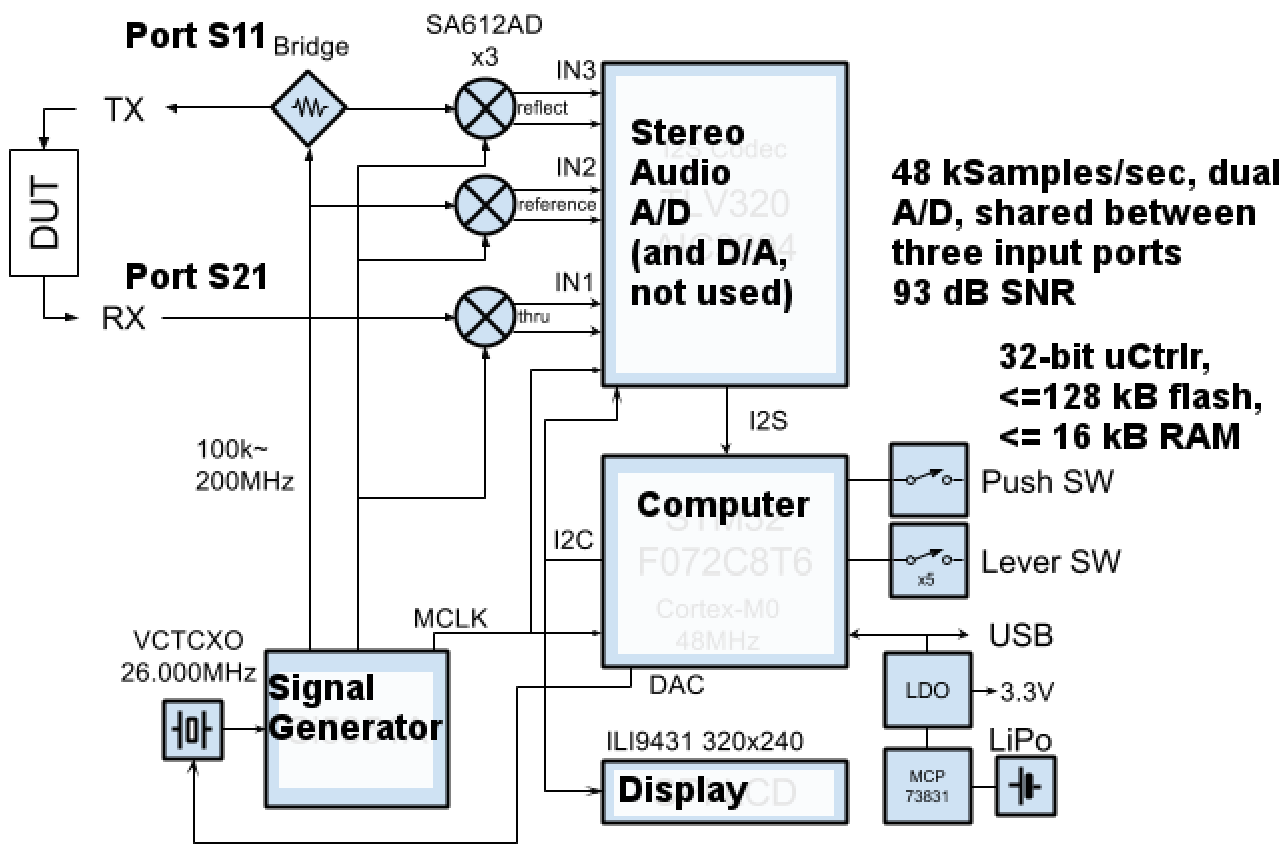
The nanoVNA: an affordable vector network analyzer.
2026-06-14; Chuck Dorcey, AB3NA

Introduction:

A vector network analyzer measures the "scattering parameters" of analog circuits, such as cables, antennas, filters, and amplifiers. It injects a test signal into Port 1, and measures both the magnitude and phase (the vector) of signals, both reflected from Port 1 and transmitted to Port 2, as a function of frequency. In the nanoVNA, the test-signal generator can be controlled from 1 kHz to 300 MHz, and analysis of the harmonics of the test signal extend its analysis range up to 1500 MHz.

Circuit:

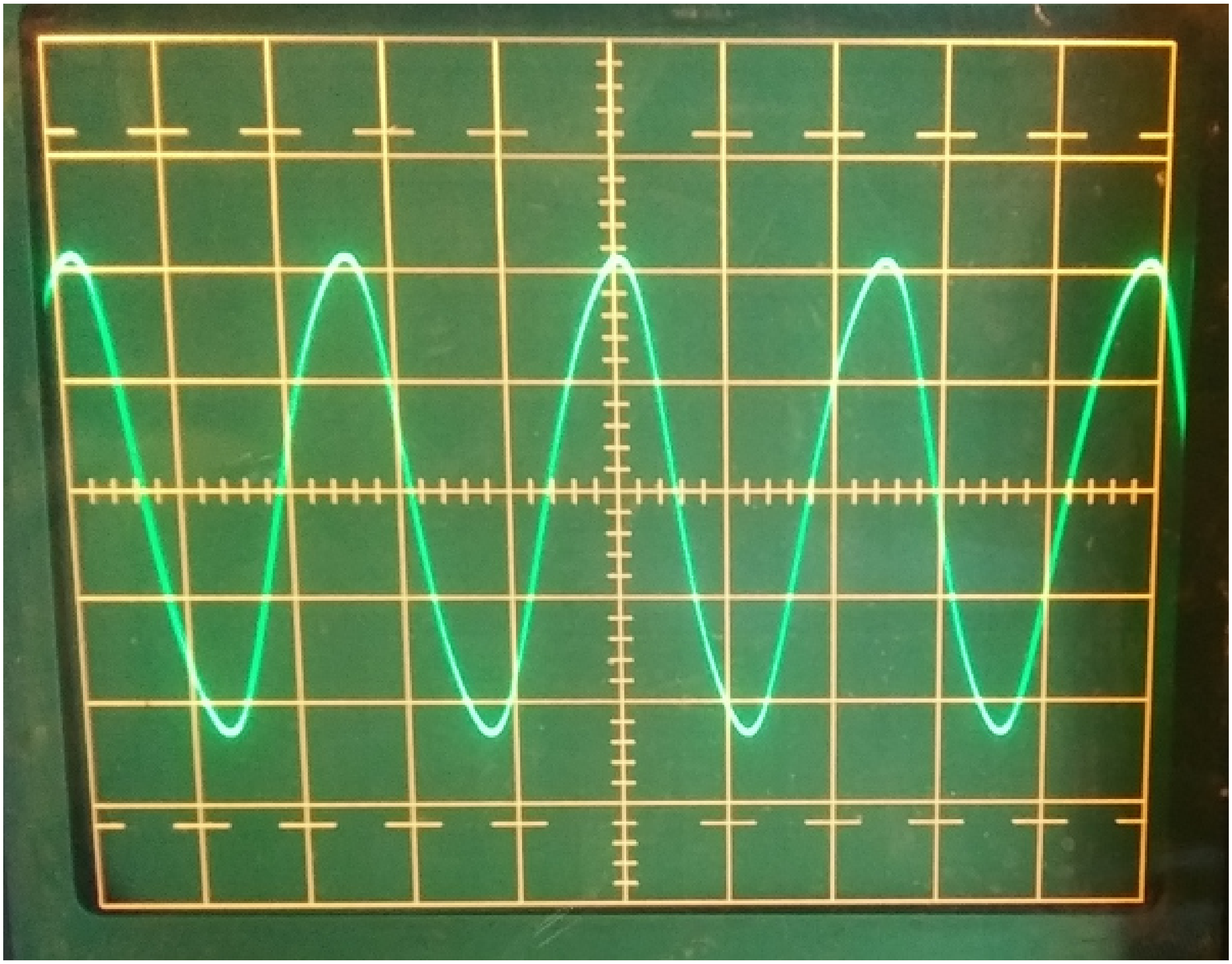


Blockdiagram

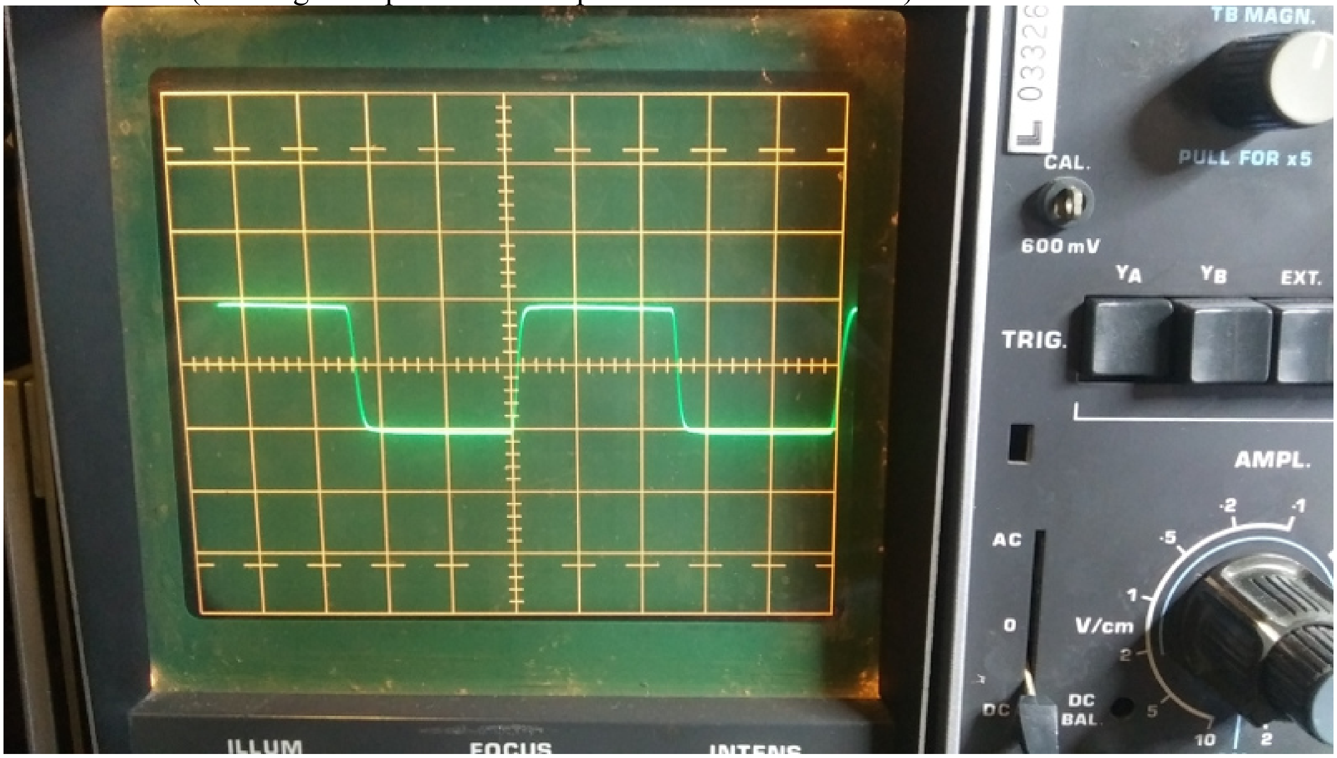
An output from the Signal Generator goes to the Bridge circuit (upper left). The bridge drives Port S11 and also passes any reflected signal to the A/D converter (IN3). Whatever gets transmitted through the DUT gets mixed with another output from the signal generator, to form IN1. (The two outputs from the Signal Generator get mixed together to drive IN2.) Note that the difference between signals going into the mixers is low enough that an audio-frequency A/D is fast enough to record the result.

Signal Generator

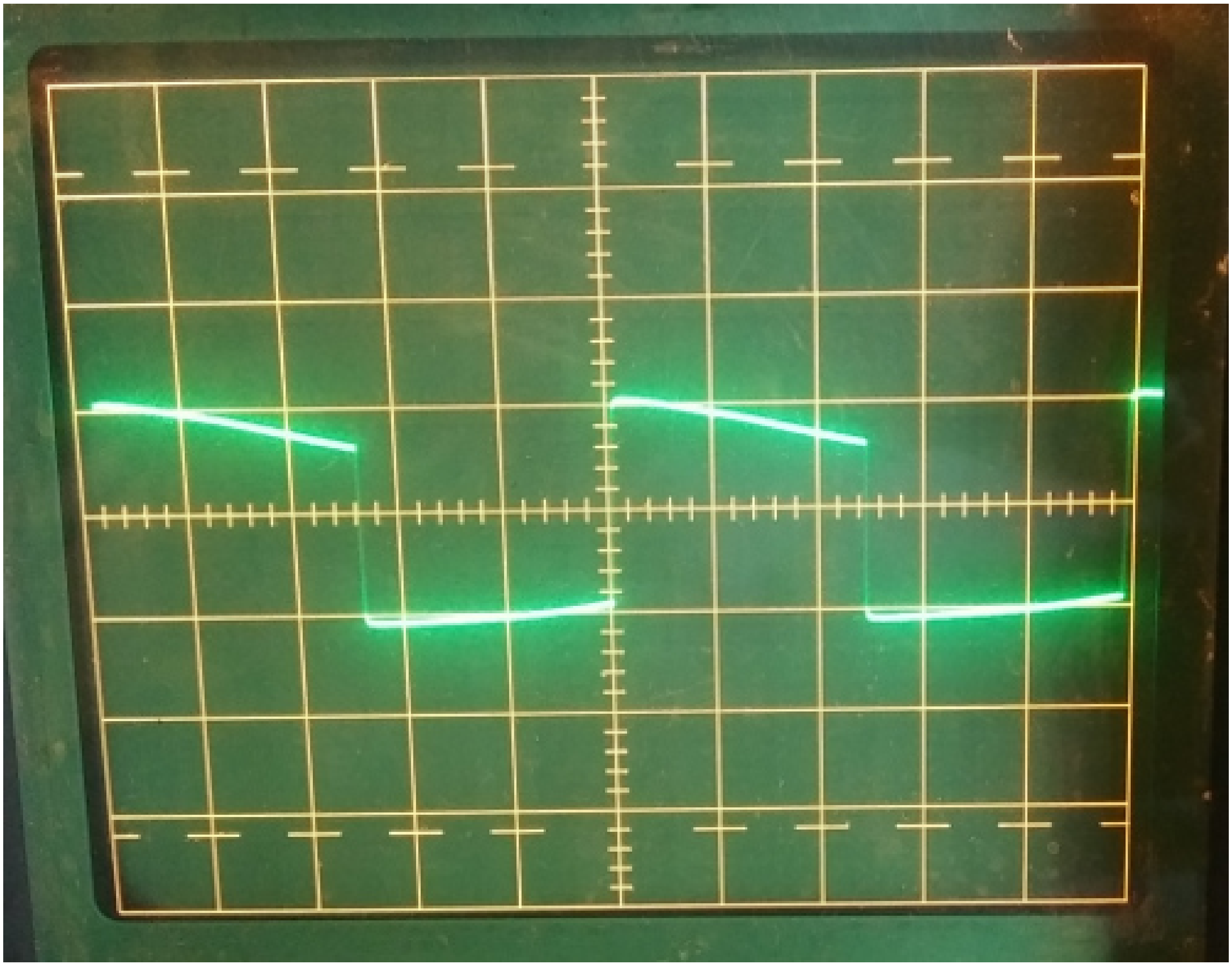
First, let's look at the signal generator output. Note that my 'scope is only rated to operate from 0 to 10 MHz, so we won't be able to observe the full range of the signal generator. Here's 10 MHz.



Here's 1 MHz (showing the square-wave shape from the test oscillator):

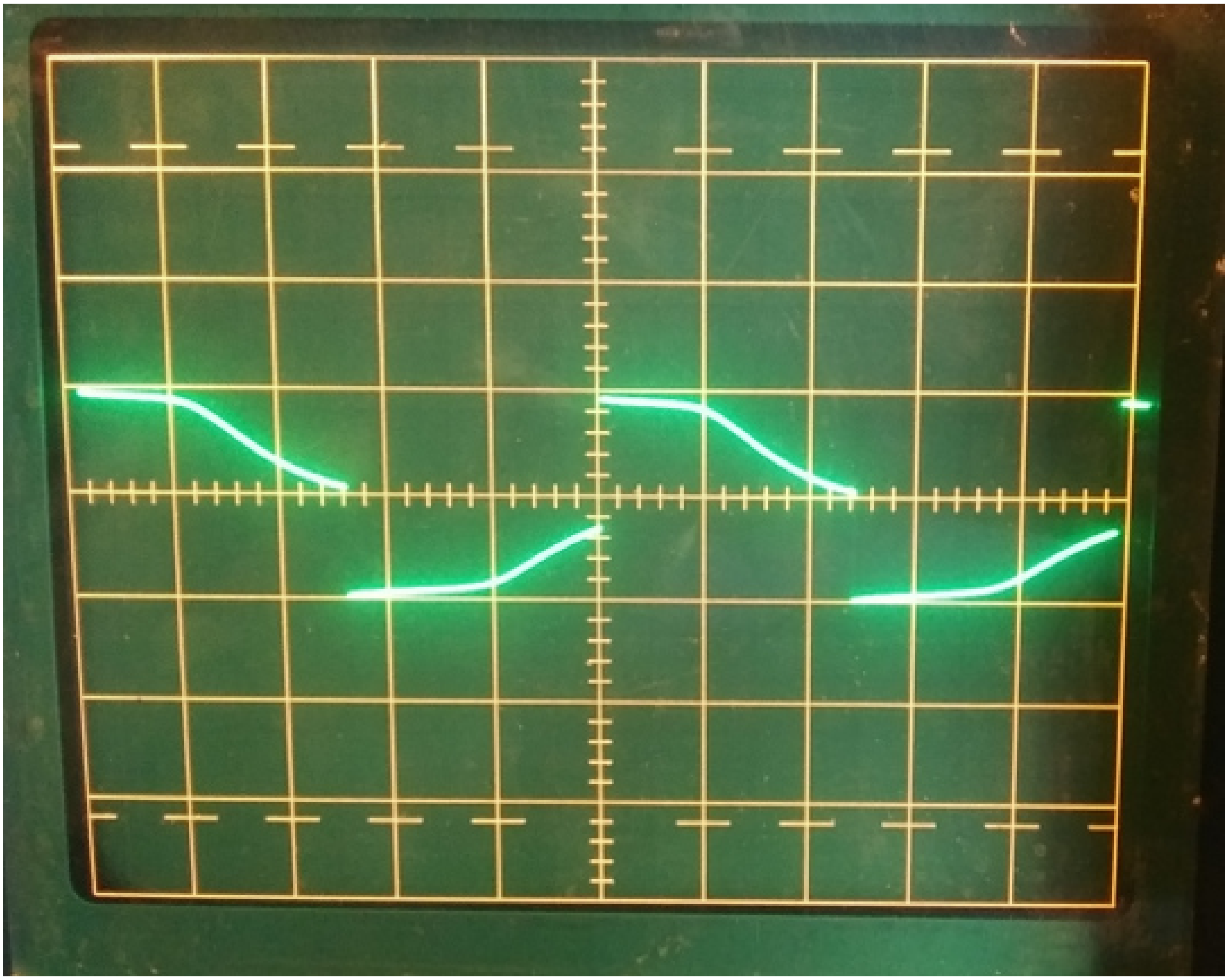


And here's 100 kHz.

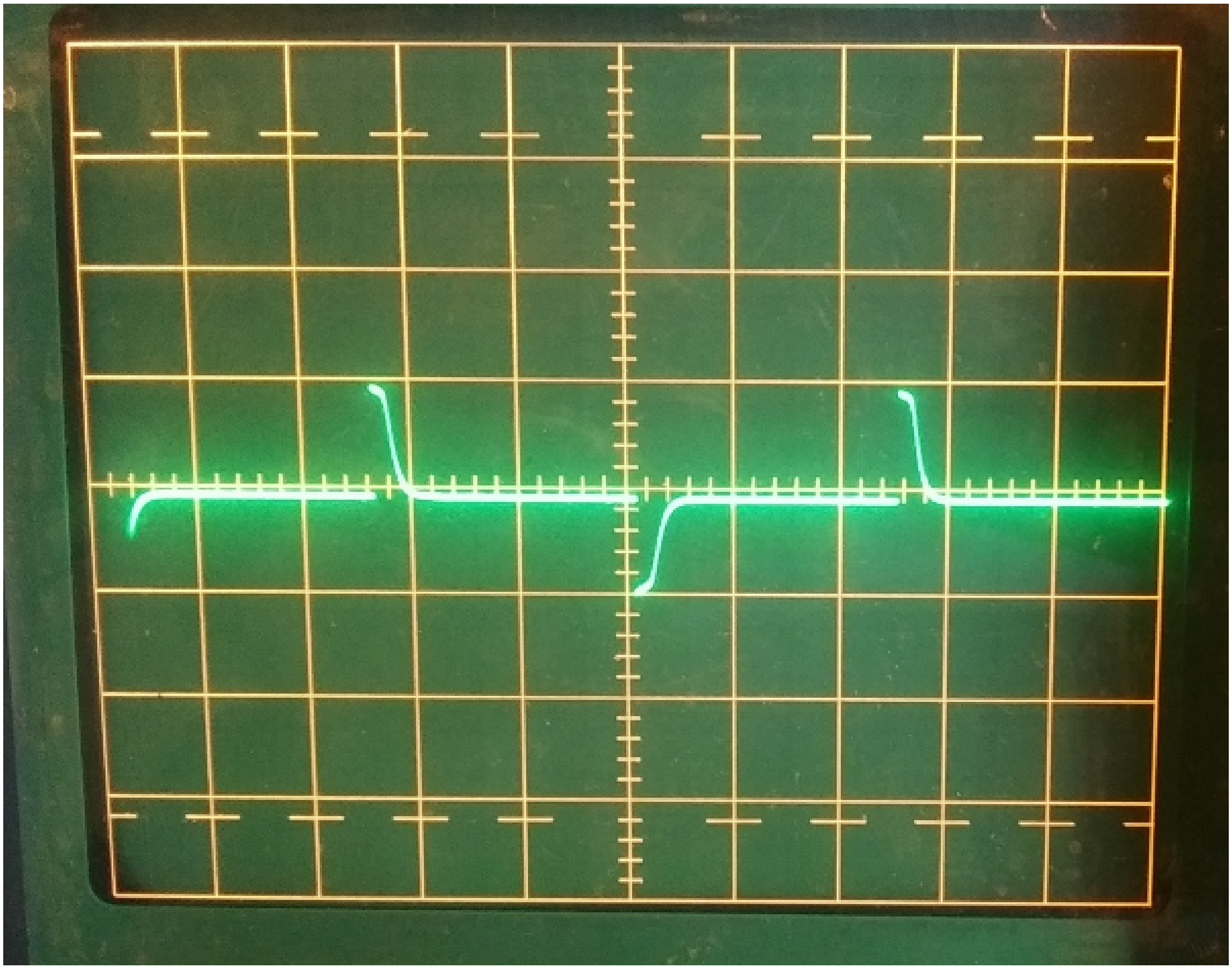


At 100 kHz, the waveform is getting a little distorted. (I don't know why.)

What about 10 kHz?



We've got a serious problem at 10 kHz, though that is outside the advertised range of operation. So, let's push onward to 1 kHz.



At 1 kHz, it's not at all the square-wave we expected. Buyer beware! Know the limitations of your equipment.

nanoVNA displays:

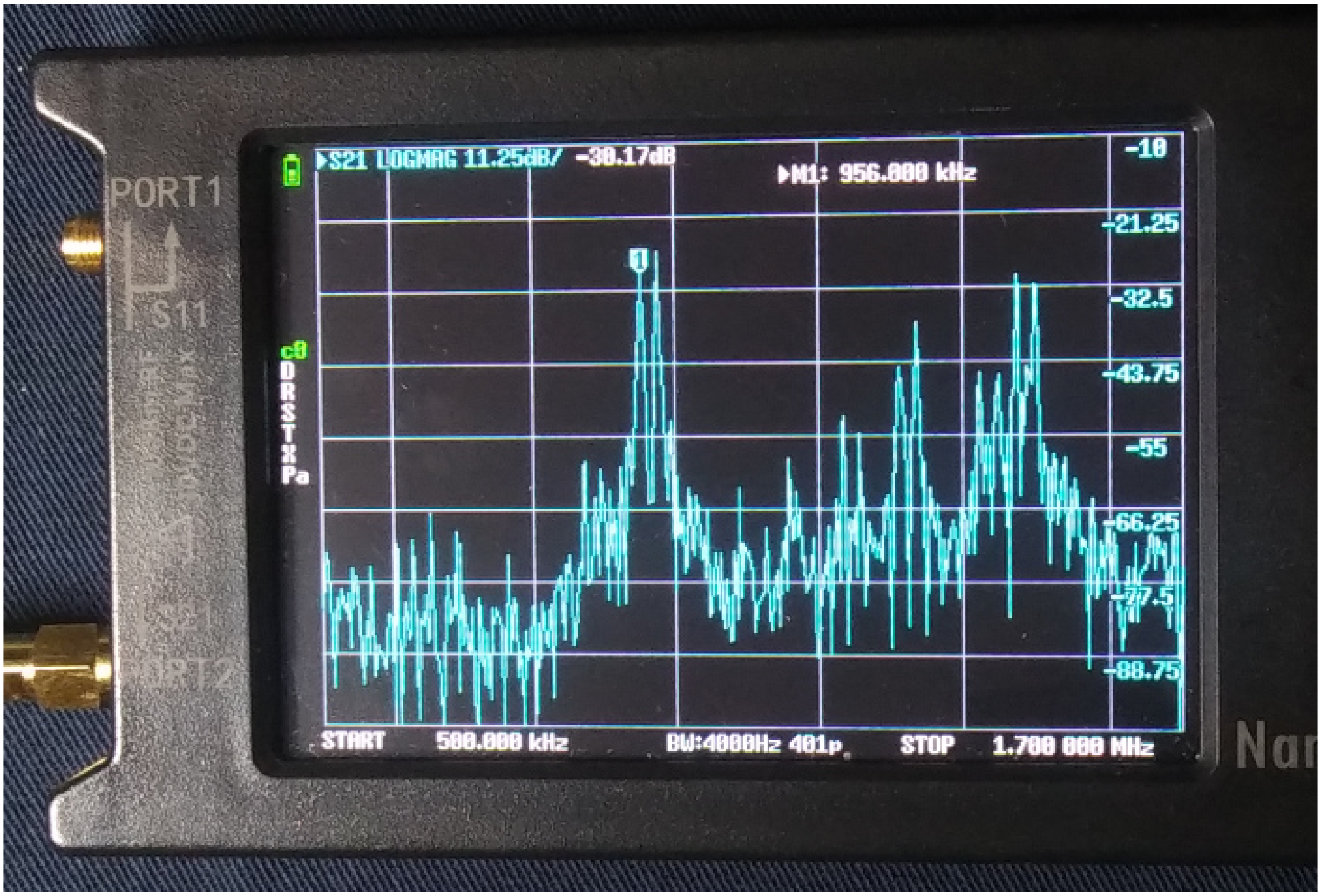
When the nanoVNA is first turned on, you'll see something like this:

Fear not! We have the S11 (reflected power) plotted in yellow on the vertical dB scale, and because there's no load connected, all of the power is reflected, with "0 dB" loss. In blue, S21 (transmitted power) is at least 60 dB down, because there's no physical connection between the ports. The default range of test frequencies is 50 kHz to 900 MHz, at 101 test frequencies. The green trace is plotted on a Smith Chart. There are markers on each trace, with values read out at the top.

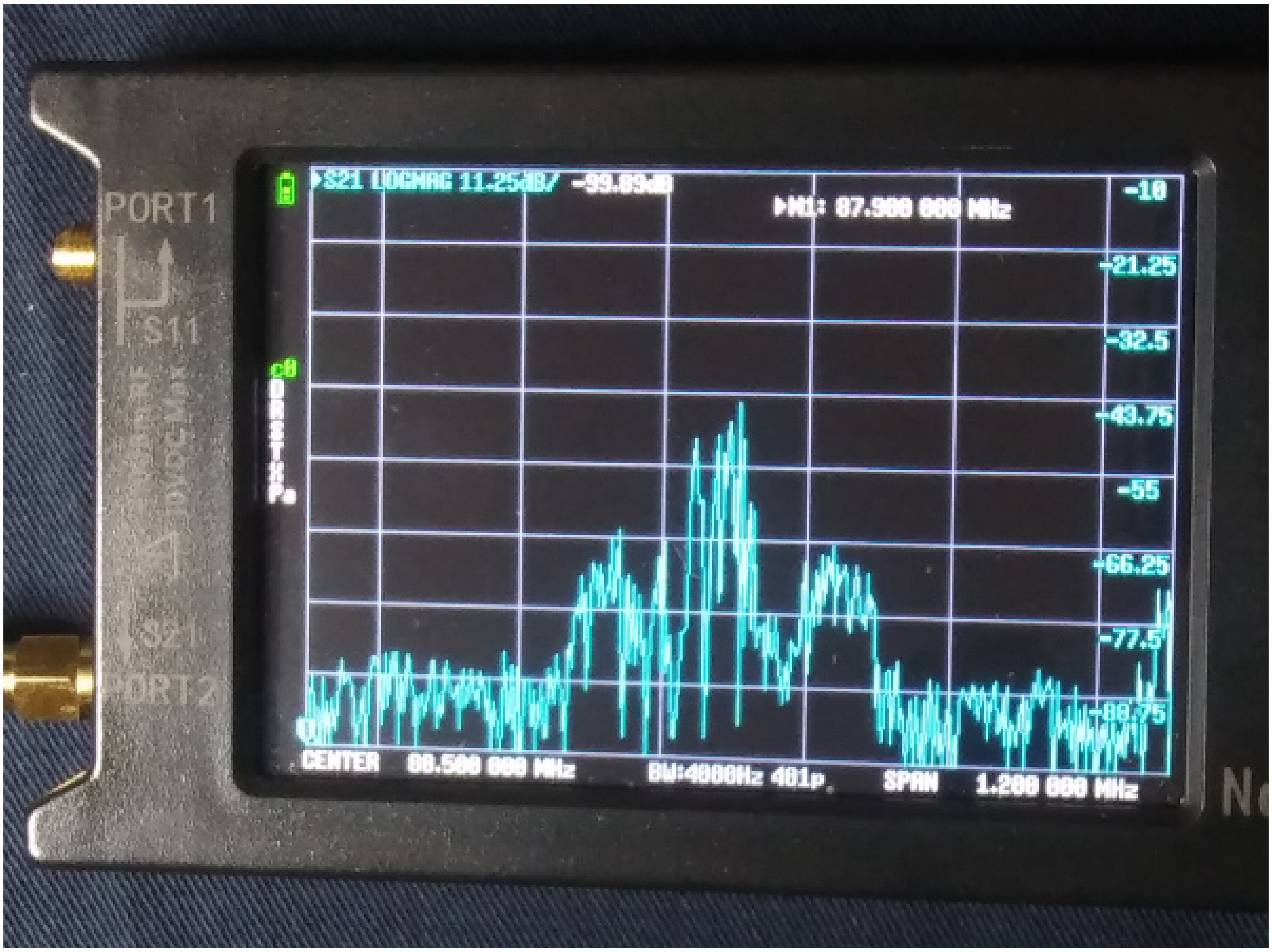
So, the first thing I do is tap the screen with a stylus, which brings up the trace-control menu, and I can disable the traces that I'm not interested in.

Spectrum Analysis:

If you ignore the fact that the signal generator is driving Port 1, you can put an antenna onto Port 2 and measure whatever energy happens to be there.



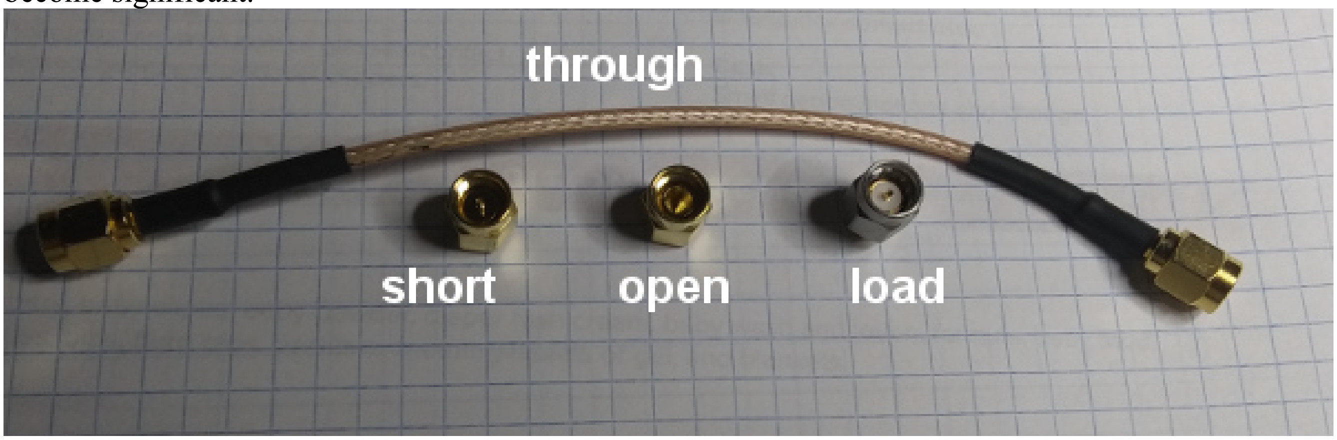
Here's a scan of 500 to 1700 kHz, the AM broadcast band, as seen with my 80m dipole antenna attached. Several strong local stations are visible.



I also tuned to 88.5 +/- 0.6 MHz, WAMU-FM, and we see the FM-stereo carrier and the HD-radio sidebands. I don't think that there's any way to average successive traces to build up a better plot. This one is somewhat distorted by the fact that the FM-modulated signal doesn't sit still, and may not coincide with the current sweep frequency. A traditional spectrum analyzer would have a "peak-hold" option to fill in the gaps on successive sweeps.

Calibration:

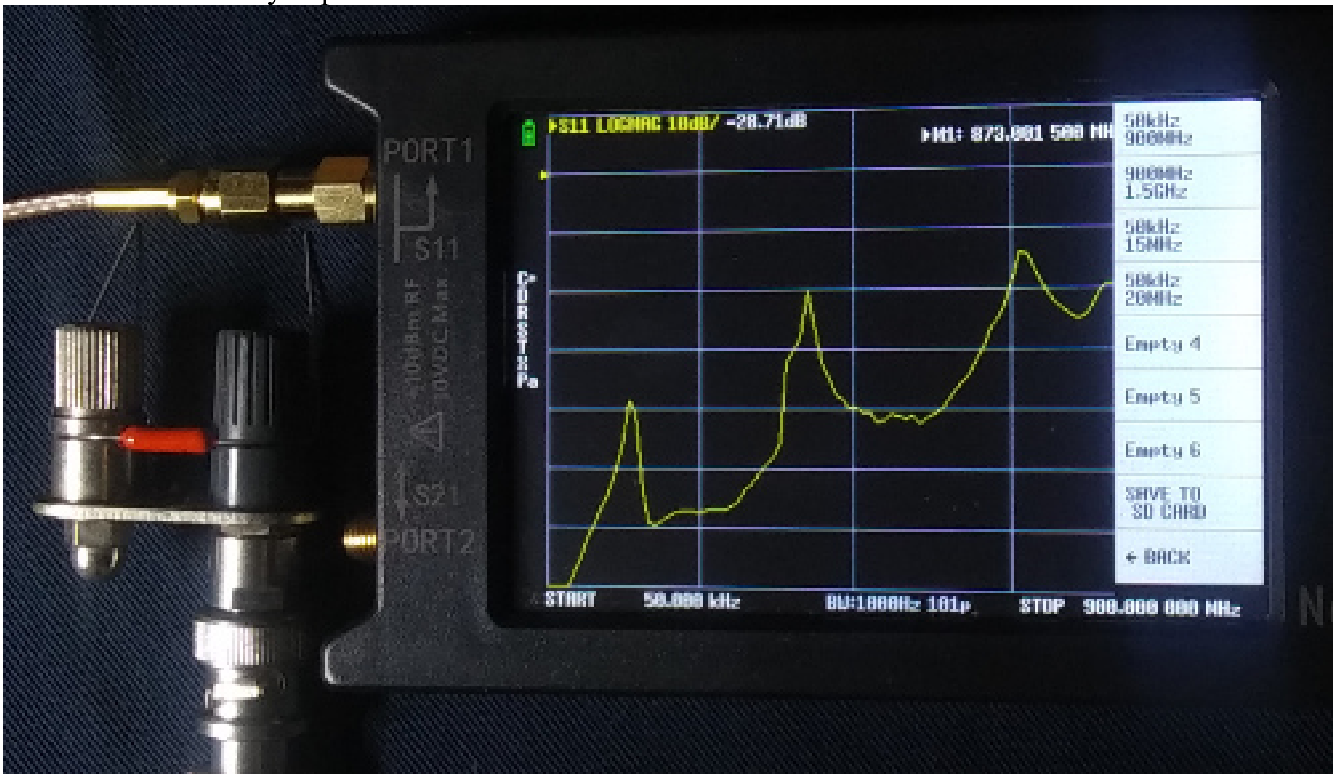
When you use an oscilloscope, you know that the probe is part of the instrument, and the circuit starts where the probe ends. A Vector Network Analyzer has no way of knowing how much of the cable(s) attached to its ports are to be considered "circuit" vs. "test fixture", so a calibration process is needed. Sometimes, this is called "de-embedding" the circuit from the test fixture. It requires four components: a short-circuit, an open-circuit, and 50-ohm load, and a "through" cable. You might suppose that an "open circuit" component is just what you get with nothing at all connected to the test cable, and at lower frequencies, that would be right. But as the frequency of interest increases, even small things become significant.



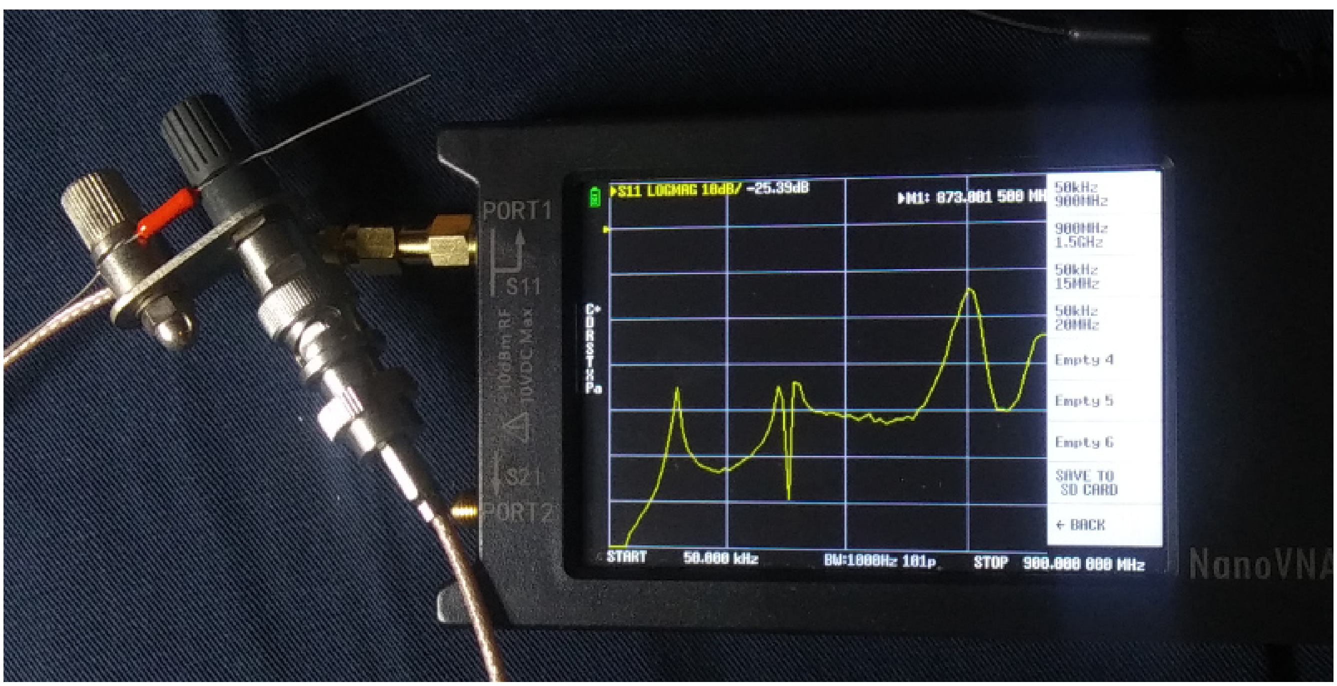
After calibration, either a short or an open shows reflected power equal to transmitted (0 dB return loss).

What if I just make my own cal kit, using a wire for the short, nothing for open, and a resistor as a 50-

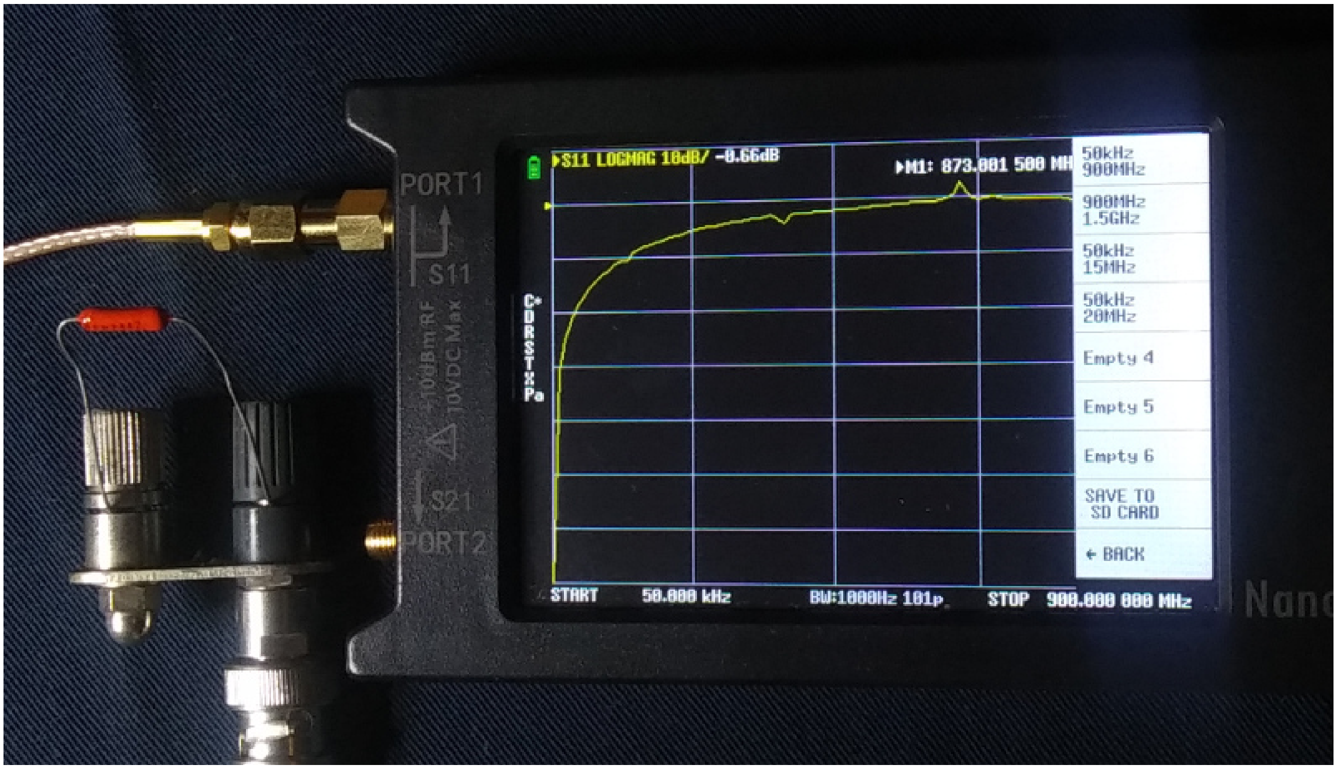
ohm load? Here's my experiment:



After calibrating with the load device, I put a BNC-to-binding-post adapter on the cable, with a precision 50-ohm resistor tightly between the posts. The return loss for a matched load should be flat at the bottom of the screen, but we see a general rising trend, due to the inductance of the resistor, and several frequencies with some kind of resonances. Note the resistor leads sticking out the back of the binding posts.

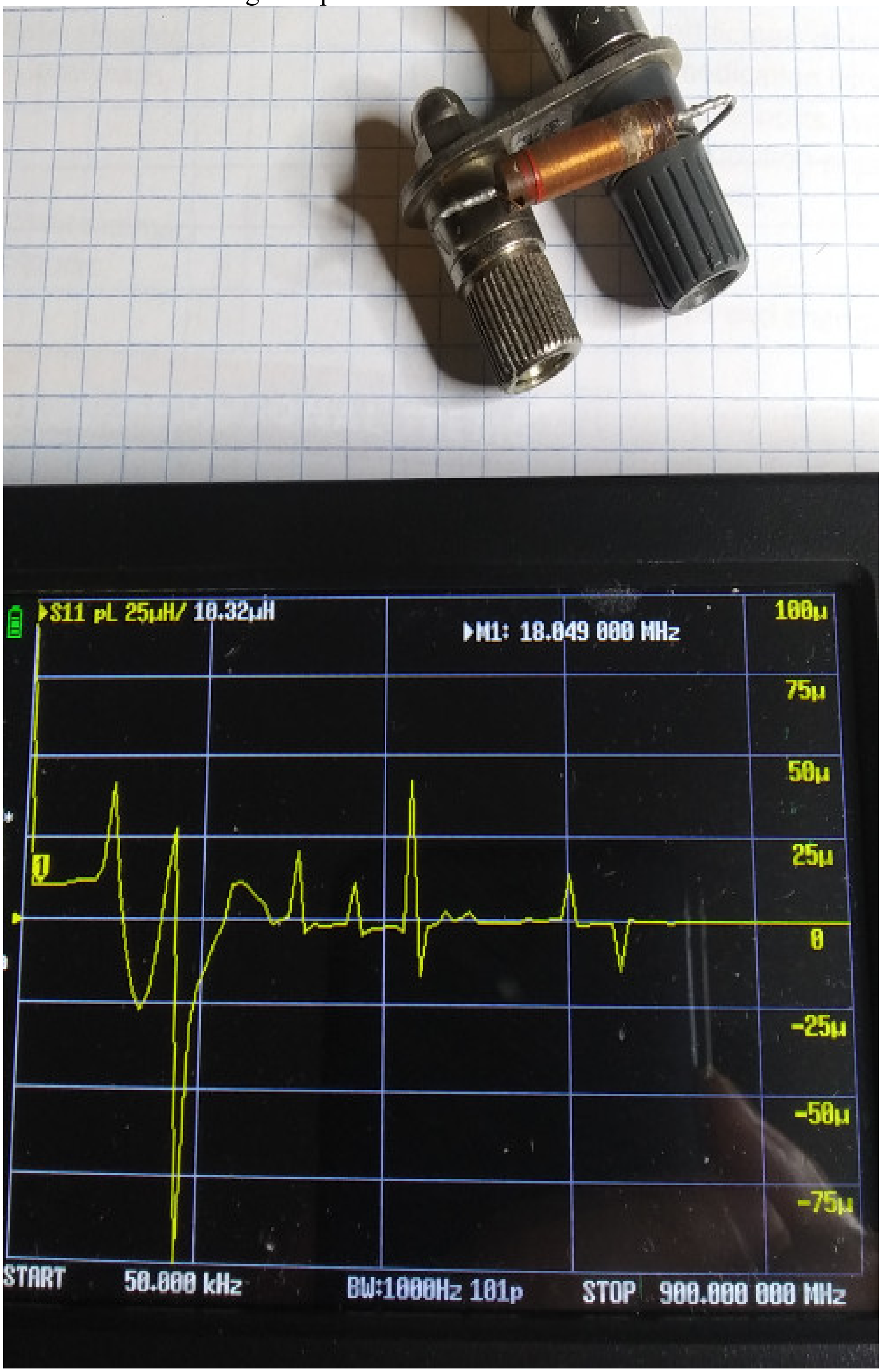


All I've done is to bend the resistor leads out straight, and the S11 traces changes. What if we just bind the ends of the resistor leads?



As soon as we exceed a few MHz, the inductance of the leads causes significant deviation from the expected behavior. The inductance of 5 cm of 20 ga. copper wire is about 60 nH, which has a reactance of about 200 ohms at 500 MHz. So, our "precision 50 ohm resistor" has an impedance of 50+j200 ohms.

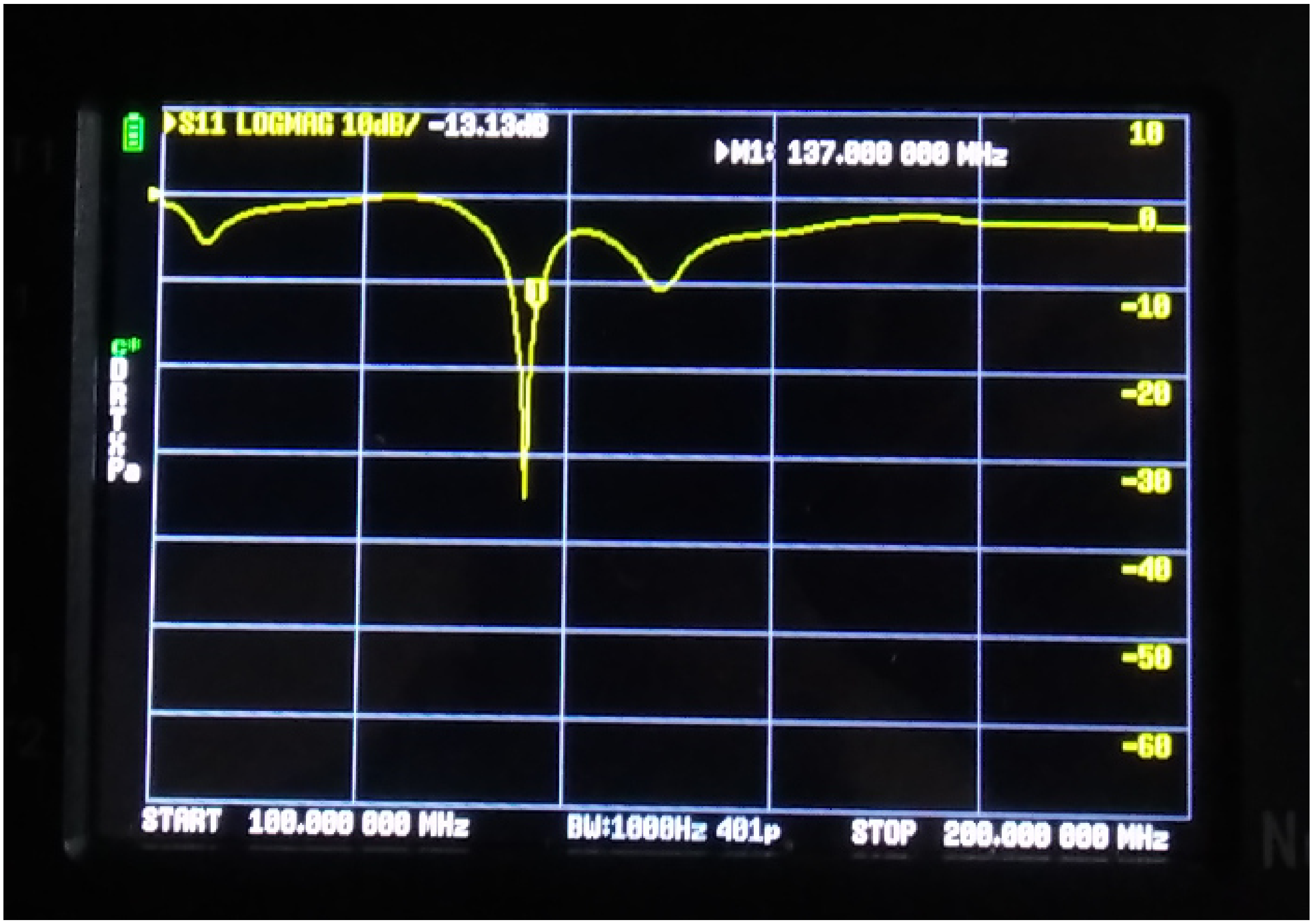
How does an inductor behave at high frequencies?



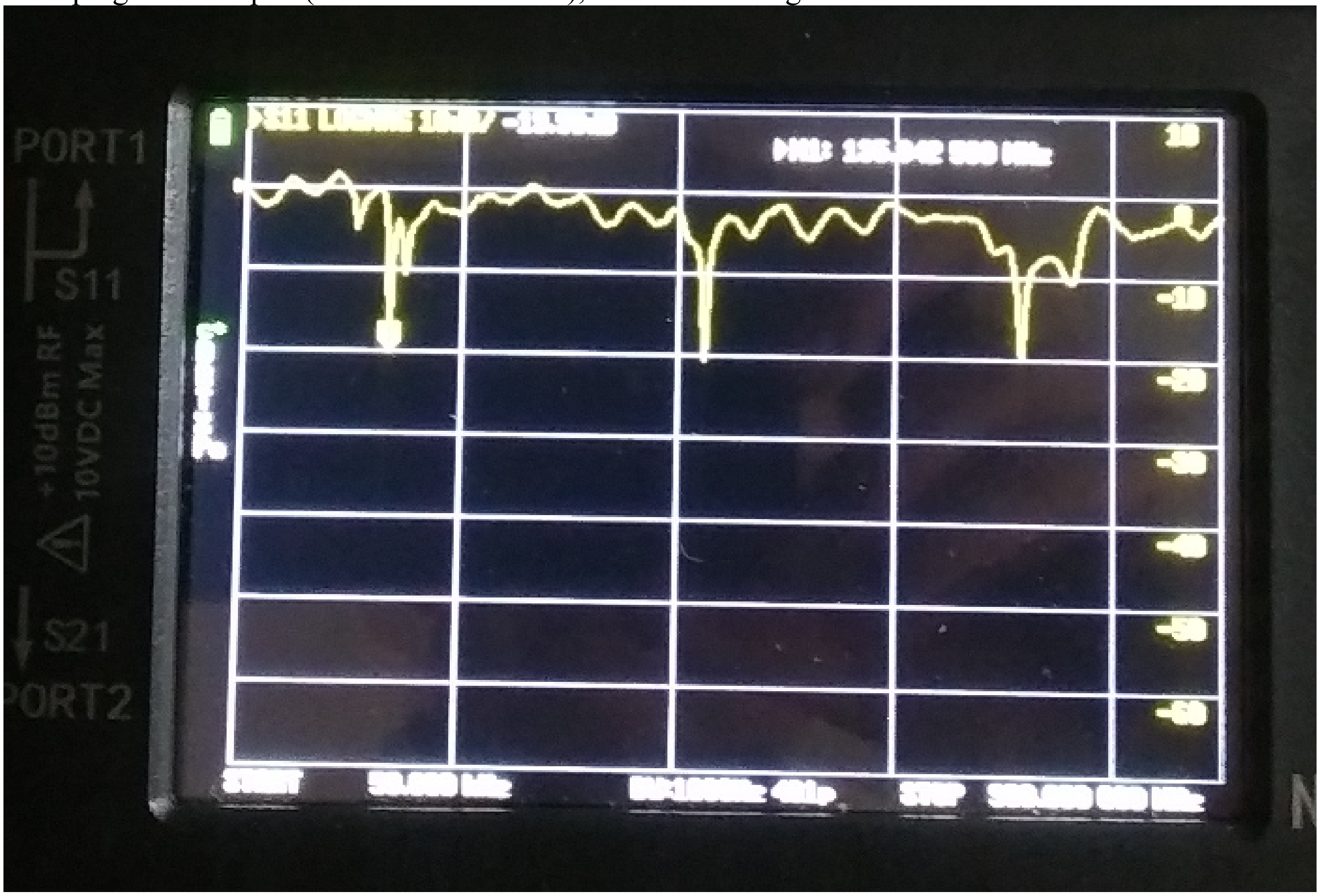
We can measure effective inductance, rather than simply return loss. This shows us that the inductor is running about 10 uH, below about 15 MHz, but after that, capacitance between turns leads to resonances below 500 MHz, and no inductance at all above that point. (A 10 uH inductor at 15 MHz has about 1k ohm reactance, by the way.)

Antenna measurements:

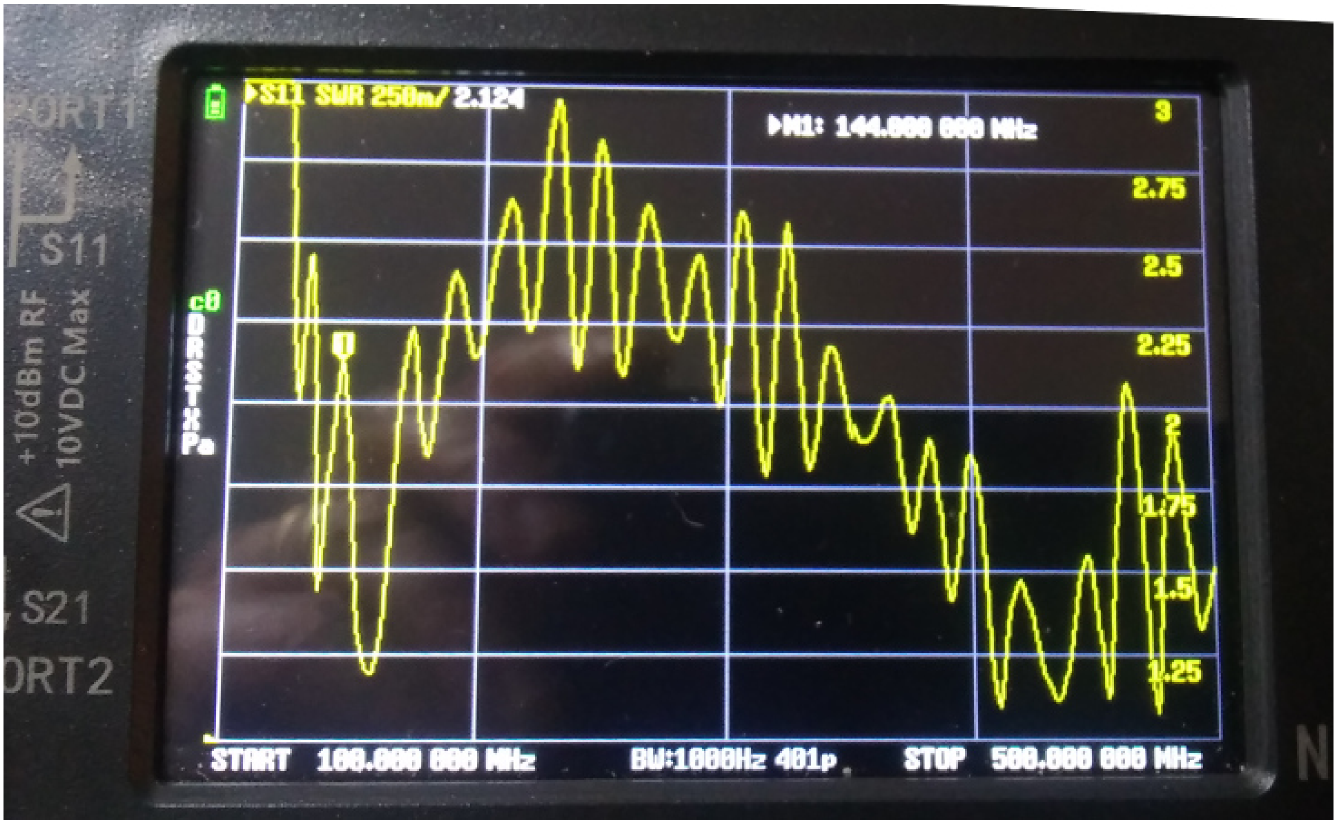
Sweeping 100 - 200 MHz, and plotting S11 in dB, we see that my DIY flexible J-pole resonates around 137 MHz, rather than 145, so I should shorten it a little to bring it onto the band of interest. (Unless, that is, I actually want to receive 137 MHz...)



Sweeping a wider span (50 kHz to 900 MHz), we see some higher-order resonances.



I also tested a commercial dual band (144/440) magnetic-mount monopole.

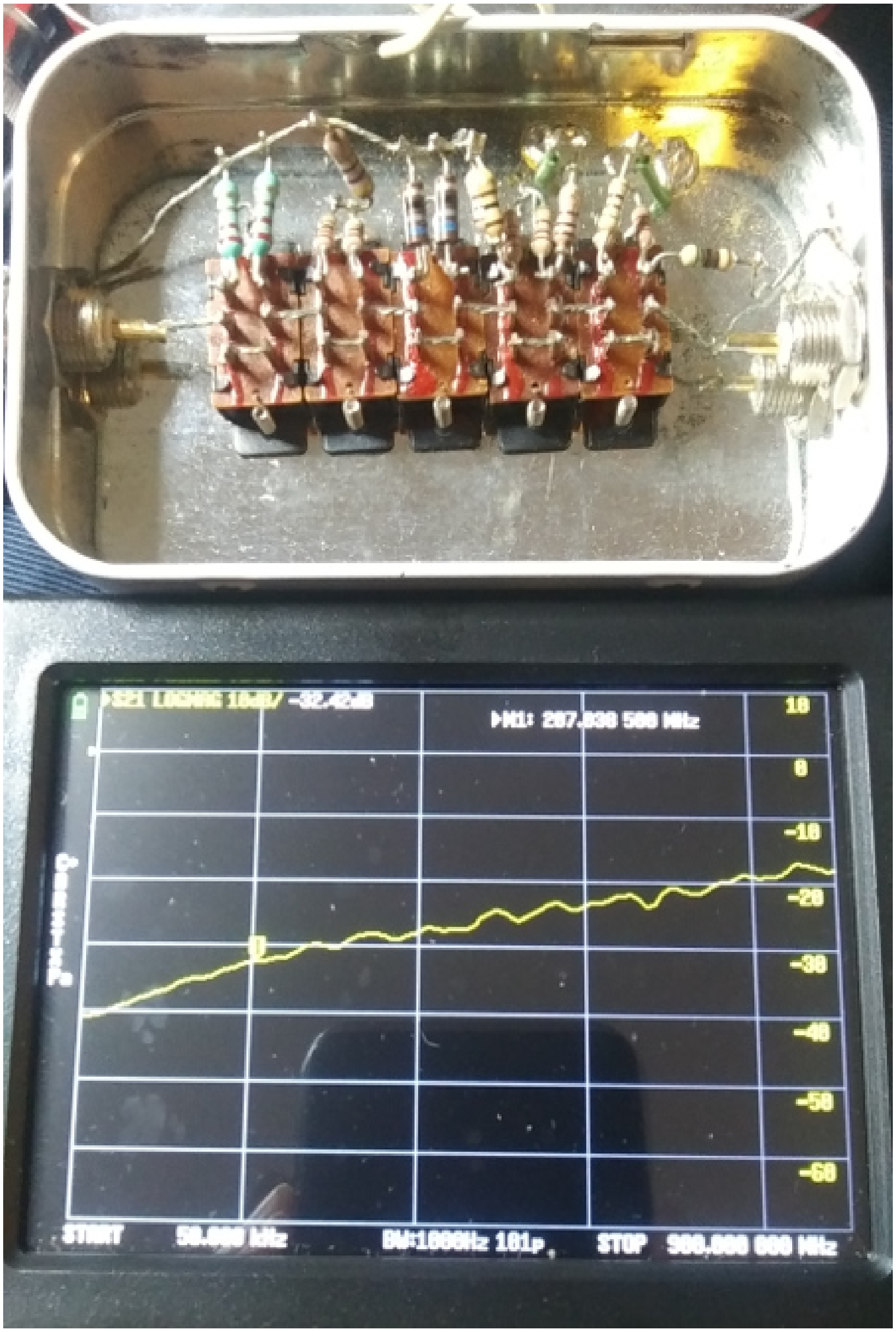


You can see that the SWR is below 2.0 for the bands of interest.

Attenuation (S21) measurements:

I built a switched attenuator into an Altoids candy box.

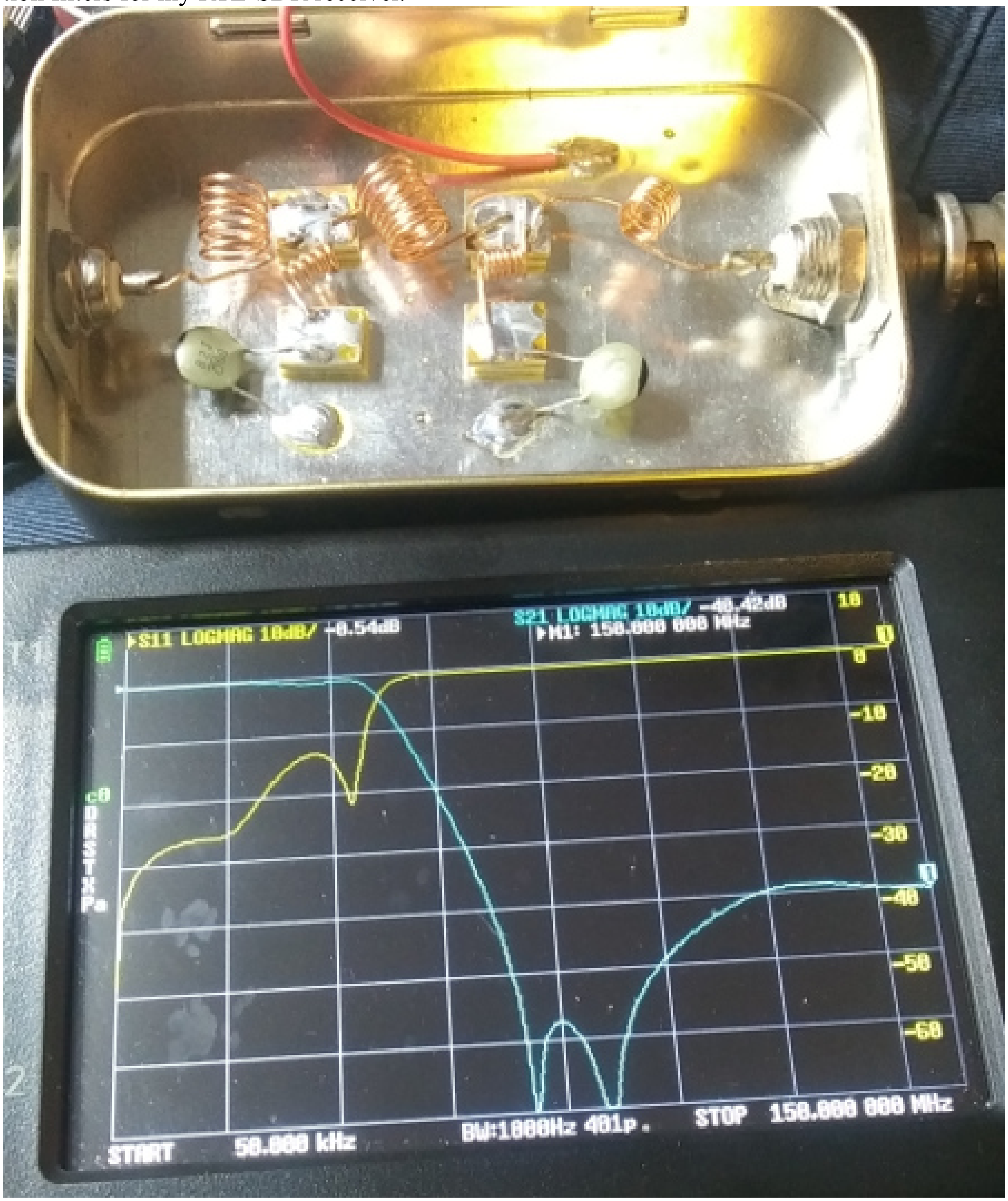
I just used resistors that I had on-hand, so I didn't care exactly what the attenuation values would be, and ended up with 3.6, 8, 13.5, 40, and 40-more dB. They're all in series, so the dBs add. With all of the switches in the "thru" position, the response is "not to bad, for DIY'.



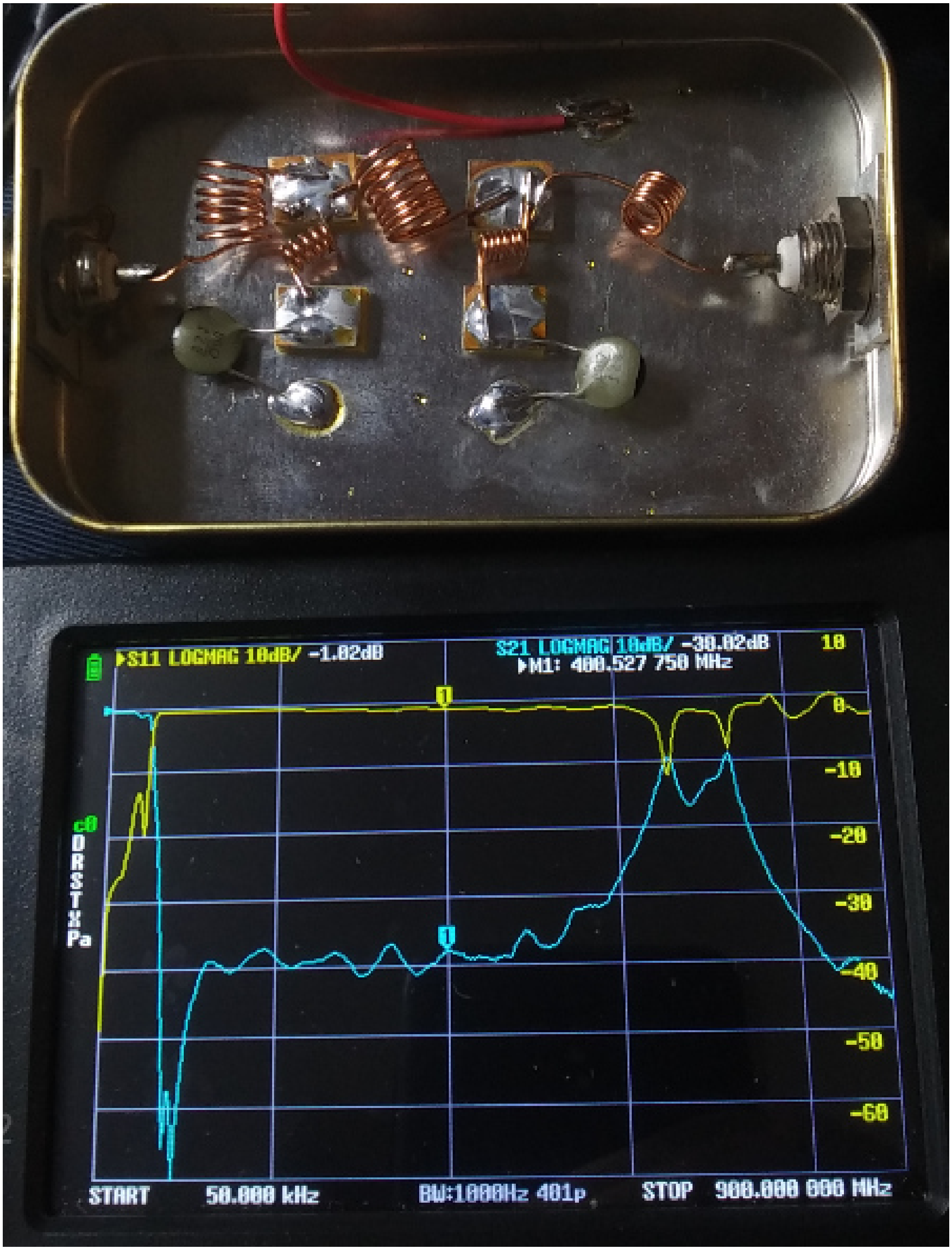
Here, one of the 40 dB switches is closed, and you can see that we get about 40 dB of loss ... for a few tens of MHz. (The scale is 50 kHz to 900 MHz, so the 30 dB point is about 225 MHz.) As the frequency goes up, more and more signal creeps past the attenuator through small stray capacitances.

Filters:

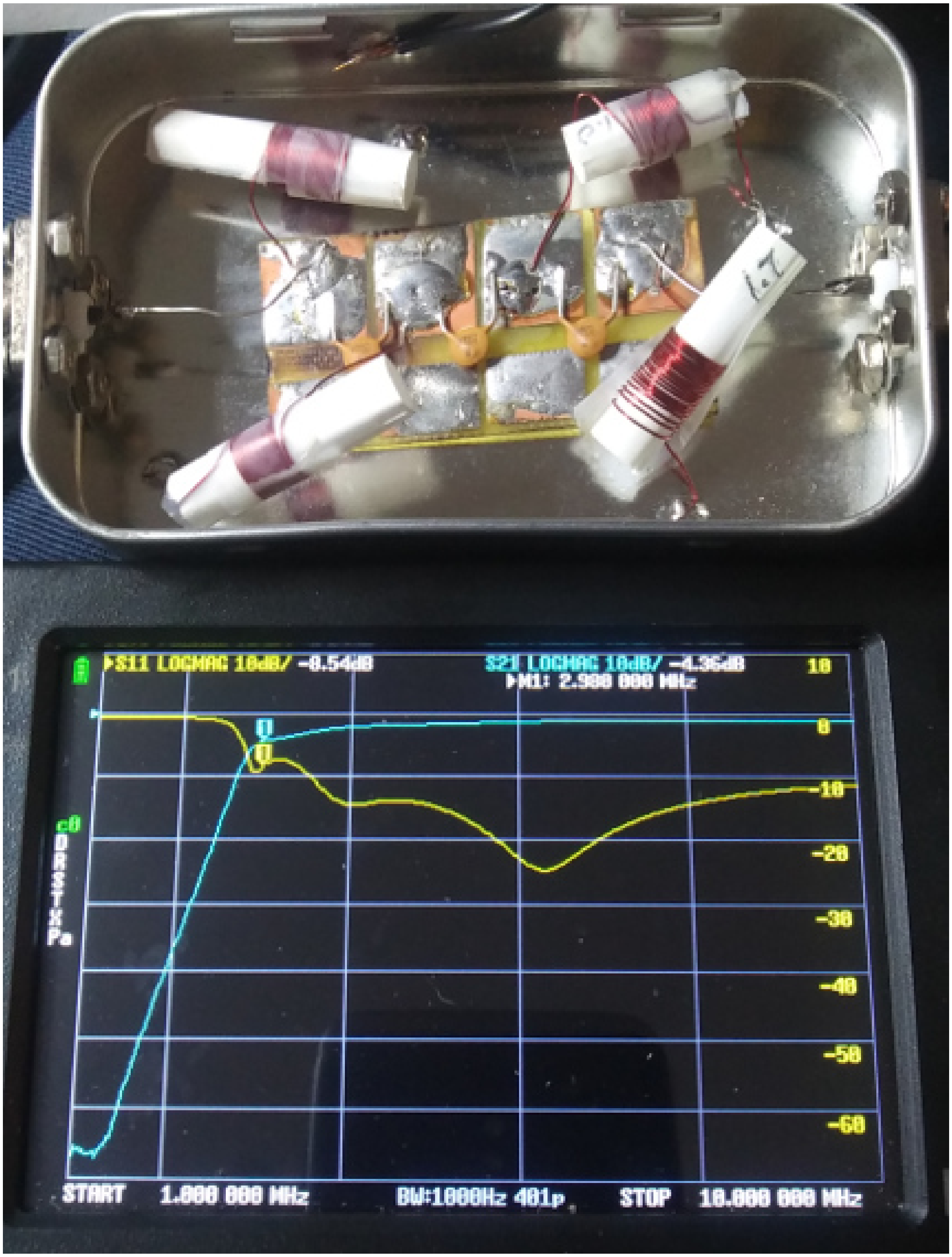
I built several lumped-element inductor/capacitor (LC) filters to serve as overload-immune pre-selection filters for my RTL-SDR receiver.



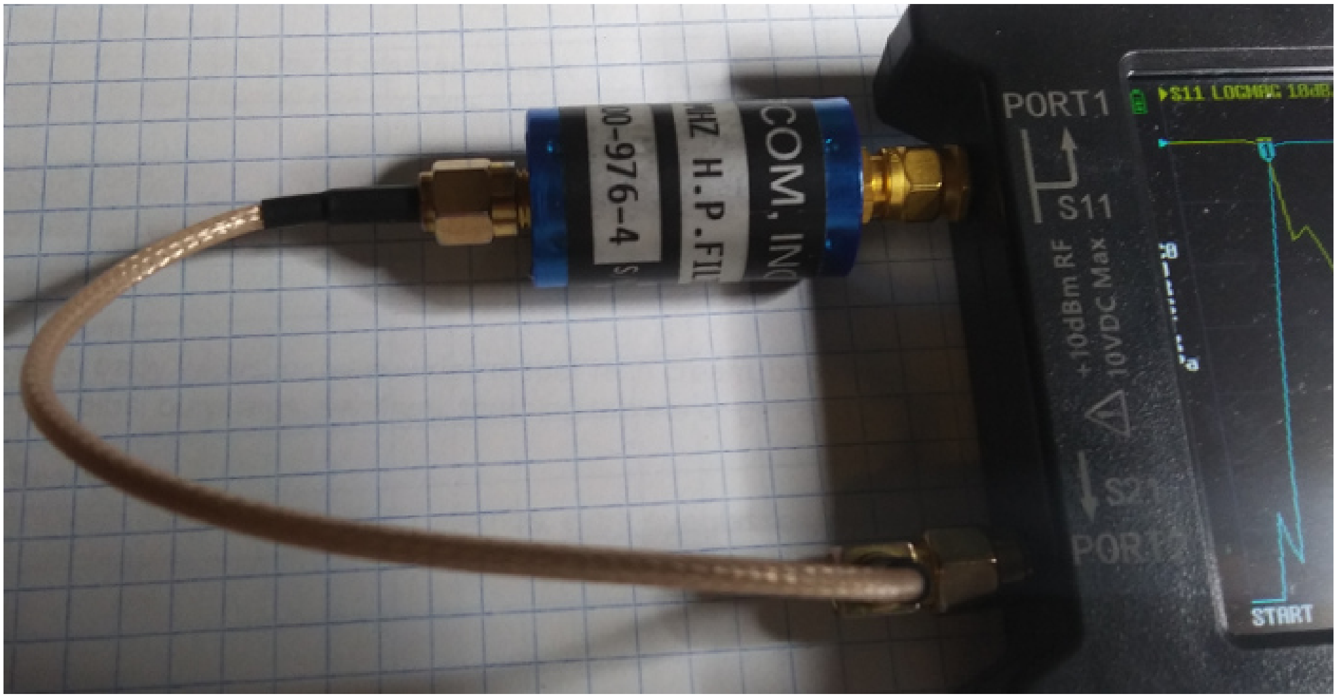
This filter is designed to pass MF and HF, while suppressing FM broadcast stations. The blue trace shows S21, the "through" signal; the yellow trace is S11, power reflected out of the filter back to the generator. The filter circuit has three inductors in series, with series L/C shunts that resonate in the FM band, putting notches in the response. My ARRL Handbook came with a DVD with "Elsie", a filter-design program, that told me how to wind the inductors. (I use drill-bits as forms, to get the right diameters.)



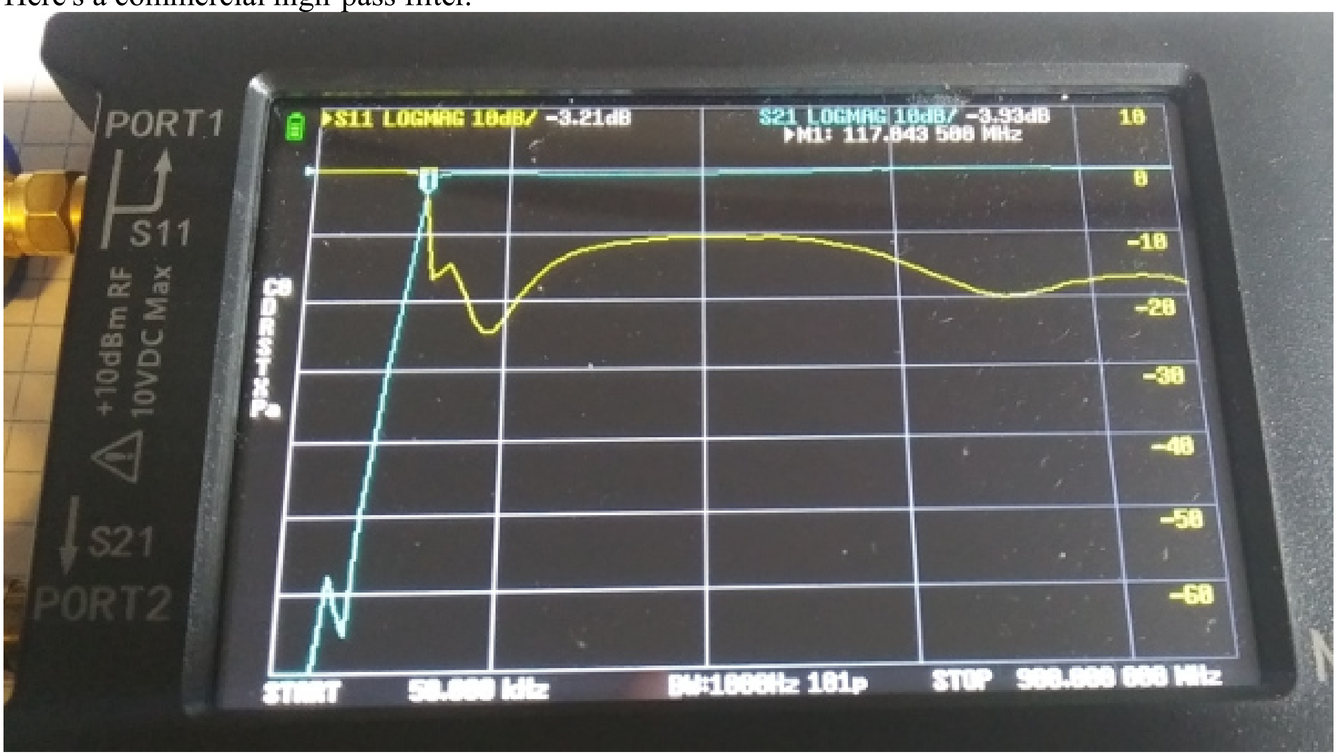
Here's the same filter, scanned up to 900 MHz. Some spurious pass-bands show up around 700-800 MHz, due to the distributed capacitance of the series inductors.



Here's a 2 MHz high-pass filter, to suppress AM broadcast signals (e.g., AM1500). The marker is at 2.9 MHz, so everything above that is good. The filter has three capacitors in series, with four shunt inductors.



Here's a commercial high-pass filter.



And here's its lovely response (50 kHz to 900 MHz).

Conclusion:

This document describes some of the more easily understood applications of the Vector Network Analyzer. More expensive units can measure all four scattering parameters: S22 and S12, as well as S11 and S21. In higher frequency ranges, directional-coupler devices isolate the reflected and driving signals. Other units may be used to measure devices with more than two ports. Even this simple unit can display results in many formats other than those shown here.