Wright State University
Department of Electrical Engineering

EE 482
Senior Design Project
Final Report

Project Title: GPS Repeater System
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INTRODUCTION

Purpose

The purpose of this document is to provide an overview of our Senior Design project (the GPS Repeater System within the High Altitude Balloon Project), give a final status update, and fulfill the last requirement of the Senior Design course.

Project Scope

GPS location plays an integral role in many phases of the HIBAL team’s experiments, and frequent testing of payload system components is a necessity. GPS receivers often cannot obtain a usable signal from satellite sources while indoors due to the imposing physical structures between GPS satellites and GPS receivers. Testing previously required that the equipment be transported outdoors to obtain a GPS signal. Our project aims to bypass this problem by installing an outdoor GPS antenna, passing the signal through a coaxial line, and radiating the signal throughout the balloon lab at typical ground level strength. This would allow teams to complete GPS testing indoors and make more efficient use of their time.

DESIGN REQUIREMENTS

GPS is in widespread use today, and GPS repeater systems are commercially available. However, due to regulatory considerations in the United States, it is not permissible to purchase a complete repeater system. However, if certain qualifications are met, such as having an Experimental License under FCC rules part 5, or operating in a shielded room, it is allowable to purchase components and construct a system independently. As we intend to radiate throughout Russ 018 at the standard ground-level GPS signal strength, we expect no interference to occur outside of the room, and thus we would meet the shielded room requirement. Furthermore, the repeater system will only run during periods of testing.

We will be working with the GPS L1 frequency, which is 1575.42 MHz, and all system elements should be optimized to operate at this frequency. Another important goal of our design is to re-radiate the GPS signal at the same signal strength that is encountered at the receiving antenna (-130 dBm at 1 MHz). Finally, any outside installations must be able to withstand local weather conditions.

Our conceptual design consists of: an active antenna to receive the GPS signal outside Russ; a coax cable to transmit the acquired signal to the basement; a two-port splitter to direct the signal
simultaneously to a GPS receiver and the radiating antenna; an amplifier to increase signal strength; a bias tee circuit that will power the active antenna and allow the GPS signal to pass; and a passive antenna that radiates the signal throughout the lab. Provided is a block diagram of our proposed design (Figure 1).

![Figure 1]

**Figure 1**
GPS Repeater Block Diagram

**DESIGN SPECIFICATIONS**

**Active Antenna**

The design begins with a Radiall/Larsen GPS Base Station Timing Antenna #GPS0015-C active antenna. This antenna is made to receive the 1575.42 MHz GPS signal, and will be mounted on the roof just above Russ 018. The chosen antenna, shown in Figure 2, will provide a 25 dB gain, as well as a noise figure of 2.5 dB. Furthermore, the bandwidth of the active antenna is ± 1.023 MHz and will require a 4.5-12 V supply voltage with 30 mA max current.
Coax Cable

Connected to the active antenna is 50 feet of RG 213 coax cable (Figure 3) that is to run from the outside roof to Russ 018. The coax will be crimped with N-type/female connectors. The typical attenuation of RG 213 at 1575.42 MHz is about 9.3 dB per 100 feet².

Splitter

The RG 213 will then be connected to an active splitter to divide the signal in half. The selected splitter is a GPS Active Splitter-58535A by Symmetricom (Figure 4) and has a gain of 3 dB to negate the -3 dB loss of splitting the signal and a noise figure of 5 dB. The GPS Active Splitter-58535A has a bandwidth of ± 20 MHz and will require a 4.5-13 V supply voltage and 23-48 mA of current. Furthermore, the GPS Splitter is able to pass a DC voltage through its output ports to the input port, allowing it to pass DC voltage to an active antenna³.
Amplifier

Connected to port 1 of the GPS Active Splitter will be an amplifier to strengthen the GPS signal. We have selected a Symmetricom 58529A Amplifier with L1 bandpass filter (Figure 5). The amplifier provides a gain of 25 dB and a noise figure of 3.8 dB, as well as a bandwidth of ± 1.023 MHz and requires between 4.5-13 V DC. Like the splitter, the GPS amplifier is able to use a DC voltage and pass it from output to input ports, allowing other devices such as the splitter and antenna to be powered.

Bias Tee

Connected to the amplifier will be a bias tee designed and built by our team. When connected to a power supply, the bias tee is able to pass power to the amplifier, splitter, and the active antenna with minimal disruption to GPS signal. Figure 6 shows the bias tee our team built. Our initial designs for the bias tee aimed to have a loss of less than 2 dB and operate with 4.5-13 V of input.
Finally, connected to the bias tee is a passive antenna (Figure 7) to radiate the GPS signal. The chosen passive antenna is the GPS Antenna 72009002 Rev. B which features a gain of approximately 5 dBi due to the patch antenna style design.

![Figure 6](image)
**Figure 6**
Bias Tee

**Passive Antenna**

Finally, connected to the bias tee is a passive antenna (Figure 7) to radiate the GPS signal.

The chosen passive antenna is the GPS Antenna 72009002 Rev. B which features a gain of approximately 5 dBi due to the patch antenna style design.

![Figure 7](image)
**Figure 7**
GPS Antenna 72009002 Rev B.

**Table 1:** Part List for Design Specifications

<table>
<thead>
<tr>
<th>Component</th>
<th>Decibel Gain/Loss</th>
<th>Noise Figure</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Antenna</td>
<td>25 dB Gain</td>
<td>2.5 dB</td>
<td>±1.023 MHz*</td>
</tr>
<tr>
<td>RG 213</td>
<td>4.65 dB Loss</td>
<td>4.65 dB</td>
<td>-----</td>
</tr>
<tr>
<td>GPS Active Splitter</td>
<td>3 dB Gain</td>
<td>5 dB</td>
<td>±20 MHz*</td>
</tr>
<tr>
<td>GPS Amplifier</td>
<td>25 dB Gain</td>
<td>3.8 dB</td>
<td>L1 Bandpass Filter*</td>
</tr>
<tr>
<td>Bias Tee</td>
<td>6 dB Loss*</td>
<td>6 dB *</td>
<td>±25 MHz**</td>
</tr>
<tr>
<td>Passive Antenna</td>
<td>5 dBi Gain</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Power Supply</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
</tbody>
</table>

*All components have a center frequency of 1575.42 MHz (L1 GPS)

** Bias Tee Specifications are from the bias tee we constructed and tested
BIAS TEE

When designing our GPS repeater system, we weighed the benefits and drawbacks of purchasing each system component or constructing our own, taking time and financial costs into consideration. After a few meetings and further research we concluded to buy the active antenna, GPS active splitter, GPS amplifier, passive antenna, and all necessary connectors. The coax cable was previously purchased by another group and already in place. The bias tee, however, we wanted to design and build. This was because a successful design would be cheaper than one purchased commercially, and we had all necessary equipment and components at our disposal. Discussions with our mentors eventually led us to order a commercial version as well, despite the cost, to minimize the risk of leaving the system incomplete should our fabricated units fail to perform.

The function of the bias tee is to provide DC voltage on the same line as the GPS signal, in the opposite direction, to power the active antenna, GPS active splitter, and GPS amplifier. A bias tee injects the DC voltage onto the line and directs it to the above mentioned components while allowing RF signal to pass with little attenuation.

Primary components used in the building of a bias tee are inductors and capacitors. Recalling basic complex circuit theory, we know the equations for the reactance of an inductor and capacitor to be the following.

\[ X_{\text{inductor}} = j\omega L = 2\pi f L \quad X_{\text{capacitor}} = \frac{1}{j\omega C} = -\frac{j}{2\pi f C} \] (1)

Where \( f \) is the frequency in Hertz, \( L \) is the inductance in Henries, and \( C \) is the capacitance in Farads. As can be seen from the above equations, as the input frequency increases, the impedance of the inductor will increase, while the impedance of the capacitor will decrease. At a frequency of 0 Hz, the inductor should have an impedance of near zero, while the capacitor's impedance is infinite. The opposite is true at high frequencies, where the capacitor's impedance will approach zero, while the inductor will approach infinity.

As we are dealing with two signals on the same line, one at a frequency of 0 Hz (DC) while the other is at 1.575 GHz (GPS) the inductor will work to pass the DC signal while blocking the GPS signal, and the capacitor will block DC while passing the GPS signal.
Some design challenges were involved in the building of a bias tee. First, a capacitor and inductor must still behave like a capacitor and inductor in RF. This brings up the issue of inductor and capacitor Self Resonant Frequency (SRF). In real life, inductors and capacitors are not ideal components, and contain parasitic capacitance and inductance, respectively. For example, in the case of an inductor, the inductor can be modeled as a series resistor and inductor in parallel with a capacitor, as seen in Figure 8.

![RLC Model of an Inductor](image)

In the above figure, the resistance $R_s$ represents the effective resistance of the inductor, $L$ is the ideal inductance of the inductor, and $C_{par}$ is the parasitic capacitance. This parasitic capacitance is due to the parallel wires in the inductor winding. In general, the parasitic capacitance of an inductor is very small, leading to large effective reactance. However, as the working frequency increases, the reactance of the capacitor will gradually approach that of the inductor. At a certain frequency, the reactance of the capacitor will match that of the inductor and the two values will cancel one another (capacitor reactance is negative while inductive reactance is positive). It is this point that is called the Self Resonance Frequency. An analytical approximation for resonant frequency is defined as:

$$SRF = \frac{1}{2\pi \sqrt{L C_{par}}} \text{ Hz} \quad (2)$$

Once the working frequency has surpassed the SRF, the phase of the reactance goes negative. It is then that an inductor will begin to behave like a capacitor, and a capacitor like an inductor. Figure 9, taken from a Coilcraft.com write up on SRF illustrates this effect.

**NOTE:** The above equation is the same as the equation for the resonance of an LC circuit.
Figure 9 contains two simulations, the first is of 100 nH chip inductor, while the second simulation is the same inductor with a 0.01 pF capacitance added between the input terminal and ground. As can be seen from the figure, the effective inductance becomes zero at SRF, and goes negative past the SRF. It is because of the effect of SRF that the inductor for our bias tee needed careful selection, as a poor choice of inductor will route GPS signals to the ground of the DC line, not to our radiating antenna/GPS receiver.

Additionally, even at low frequencies, there is a small amount of current that will leak through the inductor due to parasitic capacitance. This leaking current must be routed to ground, avoiding any sensitive components such as a voltage regulator.

**TESTING**

**Bias Tee- First Design**

Our original design (Figure 10) shows that we must pass GPS signal at 1575.42 MHz while injecting +5V. Our design was also conceived to be narrowband: one inductor needed with hopes of low attenuation of the RF signal (0.2-2 dB). Furthermore, we attempted to minimize the effect of RF leakage on components by including bypass/stability capacitors and a diode surrounding the regulator.
With our first design we took 9 V DC from an outlet and passed it through a regulator that suppressed 4 volts allowing for 5 volts to be directed up the DC/RF terminal. Using a multi-meter from Russ 018 we measured the voltage dropped across the power supply, the regulator, and the DC/RF terminal all with reference to ground. We measured 9 volts across the power supply, 4 volts across the regulator and 5 volts across the DC/RF terminal. Our voltage goal at the DC/RF terminal was 5 volts, and therefore we achieved our desired voltage.

When conducting the RF testing, we used the spectrum analyzer and signal generator from Russ 307. Both machines were made by Agilent. We first measured the attenuation of the bias tee including cables and connectors. We then measured various combinations of connectors and cables to calculate the losses in the cables and connectors to obtain a more accurate result for the bias tee losses. Sending a signal of 1575.42 MHz, the GPS L1 frequency, through the bias tee with the cables and connectors we measured roughly an 8 dB loss for the system. After measuring the losses for the cables and connectors of 3.9 dB and subtracting them from the system we were able to calculate
the total loss for the bias tee, which is 5 dB not including the necessary connectors. This is well above our projected loss of 0.2 dB, however, most commercially available bias tees are constructed for larger bandwidth while ours is for a particular frequency. Provided are photos (Figures 11 and 12) taken from the spectrum analyzer which shows a peak at 1575.42 MHz, as well as our test set up.

![Test Set Up](image1)

**Figure 11**
Test Set Up

![Received Power at 1575.42 MHz](image2)

**Figure 12**
Received Power at 1575.42 MHz

We also went to Dr. Elliott Brown’s lab and confirmed our findings. For testing, we made use of an Agilent Vector Network Analyzer, and performed a Scattering Parameter (S-Parameter) measurement. The results of the measurement are as follows:

\[
[S_{db}] = \begin{bmatrix}
-4.3 & -5.0 \\
-5.0 & -4
\end{bmatrix}
\]

\[
[S] = \begin{bmatrix}
0.60953 & 0.56234 \\
0.56234 & 0.63095
\end{bmatrix}
\]

Insertion Loss \( = -20 \log_{10} |S_{12}| = -20 \log_{10} |S_{21}| = 5.0 \text{dB} \)  

\( \text{Return Loss}_{input (RF+DC \text{ Port})} = = -20 \log_{10} |S_{11}| = 4.3 \text{dB} \)

\( \text{Return Loss}_{output (RF \text{ Port})} = = -20 \log_{10} |S_{22}| = 4.0 \text{dB} \)

\( |\Gamma_{in}| = |S_{11}| = 0.60953 \)

\( |\Gamma_{out}| = |S_{22}| = 0.63095 \)
\[ VSWR_{in} = \frac{1 + |S_{11}|}{1 - |S_{11}|} = 4.122 \] \hspace{1cm} (10)

\[ VSWR_{out} = \frac{1 + |S_{22}|}{1 - |S_{22}|} = 4.419 \] \hspace{1cm} (11)

Note: While the calculated losses are fairly accurate, there is a margin of error of about 1-1.5 dB due to VNA calibration. Due to time constraints we did not have enough time to perform a full calibration.

Though our design works it does have up to 7.7 dB attenuation at operating frequency. Possible reasons for this include soldering, capacitor and inductor Self Resonant Frequency, and reflection between input connectors and the circuit due to impedance mismatch.

**Second Bias Tee Design**

With these findings and some instructions from Dr. Brown we built a second bias tee (Figure 13).

![Second Bias Tee Block Diagram](image)
As one can see the concept stayed the same, however, we are sending 9 volts up the DC/RF port and our capacitor and inductor values were changed. We wound our own inductor on a ferrite bead and used copper foil to create a ground plane. As with the first bias tee, a vector network analyzer was used to obtain S-parameter data for the bias tee. Initial testing proved disappointing, as we encountered an insertion loss of the bias tee system of nearly -9 dB, worse than the first bias tee. Later testing of cables and the N-Female/N-Female connectors used in the bias tee testing revealed that each connector provides a 1.2 dB loss, while the cables provided an attenuation of 0.7 dB and 0.8 dB. The below data for the bias tee has been adjusted for cable/connector losses.

\[
[S_{db}] = \begin{bmatrix} -4.2 & -4.9 \\ -4.9 & -5.6 \end{bmatrix}
\]  

(12)

\[
|S| = \begin{bmatrix} 0.61659 & 0.56885 \\ 0.41209 & 0.52480 \end{bmatrix}
\]  

(13)

\[\text{Insertion Loss} = -20 \log_{10}|S_{12}| = -20 \log_{10}|S_{21}| = 4.9 \text{ dB}\]  

(14)

\[\text{Return Loss}_{\text{Input (RF+DC port)}} = -20 \log_{10}|S_{11}| = 4.2 \text{ dB}\]  

(15)

\[\text{Return Loss}_{\text{Output (RF port)}} = -20 \log_{10}|S_{11}| = 5.6 \text{ dB}\]  

(16)

\[|\Gamma_{in}| = |S_{11}| = 0.61659\]  

(17)

\[|\Gamma_{out}| = |S_{22}| = 0.52480\]  

(18)

\[VSWR_{in} = \frac{1 + |S_{11}|}{1 - |S_{11}|} = 4.216\]  

(19)

\[VSWR_{out} = \frac{1 + |S_{22}|}{1 - |S_{22}|} = 3.208\]  

(20)

In addition to S-parameter testing, we performed a frequency sweep from 50 MHz to 3GHz to see the insertion loss \(S_{21/12}\) of the bias tee, the results of which can be seen in Figure 14.
From the above data, the performance of the second bias tee is disappointing at best. At the desired frequency of 1575.42 MHz, the attenuation is nearly 9 dB. However, this figure does include losses from connectors and cables, which provide a combined attenuation of approximately 3.9 dB, 2.4 of which is provided by connectors, which may easily be substituted for better performing connectors. What is interesting about the second bias tee is that there is a relatively flat region between approximately 450 MHz and 750 MHz that registers at approximately -5.5 dB. If we were to remove cable/connector losses from this figure, we would obtain an attenuation of 1.6 dB, which would be an acceptable figure if we were to operate in that frequency region. The above data suggests that the new bias tee, which was designed for the L1 GPS band, actually operates in the UHF band.

**Commercial Bias Tee**

On the advice of Dr. Kefu Xue and advisor Dr. Wu, we set out to purchase a commercially available bias tee and compare it to ours. In the event that our bias tee did not work acceptably, the commercially available bias tee would still allow the GPS repeater system to operate.

In purchasing a bias tee, we contacted the company GPS Source and designed a bias tee with N-Female connectors and a wall mount power supply. The bias tee would output 7.5 V to the active antenna, and block DC from being passed to the passive radiating antenna. A model similar to our purchase bias tee can be seen in Figure 15 below.
To test our new bias tee, we once again used the VNA in Dr. Brown’s lab. Our purchased bias tee already contains the required N-Female connections, so the use of lossy connectors was not required. The only applicable losses came from our cables, which were 0.7 dB and 0.8 dB respectively. The results of the test are as follows:

\[
[S_{db}] = \begin{pmatrix} -21.0 & -0.32 \\ -0.32 & -23.0 \end{pmatrix}
\]
(21)

\[
[S] = \begin{pmatrix} 0.08912 & 0.82985 \\ 0.82985 & 0.07079 \end{pmatrix}
\]
(22)

*Insertion Loss* \( = -20 \log_{10}|S_{12}| = -20 \log_{10}|S_{21}| = 0.32 \text{ dB} \) (23)

*Return Loss* \(_{\text{input (RF+DC Port)}} = = -20 \log_{10}|S_{11}| = 21.0 \text{ dB} \) (24)

*Return Loss* \(_{\text{output (RF Port)}} = = -20 \log_{10}|S_{11}| = 23.0 \text{ dB} \) (25)

\[
|\Gamma_{in}| = |S_{11}| = 0.08912
\]
(26)

\[
|\Gamma_{out}| = |S_{22}| = 0.07079
\]
(27)

\[
VSWR_{in} = \frac{1+|S_{11}|}{1-|S_{11}|} = 1.196
\]
(28)

\[
VSWR_{out} = \frac{1+|S_{22}|}{1-|S_{22}|} = 1.1523
\]
(29)

As with the second bias tee we conducted a frequency sweep from 50 MHz to 3 GHz and measured the insertion loss \( S_{12/21} \), the results of which are in the following figure.
As expected, the commercially available bias tee outperforms our own constructions. When cable losses are removed, the third tee has an insertion loss of less than a single dB, while return losses, which indicate reflections back to the sources, are minimal.

The results of the above testing encouraged our team to wonder exactly why we saw the performance that we did regarding our bias tees versus the commercially available bias tee. Through our questioning, we found several possible items that worked against the successful operation of our bias tees. Most notably is that the connectors that we were required to use. We decided to mount N-male connectors onto our bias tee housing, due to them being readily available in the HIBAL lab. Due to most available cables featuring N-male connections, we were required to use N-female/N-female connectors on our tee, which increased losses.

Additionally, the construction and placement of our RF blocking inductor and DC blocking capacitor may have caused some issues in terms of RF leakage. In both bias tees, we were forced to use at least one surface mount component, which often can prove difficult to solder or attach properly. The difficulty in soldering may have easily introduced areas of mismatched impedance, which cause reflections and increase the standing wave ratio.
In the case of the inductor, we attempted two approaches. Our first approach involved a small air core inductor, while in the second approach we wound a wire around a ferrite toroid to create an inductor. There were potential issues with both approaches. As the air core inductor did not have a ground plane below it, there was the possibility of the coil behaving as a magnetic dipole and radiating signals. In the case of the toroid, which was nearly an inch in diameter, we later discovered that it could potentially behave partially as a transformer, and pass more signal than intended. Furthermore, the material used in the ferrite ring was T37, and while it functions reasonably well at higher frequencies, such as 1.575 GHz, the ability of the ferrite to store energy in magnetic fields diminishes (as what is known as the “loss tangent” of the ferrite, the ratio of the imaginary to real parts of the magnetic permittivity, increases).

In terms of the capacitors used, two issues arose. In the first bias tee we had used a simple ceramic disc through-hole capacitor, which required solder connections and possibly introduced impedance mismatches. For the second bias tee we attempted to use a surface mount capacitor with a resonance frequency much higher than 1.575 GHz. The surface mount capacitor proved more difficult to attach than the through-hole capacitor, and we encountered the same possibility as in the first; possible reflections due to soldering.

Another consideration regarding our bias tee construction was brought to our attention during the senior design poster presentation concerning the housing unit for the bias tee (our thanks to Chris Kretzler’s father). In both of our constructed tees, we used a plastic housing. We found that the commercially available tee featured a metal case, and realized that a metal case would work to provide shielding and a ground plane, as well as isolate the system from outside sources.

If we were to attempt to construct a third bias tee, we would make several changes. If time was not an issue, our first choice would be to fabricate a circuit board that contained pads for both our DC and RF components, in order to alleviate or completely eliminate concerns with impedance mismatching as well as difficulties in soldering as epoxy adhesive would be useable for the capacitor. For inductor constructions, we would return again to a small air core inductor, or, if the ferrite core option were desired, wind the inductor around a ferrite bead instead of toroid and fabricate or purchase one with an extremely high SRF.

Regardless of the end performance of the bias tees, extremely important lessons were learned regarding construction and operation of RF components.
GPS Repeater System

Though weather complications kept us from fully installing our system until early May, we were able to install and test the GPS Repeater System. As of May 24, 2011 we are able to receive a GPS signal via direct connection to our RTrak-HAB APRS system which employs a Trimble GPS receiver, using the first bias tee we constructed. However, we were unable to receive a GPS signal through our radiating antenna. Possible causes under consideration were grounding problems in the bias tee, a malfunctioning radiating antenna, or signal strength that overwhelmed the radiating antenna.

After the arrival of our GPS Source tee, we again tested our repeater system. For this test, our mentor Bruce Rahn was present, and he offered insights, as well as introduced us to the “Totally Accurate Clock (32-bit)” TAC32 program created by CNS Systems. We were able to download an evaluation copy of this program. The TAC32 program has the ability to display GPS time as well as the ID and SNR of GPS satellites that the GPS receiver is able to see. For these tests we utilized our Garmin 15-L GPS receivers.

For our first test we connected the 15-L receiver directly into our repeater system and measured SNR and satellites seen by the system, the results of which are in Figure 17. Our tests indicate that our system is operational, and a good SNR between 25-30 dB can be seen between the receiver antenna and most satellites, with 10 satellites visible and 7-8 satellites locked onto. The satellite with the ID of PRN 11 appears to have a low SNR due to a low elevation angle.

After the above test, we tested the radiating portion of our system. GPS patch antennas were connected to the output of our repeater and our receiver and placed 9 inches apart. For this test, our team decided to see if our GPS splitter did indeed have a 3 dB gain when only one port is connected. The results are as follows in the following Figures 17 and 18. The following figures indicate that there is a small gain when the splitter is connected to only one output port, we can use this to our advantage when radiating signals.

For our final testing we removed the splitter and replaced the bias tee with our constructed bias tees. Unfortunately, the results were not as expected (Figure 20):
Figure 17
Direct Connection to Repeater System

Figure 18
Radiating SNR with Splitter on one port
Figure 19
Radiating system with no Splitter

Figure 20
Repeater System with constructed bias tees
While the GPS receivers were able to “see” several satellites, the signal that entered the receiver was much too weak or distorted for the receiver to get a good lock on the satellites. We repeated this test several times, both with radiating signals, the splitter, and direction connection, but still no usable signal passes through. We then attempted to attach our amplifier to our system, but all satellites disappeared from our logger. At this point, we came to the conclusion that while our constructed tees do work with some attenuation, there is some contamination or disruption of the signal that prevents the receiver from locking on, regardless of the amplifier presence. We re-ran several tests and found that attaching our amplifier seemed to cause problems for our system, even in cases where desired outcomes had previously been attained.

We found that we can receive a GPS signal via direct connection, as well as radiate the signal approximately three feet, but only if our amplifier was not installed in the system. With our amplifier installed we could not receive any signal. Discussing the matter with our mentor Bruce Rahn led us to conclude that our amplifier was not working properly. We are currently attempting to contact the vendor to rectify the situation.

**COST ANALYSIS**

<table>
<thead>
<tr>
<th>Component</th>
<th>Company</th>
<th>Quantity</th>
<th>Cost per Component</th>
<th>Subtotal</th>
<th>S&amp;H</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Antenna</td>
<td>Radiall/Larsen GPS Base Station Timing Antenna #GPS0015-C</td>
<td>4</td>
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<td>$45.00</td>
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<td>Coax Cable</td>
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<td>50 ft</td>
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</tr>
<tr>
<td>GPS Active Splitter</td>
<td>Symmetricon 58535A</td>
<td>2</td>
<td>$32.50</td>
<td>$65.00</td>
<td>$5.20</td>
<td>$70.20</td>
</tr>
<tr>
<td>GPS Amplifier</td>
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<td>1</td>
<td>$125.00</td>
<td>$125.00</td>
<td>$5.95</td>
<td>$130.95</td>
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<tr>
<td>Bias Tee</td>
<td>First Bias Tee</td>
<td>1</td>
<td>$26.89</td>
<td>$26.89</td>
<td>$5.95</td>
<td>$32.84</td>
</tr>
<tr>
<td>Bias Tee</td>
<td>Second Bias Tee</td>
<td>1</td>
<td>$23.67</td>
<td>$23.67</td>
<td>$5.95</td>
<td>$29.62</td>
</tr>
<tr>
<td>Bias Tee</td>
<td>GPS Source BT1-P110/7.5-NF</td>
<td>1</td>
<td>$175.00</td>
<td>$175.00</td>
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<td>$175.00</td>
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<tr>
<td>Connectors</td>
<td>N-type(M/F)</td>
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</tr>
<tr>
<td>Overall Total</td>
<td></td>
<td></td>
<td>$410.30</td>
<td>$476.55</td>
<td>$41.54</td>
<td>$518.09</td>
</tr>
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</table>
Table 3: Cost for components of First Bias Tee

<table>
<thead>
<tr>
<th>Component</th>
<th>Company</th>
<th>Quantity</th>
<th>Cost per Component</th>
<th>Subtotal</th>
<th>S&amp;H</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perf Board</td>
<td>Radio Shack</td>
<td>1</td>
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<td>-----</td>
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</tr>
<tr>
<td>Wall Mount Transformer</td>
<td>T1020-PSRP-ND*</td>
<td>1</td>
<td>$5.93</td>
<td>$5.93</td>
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<td>$5.93</td>
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<td>Barrel Power Jack</td>
<td>CP-002A-ND*</td>
<td>4</td>
<td>$0.80</td>
<td>$3.20</td>
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<td>$3.20</td>
</tr>
<tr>
<td>RF inductor</td>
<td>1515SQ-68NJEB*</td>
<td>4</td>
<td>$1.08</td>
<td>$4.32</td>
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<td>$4.32</td>
</tr>
<tr>
<td>0.33 μF Cap</td>
<td>478-5122-ND*</td>
<td>2</td>
<td>$1.84</td>
<td>$3.68</td>
<td>-----</td>
<td>$3.68</td>
</tr>
<tr>
<td>0.10 μF Cap</td>
<td>478-6008-ND*</td>
<td>4</td>
<td>$0.48</td>
<td>$1.92</td>
<td>-----</td>
<td>$1.92</td>
</tr>
<tr>
<td>LM78M05 Regulator</td>
<td>LM78M05CTFS-ND*</td>
<td>2</td>
<td>$0.61</td>
<td>$1.22</td>
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<td>$1.22</td>
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<tr>
<td>1 N40001</td>
<td>1N4001FSCT-ND*</td>
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<td><strong>Overall Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td><strong>$32.84</strong></td>
</tr>
</tbody>
</table>

* Components bought from DigiKey

Table 4: Cost for components of Second Bias Tee

<table>
<thead>
<tr>
<th>Component</th>
<th>Company</th>
<th>Quantity</th>
<th>Cost per Component</th>
<th>Subtotal</th>
<th>S&amp;H</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrite Toroid 16mm</td>
<td>495-3855-ND*</td>
<td>2</td>
<td>$1.02</td>
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<tr>
<td>Ferrite Toroid 20mm</td>
<td>495-3863-ND*</td>
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<td>$1.42</td>
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<td>$2.84</td>
</tr>
<tr>
<td>XFRMR Wall Mount</td>
<td>T1021-P5RP-ND*</td>
<td>1</td>
<td>$7.85</td>
<td>$7.85</td>
<td>-----</td>
<td>$7.85</td>
</tr>
<tr>
<td>LM7809 Regulator</td>
<td>LM7809CT-ND*</td>
<td>2</td>
<td>$0.70</td>
<td>$1.40</td>
<td>-----</td>
<td>$1.40</td>
</tr>
<tr>
<td>Tape Copper Foil 6&quot; by 1’</td>
<td>3M1125D-1FT-ND*</td>
<td>1</td>
<td>$3.06</td>
<td>$3.06</td>
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</tr>
<tr>
<td>22000pF Cap</td>
<td>455-2609-ND*</td>
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<td>$0.86</td>
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<td>4.7 pF Cap</td>
<td>478-3498-1-ND*</td>
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<tr>
<td><strong>Overall Total</strong></td>
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<td></td>
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<td></td>
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<td><strong>$29.26</strong></td>
</tr>
</tbody>
</table>

* Components bought from DigiKey
RECOMMENDATIONS

At this time we believe that the entire system will be fully functioning by the time we leave the school. In the meantime, direct connection to the system can be used to test GPS receivers in the lab. It is advised that any new GPS equipment purchases be inspected for compatibility with the test system and necessary connectors/adaptors also be purchased. We hope to have the issue with the faulty amplifier resolved soon. If this not be possible, another in-line GPS amplifier should be purchased. If the option is available, bringing a spectrum analyzer into the lab to determine the strength of signal being radiated without an amplifier could help determine the exact amount of gain a new amplifier would need to provide. Finally, it is also recommended that the purchased bias tee be used in the system. Should a future group wish to attempt to build a bias tee for use at RF frequencies, our documentation and finished products, as well as careful inspection of the one we purchased, should provide enough guidance for successful construction.

CONCLUSION

The construction of a GPS repeater system proved to be more complex than our group had anticipated, and the difficulties introduced by the choice to construct a bias tee for use at GPS L1 frequency were many. However, the purpose of the project was served: we worked as a group to research, design, revise, purchase, sweat, swear, and finally, celebrate. We each gained valuable experience, learned how to make the most of each members’ particular strengths, and how to quickly deal with unexpected problems. Despite the disappointingly poor performance of our bias tees and the as yet unresolved amplifier issue, we are proud of what we have achieved, and we hope that future members of the balloon team find our small contribution useful.
REFERENCES