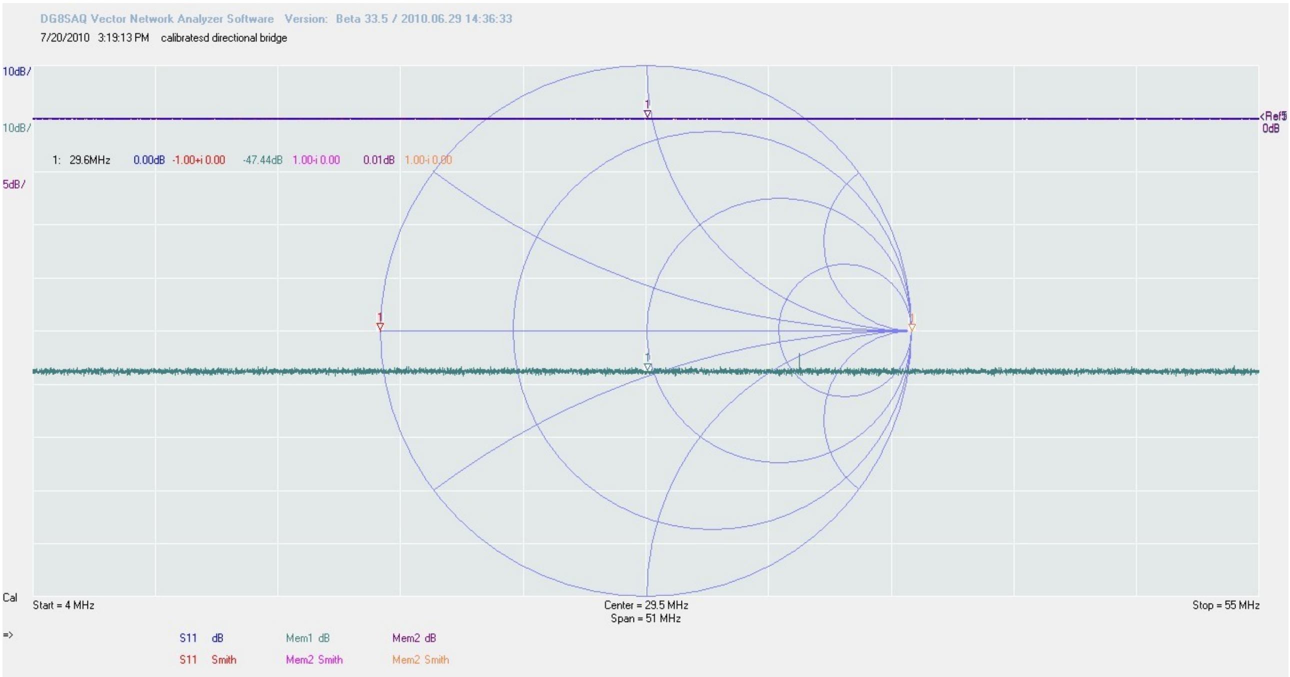




If you use a bridge you can add 20 to 40dB between the bridge and the VNA to protect your VNA. This is not a protection against static but it will take the first blow. However your TX is unprotected. It is possible to add a attenuator there too. But keep in mind you need dynamic range. If this is 90dB and you sacrifice 40dB for the coupler or bridge then you have only 50dB left (most times more then enough)

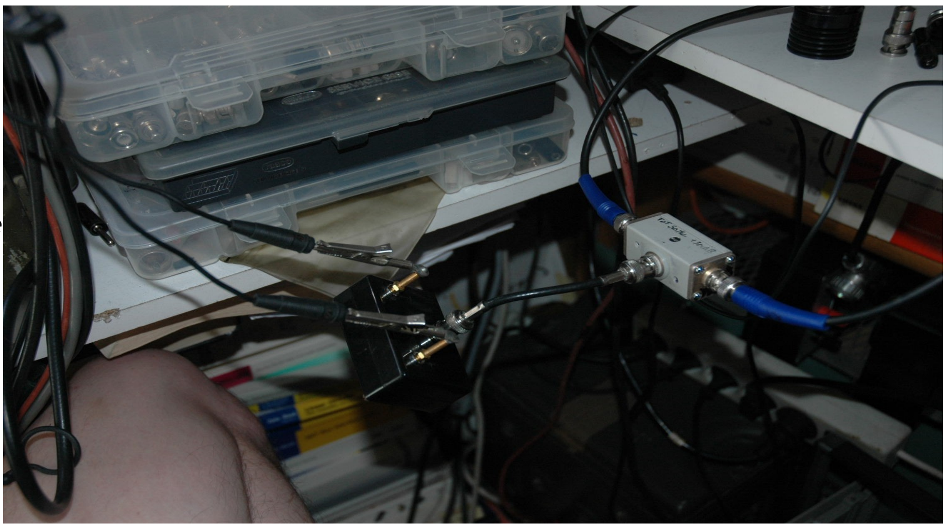
Suppose you build or buy one of them. Couplers are new very expensive. Bridges you can get from Minicircuits. But that is without a cabinet or connectors. Then you want to know if they are good. This is very easy to test. They have a few important things. They must give a very good isolation between ports. You do not want a part of the outgoing TX signal to be mixed with the reflections. In that case a perfect Return loss looks very bad. Besides that it has to have good directivity. There are three important situations. Open, short and load.

Hé, this is like calibrating. Yep, it is. If you do an open or short, all signal is reflected, so the RX should see all signal coming back. There is no loss so the return loss is zero. But there is attenuation in the coupler/bridge. As long as the open and short give the same loss it is OK. If they do not, the thing stinks and is useless (a bit like 3dB or so is OK for HF). When you do a load nothing comes back, so the VNA does not hear a thing. OK it has noise, is leaky, the load is not perfect so it will hear something. If you have a return loss better then 25dB it is usable. A real good one, the one you only touch with silk gloves in a climate corrected room will be up to 50dB. The difference between the open/short and the load is the directivity. This must be around 30-40dB to be usable.



Here, you see a calibrated homemade directional bridge, it has about 35-40 dB directivity upto 501MHz (measured before calibrating).

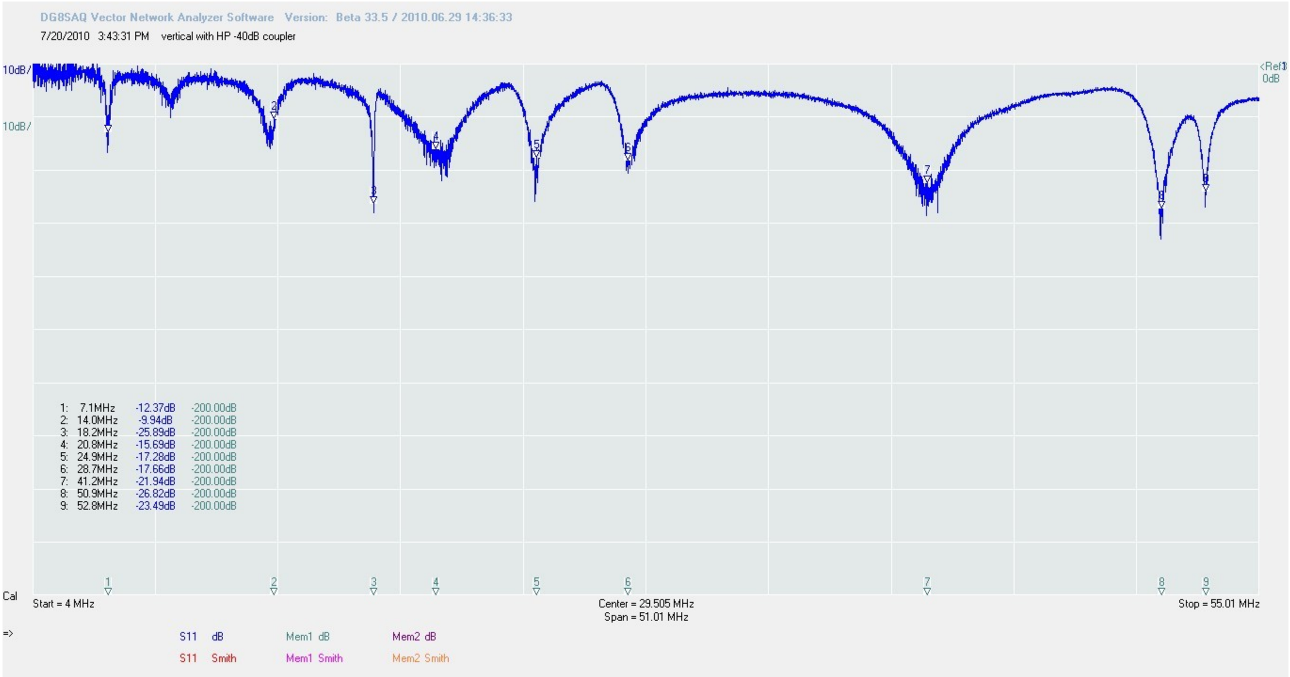
After calibrating you do a short test. You remember, open short and load in smith and then three nice points at the right place. If this is the case you are ready to roll. (see picture above).



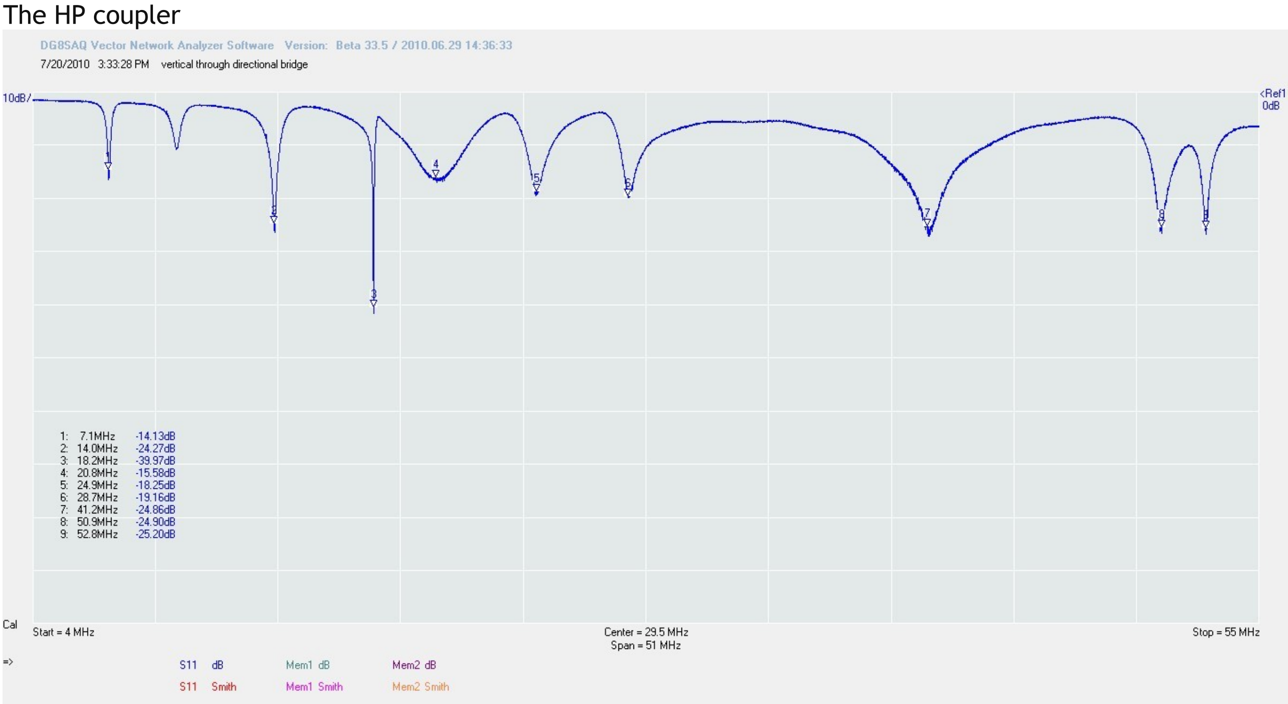
Picture to the right:
Directional bridge and balun coupled to dipole feeders.

You do not need a measure balun but if there is normally a balun in the dipole, include it in your measurements. (and use current baluns, not voltage baluns).

To show you the difference that you get from using a bridge with 20dB at the RX and 20dB at the TX. I measured my dipole. The pphoto is with balun. The sweep is done without one. But I tried both and there was (after calibration of cause , no difference of importance). You see the HP is usable but the attenuation at HF is much bigger then at high frequency. You see at the noise the VNA is already at its limit.



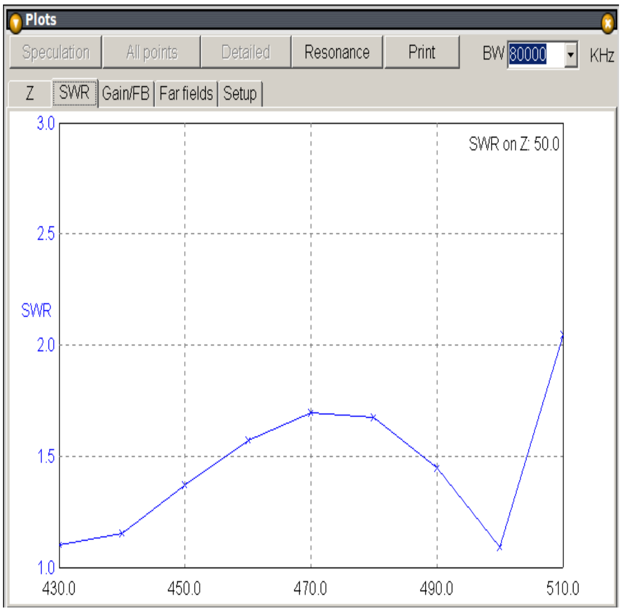
The HP coupler

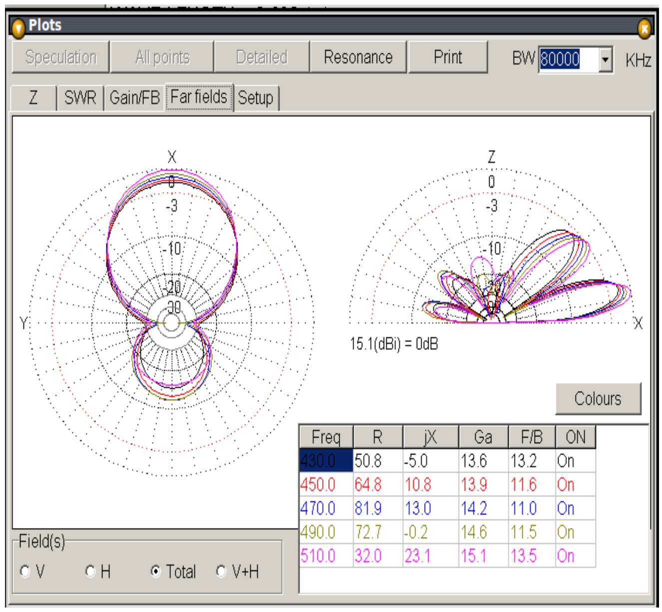


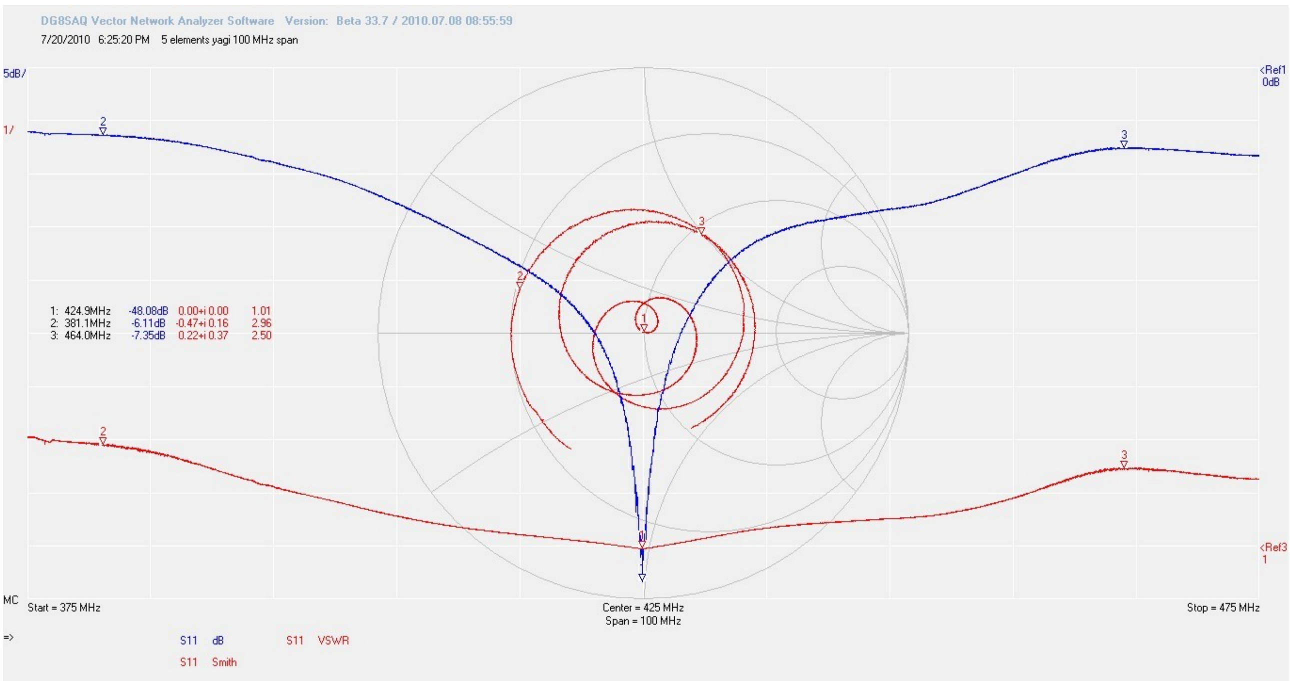
The home made bridge.

You see the results are similar.

Before we go to baluns just a few pictures to show you how easy it is to make an antenna. I have draw this small yagi in Mmana gal. You see this yagi in the picture at the beginning of this chapter. I made it from some weldingrods and a piece of wood. A small current balun and a BNC. Building was about 5 minutes work. Then I swept it to see how it was in real life:







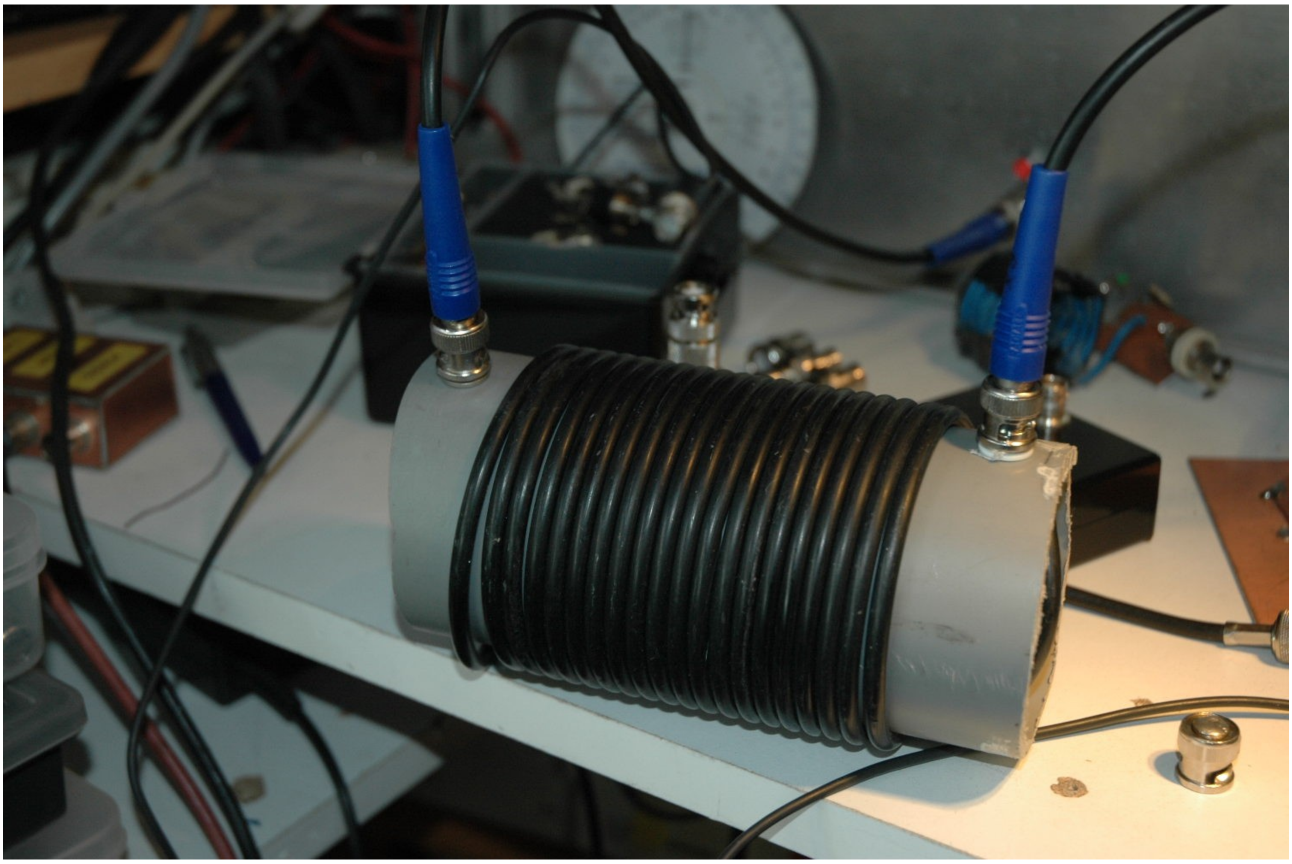
The span in Mmana is max 80Mhz so I could not show the whole bandwidth but it was under VSWR 2 from 395 to 510MHz. You see here above this is a rather good simulation. The bandwidth is not that wide as in the simulation but you see, without altering any size I have a working Yagi for 70cm.

Baluns

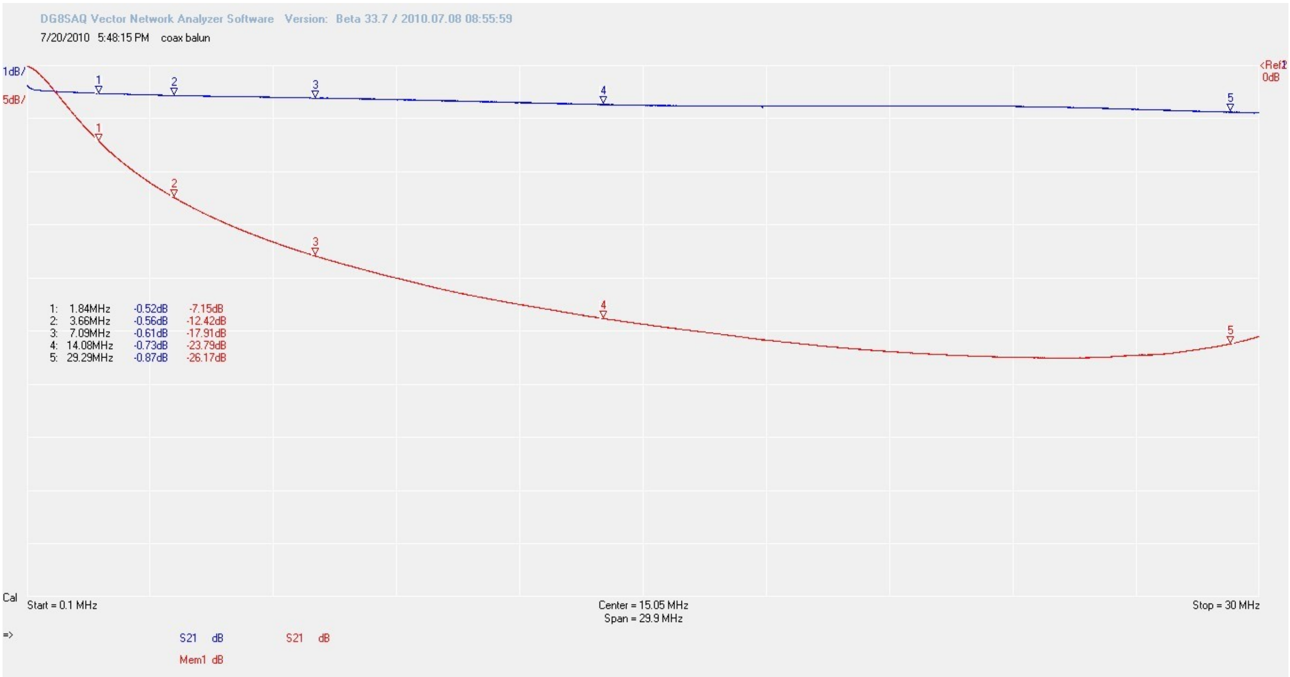
Just some info about current baluns. The function of a balun it to go from balanced to unbalanced. That is why it is called balun. If we go from unbalanced to unbalanced we have an unun. This are the most common forms A 1:9 voltage unun is often used for an endfed antenna. A 1:1 current unun at the TX side of a tuner.
The most important balun/unun however is the current choke. When radiating, the lazy electrons like to go the fastest and easiest way back to the transmitter. That easy way is in most cases the outside of the coax. Inside it is a transmission line, the outside is just a big conductor straight to ground (via your set)
So we must block that way. By making a coil from the coax we make a big impedance for the signal on the outside. Because the inside stays transmission line it does not notice the braiding being a coil at the outside.

But how we do that and how we measure it. Two many used forms are the coaxbalun and the choke made by ferite.
The advantage of the first is it does not cost a lot and is easy to make. The downside is that it is big and

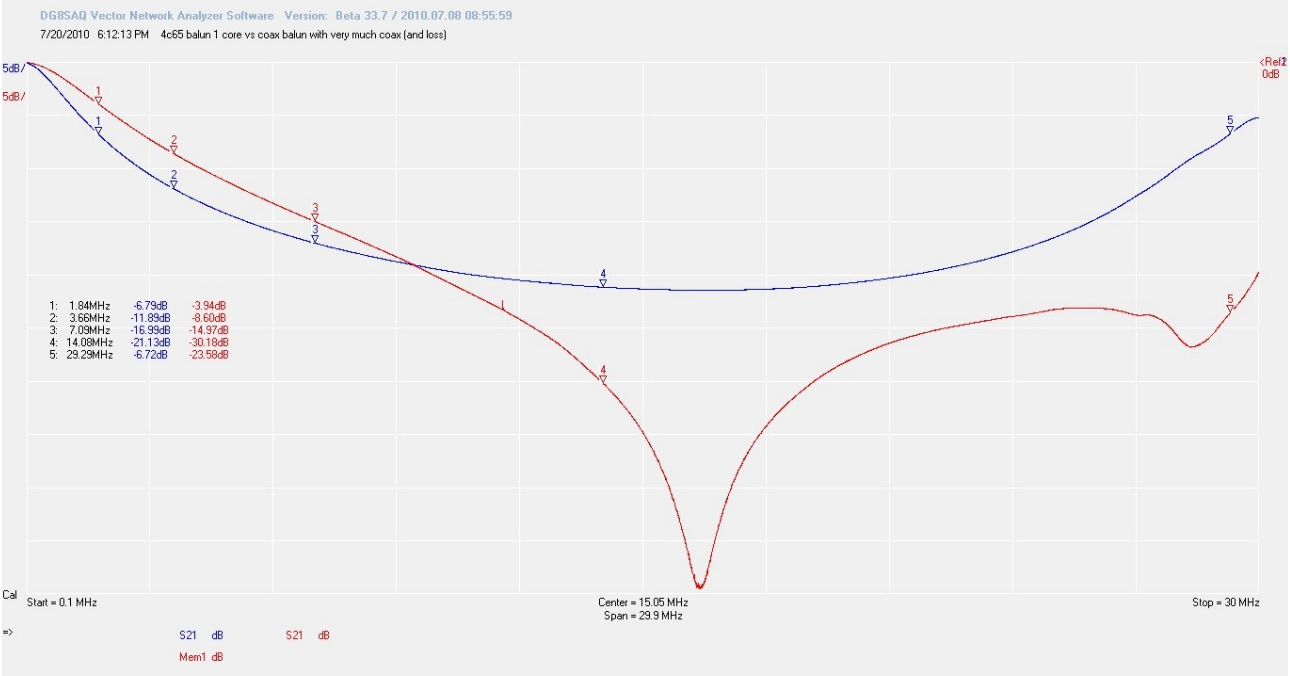
heavy and it must be right under the antenna where current and radiation is high. The other point is the coax introduces more loss as the ferite one. You need more meters.



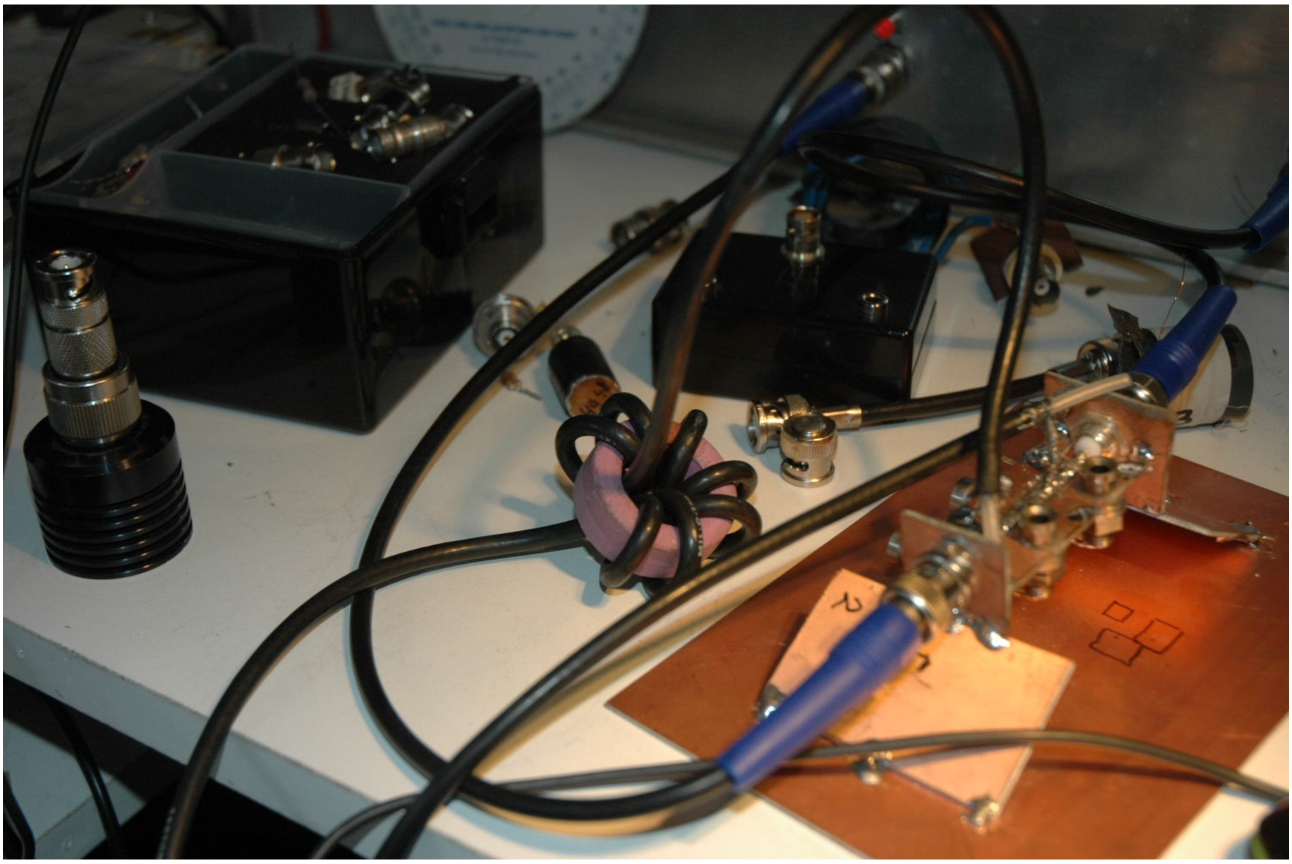
This is the coax one. To measure it I soldered the braiding to the centre of the BNC's so the signal from the VNA has to travel through the formed coil.



Swept, this gives a red curve that is the reactance of the coil. It is 7dB at 160 meters and peaks at about 27dB. If this is enough is not so easy. 7DB attenuation is not much. If you have 100W travelling back to your TX it will not do much. But if you have just 10W travelling back 7dB could be just enough. It depends on your antenna. For the king of common mode currents, the OCF dipole (often called windom) this will not be close. For a perfect dipole this is more than needed. But you see the downside; 0,5 to 0.9dB loss because the extra meters.



Here you see both of them. The red trace is the ferite choke on the picture below. It is 8 turns, so not even a meter coax.



You see the coax balun is better at low frequencies but if you want it really good there you need more then twice the size. If you take two 4C65 at each other or a 3E11 and a 4C65 it needs only slightly more cable but it becomes much better. Even better are three toroids after each other. So you make three coils. The first attenuates, say 10dB. The signal that passes is again attenuated bij 10dB and so on. Very effective. Not effective at all, but seen a lot: T200 toroids. Do not believe me, look at it yourself. Even twisted to the max it is virtually not there.

So I hope this was a bit helpful to get a basis for doing your own testing and experimenting. But always think before you sweep. What should I expect to see. If you see something different you know you do something wrong.
73 Fred PA4TIM 20-07-2010