The Construction of a Radio Telescope for the Measurement of the Emission of Neutral Hydrogen

Eric A. Bonfadini

A Comprehensive Research Project submitted to the Department of Physics, Allegheny College, in partial fulfillment of the requirements for the degree of Bachelor of Science in the Field of Physics



Advisor: Dr. Daniel Willey
Allegheny College: Meadville, PA
Wednesday, April 16, 2014

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Committee Members

(Advisor): Dr. Daniel Willey_____

(2nd Reader): Dr. Shafiqur Rahman_____

I, Eric A. Bonfadini, hereby recognize and pledge to fulfill my responsibilities as defined in the Honor Code, and to maintain the integrity of both myself and the college community as a whole.

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Chapter 1: Introduction

1.1 Abstract

Radio astronomy is a widely used practice by many researchers for mapping out space. The dish outside of Carr will be used to build an entire Radio Telescope that will be able to measure the emission of Neutral Hydrogen. This will be accomplished by combining the parts that Kyle Keelan and I made in order to develop a fully functioning Radio Telescope for the Physics Department. The development of the Radio Telescope was successful and the result is outside of Carr Hall in the sustainability garden. The dish is now ready to be successfully used to take data on space.

1.2 Brief Overview

Since the beginning of time, the night sky, with its glistening lights and intriguing constellations, has been a wondrous mystery to man. Many civilizations and empires looked up to the infinite number of stars staring in awe and amazement, searching for answers to questions that seemed answerless. The Greeks looked upon the sky with such inspiration that they even created legends of heroes and beasts from the constellations that flood it. The beautiful appeal gave hope to the weak, poor, and helpless, inspiring them to push on and continue to fight and question. The puzzling mysteries in the sky continued to stump man until only recently.

Unveiling the mysteries in the sky seemed an impossible task, and astronomy was extremely limited. This all began to change with a breakthrough in astronomy thanks to Hans Lippershey. In 1608, Hans invented the tool that would change optical astronomy for years to come, the telescope [7]. With the invention of the telescope, astronomers were now able to

view the mysterious stars and planets in the sky with much greater detail; allowing other famous astronomers, such as Galileo, to begin mapping out the galaxy we live in.

Up until a few decades ago, radio astronomy did not exist. Radio astronomy allows us to study things outside of the visible spectrum. While optical astronomy is limited to the visible spectrum, radio astronomy allows us to view the unseen. Being able to read radio waves has led to new breakthroughs in astronomy, such as letting us map space that we're limited to mapping with optical astronomy [5].

The beginning of radio astronomy dates back to 1931, with Karl G. Jansky's successful experiments. Bell Labs tasked Jansky with studying the direction and arrival of thunderstorm static. In his experiment, Jansky found 3 types of static: static from nearby thunderstorms, static from distant thunderstorms, and static from an unknown source [5]. This static was later discovered to come from the Milky Way. Later, in 1944 Dr. Hendrick van de Hulst proposed that the source of these radio emissions was from neutral hydrogen [5]. In 1950, research by two astronomers in the U.S. led to the discovery of the 21cm emission line of neutral hydrogen that my project is based on.

1.3 My Project

Last year Kyle Keelan decided to continue working on the same project that others, such as Andrew Cutler (2003) and Michael Fisher (2006), have been working on for years. Only this time, Kyle did not have the same luxuries that the other two had. When Kyle took on the project, the telescope was in horrible condition. The support beams that hold the canister that contains the detector were so worn down by the elements that they needed to be replaced.

The old dish was accidently thrown out, so a new dish donated by Murray was acquired. The entire telescope was in disarray.

Kyle purchased, bent, and drilled new cylindrical pipes of aluminum to be used as the support beams for the canister. He also attached adjustable extensions on the canister so that the canister can be adjusted in order to place the canister directly at the focal point of the dish, maximizing efficiency. A new hollow rectangular piece of aluminum was purchased and cut to be used on the mounting harness of the motor mount to stabilize the entire system.

I took on this project with the expectations of fully constructing the radio telescope, and hopefully, being able to get all the programs running so that I can take data of neutral hydrogen. Unfortunately, the telescope was not left in good enough shape to simply attach all the pieces and begin taking data.

Chapter 2: Background

2.1 Neutral Hydrogen (H1)

Neutral Hydrogen (H1) is the most abundant element in the universe, consisting of about 70 percent of the total mass and about 90 percent of the atoms in interstellar gas [1]. Because it is such a large part of our universe, the radiation emitted from neutral hydrogen can be used to help us map out the universe. In the dense interstellar clouds of neutral hydrogen, interactions between hydrogen atoms are abundant and photon emission is plentiful. Even though the frequency of emission of these neutral hydrogen photons is once every few million years, hydrogen is so abundant that photons are emitted and readings picked up all the time.

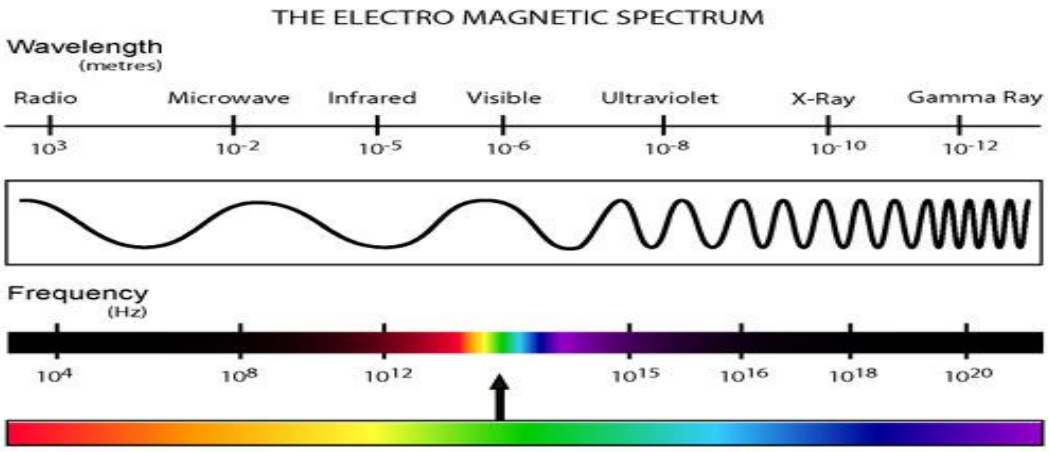
An atom of neutral hydrogen consists of a single electron revolving around a single proton in its nucleus. Both the proton and the electron have properties called spin, and can

either be oriented parallel or antiparallel with relation to one another. The total energy of the atom is different depending on the arrangement of the spin states. A higher energy state is achieved when the proton and electron are in a parallel spin state, while a lower energy state exists when they're anti-parallel [8]. When the hydrogen atom goes from a parallel to an anti-parallel spin state, the difference in total energy is compensated for through the emission of a spectral line. This spectral line is emitted at a frequency of 1420.405 MHz, also known as the 21cm emission line discussed above [8]. The radio telescope that I will be building for my comp is adjusted to be able to read this 21cm line, and thus let me take data.

2.2 The Electromagnetic Spectrum

The electromagnetic spectrum is the complete range of frequencies of electromagnetic radiation. Electromagnetic radiation behaves both as a wave propagating and a photon particle traveling through space. The spectrum, from left to right, is in order of increasing frequency and decreasing wavelengths; starting with radio waves and ending with gamma rays. The types of electromagnetic radiation in the spectrum can be classified in 8 different sections; Gamma radiation, X-ray radiation, Ultraviolet radiation, visible radiation, Infrared radiation, Terahertz radiation, Microwave radiation, and Radio Waves. These different types can be seen in figure 1 below.

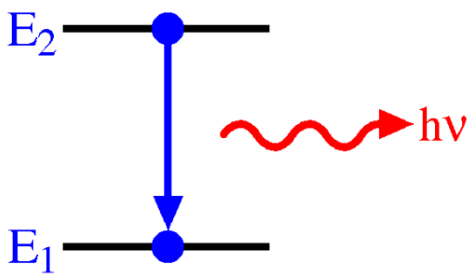
Figure 1 – A picture of the electromagnetic spectrum and the wavelengths of the different radiation in it.



2.3 The Emission Spectrum

Radio telescopes pick up and record emitted photons from space that are released as a result of changing energy states (high to low). Whenever an atom goes from a higher energy state to a lower energy state a photon is released to compensate for the difference in energy. Alternately, a photon is absorbed when an electron is excited to a higher energy state from a lower one, in order to compensate for the increase in energy. In my project I will be looking at the energy state change of atoms of hydrogen with the radio telescope. The photons from hydrogen are emitted when it switches from a high energy state to a lower energy state. This can be seen in figure 2 below.

Figure 2 – Emission of a photon due to changing energy states.



The energy of a photon emitted in this way can be found using the following equation. Where h is Planck's constant, c is the speed of light, $\hbar$ is Planck's constant over 2 times pi, and λ is the wavelength of the photon.

$$E = \hbar\nu = \frac{hc}{\lambda} \text{ ……. Equation 1}$$

The momentum of the emitted photon can also be found using the following equation. The variables in this equation are the same as in the prior one.

$$p = \frac{h\nu}{c} = \frac{h}{\lambda} \text{……Equation 2}$$

2.4 Other Sources of Radiation

Although the main focus of my project will be the 21cm emission line of hydrogen when switching spin states, there are actually two more types of radio signals in radio astronomy; thermal and non-thermal radio signals [3]. Anything that is above absolute zero generates broadband electromagnetic energy. The strength of this energy is directly proportional to the temperature of the object, meaning the hotter the object, the stronger the energy. When a bar of metal is heated above absolute zero, it gives off thermal radiation. If this same bar is heated hot enough we can see it begin to glow until it becomes white hot and is then giving off "white noise" radiation.

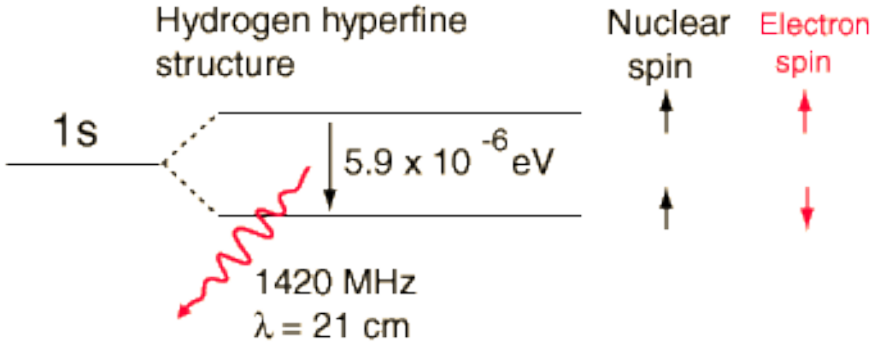
Radio telescopes are tuned to pick up radiation outside the visible spectrum. Another source of radio signals are non-thermal radio signals. Unfortunately, very little of our universe consists of non-thermal radiation. One of the main types of non-thermal radiation is called synchrotron radiation. Synchrotron radiation occurs when a moving electron is accelerated in a magnetic field to speeds close to the speed of light. The radio emissions given off are surprisingly strong [3].

Chapter 3: Theory

3.1 Derivation of the 21cm line: Hyperfine Splitting

As I stated earlier, the emission spectrum equations are nice and simple, but they are not used to solve for the 21cm emission line of neutral hydrogen (H1). The theory of hyperfine structure is the best means of both describing and solving for the 21cm emission line of hydrogen. The H1 transition, responsible for the creation of the 21cm line, is a result of two closely spaced energy levels of the ground state, related to the electron and proton spin, or magnetic dipole orientation. A slightly higher energy state is achieved when the spin of the electron is parallel to that of the nucleus, and a slightly lower energy state is achieved when the spin of the electron is anti-parallel to that of the nucleus. This transition of energy levels, parallel to anti-parallel, is the hyperfine transition which produces the 21cm line. These smaller hyperfine transitions exist in the n=1 energy level of hydrogen, and can be thought of as subgroups in that energy level. A basic pictorial description of this can be seen below in figure 3 [9].

Figure 3 – A diagram of the ground state of hydrogen and its two different hyperfine splitting energy levels (spin up and spin down.).



Within the n=1 ground state of neutral hydrogen there are two slightly different energy states that exist above and below the n=1 energy state (as seen in figure 3 above). These energy states are created as a result of the electron and proton either having the same spin states (parallel) or different spin states (anti-parallel). The nucleus is responsible for having an intrinsic magnetic dipole moment that can be oriented parallel or anti-parallel. The resulting energy is essentially the dot product of the intrinsic magnetic dipole moment of the nucleus and the spin of the electron, multiplied by the cosine of the angle between them. This is shown in the two figures below:

Figure 4a – The lower hyperfine energy state that exists when the spin of the electron is anti-parallel to that of the nucleus.

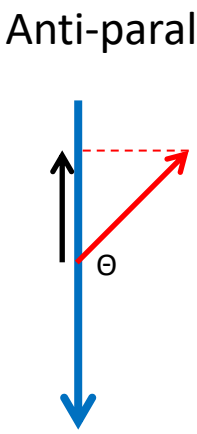
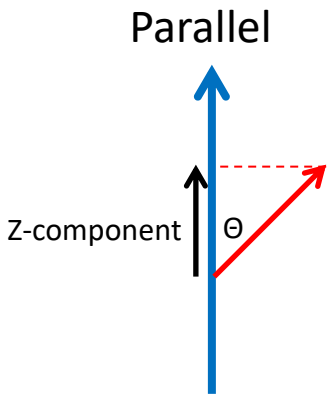


Figure 4b – The higher hyperfine energy state that exists when the spin of the electron is parallel to that of the nucleus.



In figures 4a and 4b, the red arrow shows the orientation of the spin of the electron, while the blue arrow is the direction of the intrinsic magnetic dipole moment created by the nucleus. The black arrow is the direction of the z-component of the spin of the electron, which is essential. Since it is nearly impossible to have the spins of the electron and proton

completely parallel or anti-parallel, determining whether or not they're anti-parallel or parallel is done by taking the dot product of the magnetic dipole moment of the nucleus with (according to the figures) the z-component of the electron's spin.

In order to begin the calculation of the 21cm line, a few basic things must be known. First off, hydrogen consists of a single electron and a single proton, both possessing a spin angular momentum of S=1/2 (S_p for the proton and S_e for the electron [4]. The dipole moment of the electron is expressed as:

$$\vec{\mu}_e = \gamma_e \frac{e}{mc} \vec{S}_e \text{ ----- Equation 3}$$

Where e is the charge of the electron, m is the mass of the electron, and c is the speed of light. The proton's dipole moment is expressed as:

$$\vec{\mu}_p = \gamma_p \frac{e}{Mc} \vec{S}_p \text{ --------- Equation 4}$$

M is the mass of the proton. In both of these equations, γ is the experimentally found numerical value; γ_p=2.7928 and γ_e=2.0032. The electron dipole moment is much stronger by a factor of M/m ~ 2000 [4].

The proton has two possible orientations of its magnetic moment, which produces a magnetic field of [4].

$$\vec{B}(r) = \frac{1}{r^3}\left[3\frac{(\overrightarrow{\mu_p} * \vec{r})\vec{r}}{r^2} - \overrightarrow{\mu_p}\right] + \frac{8\pi}{3}\overrightarrow{\mu_p}\delta^3(\vec{r}) \text{ ---------- Equation 5}$$

In this equation δ is the delta function (this is used to evaluate the expression at the origin of what you are looking at), and r is the distance away from the origin. In equation 5, the first term represents an ordinary magnetic dipole with the field far away from the origin, while

the second term represents the field around the nucleus. Next, we must account for the energy of the magnetic moment of the electron in the field of the proton [4]:

$$\Delta E_{SS} = -\overrightarrow{\mu_e} * \vec{B} = -\overrightarrow{\gamma_e}\frac{e}{mc}\overrightarrow{S_e} * \vec{B}(\vec{r})$$ ---------- Equation 6

ΔE_{SS} Is the energy added to the system due to the spin dipole moment of the electron. With this addition of energy, the spin-spin Hamiltonian is [4]:

$$\Delta H_{SS} = \left(\frac{e}{mc}\vec{S}_e\right) * \left\{\frac{\vec{\gamma}_p}{Mc}\left[\frac{(\vec{S}_p * \vec{r})\vec{r}}{r^2} - \overrightarrow{S_p} + \frac{8\pi}{3}\left(\overrightarrow{S_e} * \overrightarrow{S_p}\right)\delta^3(\vec{r})\right]\right\}$$ -------- Equation 7

$$\Delta H_{SS} = \frac{\vec{\gamma}_p e^2}{mMc}\left\{\frac{1}{r^3}\left[\left[3\frac{(\vec{S}_p * \vec{r})\,(\vec{S}_e * \vec{r})\vec{r}}{r^2}\right] - (\overrightarrow{S_e} * \overrightarrow{S_p}) + \frac{8\pi}{3}\left(\overrightarrow{S_e} * \overrightarrow{S_p}\right)\delta^3(\vec{r})\right]\right\}$$ --------- Equation 8

$$\Delta H_{SS} = \frac{\vec{\gamma}_p e^2}{mMc}\left\{\frac{1}{r^3}\left[3(\overrightarrow{S_e} * \hat{r})(\overrightarrow{S_p} * \hat{r}) - (\overrightarrow{S_e} * \overrightarrow{S_p})\right] + \frac{8\pi}{3}\left(\overrightarrow{S_e} * \overrightarrow{S_p}\right)\delta^3(\vec{r})\right]\right\}$$ -------- Equation 9

Operator J_Z, where $J_Z=L+S_e$, does not communicate with the Hamiltonian. Yet, the angular momentum, F, can be defined as [4]:

$$\vec{F} = \vec{L} + \overrightarrow{S_e} + \overrightarrow{S_p} = \vec{J} + \overrightarrow{S_p}$$ --------- Equation 10

Two new operators now need to be included, F^2 and F_Z, to commute with the Hamiltonian, introducing two new quantum numbers f and m_f. These help with the use of the equations:

$$F^2\Psi = f(f+1)\hbar^2\Psi$$ ---------- Equation 11

$$F_z\Psi = m_f\hbar\Psi$$ ---------- Equation 12

Function f has possible values of f=j+1/2 and f=j-1/2, due to the fact that the proton's spin is ½. This is seen in the splitting of the ground state (n=1) being hyperfine split into two slightly different energy levels corresponding to two possible spin orientations [4].

The ground state of the hydrogen atom occurs when *l*=0, since the electron does not have angular momentum, and subsequently no nuclear spin-orbit effect. Due to the spherical

characteristic of the wave function, only the delta function term contributes from the spin-spin Hamiltonian (equations 7-9). The first order perturbation theory yields [4]:

$$\Delta E_{hf} = \frac{8\pi\vec{\gamma}_p e^2}{3mc^2}\left(\overrightarrow{S_p} * \overrightarrow{S_e}\right)|\Psi(0)|^2$$ ---------- Equation 13

The value of $S_p * S_e$ can be found by squaring F, which with *l*=0, gives:

$$\vec{F}^2 = \overrightarrow{S_e}^2 + \overrightarrow{S_p}^2 + 2(\overrightarrow{S_e} * \overrightarrow{S_p})$$ ---------- Equation 14

With this, we now yield:

$$S_p * S_e = \frac{\hbar^2}{2}\left[f(f+1) - S_p(S_p+1) - S_e(S_e+1)\right] = \frac{\hbar^2}{2}\left[f(f+1) - \frac{3}{2}\right]$$ ----------Equation 15

Plugging in the values S_p=S_e=1/2 yields the last part. The hyperfine energy shift for when *l*=0 is [4]:

$$\Delta E_{hf} = \left(\frac{m}{M}\right)\alpha^4 mc^2\,\frac{4\gamma_p}{3n^3}\left[f\left(f+1-\frac{3}{2}\right)\right]$$ ---------- Equation 16

Where $\alpha = \frac{e^2}{\hbar c}$, which is the fine structure constant. We are looking at the ground state of hydrogen, meaning n=1, and *l*=0. The energy level is split into two different states between f=0 and f=1. The resulting difference in energy is [4]:

$$\Delta E_{hf}(f=1) - \Delta E_{hf}(f=0) = 5.9x10^{-6}eV$$ -------- Equation 17

Using equation 17, we find the frequency and wavelength of the 21cm line to be [4]:

$$\nu = 1420.4\ Mhz$$ ---------- Equation 18

$$\lambda = 21.1\ cm$$ ---------- Equation 19

That was the entire derivation for the famous 21cm emission line and 1420 MHz frequency of neutral hydrogen that is so important to astronomers.

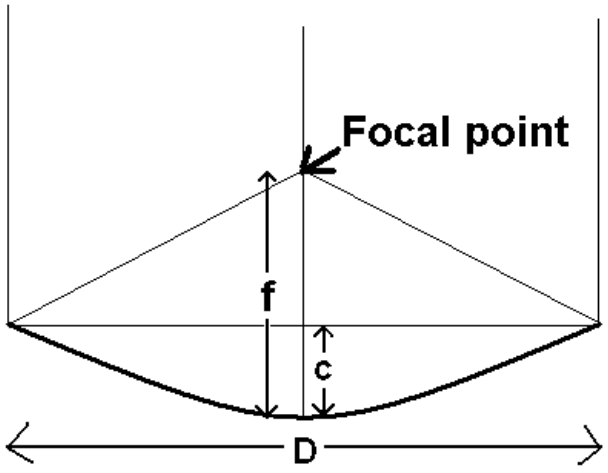
3.2 The Focal Point of the Dish

Determining the focal point of the dish for my radio telescope is actually very straightforward. All that needs to be known in order to solve for the focal point of the dish is to measure the depth of the dish (from the very center of the dip in the dish, to the rim of it), and the diameter of the entire thing. With these two things we can easily find the focal point of the dish using the following equation [2]:

$$f = \frac{D^2}{16c}$$ ---------- Equation 20

Where f is the focal point, c is the depth of the dish, and D is the diameter of the dish. Finding the focal point of the dish is easy with equation 20. The diameter of the dish is 10 ft., or 120 inches, the depth is 22 inches, and so the focal point will be at 41 inches. In order to get the best readings and results from this project, I need to make sure that the opening of the canister is placed directly at 41 inches. A figure is shown below using the same variables as Equation 20.

Figure 5 – The essential measurements needed in order to calculate the focal point of the dish.



Chapter 4: Apparatus

4.1 Components of the Telescope

I will be using the radio telescope here at Allegheny College, which consists of a parabolic dish (figure 6), detector (figure 7), low noise amplifier (figure 8), a motor mount (figure 9), a control panel, backend receiver(figure 10), and a computer. The parabolic dish that I will be using acts as a cache for all the 21cm emission lines received from wherever I take data. It catches all of the data and focuses it back to the detector located at the focal point of the dish. The holes in the mesh of the dish cannot be any bigger than one quarter of the wavelength of the data that I am taking.

The detector that I am using for my project is placed inside the canister located at the focal point of the dish. The tip of the detector will detect all of the signals that the dish picks up. This receiver will pick up many more signals than only the hydrogen. To account for this the electronics is programmed so that it only picks up the 1420 MHz frequency. As I stated earlier, a lot of thermal radiation can be picked up by radio telescopes that is considered to be noise, and scientists learned that radio telescopes had to be either programmed to pick up frequencies above or below the visible spectrum, at a certain frequency.

One of the newest additions to this radio telescope was the purchase of the motor mount. This motor mount allows the telescope to rotate a full 360 degrees, allowing us to take data anywhere in the sky and not having to move the telescope by hand. Currently, there is a control panel that you need to hook up and power up to roughly 14V in order for it to work. Then, separately, there is a program on the computer that you need to use in order to take

data. The program is called Spectra Cyber 2. All of the figures for the apparatus can be found in the Appendix A section located at the end of this paper.

Chapter 5: Experiment

5.1 Assembling the Radio Telescope

Figure 11 – Frontal view of the assembled telescope without the electronics attached.



Assembling the radio telescope was only possible with the help of a few others. Over the course of my comp work I had to assemble and disassemble the telescope many times in order to perfect the pieces I used for assembling it. The preferred method for assembling the dish is as follows:

Step 1: Attach the motor mount with the harness (figure 12) in it to the back of the dish, making sure that the dish is facing down, as in figure 6.

Step 2: Make sure the LNA is attached to the detector inside the canister.

Step 3: Attach the four poles to the canister (loosely), they will need to be adjusted later (Figure 13).

Step 4: Attach the other end of all four poles to the dish, tightening them all the way.

Step 5: Grab a tape measure and measure 41 inches from the center of the dish. Adjust the canister end of the poles until the canister sits at the focal point, then tighten the bolts.

Step 6: Lift the dish with the motor mount up, and place the motor mount into the aluminum pipe that is bolted in to the ground mount.

Step 7: Attach the output end of the LNA to the backend receiver, using a long cable.

5.2 Spectra Cyber 2

Perhaps the most frustrating obstacle I've came across so far this semester is the functionality of the program Spectra Cyber 2. It seems to not be picking up the signal from the computer through the ports, even though with the same cable the motor mount is able to connect to the computer. Because of this, the program sits in an "offline" mode, only producing the same dummy variable set of data over and over again. I was able to solve this problem by going into the settings on the computer itself and renaming the serial ports that are used for hooking up the equipment to the computer. Now that the serial ports were fixed and properly named, the program is ready to take data.

Once I was able to get Spectra Cyber into "online" mode, the next step was to test the LNA and make sure that it is working. This was accomplished by taking data both with and without the LNA connected to the backend receiver. Figure 17, pictured below, was the data taken without the LNA attached. The data in this run is a flat line around 0 volts showing that there were no readings picked up. This was what I expected to get when I did not have the LNA

attached. The next step was to attach the LNA and see if I picked up a reading unlike when the LNA was not attached. Figure 18, pictured below, is the second set of data taken over a range of frequencies. This time, the data did not give me a flat line at 0, and instead seemed to fluctuate at a value above 0 across the entire reading. This is telling me that there was an even distribution of waves around the 1420 frequency being picked up, which is also what I expected to find. With the results of these two runs, it is apparent that the LNA is working as intended and is now ready to take data once the dish is put into position.

Figure 17 – Data received with the LNA hooked up to the backend receiver.

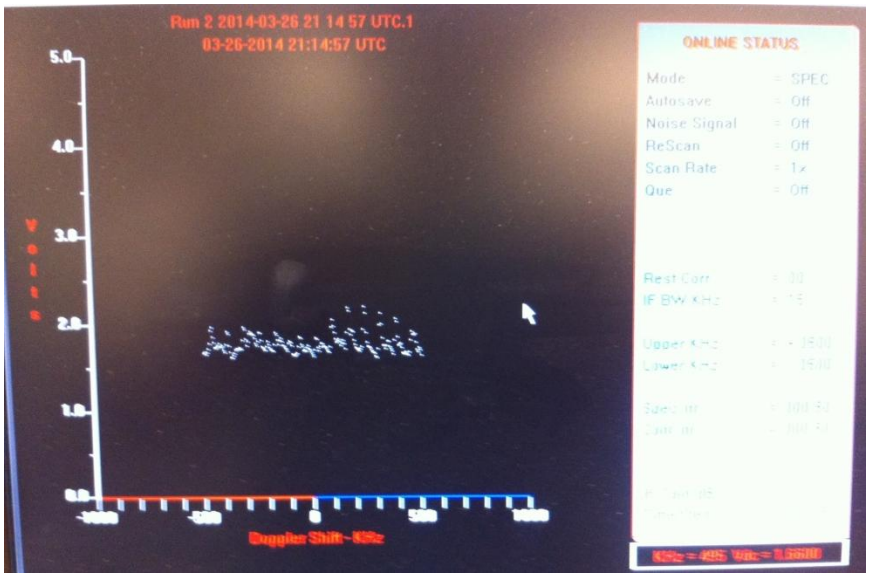
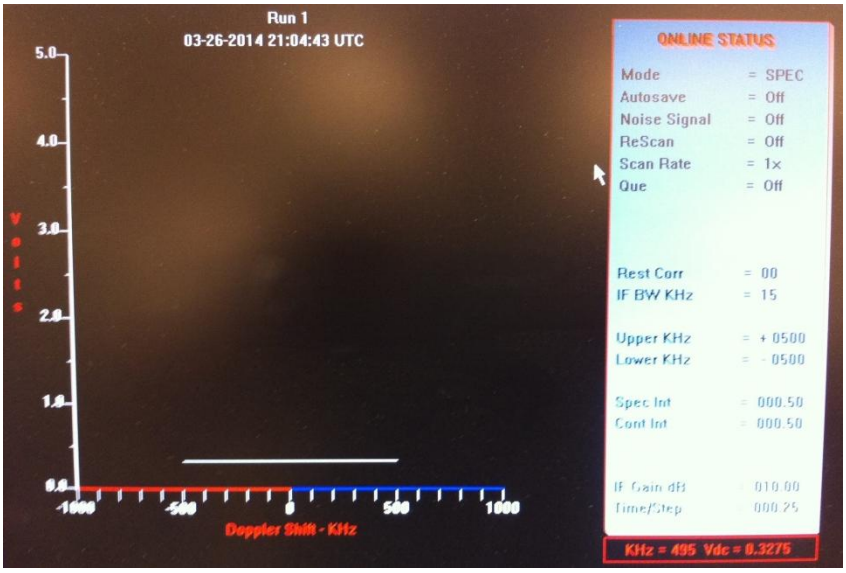


Figure 18 – Data received without the LNA hooked up to the backend receiver.



Chapter 6: Enhancing the Radio Telescope

6.1 Waterproofing the LNA

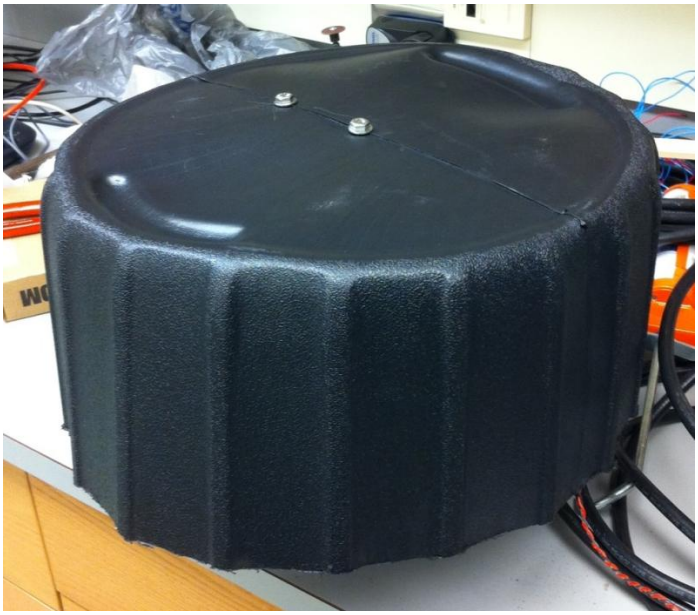
The first problem I came across when trying to assemble the radio telescope was one of finding a way to waterproof the LNA. In previous comps, the main problem that resulted in the end of being able to take data was that water would get into the LNA. Previously, due to heat messing with the signal, the LNA was placed in a cooler of ice so that it would keep cool. Although it was believed that the LNA was completely sealed, water got into the LNA when this was done. As a result I have opted to instead attach the LNA right onto the canister using a type-n elbow connector that allows the LNA to hang on the side of the canister, as seen in figure 14 below.

Figure 14 – The type-n elbow connector holds the LNA tight and close enough to the canister to allow for the covering to protect it from rain.



In order to protect the LNA from the elements outside, in addition to waterproofing it with silicon, I built a covering for the canister that attaches to the top of it (Figure 15). The process for making the covering went as follows. First I purchased a large black bucket and a Dremel. I then used the Dremel and cut the bucket at the appropriate height after measuring where the four posts would connect the canister to the dish. Lastly, I drilled two holes into the top of the covering and two holes into the top of the canister using the drill press. Overall, I am very happy with the result and feel that the covering along with the rubber silicone will be more than sufficient in protecting the LNA this time around.

Figure 15 – The covering for the canister houses the LNA and the detector and protects them from weathering.



6.2 Replacing the LNA and Motor Mount Wires

When I took over this project, one of my main concerns was the length of both the LNA and motor mount wires of the dish. The wires that powered the motor mount before were only about a foot long. Similarly, the wires that connected the LNA to the backend receiver were only about two feet long. Both of these wires needed to be replaced for obvious reasons. I decided that I was going to attach the LNA to the canister at the focal point of the dish, so there was no way that this small wire would be able to go from here to the backend receiver in the lab. The motor mount power cables needed to be much longer because the power supply for the motor mount is not waterproof and would have to remain in the lab as well.

The final destination for the telescope will be the roof of Carr. In order to make this happen, I ordered a 50 foot 18 gauge 8 wire cable for the motor mount and was able to find a

40 foot 18 gauge 2 wire cable for the LNA. I stripped both of these wires using wire strippers and spliced the old LNA wires to this new one. For the motor mount, I tinned one end of the wire and soldered the other end to the power supply, completely replacing the old wires.

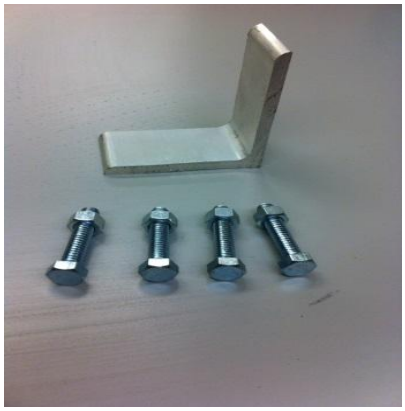
6.3 Fixing the Rectangular Mounting Harness: Adding Angle Aluminum

The hollow rectangular aluminum harness attachment that Kyle purchased was not cut well enough. It extended about an inch too far on one end in order for it to fit properly in the back of the dish. I shaved off about an inch of this piece, and now it fits on the back of the dish perfectly. Also, this piece was not sufficient to support the weight of the dish. When I bolted everything in and tightened this piece on the dish, the dish would slip on the end of this harness and slide down to touch the ground. In order to compensate for this, I came up with the idea of using a piece of angled iron in order to hold the dish in place so that the motor mount could be properly used. Unfortunately, there is no angle iron in our machine shop and I had to settle for cutting a piece of angle aluminum to fit the harness properly. Iron would be much better than aluminum for holding the dish up, but because of the sheer thickness of the aluminum, it should be sufficient.

The final piece of angle aluminum I used can be seen in figure 16 below. I began with taking a long piece of the angle iron and tightening it in the vice grip. Then, I took this new cut piece of angle aluminum and tightened it to the drill press with a clamp and drilled two holes in it and attached them together with nuts and bolts. The second part of this was much trickier, I had to use a hand drill and line up the dish with the other end of the angle aluminum and use the hand drill to drill through the dish and the angle aluminum. Lastly, the dish and the angle

aluminum were bolted together. The dish is now ready to be adjusted by the motor mount without having to worry about it slipping around.

Figure 16 – A cut piece of angle aluminum that will be attached to the harness and the dish in order to keep the dish situated in place.



6.4 Repairing the Mesh

Ideally, most of the mesh should be reordered, recut, and replaced. For the next student working on this project, I suggest just that. For the time being, I simply slid as much of the mesh back into place as I could. If I had more time, I would have ordered in more of the mesh and cut it into slices that would fit perfectly into the dish and screw them into place. The newly ordered mesh would not have to be the exact same mesh that is already in the dish; as long as the newly ordered mesh contains holes less than a quarter of the wavelength in diameter it will be fine.

Chapter7: Troubleshooting Guide

7.1 Spectra Cyber

One problem with Spectra Cyber is with the way the program uses the ports. Spectra Cyber only recognizes ports 1 and 2 in the computer. Ports can be named up to any number you would like, so be sure to label the ports on the back of the computer ports 1 and 2. They are already labeled that so no problems should arise from them. One thing to be sure of is that you must make sure to properly exit out of Spectra Cyber by going to file and then clicking close. Clicking the X on the top right of the program does not properly close the program and problems will arise. If the program is closed by clicking X, then you must go into task manager and end the program. If this is not done and Spectra Cyber is reopened, the program will still think the port is being used by the program and will give you an error. This error is alleviated by going into task manager and ending Spectra Cyber. In order to avoid any Spectra Cyber problems, be sure to properly close the program every time you use it.

7.2 Logging into the Computer

The username is telescope and the password is Scope01.

Appendix A: Figures

Figure 6 – The radio telescope dish, in its current condition.



Figure 7 – The detector for the radio telescope that needs to be placed inside the canister and located at the focal point, 41 inches.



Figure 8 – The LNA (low noise amplifier) is now sealed with silicon.



Figure 9 – The motor mount that can go up to 90 degrees vertically, and can rotate 360 degrees horizontally.

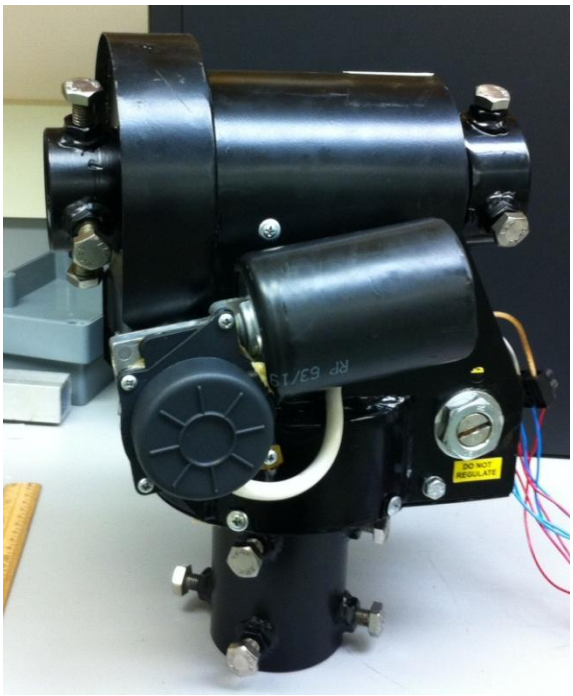


Figure 10 – The backend receiver that is compatible with the Spectra Cyber 2 software.



Figure 12 – The mounting harness that sits inside the motor mount and tightened, then attaches to the dish securely.



Figure 13 – The canister and the four support beams that attach to it and need to be adjusted so it sits at the focal point, 41 inches.



Appendix B: Works Cited

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