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To: SRT Group  
From: Jeffrey Campbell & Alan E.E. Rogers  
Subject: Low cost Small Radio Telescope

### **Summary**

The purpose of this project is to design a radio telescope capable of observing the 1420 MHz Hydrogen line that can be used for Educational Outreach. This project focuses heavily on increasing ease of construction and use while decreasing cost. The final product takes the form of a pyramidal horn telescope created mostly from sheet aluminum using common tools and materials and an LNA constructed from readily available low-cost electronics. The telescope runs on a free, open source, Linux based program available through the MIT Haystack website.

### **Specifications for the horn**

Calculated gain 17.25dB  
Coefficient of reflection -16.5dB  
H-plane beam width 16.5 degrees  
E-Plane beam width 24.06 degrees.

### **Specifications for the LNA**

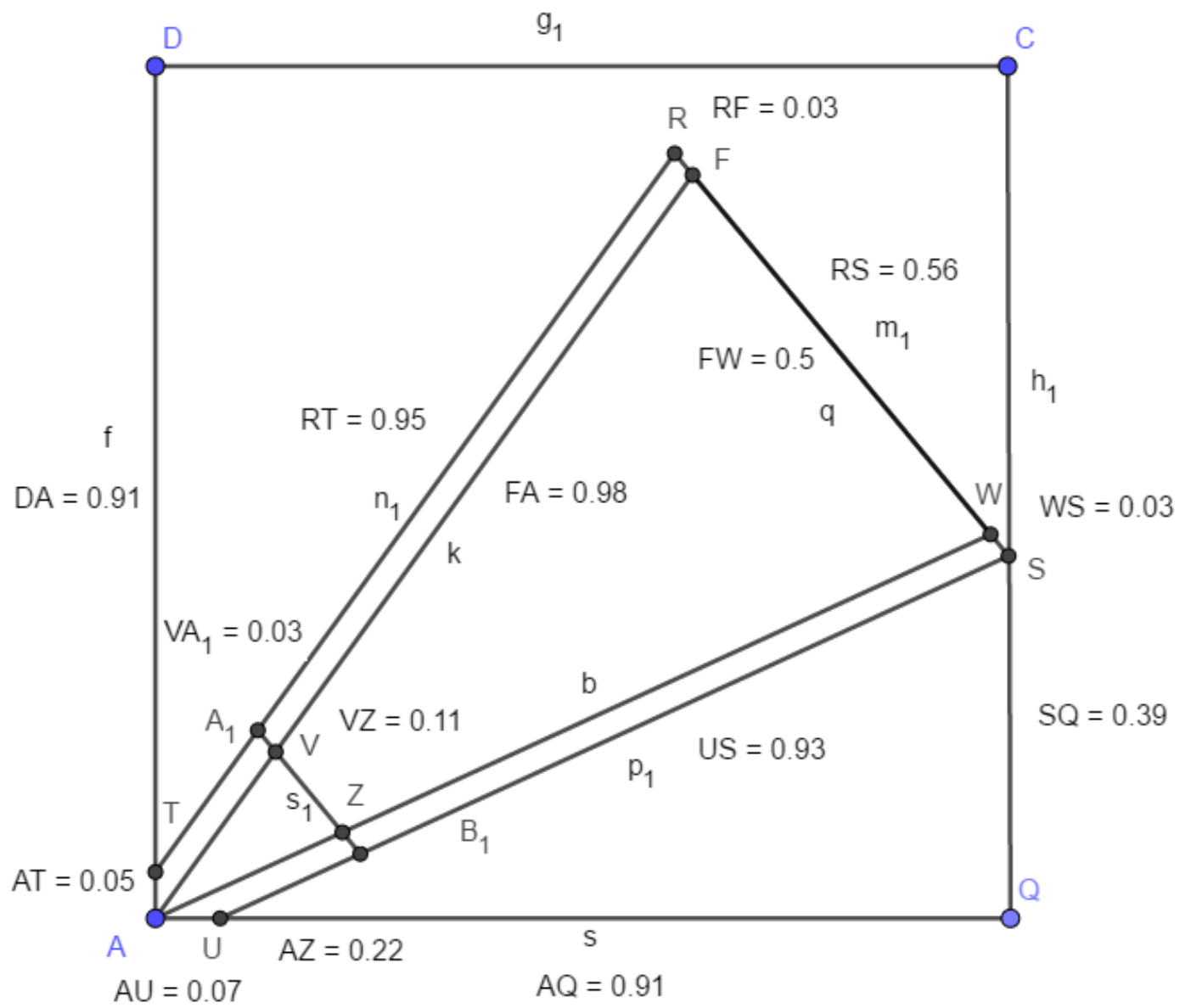
Measured Noise figure 2dB (from &-Factor on Sky and ambient absorber)  
Amplification 42dB  
Power source: 5v wall outlet adaptor

### **Constructing the horn**

#### **Materials and tools**

The following list of materials assumes that no materials or tools are available prior to construction. If any of these or a close substitute are present there is no need to purchase the analog on this list. In addition, while not listed for the reason of price, a metal brake and shear are very useful for executing long cuts or bends and should be used if possible. If not, it is recommended that a rudimentary break is constructed from a straight edge, table, and clamps and that center cut aviation snips are used in place of a shear.





**Figure 2. E-Plane side**

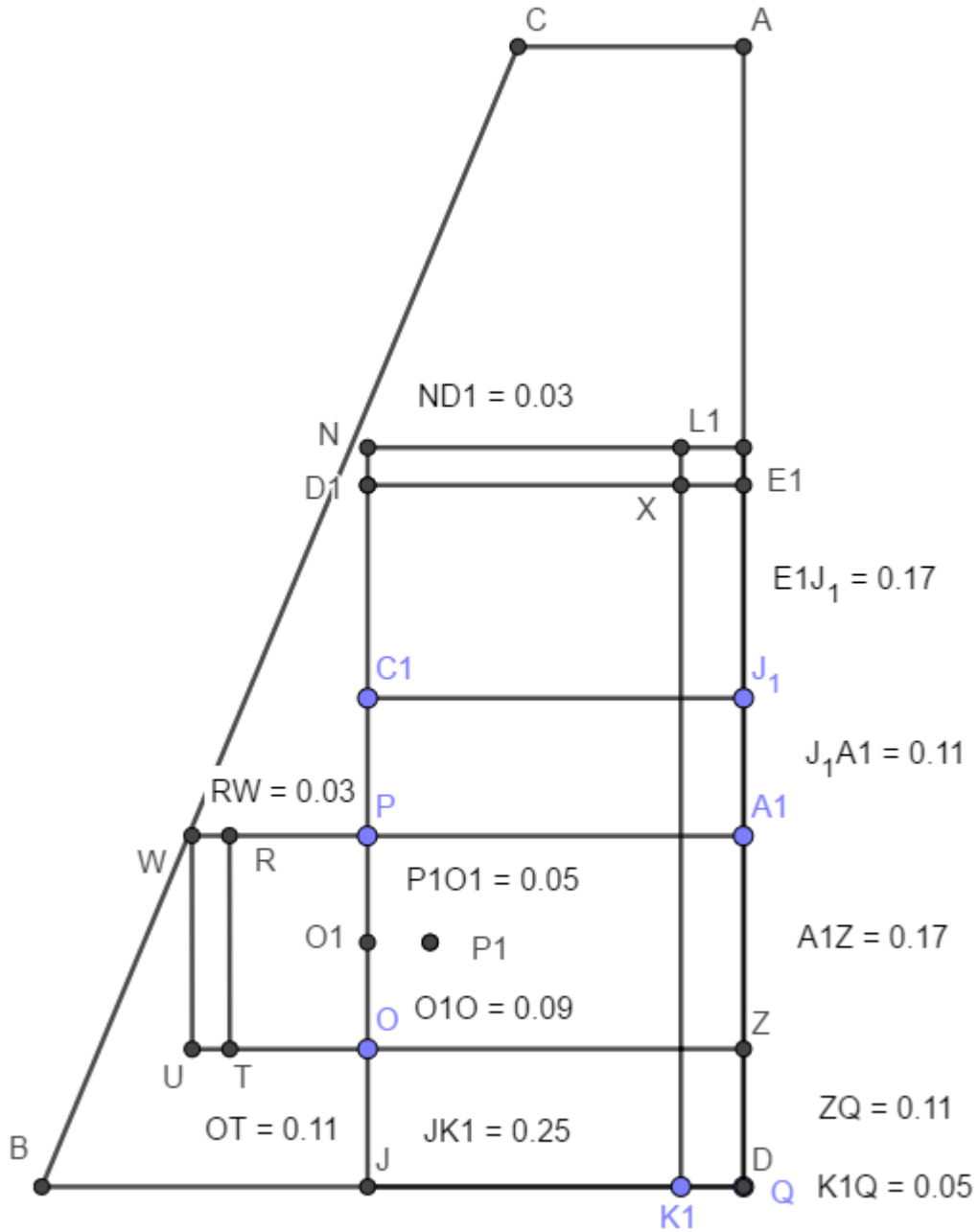


Figure 3. waveguide cut from leftover H-Plane metal

## Instructions for assembling horn

Begin by measuring and marking all of the lines shown on Figures 1-3. Once the lines have been etched, cut lines DG and FG as seen in Figure 1 onto the first two squares of aluminum, preferably using a metal shear. Carefully set aside the remaining metal for making the waveguide later.

Next, shear lines SU, TR, and RS as shown on Figure 2 from the remaining two sheets. Using tin snips, remove sections  $AZB_1$  and  $AVA_1$ .

On metal left over from cutting the H-plane side, using tin snips remove the section bounded by the segments JO, OU, UW, WP, PN,  $NL_1$ ,  $L_1X$ , and  $XE_1$  as indicated in Figure 3.

Using a metal brake or equivalent, bend segments ZW and VF in Figure 2 to approximately right angles, ensuring that all the segments are bent towards the center of the sheet. Then bend along the segment HI in Figure 1 for both H-Plane sides to slightly beyond a right angle. The H-Plane segment should now look like the one shown in Figure 4 and the E-Plane segment should match the one shown in Figure 5.



**Figure 4: Cut and bent H-Plane**



**Figure 5: cut and bent E-Plane**

Do the same for segments VZ in Figure 2 for both E-Plane sides so that the flange created is facing the opposite direction as the ones already made on the ZW and VF segments.

Then, use the brake to bend segments OZ,  $PA_1$ ,  $C_1B_1$ , and  $D_1E_1$  in Figure 3 to right angles so that they form a rectangular prism held together by the lip formed by the section bent along  $D_1E_1$ . Next bend along PO and RT in the same manner to create a cap on one end of the rectangle. Depending on the bending setup being used, this may have to be done by hand using a metal ruler or straight edge in place of a brake.

Next use tin snips to cut from points Z, A<sub>1</sub>, and B<sub>1</sub> down to the segment formed by K<sub>1</sub>L<sub>1</sub> and then use a brake or metal straight edge to bend the segments formed out at a right angle to form a flange at the front of the guide.

Place the bent lip that runs along the length of the guide over the next edge and use the aluminum tape to secure the two pieces. Then, using a scribe or metal punch, create three marks along the outside lip, the first being two centimeters from the bottom of the guide, the next two centimeters from the top, and the final one exactly in the center. Place the guide over a piece of wood and drill through both the lip and side of the guide in these places as well as at point P<sub>1</sub>. Make sure that the holes on the lip are the same size as the pop rivets being used and that the hole for point P<sub>1</sub> is the size of the base of the coaxial connector being used, approximately ¼". Repeat this process for the lip formed at the bottom of the guide. Using tape, secure the edges of the guide to each other so there are no gaps in the guides seams and then pop rivet the edges together with the ball of the rivet facing outward. If any bent edge in the guide is rounded or too shallow, try using a hammer to tap down these edges at the crease.

Repeat this process for assembling the horn except using four evenly spaced rivets to secure each H-plane piece to the adjacent E-plane. This should form a pyramidal cone open at both ends. If possible for both the guide and the horn, try to pop rivet from the inside out so that the shafts of the rivets are outside the antenna and the flush heads are on the inside.

Once both the horn and guide have been assembled, line up the corners of the guide and the small end of the horn. One aligned use tape or clamps to secure the two pieces together. Make a mark 3 cm away from each edge on all flanges as close to the body of the antenna as possible. Drill on these marks, double check to ensure that the guide and horn are still well aligned and then pop rivet the two pieces together. Once the rivets are in and secure, trim the excess flange from the horn and use the aluminum tape to cover all edges and seams, especially the joint between the horn and guide.



## Completed antenna



**Figure 6. H-Plane profile**



**Figure 7. E-Plane profile**



**Figure 8: Front Profile**

## Telescope stand

In order for the telescope to be useful when taking data over long periods, a stand is required to ensure its stability. Use aluminum tape to secure a plastic dowel parallel to the aperture of the scope along the exterior balance point and then resting each end of this dowel on a sawhorse. By using string or tape to secure the rear end of the scope to a ladder and taping the dowel to the

sawhorse. A stand capable of keeping the scope steady and adjusting the Y-axis of observation has been tested to work well.

### **Antenna mounted on the stand**



**Figure 9: front Profile of antenna on stand**



**Figure 10: Back Profile antenna on stand**

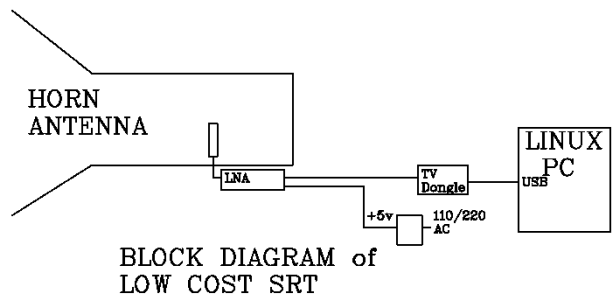


**Figure 11: side profile of antenna on stand**

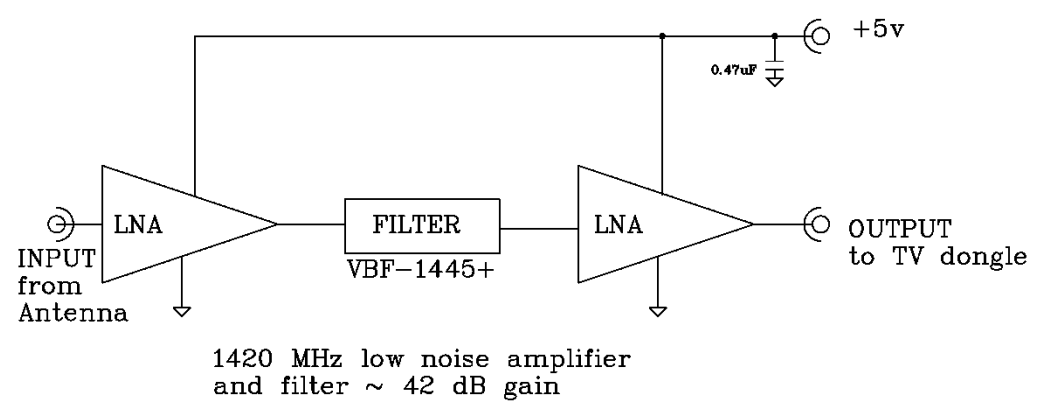
### **Constructing and integrating the LNA**

Figure 12 shows a block diagram of the low cost SRT which consists of the horn antenna, a LNA consisting of 2 amplifiers and a filter, a power supply, TV dongle and PC. The LNA circuit is shown in Figure 13 and Figure 14 is a photo of the LNA and the probe which ends up inside the horn antenna in the final assembly.

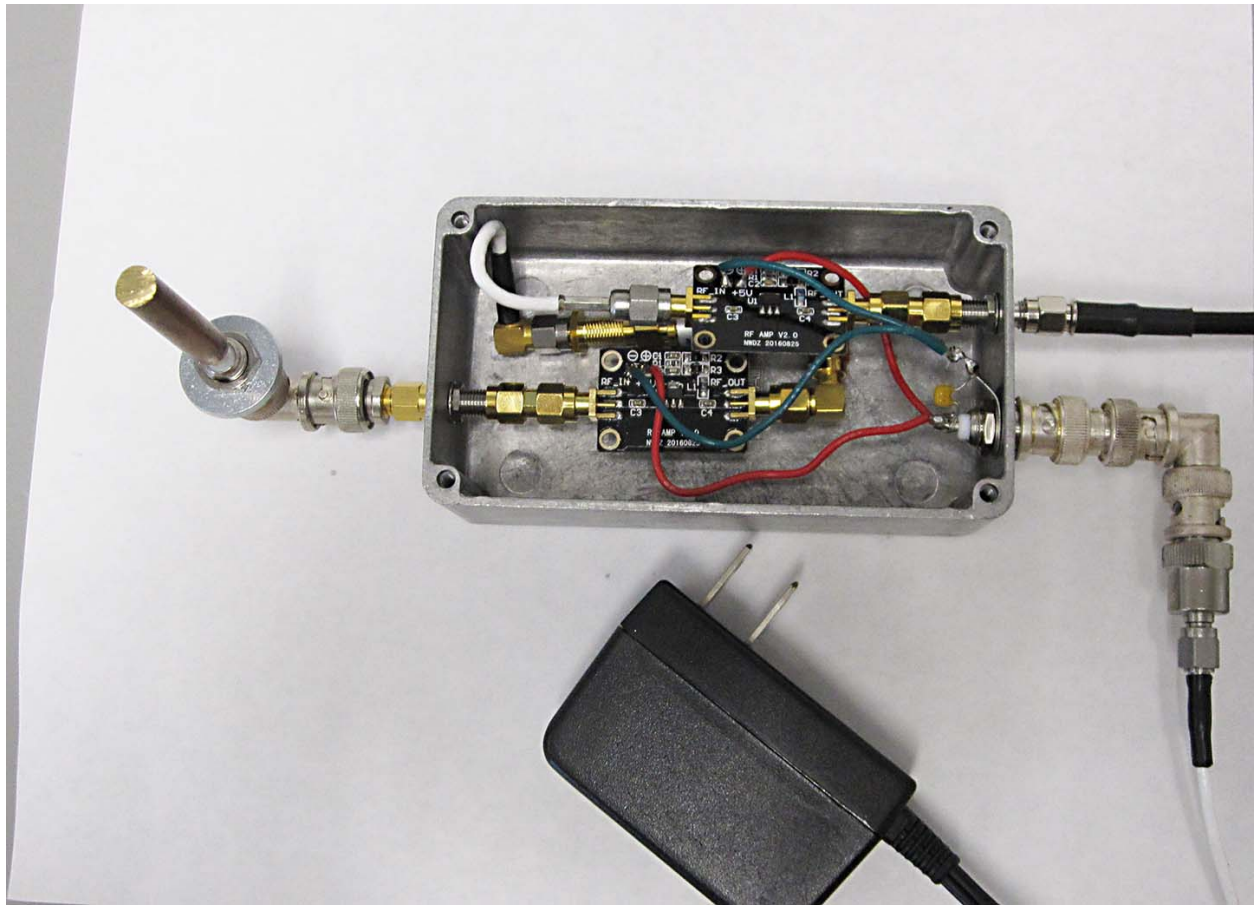




**Figure 12. Block diagram of receiver**



**Figure 13. LNA circuit**



**Figure 14. Horn probe (prior to installation in the horn) connected to the LNA filter and second LNA. Circuit is shown in Figure 13.**

## **Assembly instructions**

### Probe

Using the hacksaw, cut the 1/4" copper rod down to approximately 5.25cm. Then use the soldering iron to heat the cut piece until the solder melts on contact with the metal. Once the rod is hot enough, tin it to the exposed end of the BNC bulkhead making the connection as straight as possible. Then measure from the base of the bulkhead, the lowest point that will be on the inside of the waveguide and cut the probe so that the distance from the base of the bulkhead to the tip of the probe is 5cm.

### Amplifier and filter array

Using the BNC to SMA, then the SMA male to male adaptor, chain the probe to the first amplifier. Then attach the bandpass filter to the amplifier output. Using the second SMA male to male attach the next amplifier to the bandpass filter. Then using the third SMA male to male, connect the output of the final amplifier to the SMA to MCX coaxial wire and then attach that wire to the USB dongle.

Once this has been done and positions have been established for the components, the next step is to integrate the power. Take the 5-volt power supply and identify the positive and negative wires running from the transformer using the diagram on the back of the casing. Once the charge of the wires has been noted, cut the output off the power supply and the MCX connector of the second SMA to MCX wire. Strip the copper mesh away from the dielectric and using the soldering iron, connect the positive wire from the power supply to the coax core and the negative to the mesh. Connect the SMA side to the second BNC bulkhead using a SMA male to male connector and the SMA to BNC adaptor. Solder two lengths of wire to the bulkhead handle and connect each of these wires to the negative terminals of the amplifiers. Repeat this process for the positive terminals attaching the powered end of the wires to the core of the bulkhead.

### Integrating the LNA to the horn

Insert the probe into the hole drilled at P<sub>1</sub> on Figure 3 in the waveguide and use a nut, and a washer if necessary, to secure the probe in the hole. Make sure the rest of the LNA setup is electrically distinct from the horn with the only point of connection being the bulkhead.

## **Operating the telescope and software**

### **Using the SRT code**

The source code that the SRT uses can be acquired from the page linked below by going to the section labeled SRT program downloads and downloading and installing the latest version of the source code as well as the necessary dependencies. For all versions 7 and earlier, the additional dependency +- GTK2 may need to be integrated.

<https://www.haystack.mit.edu/edu/undergrad/srt/index.html>

Once the program has been installed, open a terminal and go the SRTN directory by typing "cd srtn", then type "vi srt.cat". Go to the line "\*simulate antenna" and remove the star. Open a new terminal and go back to the srtn directory and run the program by typing "./srtn".

### **Operating the telescope**

Before taking any data measurements, be sure to calibrate the scope by pointing the aperture at the ground<sup>1</sup> and hitting the calibrate button and waiting for it to turn green. Care should still be taken to use the scope in areas away from major radio pulses such as cell towers as these can damage the amplifiers and cause the connections between the computer and the scope to fail. The failed connection problem is especially prevalent with USB 3 connectors, likely due to their expanded bandwidth.

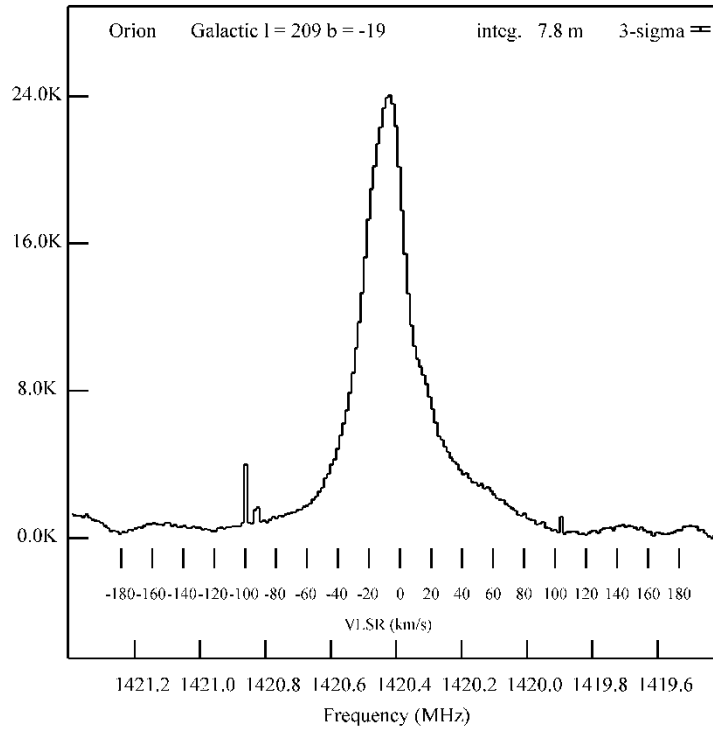
In order to observe a desired target in the sky, first select it on the sky map in the bottom of the window and wait for the simulated antenna to reach the selected point. Then take note of the azimuth and elevation of the point in the top right corner of the screen and angle the telescope accordingly. Then hit record for as long an observational period as desired to export the data in numerical form. To export data from a single observation as an image, click the bottom graph in the top right corner of the window and when a window pops up with the desired graph hit “click to write postscript file”. These files can be found in the srtn directory.

### **Interpreting the data**

These graphs represent the line of sight velocity of neutral hydrogen being observed in km/s and the intensity of the signal received in degrees Kelvin. Figure 15 on the next page is a measurement taken using the telescope and program setup of the constellation Orion.

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<sup>1</sup> Other options to pointing at the ground are pointing the antenna trees that block a view of the sky or placing a microwave absorber over the horn.



**Figure 15. Hydrogen line spectrum with horn pointed at Orion.**



### Cost breakdown

Part	Cost	Where to purchase
Metal punch/scribe	\$4.34	<a href="#">Amazon</a>
Sheet metal(4)	\$21.98	<a href="#">Home Depot</a>
Pop rivets 100pc	\$6.00	<a href="#">Amazon</a>
Pop rivet gun	\$11.89	<a href="#">Amazon</a>
Center cut aviation snips	\$6.88	<a href="#">Amazon</a>
Electric drill	\$25.00	<a href="#">Amazon</a>
1/8" Drill bit	\$1.74	<a href="#">Amazon</a>
Spring clamps 4pc	\$6.00	<a href="#">Amazon</a>

### Cost breakdown of LNA

Soldering iron	\$6.99	<a href="#">Amazon</a>
Tin solder 0.8mm 50g	\$6.88	<a href="#">Amazon</a>
Hacksaw	\$8.79	<a href="#">Amazon</a>
USB dongle		RTL2832+R820T
volt power supply (5)	\$7.99	<a href="#">Amazon</a>
Amplifier (2)	\$8.89	<a href="#">Amazon</a>
3/16" Copper rod	\$8.49	<a href="#">Amazon</a>
BNC bulkhead (2)	\$7.99	<a href="#">Amazon</a>
BNC to SMA 2 pc	\$4.99	<a href="#">Amazon</a>
Sma to mcx 2pc	\$8.99	<a href="#">Amazon</a>
Sma male to male 3pc (2)	\$4.89	<a href="#">Amazon</a>
Wire 20m	\$8.99	<a href="#">Amazon</a>