RECEIVING EARTH-MOON-EARTH RADIO TRANSMISSIONS

FINAL REPORT

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1 Abstract

This capstone is focused on receiving Earth-Moon-Earth transmissions using 144MHz radio signals. These transmissions consist of a radio signal being transmitted towards the moon by a separate party where it undergoes large amounts of path loss. The returning weakened signal that is reflected by the Moon is then picked up by an eight element cross yagi antenna. The signal will then be run through a decoding software capable of decoding the weakened signal. The purpose of this project is to test whether a lower cost budget is capable of receiving Earth-Moon-Earth transmissions, while also analyzing the changes the radio signal undergoes.

2 Introduction

Earth-Moon-Earth Transmissions are commonly referred to as moonbounce or EME for short. EME refers to the process of one party transmitting a signal towards the moon for another party (or the same party) to receive. This form of communication is accomplished using the reflectivity of the moon to reflect the signal. The Moon reflects roughly seven percent of the transmitted signal and only a small fraction of this reflected signal is directed back towards Earth due to its rough terrain and spherical nature, making it incredibly weak and difficult to pick up without the proper equipment. The weak signal makes EME a challenging project, considered challenging even among those within the amateur radio community. Although the path loss is already quite a large challenge to overcome, this is only the beginning when it comes to the challenges one faces when attempting EME. Some other obstacles include the spatial polarization offset, licensing, investment, Faraday rotation, ground and sky noise, and liberation fading. Each of these challenges will be further discussed in the **Theory** section along with how these are combatted in order to best improve the chances of a successful EME transmission.

The first successful EME communication occurred in 1954, preexisting the first satellite by three years. The idea behind attempting EME transmissions sparked from the idea of long distance communication. Using the Moon as a satellite one would be able to communicate with others just about anywhere on Earth. The downsides of this method of communication fall primarily under convenience. Each EME attempt requires specific conditions to be met for another party to receive the signal, which are often times not being met. Another downside to EME is that the signal is being reflected back down to Earth for anybody to pick up, making EME not a very private source of communication.

These initial EME attempts required large and expensive equipment in order to transmit, receive, and decode the signals. From the initial EME attempts to today technology has advanced to allow for smaller equipment to be commercially available and affordable, however, the largest technological advancement in regards to EME was the software. The software WSJT/JT65 revolutionized EME communication by allowing signals to be decoded by as low as -27 dB relative to the noise floor.

3 Theory

Radio signals transmitted have to travel an average distance of 384400Km between the Earth and the Moon. Meaning that the radio signals have to travel twice that distance before it is received. Using the speed of light

$$c = 299,792,458m/s \tag{1}$$

One is able to find how long it will take a transmitted signal to be received again.

$$t = 2(D/c) \tag{2}$$

The time it takes a radio signal to reach the moon, reflect, travel back, and be received is 2.56s on average.

The time it takes for a radio signal to travel may seem fast, however, the signal is going through a lot of changes during that time. The propagation path can be considered line-of-sight meaning they travel in a direct path and the strength of the signal follows the inverse square law ($1/D^2$). The inverse square law follows how far the signal has traveled as well as the spread of the signal as it travels. The inverse square law then becomes $1/D^4$ due to the signal making the trip a second time from the Moon back towards Earth.

If we were to assume that both the transmitting end and the receiving end of the EME communication were using isotropic antennas we could find path loss using

$$L = 10Log(\frac{\mu r^2 \lambda^2}{64\pi^2 D^4}) \tag{3}$$

where **L** is free-space path loss

μ is the lunar surface reflection coefficient **0.065**

r is the radius of the moon **1.738 x** 10^6m

λ is the wavelength **2m**

A typical EME Moonbounce path loss for 144MHz is around -252.1dB. Due to the large amount of path loss one must aim for a large amount of gain when transmitting and receiving.

Gain can be found using

$$G = 10Log(\frac{4\pi A}{\lambda^2}) \tag{4}$$

Where **A** is the **Effective Aperture** or the physical size of the antenna for both the transmitting and receiving antennas. Adding those two together with the free space path loss

$$L_{path} = L + G_T + G_R \tag{5}$$

gives the net path loss.

The signal will also undergo a unique shift in frequency depending on where the moon is in the sky. The unique shift is referred to as the Doppler Shift. 144MHz varies by around 350Hz in both the positive and negative directions when considering the speed of the transmitting antenna and the receiving antenna relative to the moon.

$$f_r = f_t(\frac{c + v_r}{c + v_t}) \tag{6}$$

where v_r is the speed of the receiver relative to the Moon, v_t is the speed of the transmitter relative to the moon and f_t is the transmitted frequency. The Doppler shift becomes zero and the frequency remains the same when the Moon reaches its zenith, however the day will typically begin on the upper end of the shift and fall to the lower end by the time the Moon is falling below the horizon. This shift in frequency is not enough to become an obstacle when receiving the signal, however, it would be very interesting to test out if data was able to be taken.

3.1 Conceptual Theory

When antennas receive a radio signal this is created by the radio waves vibrating electrons between the elements on the antenna and converting the radio wave into an electric current. This current is directed to the direct elements of the antenna, these being the elements that are connected together at the ends (See Figure 1). If current passes by the direct element it is then reflected back by the reflector, this being the largest element at the base. The reflector is also useful in reflecting outside signals coming from the other direction. This electric current is then picked up by the coaxial cable located on the direct elements of the antenna and sent to the amplifier.

The spatial polarization offset and Faraday rotation occur when the signal reflects off of the Moon as well as when it passes through the ionosphere. The free electron within the ionosphere interact with the radio waves and rotate the polarization, making the final polarization random by the time it reaches the receiving antenna. The antenna used for this project has ways to combat this issue, which are noted in the **Methods** section if more parts are ordered in the future. However the simplest solution was selected for this project, which is to combat this issue by simply rotating the antenna.

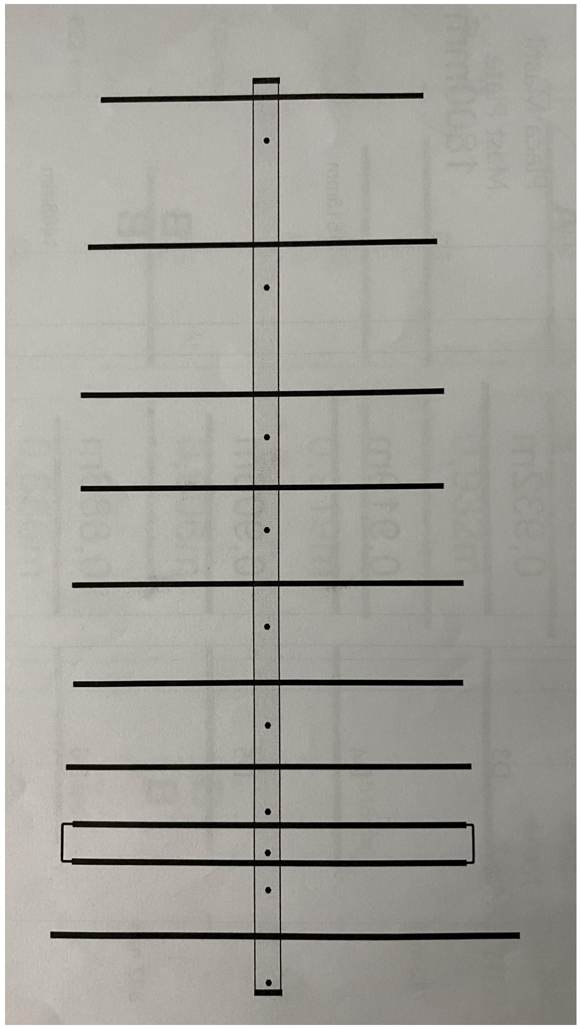

Figure 1: Antenna

Noise becomes a large issue when working with weak signals. There are two forms of noise to look out for when performing EME. The first of which being ground noise. Ground noise is most common in urban areas where extraneous noise is most common. This leads to other signals interfering with the antenna and making the weak signal coming from the moon almost impossible to detect. This project faced this issue by using a highly directional antenna and relocating the antenna to a more rural area. Open fields tend to be the most reliable when performing EME transmissions.

Another form of noise to watch out for is sky noise. If other celestial bodies are behind the moon they can emit radio frequencies that interfere with the attempted EME transmission. The largest celestial body that would be an issue is the sun, however, galactic cosmic rays can also become an issue. There are websites online that document these interferences and predict the most optimal days to conduct EME. The primary way to combat sky noise is to simply be aware and plan ahead of time before making an attempt.

Liberation fading is another obstacle one may face when conducting EME. Liberation fading refers to partial signal loss or fluctuation as the signal reflects off of the moon. As the signal reflects a few decibels can be lost depending on the are of the moon. The rough surface of the moon and varying distances the signal may have to travel can interfere with the transmitted radio signal. There is not much one can do to combat this issue other than be aware that this may occur.

4 Methods

4.1 Overview

The setup for receiving EME signals consisted of an eight element cross yagi, a homemade mast, coaxial cable, amplifier, software defined radio, and a laptop with the WSJT software installed. Each component was chosen based on performance and ability to increase signal strength as well as being affordable.

This project focuses solely on receiving these signals and not transmitting. In order to transmit a very strong amplifier would be needed, and this would only increase the cost of the project. Another reason for focusing only on receiving is due to the fact that a license is needed in order to transmit these signals. The license is not necessarily too difficult to obtain, however, this in addition to the cost put this aspect outside of the scope of the project.

4.2 Antenna

There were a few factors that went into the selection of the antenna. The first of these factors being that this antenna is designed to work with 144 MHz, this being the two meter band, which is one of the most common frequencies used in regards to EME. The lengths of the elements on the yagi antenna were designed to focus a wavelength of 2m. Another reason for this selection is due to the directional ability of a yagi, as well as the gain received due to the yagi's length (roughly 16 feet). Yagi antennas are great at picking up radio signals from a specific direction with minimal interference from other directions when compared to other antenna models. This allows the antenna to minimize the amount of extra noise being received. With this antenna model being a cross yagi it should allow for the antenna to combat spatial polarization offset and Faraday rotation. This is done by switching between the vertical and horizontal yagis or connecting the both of them.

Figure 2: Full Setup

This project did not use the vertical side of the yagi antenna, however, this should be looked into if the project is continued into the future. Note that the switching between the vertical and horizontal is not necessary and random rotation of polarization can be combated by rotating the antenna, however, this could very well be useful if the project is taken further. One could either switch between vertical and horizontal polarization or connect the two for a circular polarization, which would allow for all polarization angles to be received. This can be achieved with a coupler and another coaxial cable of different length.

One of the first setbacks of this project occurred when constructing the antenna. The manufacturer made the diameter of the holes on the boom too small to allow the elements to pass through. In the end this was solved by simply drilling holes just large enough for each element to pass through while still remaining secure. However, this was a much larger concern at the time due to the possibility of the manufacturer skewing other measurement of the antenna. Each measurement from the outline was thoroughly remeasured before widening any of the holes.

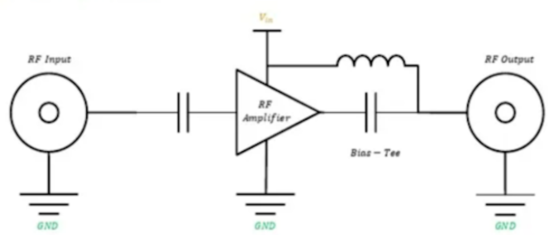

Figure 3: Amplifier Schematic

4.3 Mast

The reason for the mast being constructed with spare parts was primarily due to minimizing budget costs. However, the mast was constructed to meet certain specifications in order to maximize the antennas functionality. The mast was constructed roughly ten feet tall in order to maximize ground gain received by the antenna and increase the effectiveness overall. The top of the mast, where the antenna rests, was constructed to allow for the antenna to be angled up as the moon rises and sets to play into the directional ability of the antenna. This was done simply using two pieces of wood and a door hinge. The mast was held in place by a Christmas tree base and string to keep the setup from tipping over. The height of the mast comes from a thick, hollow cardboard tube capable of holding the weight of the antenna while remaining light enough to be moved easily.

The antenna was kept in Luter 339, meaning that the antenna needed to be easily constructed and deconstructed. This also required the parts of the antenna to be light enough to repeatedly transport up and down two flights of stairs.

4.4 Amplifier

The amplifier is able to be powered by USB or 5V (See Figure 3). The amplifier is connected to the antenna via the coaxial cable and was chosen due to its compatibility with the software defined radio as well as the frequency in use. The purpose of the incoming signal traveling through the amplifier first is to strengthen the signal as much as possible before reaching the software to be decoded.

4.5 Software Defined Radio (SDR)

The software defined radio put simply is to use the computer it is connected to as if it were a radio (See Figure 4). The software defined radio substitutes the analog hardware of a regular radio with software downloaded onto the computer. The purpose of this selection stemmed from its ability to receive USB signals, which are the most common signals used

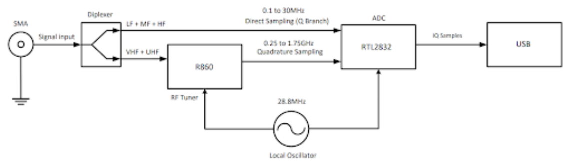

Figure 4: SDR Schematic

with EME, as well as the cost of the SDR. The plan for this project was to connect the software defined radio to the WSJT software using a virtual audio cable control panel that was also downloaded onto the computer.

The software defined radio is where the project received the most trouble. When first attempting to receive a signal using the software defined radio the WSJT software was not in use and instead a more compatible software was downloaded. The purpose of this step was to make sure that the software defined radio was working before connecting it to a separate software using the virtual audio cable.

The driver installer used to download the necessary software recognized that the USB was in use in the downloading process. The disconnect happened between the driver installer and the software because after repeated trial and error the software refused to use the SDR to collect radio signals. Multiple software listed as compatible with the SDR were attempted, however, each one would show one large block of static regardless of whether the the SDR was plugged into the computer or not. These software include HDSDR and CubicSDR. In order to combat this situation multiple parties were contacted, these include the manufacturer, engineers who specialize in radios, and a member of the local amateur radio community. Multiple suggestions by these parties were looked into along with a 1 on 1 meeting with the local amateur radio community who helped look for the issue. The suggestions ranged from downloading more files to malfunctioning hardware, unfortunately none of the suggestions or meetings were able to resolve the issue.

In the end it was concluded that the issue seems to stem from a disconnect between the driver installer and the virtual audio cable, however, the exact reasoning for this issue was unable to be solved.

4.6 WSJT Software

The WSJT software was a very important part of this project, although it was never used. This software was supposed to be used to decode the signals upon reception, however, the project was never able to advance this far. As mentioned in the **Introduction** section this software is very commonly used for EME due to its ability to decode signals as low as -27dB relative to the noise floor.

5 Results and Analysis

The project was unable to conclude any results when it came to EME transmission due to being unable to pinpoint the issue with the software defined radio. Despite lacking the final result the antenna was tested before hand to make sure that the impedance would match the radio to avoid possible harm to it and maximize performance. A higher impedance leads to higher signal reflection, which will cause more path loss as the signal travels through the antenna. The antenna was tested twice, the first time the antenna was tested in an environment surrounded by variables that could effect its performance. The first test was taken with the antenna indoors, laying on chairs, surrounded by multiple factors that could interfere with its performance. The second test was taken outdoor, on the mast, with a setup typical to how EME would be performed.

The device used to test the antenna was a RigExpert/AA-2000 Zoom. The device is connected to the coaxial cable and sends a signal that travels through the antenna measuring the Standing Wave Ratio or SWR. The SWR is ratio between the maximum amplitude of the signal wave and the minimum amplitude of both forward and reflected waves. As the ratio of these two grows larger so is the amount of signal that is lost throughout the antenna (See Figure 8). The device also measures the mismatch between the transmission line and load. If the mismatch of impedance between these two becomes too large this could possibly cause issues within the radio, making it important to check that the antenna functions correctly prior to an attempt. The ideal impedance or |Z| in the figures are typically in the 45-55 Ohm range, and this is the most important variable when looking at the figures containing multiple variables. Some of the other variables contain resistance and reactance, which are both variables used to calculate impedance.

The initial indoor antenna test result are shown in Figures 5, 6, and 7. The purpose of this initial test was to see just how much factors outside of the antenna can influence the results. Figure 5 shows the results of the initial SWR test showing a decibel loss ranging from roughly 2.5-0.2 dB. Although these results are average at best the frequency with the least amount of signal loss is outside of the scope of this project, meaning that the antenna would need to see improvement before being capable of picking up EME transmissions. In both Figure 6 and 7 each impedance is much larger than 50 Ohms, further showing needed improvement before an EME attempt. These values are to be expected considering the antenna was low to the ground as well as being surrounded by other metal in the chairs it

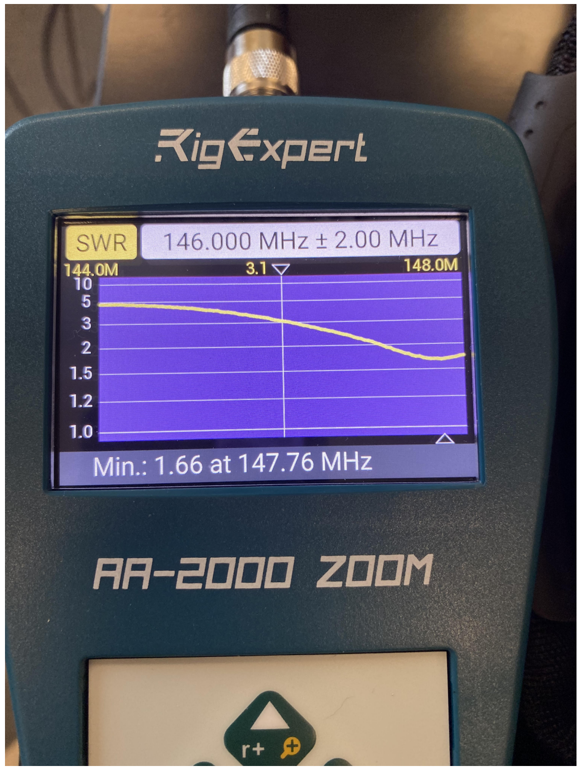

Figure 5: Antenna Test 1 SWR

is resting on. Multiple variables played into the results, however, the variable I found the most intriguing was the coaxial cable. In Figure 6 the coaxial cable is laying on the ground with no order, but once the coaxial cable is straightened out the impedance improves rather drastically for a minor alteration. This one variable change is shown in the improvement from Figure 6 to Figure 7. This test shows just how susceptible to change this antenna can be and how careful one needs to be when setting up this project.

During the second antenna test when the majority of extraneous variables are taken out of play the antenna performed wonderfully. The antenna was tested outside on the mast and away from anything else. With under one percent of reflected power and an average decibel loss of 0.035 dB the antenna is certainly capable of receiving EME transmissions (Figure 9). The impedance also decreased drastically (Figure 10), falling just outside of the desired range, however, this value will still cause minimal signal reflection and signal loss.

5.1 Ideal Analysis

Ideally this project would have looked further into Doppler shift and whether the received frequencies matched the theoretical frequencies. The project was also planned to document angle of the moon and the conditions of each attempt, as well as the decibels of the received

Figure 6: Antenna Test 1 Impedance 1

Figure 7: Antenna Test 1 Impedance 2

VSWR	Reflection Coefficient, Γ	Mismatch Loss (dB)	Reflected Power (%)
17.39	0.891	6.868	79.43
8.72	0.794	4.329	63.10
5.85	0.708	3.021	50.12
4.42	0.631	2.205	39.81
3.57	0.562	1.651	31.62
3.01	0.501	1.256	25.12
2.61	0.447	0.967	19.95
2.32	0.398	0.749	15.85
2.10	0.355	0.584	12.59
1.92	0.316	0.458	10.00
1.78	0.282	0.359	7.94
1.67	0.251	0.283	6.31
1.58	0.224	0.223	5.01
1.50	0.200	0.176	3.98
1.43	0.178	0.140	3.16
1.38	0.158	0.110	2.51
1.33	0.141	0.088	2.00
1.29	0.126	0.069	1.58
1.25	0.112	0.055	1.26
1.22	0.100	0.044	1.00
1.20	0.089	0.035	0.79
1.17	0.079	0.027	0.63
1.15	0.071	0.022	0.50
1.13	0.063	0.017	0.40
1.12	0.056	0.014	0.32
1.11	0.050	0.011	0.25
1.09	0.045	0.009	0.20
1.08	0.040	0.007	0.16
1.07	0.035	0.005	0.13
1.07	0.032	0.004	0.10
1.06	0.028	0.003	0.08
1.05	0.025	0.003	0.06
1.05	0.022	0.002	0.05
1.04	0.020	0.002	0.04
1.04	0.018	0.001	0.03
1.03	0.016	0.001	0.03
1.03	0.014	0.001	0.02
1.03	0.013	0.001	0.02
1.02	0.011	0.001	0.01

Figure 8: VSWR Chart

signal, and at what angle the antenna was rotated for the most ideal reception on each attempt. Each of these contain variables that could make the values "random", however, an analysis of the similarities and differences between these attempts would have also been ideal.

5.2 Conclusion

Although the project did not function as originally intended, this project remained challenging until the end and required a substantial increase in understanding of how radio waves function. Hopefully this project can be continued in the future and this final report will prove beneficial to begin understanding what goes into Earth-Moon-Earth transmissions.

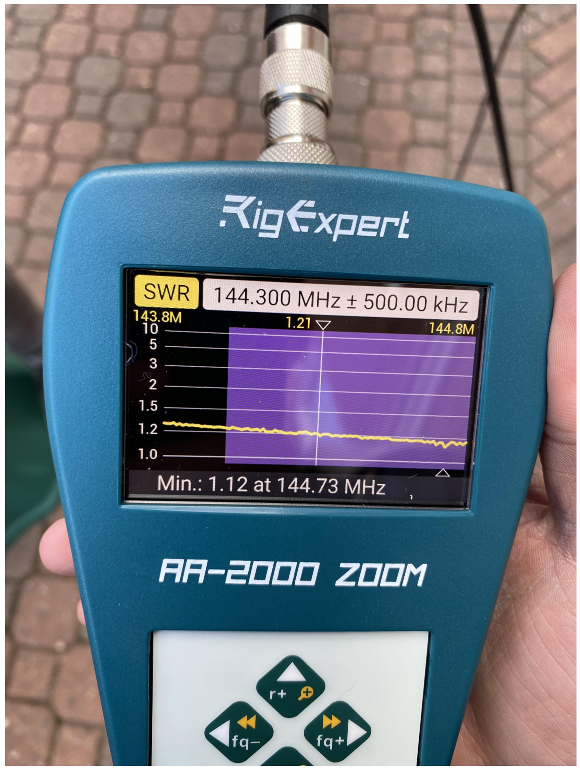

Figure 9: Antenna Test 2 SWR

Figure 10: Antenna Test 2 Impedance

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