Random RF Attenuator

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1 Motivation

The main reason behind this project is me getting more involved with Software Defined Radios. Because every RF project needs an attenuator, even if just for testing, I decided to need one.

My initial idea was to layout a PCB that I can use for filters and attenuators. A pi network can be used to build both, depending on the components used (resistors, capacitors and inductors with different positions). After talking to a more experienced colleague about the topic I was conviced that coming up with such a layout that can be used up to about 6GHz by myself with basically no experience would indeed be a bit too much to ask for. Instead I will soon look up common layouts and probably reuse an approved reference design.

However I still had the idea in my head to build an attenuator for myself, especially after having watched this YouTube video where some guy build an attenuator which performed really well and it did not look too complicated as well. I took a look at the components I already had laying around and figured that I would just go for it and then see what I get out. There is basically no cost but a lot of experience to get be earned.

2 Building

2.1 Calculations

Since I am using components I have on hand, the calculations are only used as reference to what should come out at the end.

$$R_1 = R_2 = Z_0 * \frac{N+1}{N-1}$$

$$R_3 = Z_0 * \frac{N^2-1}{2N}$$

I used two 100 Ohm resisitors in parallel as R_1 and R_2. For the center resistor I used two 1k Ohm resistors so $R_3 = 500$ Ohm. This should result in about 25dB attenuation at an impedance of 45 Ohm.

2.2 HF Path

The HF path is not build like a simple pi, but with every resistor being two resistors in parallel. On the "feet" of the pi, the resistors are placed symmetrically around the center conductor of the SMA connector and the two "top" resistors are stacked together and then soldered in as a replacement for the center conductor of which I cut off a section as long as the two resistors. This way I was able to have the path as short as possible.

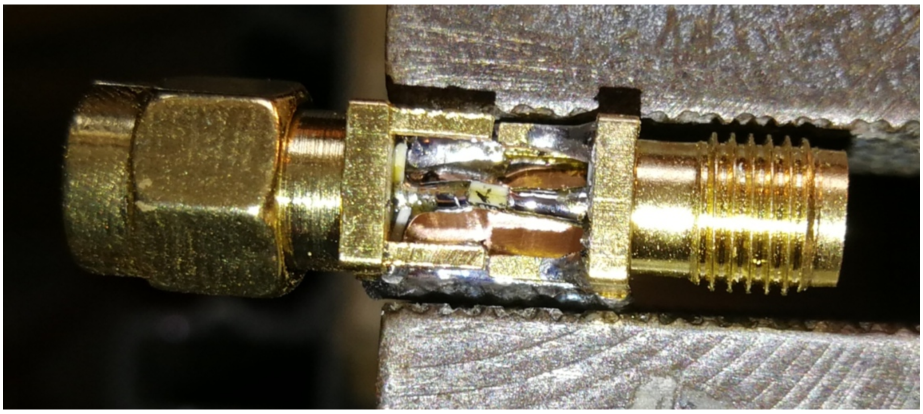

Figure 1: Attenuator top view

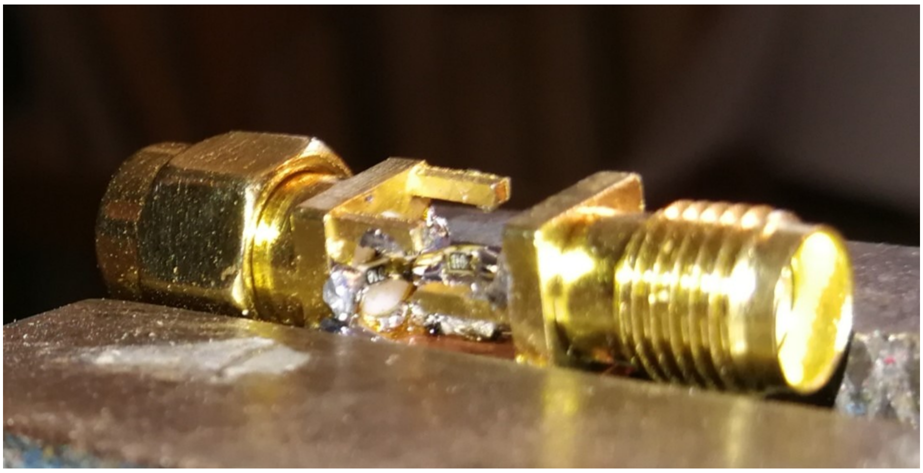

Figure 2: Attenuator side view

2.3 Housing

Once the assembly was finished I put it inside a piece of aluminium tubing. I had some of the right diameter laying around and figured it would look more professional and probably also helps with external noise. The assembly was a nice fit with only very little resistance when pushing it inside. The ends were sealed with hot glue, which was not the brightest idea, but for the target frequency range still good enough.

Figure 3: Attenuator testing with Nano VNA

3 Measurements

Let's first have a look at the whole span my NanoVNA can measure. The signal is yellow. Blue is the reference data I captured with only the cable connected.

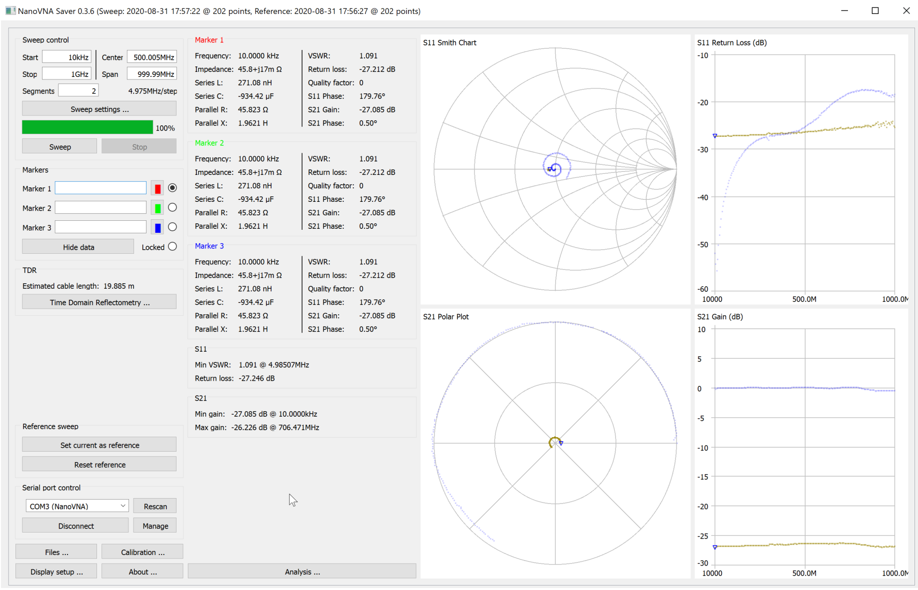

Figure 4: Sweep 10kHz to 1GHz with cable as reference

Talking about the cable, it is worse than I thought. According to my colleague, a return loss S11, in other words the power reflected back to the transmitter, of more than -20dB should not be used. With this is mind, the cable can be used up to about 650MHz. The return loss in this case is mostly influenced by the connectors or, but I don't suspect this, the cable not having a 50 Ohm impedance. At low frequencies the return loss of the cable is great, but that is to be expected from a cable to be honest. The gain S21, or in other words the power coming out at the receiving side, however shows a very nice straight line over the frequency range. There is a small drop at roughly 800MHz, but it's small enough for me to ignore.

Now about the attenuator. The gain S21 is negative, which is to be expected from an attenuator. With a value of about -27dB it is also quite high for a "build at home" style attenuator. My colleague told me that lower attenuations of -10dB to maybe -15dB can be build without much hassle. Values of -25dB however are harder to reach (with the other factors being still useful). The drop at the high end can be explained by the drop of the cable adding to the attenuation. As expected, the attenuation get's slightly worse at higher frequencies, but is still under -25dB at 1GHz. The smith chart for S11 shows all measurements very close together at about 45Ohms real resistance. That was also expected from the calculations above. In fact, this is quite promissing. To have the value at 50Ohm real impedance different resistors for R_1 and R_2 would have been necessary, but these were the values I had on hand. The smith chart for the gain shows the same impedance, but with the phase being shifted due to the cable I used for connecting the attenuator to the VNA.

For ammature radio, narrower bandwiths can be inspected. I expect better performance here, since the frequency bands are quite narrow compared to the sweep before so the linearity at any given point should be better.

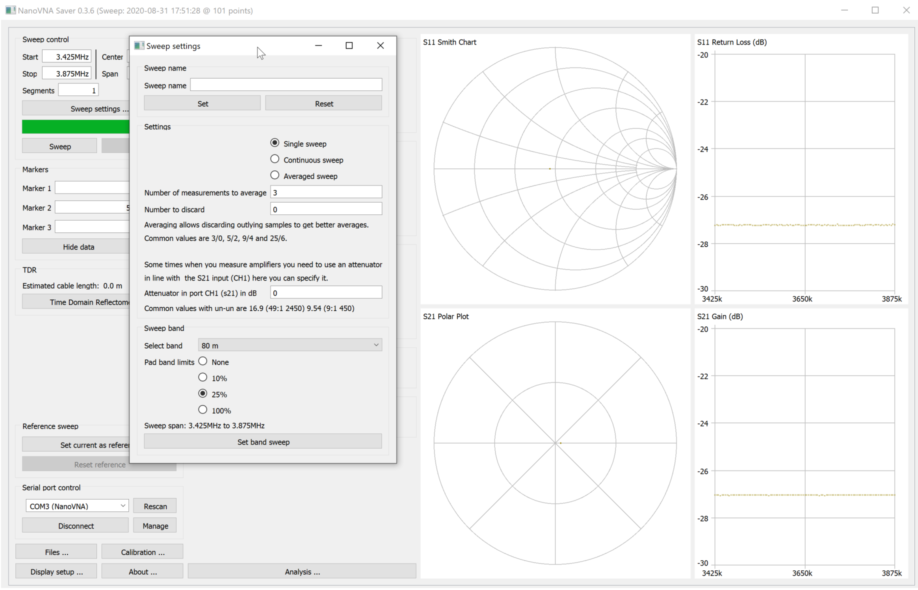

Figure 5: Measurements in the 80m band

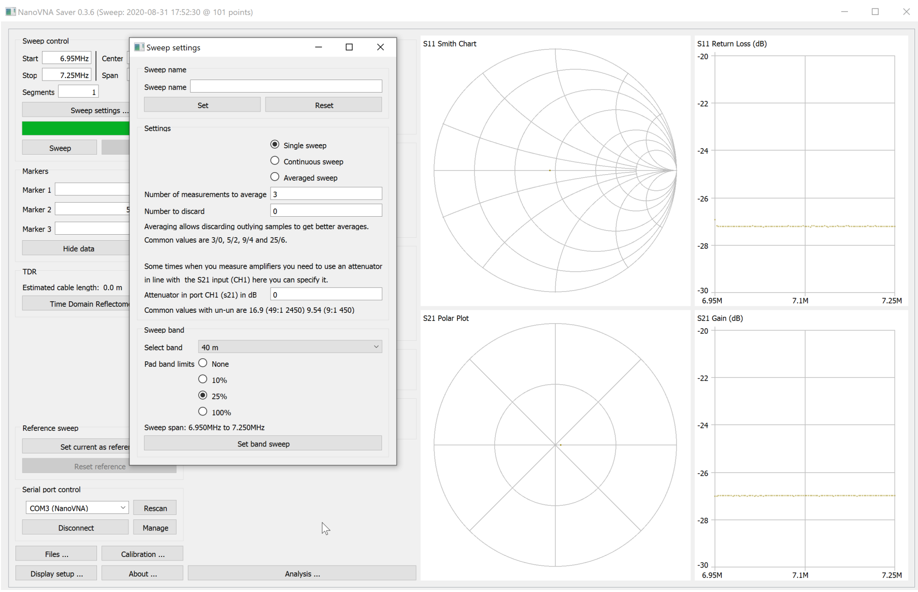

Figure 6: Measurements in the 40m band

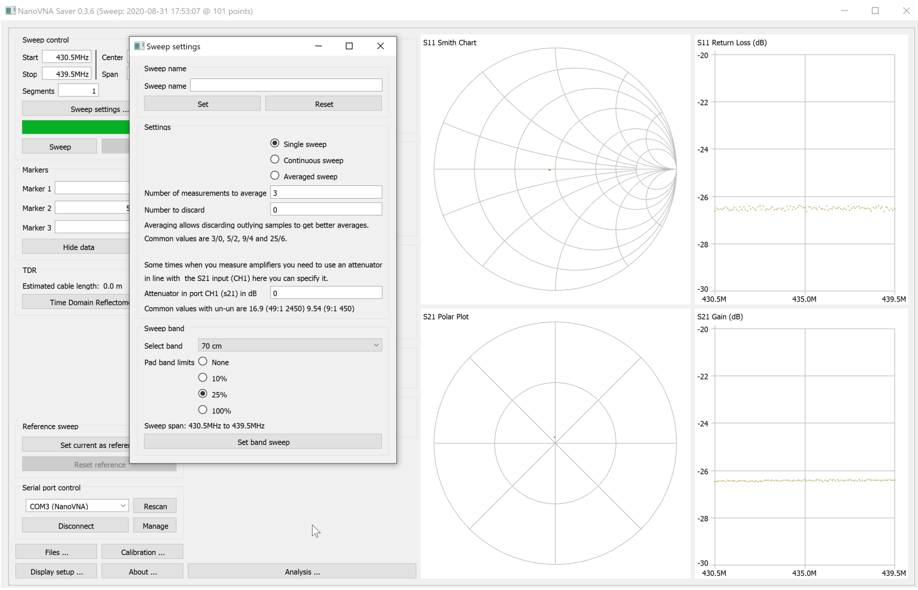

Figure 7: Measurements in the 70cm band

4 Thoughts

For a 2 hour build, and my first attenuator build at all, I think the performance is really good. The attenuator can be used up to 1GHz without any problems which is fine for most ammature radio bands (I don't have a license yet but those bands are useful anyway). I have a feeling that for better performance, the "feet" resistors of the pi should meet the ground in the middle, such that all signals paths are (closer to) the same length. I bet that would improve the performance at the high end.