

Subject: Science Aficionados Amplifier Box
 Memo: 15, Revision 2
 From: Glen Langston
 Date: 2017 May 11

This note describes the configuration of the Radio Frequency (RF) Ultra Low Noise Amplifier (LNA) box for the *Science Aficionados* Radio Telescope. The system has very high gain, +44 dB (a factor of 25,000). The first ultra low amplifier has an excellent noise figure (< 0.6 dB), corresponding to an effective receiver temperature of < 45 Kelvin. The measured system temperature of the telescope is better than 95 Kelvin, corresponding to a noise figure of 1.2 dB for the entire system. This memo describes the Amplifier Box component configuration.

Telescope Overview

The Amplifier Box is a critical component of the *Science Aficionados* Radio Telescope. Figure 1 shows the major components of the system. The radio signals from the universe are collected in a funnel-shaped radio horn which guides the signals into a resonant cavity. The cavity shape is tuned to the frequency of interest. For us the important frequency is the natural frequency of hydrogen atoms. This frequency, 1420.4 MHz, called the H_I frequency (pronounced *H-one*) and corresponds to a wavelength of 21.12 cm (about 8 inches). Because our Milky Way galaxy contains a vast amount of H_I, *Science Aficionados* can easily observe the motions of the arms of our Milky Way galaxy with this telescope.

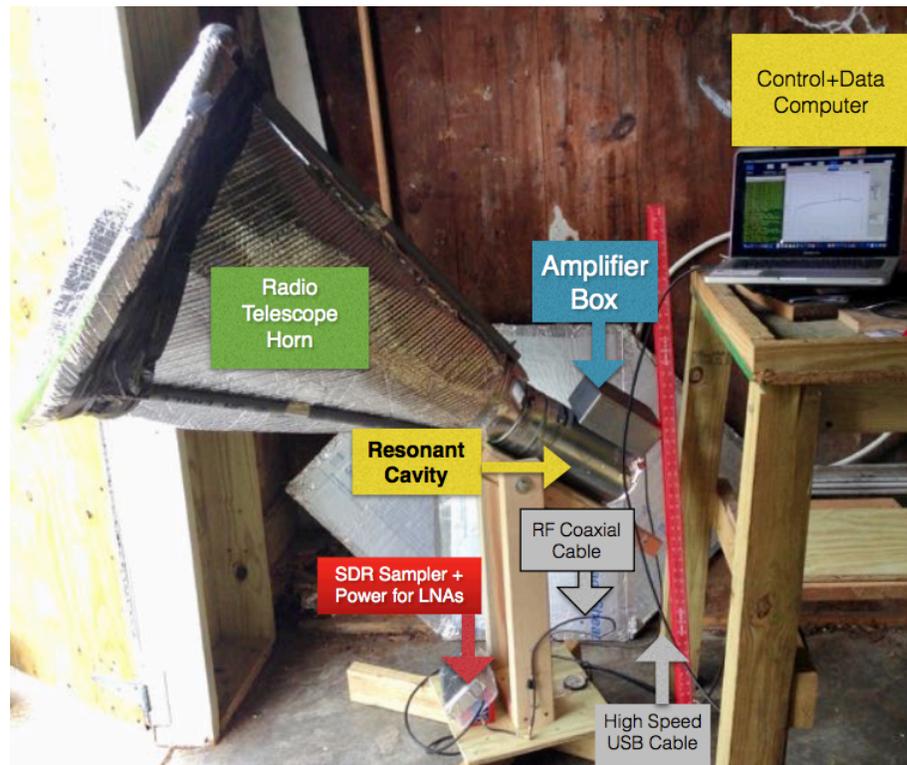


Figure 1: Image of the entire *Science Aficionados* radio telescope, including:

1. Telescope horn,
2. Resonant Cavity,
3. Amplifier box,
4. RF coaxial cable,
5. SDR Sampler plus LNA power supply,
6. High speed USB extension cable and
7. Control and data collection computer.

For scale, the red ruler is four feet long. The wooden telescope mount bends in the middle, to point the horn at different directions.

The radio signals from the horn are collected in a resonant cavity, where they are connected to the electronics in the Amplifier box by a feed probe. The output of the electronics box is

connected the input of the Software Defined Radio (SDR) device, which samples the radio signals. The SDR also provides the voltage to power the LNAs. The output of the SDR is provided to the control computer, which averages and records the signals from the sky. The SDR provides the power to the amplifiers via a “Bias-tee” over the same coaxial cable that brings the radio signals to the SDR. For these tests we used an AIRSPY SDR (airspy.com), which has a 20 MHz sampler, yielding a 10 MHz spectrum of observations.

Amplifier box

The Amplifier box contains several components. First we list the components used for system temperature measurements, which was found to have an effective system temperature of 95 Kelvin, confirming the good performance of this configuration.

Figure 2 shows two wave guide probes, used to extract the radio signal from the resonant cavity. The cavity has a shape matched to the radio wavelength. Different places in the cavity have stronger signal. The trick of creating a sensitive system is finding the best place to put the probe.

The probe is very simple, a short piece of copper wire or pipe, soldered on to a female N-connector for a metal box. This N-connector is called a bulk-head connector and has holes for 4 mounting screws. In this case we’ve drilled 2 holes into the resonant cavity and bolted the N-connector to it. For this telescope, the resonant cavity is a 6” diameter circular stove pipe, 1 foot long and sealed at one end. The probe is placed at the location of maximum signal, about one quarter of a wave length, 2.1 inches, from the sealed end of the pipe.



Figure 2: Two waveguide probes, of different lengths, used to test the efficiency of different configurations. The probes are soldered on to female bulkhead N-connectors. The ruler show measurements in inches. These probes are roughly 1/4 of the wavelength of interest.

In the end it was found that a very narrow (20 gauge wire) probe provided the strongest signal.

The Amplifier Box, shown in Figure 1, is bolted to the resonant cavity, the 6” diameter stove pipe.

Figure 3 shows the inside of the amplifier box. This system is built from two ultra low noise amplifier evaluation boards. The first board is a TQL9092 amplifier, sold by Mouser inc. The second board is an evaluation board for the TAMP-152GLN+ amplifier, sold by Mini-Circuits. Between these two boards are 1) a VBF-1445+ band pass filter and 2) a 1 dB attenuator (VAT-1+), to reduce ringing between the two amplifiers. The filter and attenuator are sold by Mini-Circuits. All components have SMA connectors. As noted above, the DC voltage for powering the amplifiers is provided on the signal (coaxial) cable. The voltage and signal are merged using a Bias-tee, ZDPLX-2150-S+, sold by Mini-Circuits. The input to the first amplifier

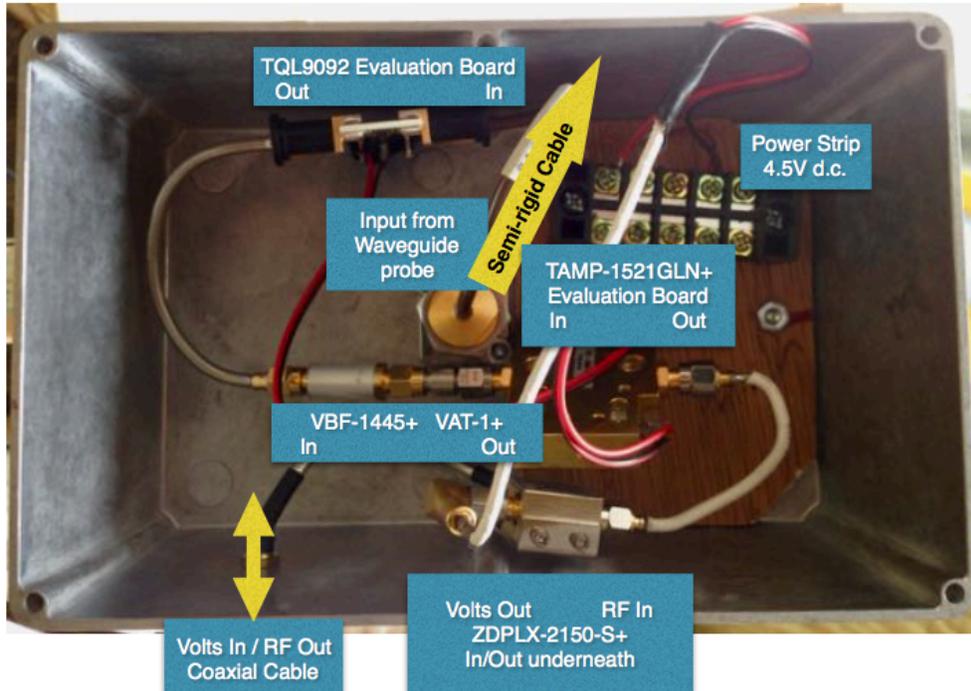


Figure 3: Picture of Components in the Amplifier Box. The radio signals come into the box from the semi-rigid cable connector in the center of the box. This is directly connected to the TQL9092 board. The output of this board is filtered and attenuated. The second amplifier has higher gain. The output of the second amplifier is input to the duplexer. The Output is via coaxial cable.

is provided by a semi-rigid cable with Male N-connector on one end and male SMA-connector on the other. In this case the cable length is 3 inches, but a shorter cable would be better.

The parts used for our Amplifier Box are listed below:

1. TQL9092 (Mouser), +17dB, \$67 on evaluation board
2. VBF-1445+ -2dB \$17
3. VAT-1+, -1 dB, \$14.
4. Power Strip \$1
5. TAMP-1521GLN+ (Mini-Circuits) + 33dB, \$79 on evaluation board
6. ZDPLX-2150-S+ (Mini-Circuits) Bias-tee, duplexer, -3dB, \$39

The aluminum box itself costs \$18. The N-connector for the probe costs \$1, and the other cables cost \$6, roughly. The total parts cost is \$242 for the complete amplifier box.

It is desirable to reduce the parts costs to enable more Aficionados to participate. It seems likely, by putting most components on a single board, the cost could be reduced below \$150.

Conclusion

The Bias T system works well with a TQL9092 and TAMP+1521GLN+ amplifiers, has good gain and shows system temperature less than 95 Kelvin. This configuration has improved convenience and robustness.

We are looking for off-the-shelf components, and also custom parts, to reduce the system cost.

Appendix: Hot/Cold Load Measurements

The amplifier box performance is assessed by measurements of “hot” and “cold” load measurements. For this system the hot load is made by observations of the ground, with an

assumed temperature of 295 Kelvin. The cold load observation is made looking at the sky, far from the Milky Way's galactic plane. The cold load has an assumed temperature of 15 Kelvin, from both the atmosphere and the cosmic background radiation, 2.7 Kelvin.

Figure 4 shows measurements of Hot/Red and Cold/Blue spectra from the data collection computer. The lower curves are additional measurements of empty sky. The thick green curve is a 30 second average observation. The spike at 1.420 GHz is internal to the SDR (AIRSPY revision 2). The small lump, marked with a yellow arrow Figure 4, at 1.4204 GHz shows motions of the hydrogen in the Milky Way Galaxy. Figure 5 shows the calibrated spectra for different directions in our galaxy. The width, height and frequency of this feature lead to important measurements of the structure of our galaxy.

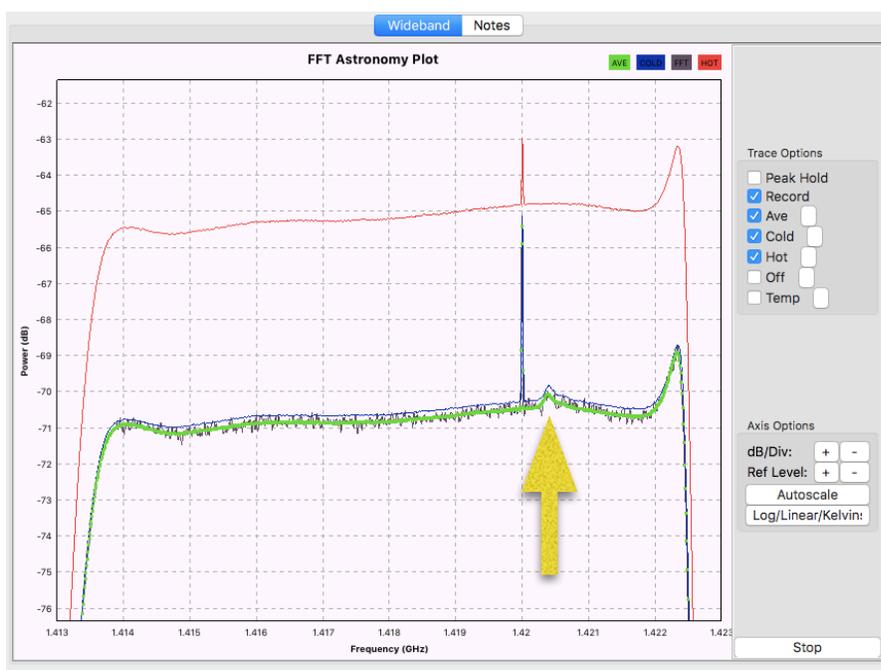


Figure 4: Hot and Cold load observations with the amplifier system described above. The upper, red, curve is the hot load spectrum. The lower, blue, curve is the cold load observation. The X axis is frequency from 1.4155 to 1.4255 GHz. The Y axis is amplitude in dB. The 6 dB difference in intensity corresponds to a factor of 4 in intensity.

The program, called NSF-watch, is used to collect the observations.

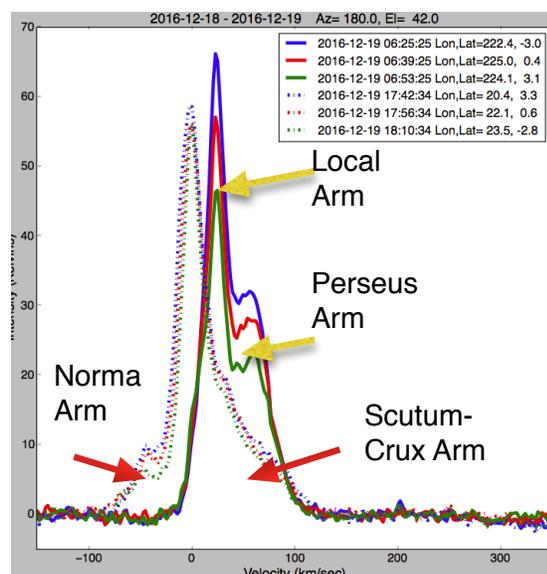


Figure 5: Comparison of HI emission in different directions in the sky. The plot shows intensity in Kelvins versus velocity of the gas. The plots show 15 minutes averages to show measurement uncertainty and changes with small changes of position. The plot shows observations along the galactic plane (latitude=0), at 22 and 225 degrees longitude.

The observations at close to the direction of our galactic center, at 22 degrees longitude (dashed lines) show parts of arms of the Milky Way. The solid lines show observations out of our galaxy, towards 225 degrees longitude, toward the Perseus and Local arms.