Subject: Horn+TAMP-1521GLN+ LNA with Improved Infrastructure
Memo: 10, Revision 4
From: Glen Langston
Date: 2016 July 8-August 30

This note describes measurements of a radio frequency receiving system based on a horn and upgraded amplifiers. The system has been repackaged cabling has been made more efficient, to take advantage of a newly available, high sensitivity, low noise amplifier (LNA). The LNA, Mini-circuits model TAMP-1521GLN+ has very low noise figure 0.6+/-0.1 dB at 1420 MHz. This horn was configured for minimum system temperature powered by a Bias-Tee. The project goal is designing a prototype system for astronomical observations that has high sensitivity (low system temperature and large aperture) and wide frequency coverage.

The horn tested is a modified version of the horn described in Memos 4 and 8. It appears that earlier hight system temperature test results in Memo 8 were partially due to insufficient gain in the LNA chain. The RTLSDR dongle appears to have a significant noise figure when operating with high gain (> 40 dB). The current system temperature measurements are in the range of 110 to 120 K. This performance is close to the design goal and is acceptable for a variety of applications.

Hardware Tested

The Hot-Cold load performance was measured in the same manner as described in LightWork Memo 4. The horn is shown in Figure 1. The features the system are summarized below:

- Rectangular aperture with 24”x20”, constructed from aluminized foam and reflective tape.
- The Horn feeds a custom waveguide with integrated band pass filter.
- Feed probe is a 4mm diameter cooper tube soldered onto a female N connector.
- Low loss, 1-ft long, cable feeds into first stage amplifier a TAMP-1521GLN+ from Mini-circuits (http://www.minicircuits.com/pages/npa/TAMP-1521GLN+_NPA.pdf). The amplifier is mounted in the Mini-circuits
- Output through a bias-T to 20ft coaxial cable.
- Input through a bias-T to a second a TAMP-1521GLN+ amplifier.
- Output to RTLSDR dongle
- RTLSDR dongle connected to PC by 10’ USB 2.0 extension cable.

The following sections describe selected components of the system in the order of horn through amplifier chain, data sampling and data processing using software based on the GNU RADIO programming environment..

The measurements were carried out on August 6, 2016 under warm, relatively dry, weather conditions. The horn was either pointed at zenith (elevation 90). or at the ground (elevation -90).

Figure 1: Images of the horn used for the system temperature tests. The image at left shows the exterior of the horn, which is a 4 sided pyramid, with large, open end pointed at the sky. For scale the red level has a length of 4 feet. The opening is a 24x20 inch rectangle. The horn is constructed of aluminized foam insulation, held together with aluminum tape. The lower end feeds a 4x8 inch wave guide. The wave guide includes two fins that are shaped to form a band pass filter centered approximately on 1420 MHz. The waveguide is constructed from a riveted aluminum sheet. The image at right shows the interior of the horn, the fins constituting the band pass filter and the copper feed probe.

Horn, Wave Guide and RF Probe

The horn and waveguide feed probe are modified versions of those described in LightWork memo 4. The feed probe is a copper pipe with length equal to one quarter of 21cm wavelength.The probe is soldered to an N-connector. The probe is 4mm in diameter with end sealed with solder. The output is connected to the feed amplifier box via a 1 ft coaxial cable with male N-connectors. The combined signal losses due to the connectors and coax should be less than 0.2 dB. Assuming a 290 Kelvin physical temperature, these components should add roughly 14 Kelvin to the system temperature.

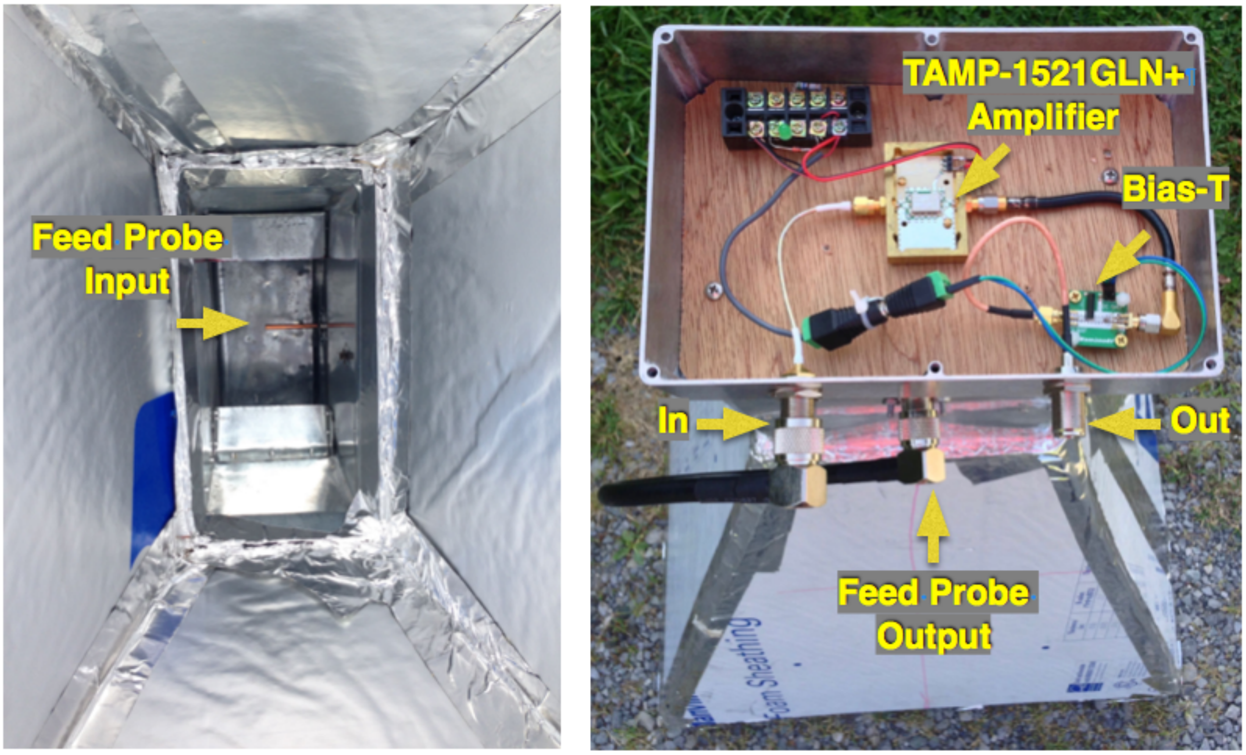

Figure 2: At left is an image of the interior of the horn, showing the waveguide connection, the fins implementing the band pass filter and the copper tube probing the radio frequency field. At right is the exterior of the horn, showing the output of the horn connected by a 1 ft low loss cable to the input of the first LNA box. In this figure the RF signal is connected directly to the TAMP-1521GLN + amplifier. The amplifier output is connected to the bias-T. The bias-T extracts the DC power from the coaxial cable. The DC cabling is attached to a power strip. The power strip includes a 5V diode to prevent over voltage and an LED to indicate the system is properly configured.

LNA Box 1

The quality of the feed port and cabling before the first LNA are critical to achieving a low system temperature. The low system temperature is needed for developing a system capable of detecting faint astronomical sources. The TAMP-1521GLN+ amplifier has a very low noise figure of 0.6 dB at 1420 MHz. This corresponds to a 43 Kelvin amplifier noise temperature.

The amplifier has +35 dB of gain (a factor of 3160).The output of the LNA is connected to a Bias T separating the input 5V power supply from the RF path. The bias T and connector components should only make a small contribution to the system temperature.

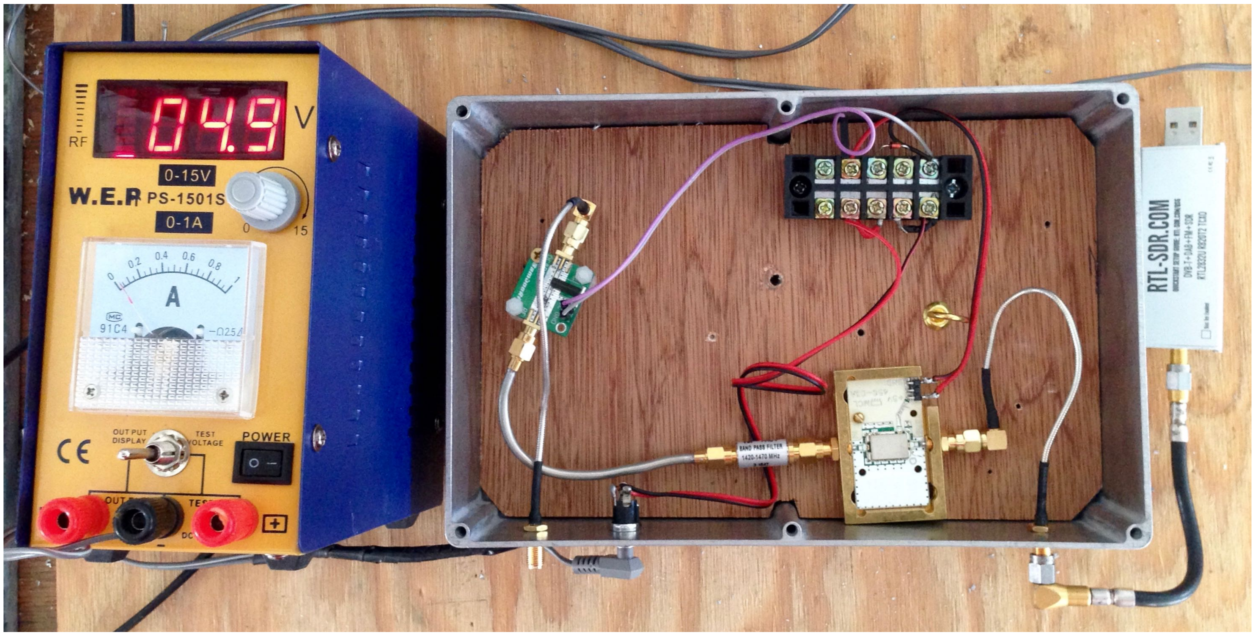

Figure 3: This image shows power supply and second LNA box. At left, the power supply is set at 4.9V output. Note the very low current drawn by the TAMP-1521GLN+LNA, less that 0.05 Amps. At right is second LNA box includes the amplifier, input to the power strip. The power strip has connections to the bias T and to the amplifier. Between the bias T and amplifier a band pass filter is installed via SMA connectors. The output is to the software defined radio (SDR) dongle. It is important to include a flexible cable to void breaking the SMA connector on the SDR dongle. There should also be stress relief on the USB connector between the dongle and computer (not shown).

LNA Box 2

The second LNA box contains nearly identical components to those in box 1. For these tests, the two boxes were connected by 20 ft of very low loss cable. The total loss between the two boxes was measured to be 9 +/- 1 dB. The amplifier gain was an additional +35dB.

A Mini-circuits VBF-1445+ band pass filter was added before input to the 2nd LNA. This filter has 2 dB of insertion loss in the frequency range 1420-1470 MHz. The filter has roughly 40 dB loss between 300 to 1100 MHz. The loss is 6 dB at 1300 MHz. Above 2040 MHz the filter has greater than 20 db of insertion loss.

Combining the gains of the LNA boxes, and correcting for the cable and filter losses, at 1420.4 MHz the RF gain is roughly +70 dB - 9 dB = + 61 +/- 1 dB. This corresponds to an amplification factor of 1,260,000 +/- 260,000.

The system should have acceptable performance for observations of the molecular OH lines at 1612, 1665, 1667 and 1720 MHz.

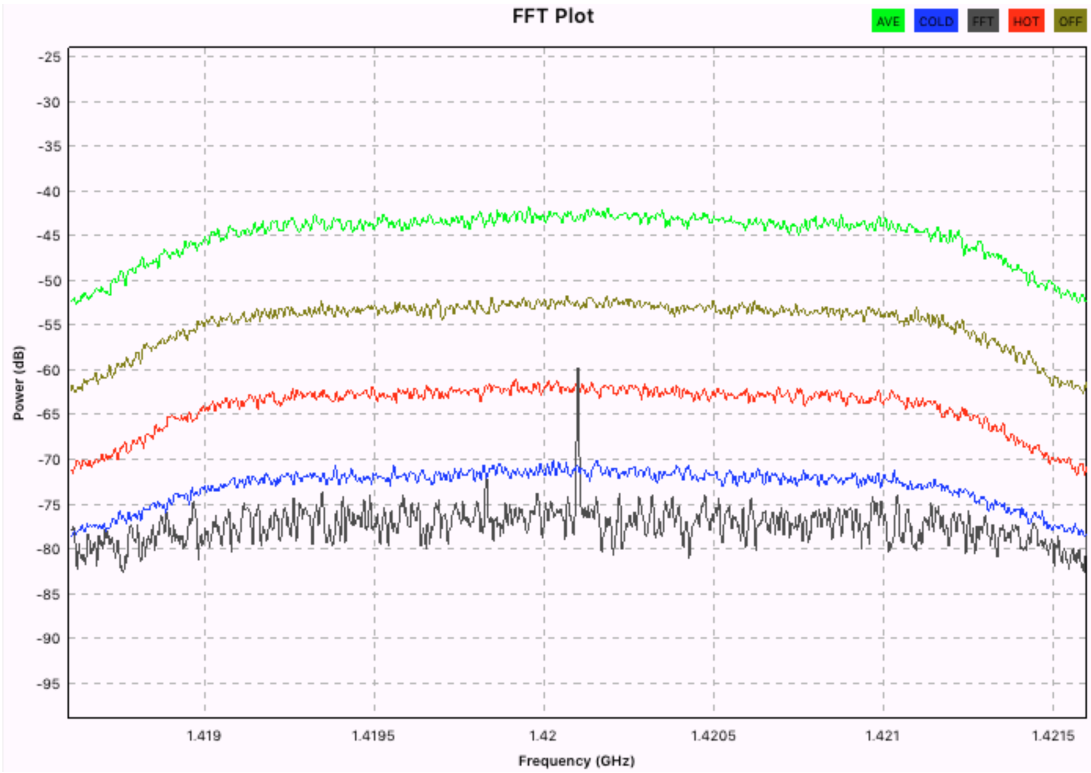

Figure 3: Noise source intensity versus frequency for 4 attenuation levels and with the noise source off. The lowest curve (grey) is with the noise source off, so is the internal minimum detectable signal from the NooElec SDR dongle. The blue curve is the noise source with 30 dB attenuation. The red curve shows 20 dB attenuation, grey 10 dB attenuation and green shows signal level with 0 dB attenuation. Gain is roughly linear in the power range of -67 to -45 dB, sufficient for astronomical observations.

SDR Linearity

While writing these test results I realized it would be relatively easy to measure the linearity of the SDR dongles. I ran two tests of the NooElec dongle, with input gain of +3 and +15 dB. Figure 3 shows the intensity (counts) versus attenuation for Off, 30 dB, 20 db, 10 dB and 0 attention from lowest to highest curves. The linearity is fairly good. There seems to be some significant gain compression above the -45 dB level. The signal tests were well below that level so should not be adversely impacted by SDR linearity.

I intended to tabulate gain corrections as a function of power level, but below -65 dB these corrections are smaller than I could measure with my step attenuator. These values could be tabulated and applied to the counts before computation of the hot-cold load tests. If the power is kept in this range, the gain linearity of the SDR dongle is not a limiting factor in the system temperature measurements. Figure 3 shows the results with the 3 dB internal gain of the NooElec. Above a signal level of -45 dB, the gain was clearly compressed, only gaining a few dB more intensity when increasing the power level by 10 dB.

My impression is that the dongles are more linear at lower power levels.

For the remainder of these tests the RTLSDR dongle was used. The RTLSDR dongle measurements were done with the input gain set to +8 dB. This input powers set to -65 dB on input. This is somewhat close to the noise floor of the dongle, at -75 dB.

Hot-Cold Load Measurements

The system temperature was measured by observing the zenith and ground on August 6, 2016. The table below shows the number of measurements, horn azimuth, elevation and corresponding galactic longitude and latitude. For most of these observations the sky intensities were averaged for 5 minutes.

#	Time (UTC)	Az,El	Lon,Lat
1st	00:52:13	180.0,-90.0	237.1, 38.9
2	00:52:13	180.0,-90.0	237.3, 39.1
7	00:54:53	180.0, 90.0	58.3,-40.2
2	01:05:12	180.0,-90.0	241.7, 43.5
106	01:23:35	180.0, 90.0	215.4, 4.9
3	11:42:56	180.0,-90.0	49.3,-29.1
76	12:09:47	180.0, 90.0	4.4, 43.1
9	18:36:31	180.0,-90.0	194.0,-32.5
41	20:12:33	180.0, 90.0	45.9,-23.9
0	23:42:35	180.0,-90.0	226.6, 25.0
2	23:47:35	180.0, 90.0	48.7,-28.3

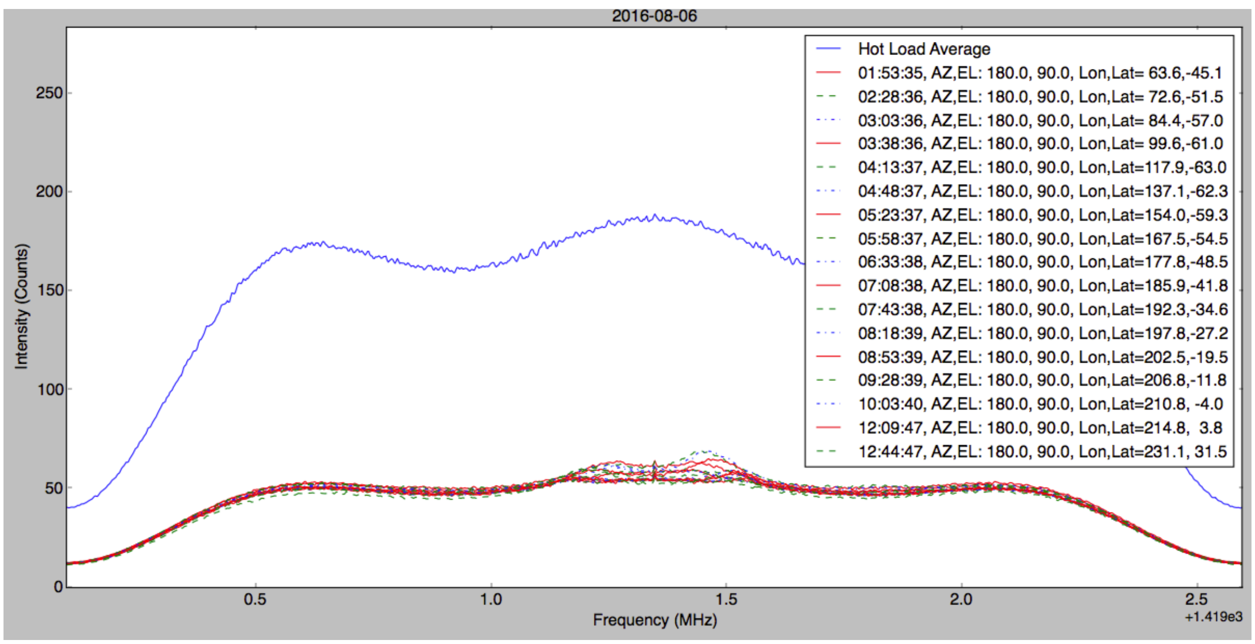

Figure 4: Plot of half hour averages of uncalibrated intensities versus frequency (MHz) on August 6, 2016. The top most plot is the average of all data when the horn was pointed at the ground. The red and other dashed curves show the variation with position on the sky.

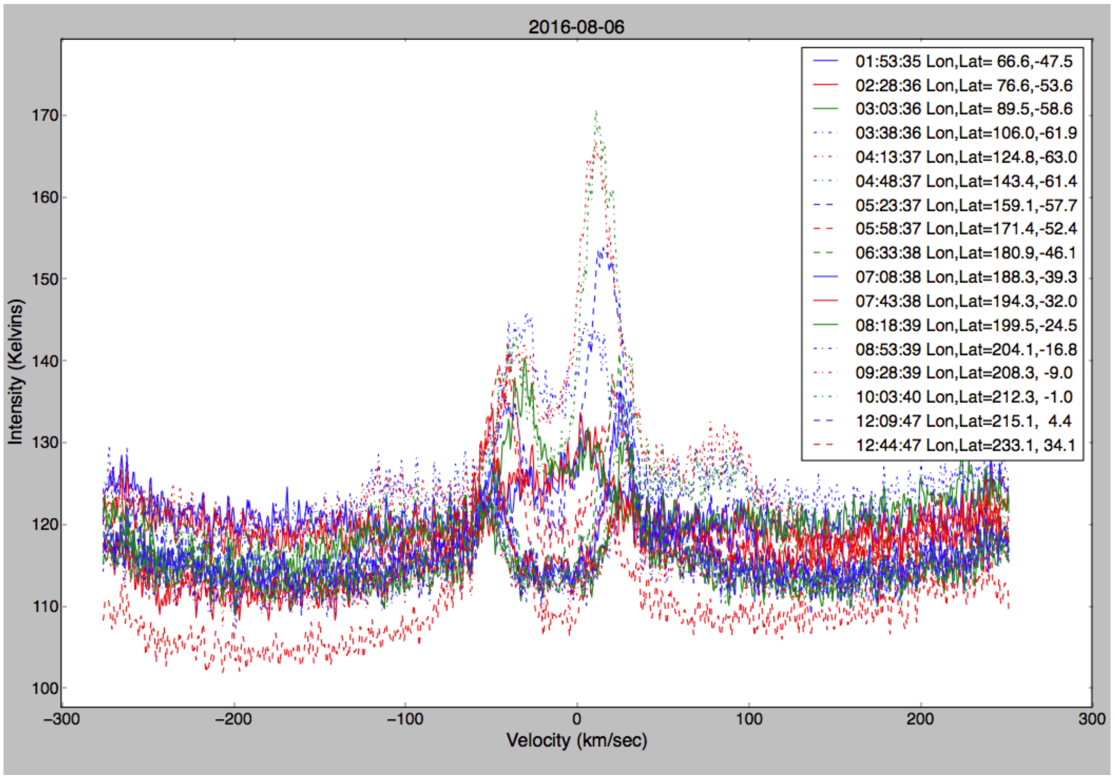

Figure 5: Plots of Hot/Cold load calibrated spectra for the same half-hour averages of intensities as are shown in Figure 4. The plots show intensity versus topocentric velocity (km/sec). The peak observed intensities occurs near zero galactic latitude, as expected.

Figure 4 shows the plots of intensity versus frequency for 12 hours of observations. The top most plot is for the average of all data when the horn was pointed at the ground.

Figure 5 shows the calibrated intensities (Kelvin) for the same data. The data are calibrated in the manner described in LightWork memo 4.

Conclusion

The Bias T system works well with the two TAMP+1521GLN+LNA amplifiers, has good gain and shows improved measurements of the system temperature. The new layout has improved convenience and robustness. The improved system works better than the system described in memo 4, primarily because of increased gain of the amplifiers. The system presented here has achieved the design performance, with system temperature of 120 Kelvins.

Further improvements in software efficiency are anticipated.