A Tale of Three DSPIRA LNAs

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The DSPIRA LNA (designed by Kevin Bandura) looked interesting so I thought I would try and construct one myself. I had some previous experience soldering surface mount components, so wasn't daunted by the prospect. I already had a small dish antenna that I thought would work on 1420 MHz and a number of different SDR receiver options to try.

Obtaining the components

When ordering the components I started with the circuit board. OSH Park only sold the circuit board in quantities of three or more, which was fine. I figured I would build a couple of LNAs for 1420 MHz (perhaps to do interferometry) and maybe use the third board for some other frequency.

The next tricky components were the 1420 MHz filters. I couldn't find anyone wanting to sell them in small quantities, so I ended up asking for free samples from MiniCircuits. Sure enough they obliged and sent me the filters free of charge.

The other component that looked difficult to get was the shield. This I found would be ridiculously expensive in small quantities so I gave up and figured I would somehow make something to fit.

The rest of the components were easily available from Digikey.

Construction

When everything arrived I started putting together the three LNAs. By now I had figured that I would actually build all three for 1420 MHz. Using the third board for a different frequency was probably never going to work anyway. Unfortunately I had only asked for enough free 1420 MHz filters from MiniCircuits to complete 2 of the boards, but I had seen some for a reasonable price on a Chinese website so had sent away for these.

Instead of the shield, I milled out some small aluminium cases for the LNAs. I made the internal dimensions of the case approximately what I expected the inside dimensions of the shield would be. Although I have a lathe I am definitely not a perfectionist when it comes to metalwork. Even so I was quite pleased with the resulting case.

The shield component may be easier to obtain if you live in the USA. However, if you do struggle getting this component and don't have the ability to mill an aluminium case, then don't give up. While my later testing showed some sort of shield is a good idea the exact shape and form of this is not critical.

I only used a simple soldering iron to assemble the boards. I found that the pads with vias to the large ground plane on the bottom of the board took quite a bit of heating. My soldering iron had a fairly sharp point which was needed for such fine work but wasn't great for transferring lots of heat. Eventually with patience I managed to complete the first two LNAs. I hadn't applied the conformal coating. While this stuff is very good it does make checking and repairing a faulty LNA very difficult. It would be nice to know they are working correctly first before applying this.

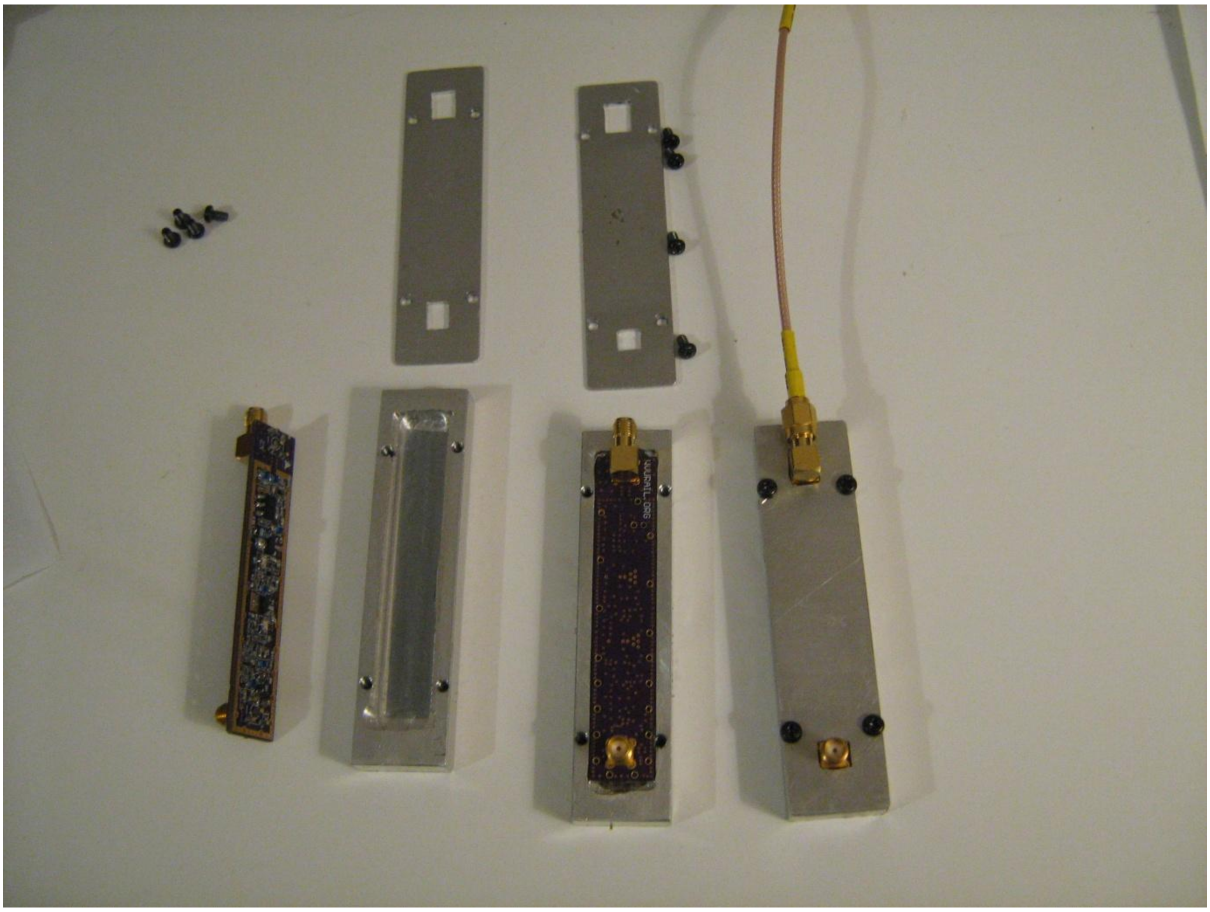

Figure 1. The 3 LNAs in various stages of disassembly showing the milled aluminium case.

Initial Testing

Powering up the first two LNAs showed they didn't draw as much current as expected, around 80mA instead of the expected 160mA. This didn't overly concern me at the time (although in hindsight it should have). Glen Langston suggested I test the LNAs before trying then on an antenna. His test method was documented in http://wvurail.org/lightwork/memos/LightWorkMemo028-r7-NoiseTemp.pdf and only required a small 50Ω SMA termination resistor (which I already had).

The test simply involves measuring the receiver signal level with the antenna connection terminated with the SMA resistor (assumed to be a 290 degrees Kelvin signal level) and unterminated (assumed to be a 0 degrees Kelvin signal level).

My initial tests were completely disappointing. I saw absolutely no change in signal level with the SMA resistor connected or disconnected on either LNA. Something was seriously wrong. I did note that the receiver signal output did increase when I powered up the LNAs and drop when I switched them off. So they weren't completely dead. There was probably something wrong with the first stage. I carefully applied a multimeter to the junction of R2 - C1 - L1 to give an idea of the voltage across the SAV-541, and with ohms law and the voltage across R2, I should also be able to work out the current through it. OK I had almost zero volts! That certainly didn't seem right. I checked the voltage on the top side of R2 and found this was the expected 5V. When I checked a little closer I found my R2 resistor was 27kΩ, when it should have been only 27Ω. I had been following an outdated version of the assembly instructions and this error was in the parts list although the schematic diagram has the correct values. I didn't actually have any 27Ω resistors but did have some 30Ω ones so gave them a try.

After installing the 30Ω resistors I found the current drawn by the LNAs now came up to the expected 160mA and I had a healthy 2.7 volts across the SAV-541. Terminating the LNA input with the SMA resistor brought the receiver noise output up nicely. It looked like I now had two functioning LNAs.

Noise Temperature Measurement

Glen put me on to this document https://www.osti.gov/servlets/purl/1562649 which among other things shows how to calculate the noise temperature of the LNA from the SMA resistor test. Well actually the noise temperature of the whole receiver chain, but the LNA is the critical component. The formula is a little strange. First you calculate the factor Y from the following;

$$Y = \frac{N_{Hot}}{N_{Cold}}$$

Where N_{Hot} is the receiver output when the SMA resistor is connected and N_{Cold} is the receiver output with no resistor. The units of N_{Hot} and N_{Cold} must be the same and linear with the noise power output of the receiver. Signal levelss from the uncalibrated GNU-Radio Spectrograph are fine. Pick a frequency near the middle of the band where there is no great change in reading Vs frequency.

The noise temperature of your LNA is then calculated by the formula;

$$T_{LNA} = (T_{hot} - Y * T_{cold})/(Y - 1)$$

Where T_{hot} is the temperature of our SMA resistor and T_{cold} is the temperature we assume the LNA is seeing when unterminated. These must be in degrees Kelvin.

If we assume T_{cold} is 0^0K, and T_{hot} is 290^0K then the formula simplifies to;

$$T_{LNA} = 290/(Y - 1)$$

My first LNA gave a reading of 830 for N_{Hot} and 115 for N_{Cold}. This gives a Y value of 7.2 and therefore a LNA noise temperature of 47^0K. The DSPIRA LNA is expected to be less than 50^0K so it looked like I had a very successful working LNA. Just to check I tried a number of different repeats of this measurement including; allowing the LNA to warm up for a length of time, and changing the gain settings on my SDR receiver. All of these tests gave repeatable measurements of 48-46^0K.

My second LNA wasn't near as good. N_{Hot} gave a reading of 160 and N_{Cold} gave a reading of 52. This gives Y of 3.1 and therefore a T_{LNA} of 140^0K. I still had the SDR receiver gain settings wound down, but increasing this didn't improve the final calculation. I checked through the LNA stages and found they were drawing the current I expected them to. A few other multimeter measurements I made didn't reveal anything. I wondered whether my case (instead of the properly specified shield) was having some effect, so I retested both LNAs with the cases removed. I noticed some effects if I placed my had near the unshielded LNAs but if I kept away from them the test results appeared little different from when installed in the case. OK the second LNA was still usable but somehow not as good as it should be.

The filters for the third LNA arrived so I installed these and tested this also. Initially this looked faulty. The output was much lower than the other LNAs and terminated or unterminated made little difference in receiver output. Multimeter readings showed all the transistor stages were drawing the expected current. However a resistance reading (with the LNA DC power off) showed a short circuit from the top of R16 to ground. There is a via to ground very close to this connection and I had managed to bridge across to it with a blob of solder. After clearing this, the LNA performed fine with again a noise temperature of better than 50^{0}K.

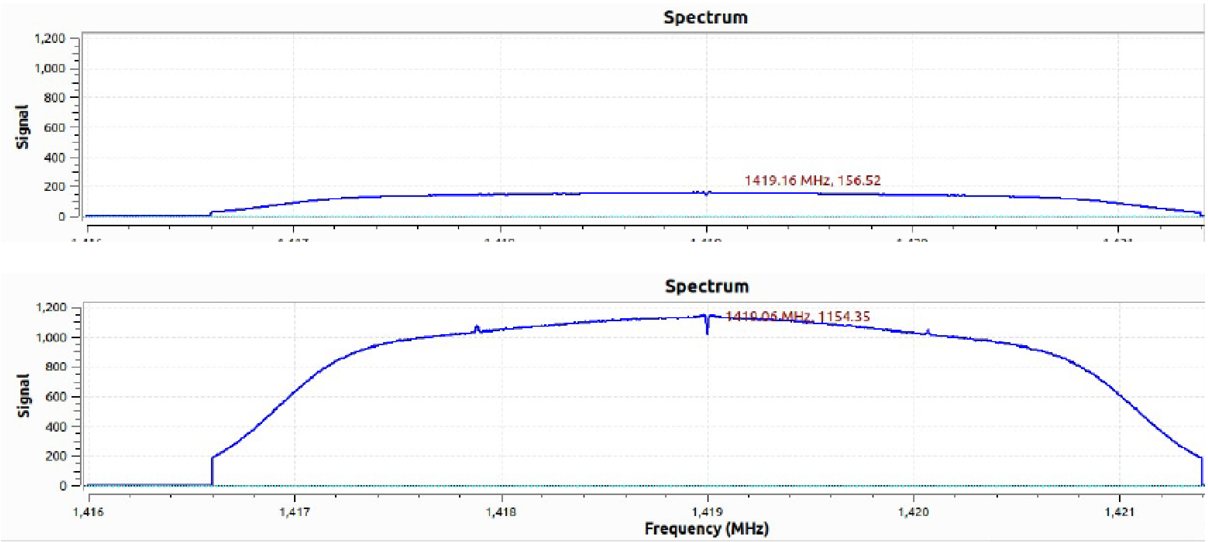

Figure 2. Cold and Hot Results for repaired LNA No.3 – These figures give 45.5^{0}K.

This made me look harder at the second LNA that didn't seem to be doing as well as it should.
I decided to try changing the SAV-541 thinking maybe I had a poor performing one. In the process of removing it I got a blob of solder on C2 and when removing this C2 fell off the board revealing that I hadn't soldered it properly on one side. I figured this was probably the source of my problem. I re-soldered C2 and installed the new SAV-541 (I figured I'd close to cooked the old one by now) and now this LNA is also working with a noise temp of less than 50^{0}K

How Valid is the Test?

Initially I had some doubts about this simple test method. Surely to properly test a LNA like this some expensive test equipment is required. I had no issue with the fact that the termination resistor would generate the 290^{0}K noise signal. As a resistor at a temperature of 290^{0}K that is what it will always do. But I wasn't so sure how valid it was to run the LNA without a termination on the input. Normally there would be an antenna connected here that should ideally also look like 50Ω at 1420MHz. There could be some small effects of having the LNA unterminated, such as some feedback from the later stages of the LNA coupling into the unloaded input giving it different gain and therefore a different noise output than it would have of terminated with a 50Ω termination of 0^{0}K.

However given the consistent readings I was getting, and the fact that the testing helped me find and fix faults in my LNAs, I eventually gained good confidence in this test method. I thoroughly recommend it.

Heat

One thing I did notice is the LNAs seemed to get fairly warm in use. My HackRF SDR was not able to provide the required voltage so I was powering them with 12 Volts via a separate bias Tee. At 12 Volts and 160 mA the LNAs are continuously dissipating about 2 Watts. Most of this is from the 5 Volt regulator IC1. This doesn't need 12 Volts to drive it so I lowered my supply voltage to about 8 Volts by adding a simple dropping resistor. I may eventually fit an 8 Volt regulator to supply this. This reduced the LNA heat significantly but I noticed the SAV-541 end of the board still seemed very warm. This stage was drawing 80 mA at 5 Volts i.e. 400 mWs. Some of this power is dissipated by resistor R2. The rest is dissipated by the SAV-541. This seems a lot for such a tiny device but is actually within specification. I did try reducing the current drawn by this stage slightly by adding a 22kΩ resistor in parallel with R5 on one of my LNAs. This didn't seem to change the noise figure noticeably and did reduce the current slightly but in hindsight it was probably a bad idea. This first stage is before any filtering and therefore receives and amplifies all the signals the antenna picks up. This includes some high powered signals from Television and other Broadcasting transmitters. It does actually need to be able to cope with a bit of power to do this.

Investigating Faults

If a newly constructed LNA is found to be faulty I would recommend the following steps;

First power the LNA from a 12 Volt supply feeding through a 25Ω resistor. This could be made with four 100Ω resistors in parallel. If the LNA draws the expected 160mA, this resistor will drop 4 Volts leaving 8 Volts for the LNA which is fine. If the LNA draws more current, the resistor will limit the current hopefully preventing damage while you do further checks, although if there is a complete short circuit in the LNA the resistor will be dissipating about 6 Watts.

The following should be checked with a multimeter set to read DC volts. The negative lead of the multimeter should be clipped to the negative lead of the 12 volt power supply. It's a good idea to first check the voltage of the ground on the circuit board (e.g. touching the positive multimeter probe to the outside of one of the SMA connectors). There will likely be a small fraction of a volt at this point due to the small voltage drop on the wiring back to the negative lead of the supply. Any other point on the board that has this same voltage is likely shorted to ground (either deliberately or accidentally).

Check the voltage at the input and output of the 5 Volt regulator IC1. The output should be fairly close to 5 Volts unless the LNA is drawing more current than it should and the input voltage is less than 7 Volts. IC1 needs 2 Volts or more across to regulate properly so if there is a low input voltage the output will be low also. If the output is zero volts and there is some voltage on the input then look for a short circuit on this output voltage line.

Check the voltages on both sides of resistors R4 and R13. These should have the 5 Volt supply on one side and about 3.5 volts on the other side. The Gali-39+ U1 and U3 each should be drawing about 35mA. This drops about 1.5 volts across the 43Ω value of R4 and R13. If either of these resistors has zero volts on one side look for a short to ground around the corresponding Gali 39+. If either of these resistors has 5 volts on both sides look for an open circuit.

Check the voltage on both sides of 27Ω resistor R2. This should have 5 volts on one side and 3 volts on the other indicating that the SAV 541+ U2 is drawing around 80mA. If this is not the case look for a voltage of 0.6 or 0.7 volts at the junction of R1 and R5. This same voltage should be present on both sides of R3.

If all the above voltages check out OK and the LNA still does not perform, switch the DC power to the LNA off and switch your multimeter to resistance measurement. Measure the resistance to ground on both sides of both R7 and R14. These points should all read about 435Ω. If not look for shorts/opens.

Do the same both sides of R6. Depending on which version of the schematic you followed these points will read either 435Ω or 150Ω. If all the above checks out OK and your LNA is still not performing as expected, you could try checking the capacitors where these should be grounded. It's a little harder to check the rest of the circuit without more complex test equipment.

Conclusion

The DSPIRA LNA performs as expected with a noise temperature of less than 50^0K in the three examples produced. The terminated/unterminated test is very simple and effective, easily identifying if the LNA is working to specification without requiring expensive test equipment. It is well worth doing this test before applying the conformal coating and possibly even before soldering in the shield as testing and repairs after these steps have been done will be more difficult.

Building the DSPIRA LNA is not simple but is practical for hobbyists with some soldering ability. A set of steps for investigating a faulty LNA with a simple multimeter has been given. Hopefully these are useful and hopefully my shared experiences encourage others to put together this very good LNA.