Pi Layout First Evaluation

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2020
November

Contents

List of Figures

1 Build and Reasoning

1.1 Through

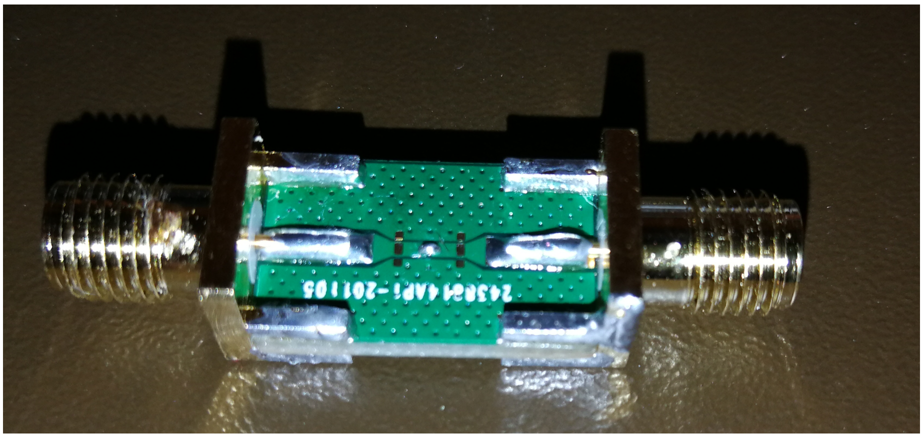

Figure 1: Through picture

For the through the center component pads have been shorted out.

This should show as a 50 Ohm track, if the impedance of the trace and the connectors is correct.

1.2 Open

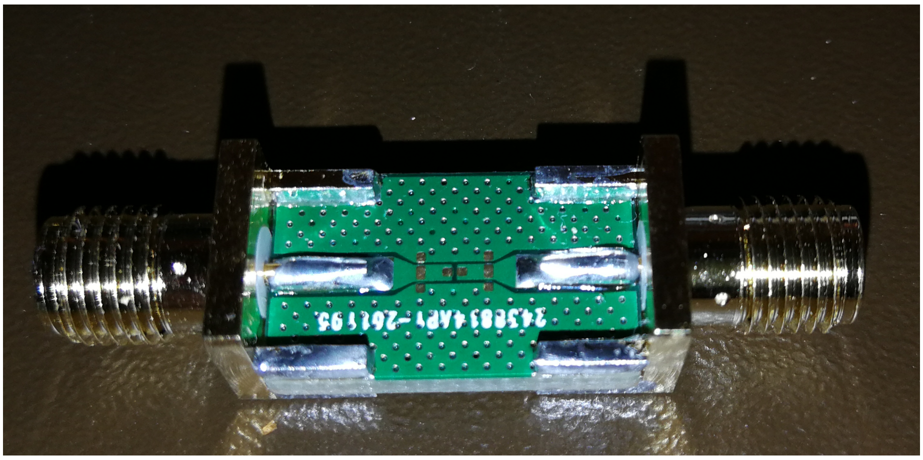

Figure 2: Open picture

To build an open, only the SMA connectors are placed.

This is supposed to work as a DC block. If the impedance is correct, as measured before.

Also the capacitance of the traces being so close should be measurable.

1.3 14dB Attenuator

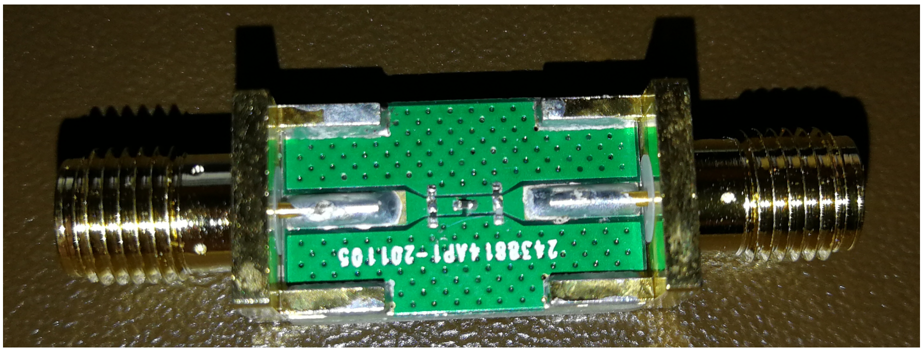

Figure 3: Attenuator picture

Even though this does not directly measure any characteristics of the PCB or the traces, if the previous builds show good results it is interesting to build an attenuator and look at it. It will also be possible to compare it to the previously build ”random attenuator”.

Because the resistor values that were availible matched this the most, an attenuation of 14 dB was chosen. This is not as practical as a more common value of 10 dB or 20 dB, but it still will be an interesting learning opportunity.

2 Results

2.1 Through

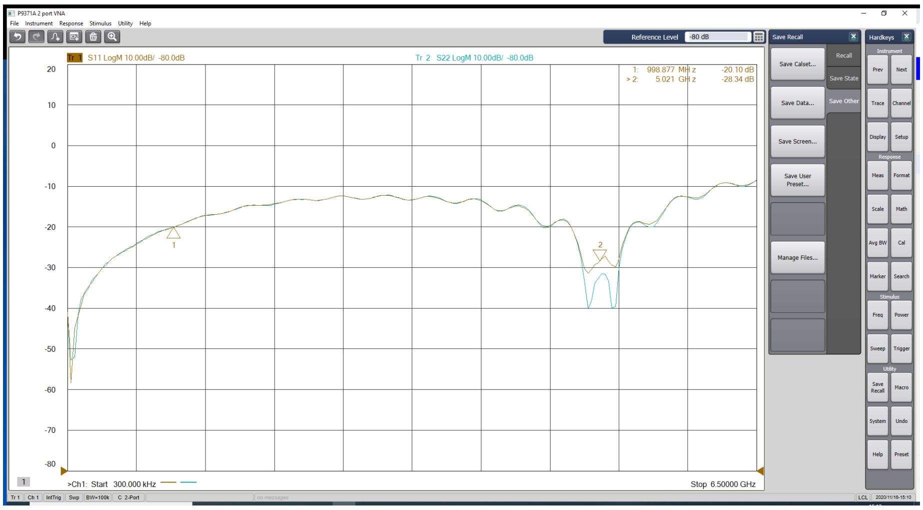

Figure 4: Through S11 and S22

S11 and S22 are almost the same. This is nice, because it shows good symmetry in the design.

There is good attenuation at lower frequency, which is good, because with the center conductor being shorted out the expected result for return losses is a low value (since all the power is being transmitted to the other side).

Then there is this region of "meh" between about 1 GHz and 4 GHz. The reflected power is quite high, with only around -15 dB or even less. At this point it is unclear if this is due to the desgin or if it is a mistake in the build. -15 dB is not too bad, but it should be more, shouldn't it?

Something interesting can be observed at about 5GHz which is where the cursor 2 is on S11 and S22. Both show a significant increase in the return loss at this frequencies. Let's do some math...

$$f = \frac{c}{\lambda}$$

Using the length of the PCB which is about 17 mm...

$$f = \frac{3*10^8}{17mm} \approx 17.6GHz$$

There is a shortening factor that is approximatly the square root of epsilon. With FR-4...

$$\sqrt{4} = 2$$

$$\frac{f}{2} \approx 8.8GHz$$

…which would be 4.4 GHz at $\frac{\lambda}{2}$.
This is very close to the first minimum.
Similarly 5.5 GHz is $\lambda = 27mm$ which is close to the length of the assembled PCB, ranging from one SMA connector to the other one, each counting from the point where the dielectric is starting inside the connector. That would make sense, assuming the leads on the VNA were calibrated also to the end of their dielectric. For sure the VNA is calibrated with the coax cables attached, but where does the calibration "end"?

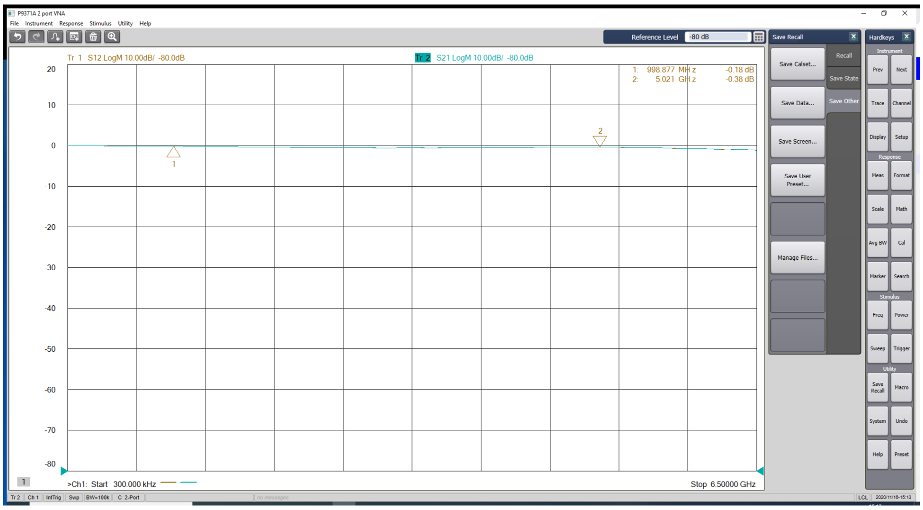

Figure 5: Through S12 and S21

Looking at the insertion loss, the graph is very close to zero, meaning almost all power that is inserted on the first port is coming out at the second one. The graph drops visibly after about 5 GHz, but still stays within -1 dB.

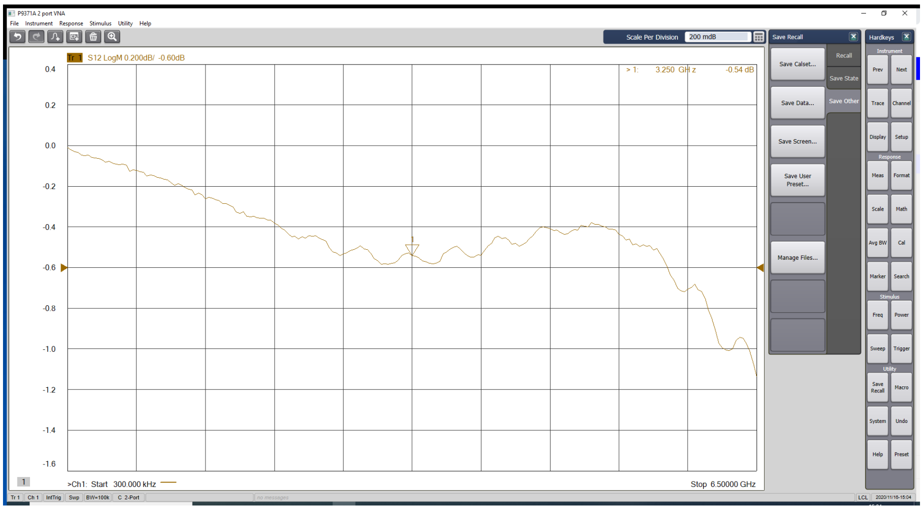

Figure 6: Through S12 zoomed

When changing the scale the non-linearity becomes a little more obviuos, but keep in mind the scale. The full range from 300 kHz to 6.5 GHz is within 1 dB! Also more obviuos in this picture is the fact that at the "resonance" frequencies at about 5 GHz, the insertion loss is slightly increased.

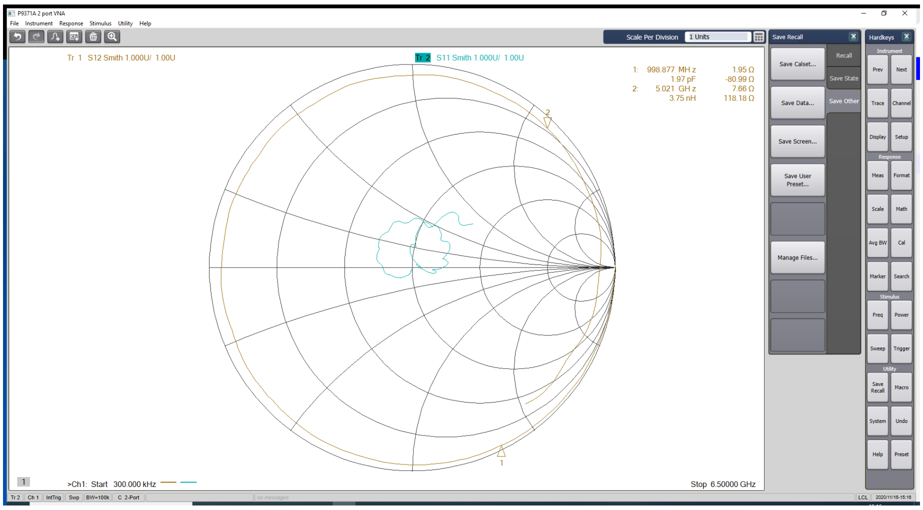

Figure 7: Through Smith

For sake of completeness, here is the smith chart. There is not too much to see. The S12 shows very close to an ideal transmission line very close to the edge of the chart. S11 is close to 50 Ohms, but not perfect. The whole thing is slightly shifted to the top, meaning inductive. This is possibly due to the inductance of the solder ball, but this is only a guess...

2.2 Open

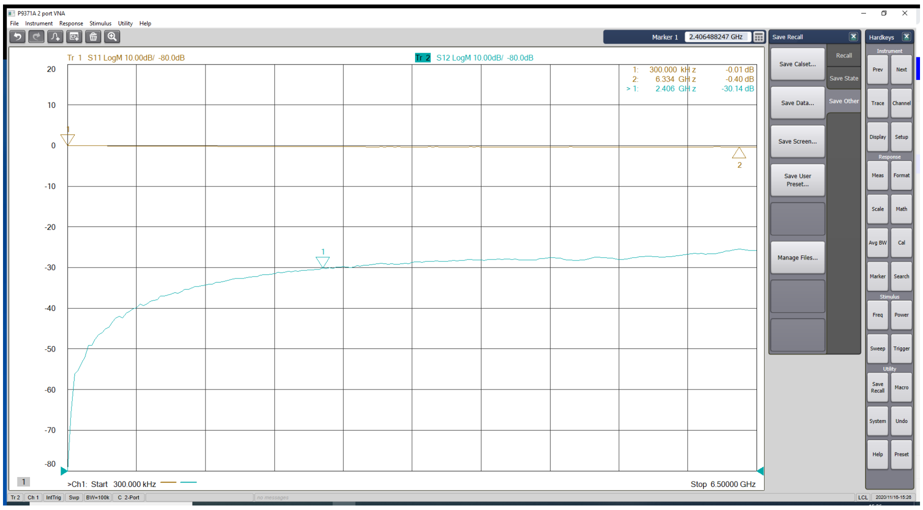

Figure 8: Open S11 and S12

Since S11 and S22 as well as S12 and S21 have proven to be so similar, they will no longer be described individually.

The return loss is almost at 0 dB, which is to be expected from an open connection, at least at low frequencies. At higher frequencies the capacitance of the traces meeting at the footprint of the center resistor has a significant influence. The capacitance is very low however, due to the fact that the traces still are ”far” appart and very narrow.

The insertion loss shows the influence of this capacitance acting as a DC block. But also high frequencies are dampened by about 30 dB, making this a rather bad DC block. Putting on a real capacitor is definitly more usefull. The increased capacitance will make the insertion loss converge quicker to 0 dB and then higher frequencies will be passed as intended.

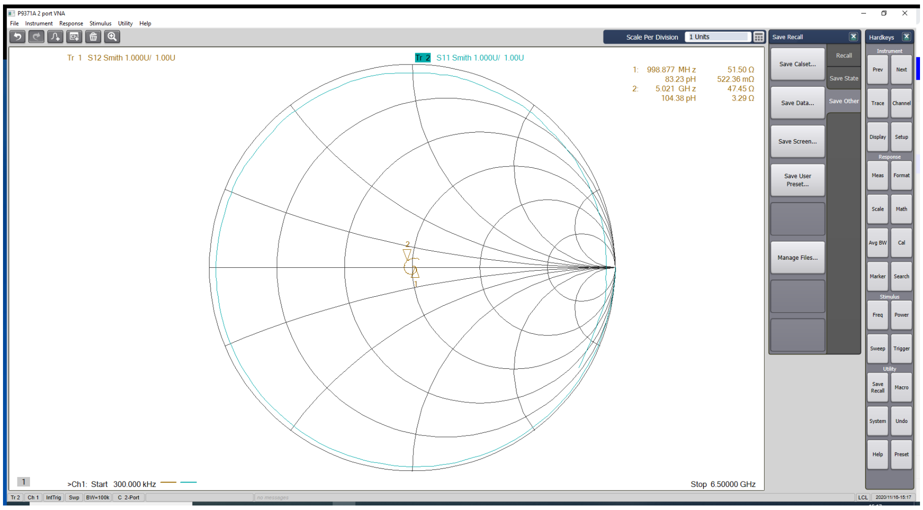

Figure 9: Open Smith

The smith chart now shows the S12 being very close to 50 Ohms and S11 being even closer to the edge of the chart as before. That is very promissing and is an indication for the coplanar waveguide with ground plane being indeed very close to a 50 Ohm impedance.

2.3 14dB Attenuator

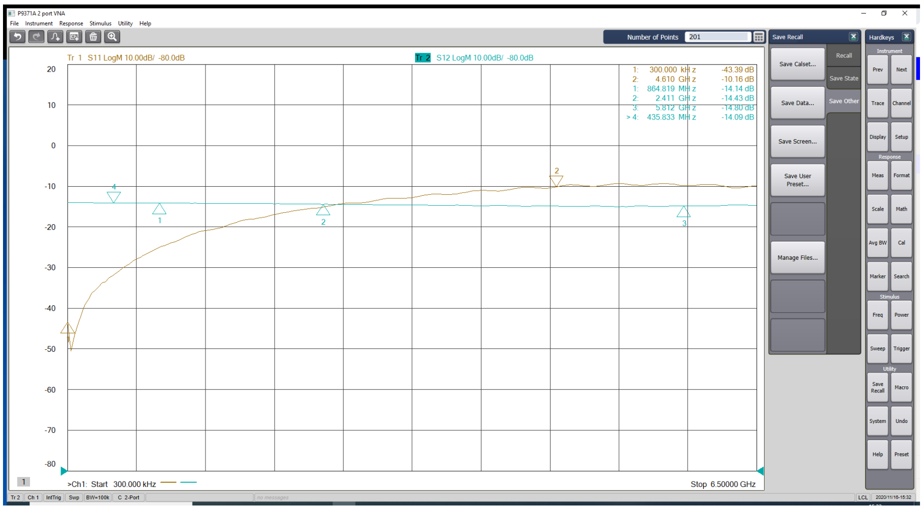

Figure 10: 14dB Attenuator S11 and S12

Now this is quite impressive. The attenuation of the attenuator is nearly linear from 300 kHz all the way up to 6.5 GHz. There were markers added at some interesting frequencies for hobbyist use. The difference in attenuation seems to be about the same 1 dB as it is in the "normal" through. It is very possible that the difference at high frequencies even is coming from the same design "mistakes"?!

The return loss also looks better than before, might be because there are actual components placed on the PCB. After about 4 GHz the retun loss is surprisingly constant.

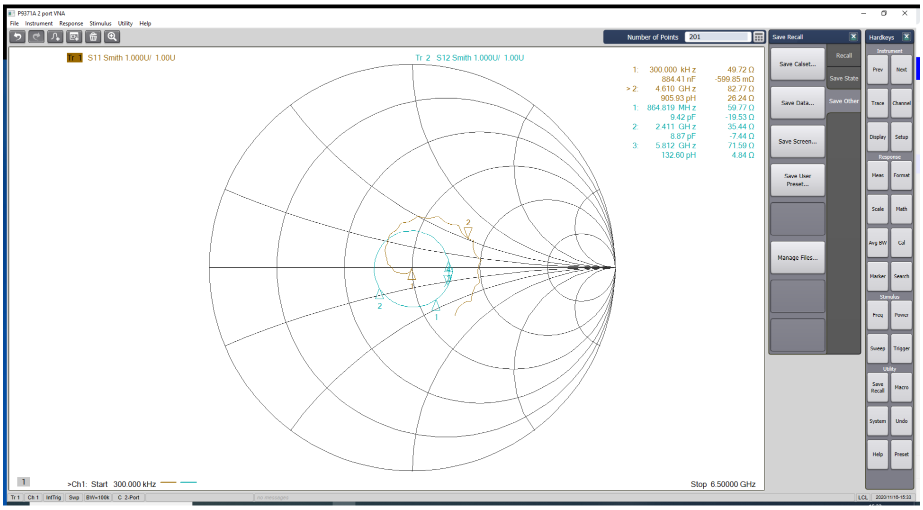

Figure 11: 14dB Attenuator Smith

The smith chart of the attenuator is a little more interesting. Starting the thought process from DC, there is a offset in S12 from 50 Ohms due to the resistors needed to get the desired attenuation. When increasing the frequency, the attenuation should stay the same, and only the phase changes, creating the "rotation" in the graph. If the attenuation would really stay the same, at higher frqeuencies (here $\approx 6GHz$ should overlap exactly with the lowest frequencies. It does not quite though, meaning the attenuation does change a little over the frequency, which already showed in the logarithmic graph. It is stil very good, especially for a hand made attenuator.

The return loss S11 does not show any particulary interesting behaviours. Well there is this "ripple" on it, but it is hard to provide an explanation...

3 Thoughts

As expected, the 0201 components are very hard to solder by hand. I managed to get two resistors on the PCB, but the third one already failed. Working with a microscope and a thinner tip for the soldering iron helps a lot. Anyhow, I will remake the PCB with 0603 components, just to have something to compare. The new layout can then also be a little shorter, or at least have the same length, by shortening the center SMA pin.

The results are very good, showing an almost linear or rather straight curve up to 6.5 GHz where the measurement equipment I have availible is at its limit. For the SDRs I own that is enough, for example the HackRF One can go up to 6 GHz which is exactly within the measurement range.