SONGS OF JUPITER: DETECTING RADIO WAVES FROM SPACE

Tom Discepola, Greg Haislip, Shereef Elnahal, Mike Fitzsimmons, John Kang, Meera Krishnan, Saee Paliwal, David Paltiel, Henry Park, Margaret Senese

Advisor: Brian Holton
Teaching Assistant: Karl Strohmaier

ABSTRACT

Signals from outer space have always fascinated both scientists and laymen alike. This paper describes our quest to detect and analyze radio emissions from both Jupiter and the sun. The proposed method for the experiment involved assembling a receiver and antenna from scratch. While electronic failures prevented the completion of the project as planned, we were able to collect data in an alternate manner. Though we were unable to detect Jovian activity due to Jupiter's unfavorable position at this time of year, we were instead able to observe solar activity and collect data indicative of radio waves from the regular Perseid meteor shower.

INTRODUCTION

Extraterrestrial Radio Waves: The Discovery

Karl Jansky first listened to extraterrestrial radio waves in 1928. Jansky, an engineer for Bell Labs, came across oddly regular noise at a frequency of around 20 MHz radio waves. He was using a shortwave, or "ham," radio. Eventually, through experimentation, he realized that the signals he was picking up could not be dismissed simply as noise and that they were coming from the center of the Milky Way. [5] After this momentous discovery, many theories on how these waves were created and what kind of celestial bodies would actively produce emissions were formed. Grote Reber, after Jansky, continued to work on tapping into radio waves and helped develop further hypotheses for this phenomenon.

In order to receive similar radio waves, our project consisted of constructing a receiver and antenna and positioning them according to the sun's motion. Though the receivers we used were not particularly sophisticated, radio wave data can be used accurately to explain properties of distant planets, such as size, shape and nature of the magnetic field. Data collected can also be used to map solar activity and the rising and setting of certain heavenly bodies. Radios set to 20.1 MHz can pick up signals from comets, certain planets, the sun, and meteors. Comparing several days of data, one can make any number of conclusions about the nature of the sun and the heavens.

Source of Radio Waves: Magnetospheres

It was later determined that the radio waves recorded by Jansky and Reber were a result of the magnetospheres of large planets in space. A magnetosphere can be defined as a very large electromagnetic field that surrounds planets and other celestial bodies. If a planet contains a sufficient amount of magnetic material, which has the potential to a carry a substantial amount of current, a magnetosphere is likely to form around it. Jupiter has a particularly large magnetosphere, which extends as far as Saturn. This magnetosphere is so large that despite the distance between the Earth and Jupiter, it would appear in the sky to be as large as a full moon, if it were possible to view the entire magnetic field around Jupiter from Earth. [11]

Formation of the Jovian Magnetosphere

The magnetosphere around Jupiter is actually quite different from those surrounding rocky planets like the Earth, in its size and characteristics. Like many magnetospheres, it is formed by the planet's magnetic field. The magnetic material needed to create this field is located in a particular area of Jupiter called the liquid metallic cell.

Jupiter's magnetosphere is very extensive, and as a result it drapes over all of its moons and other bits of celestial matter orbiting it. As Jupiter's moons, particularly Io, orbit the planet, they leave behind clouds of particles. (Earth's moon does not do this because it is not within the magnetosphere of the earth.) This cloud of charged particles, known as a torus, increases in magnitude as the moons leave more and more ions and as the volcanic atmosphere of Io is bombarded with atoms and electrons (radiation) from the planet's center. Since an electromagnetic field surrounds Jupiter's moons, these electrically charged clouds of particles travel along their own orbit. Eventually, the magnitude of these clouds of ions becomes great enough to have a significant influence on the behavior of Jupiter's magnetosphere as a whole, by creating currents. Thus, while a magnetosphere around a rocky planet would form the expected spherical extension of the magnetic field, the metallic cell produces a field which is less regular and pointed at one end, similar to the shape of a bullet. [11]

The main aspect of Jupiter's magnetosphere that is of particular interest to the experiment is the fact that Jupiter's magnetosphere emits radio waves. Scientists are still researching into this subject as it is very complex. It is believed that the heated ring of charged particles, the torus, possesses a powerful electric field, and that when this field comes in contact with Jupiter's intrinsic magnetic field, radio emissions are created. When certain particles are "pushed" into the current of ions (also called the aural flow), radio noises called DAM (decametric) are produced. [8]

Anatomy of Jupiter's Magnetosphere

Jupiter's magnetosphere has many distinct parts. Figure 1 details the major components of the planet's magnetosphere. The bow shock serves to deflect various solar winds on a tangential curve that are directed toward the planet. Solar winds, streams of protons and electrons emanating from the sun, are formed when the particles trapped in the magnetic field overcome and drag the field in a certain direction. The magnetosheath is simply the effectively empty space that exists between the bow shock and the magnetopause. The magnetopause is the direct magnetic boundary between Jupiter's field and the solar winds that try to penetrate it. Within the area called the neutral sheet, the magnetic fields from the northern and southern regions of Jupiter cancel each other out, causing the area to be relatively "neutral" in comparison to other parts of the magnetosphere. The lobes, which are an integral part of the magnetotail, are located between the magnetopause and the neutral sheet. They are characterized by their directly opposite magnetic direction, allowing for the circular flow of current. [11]

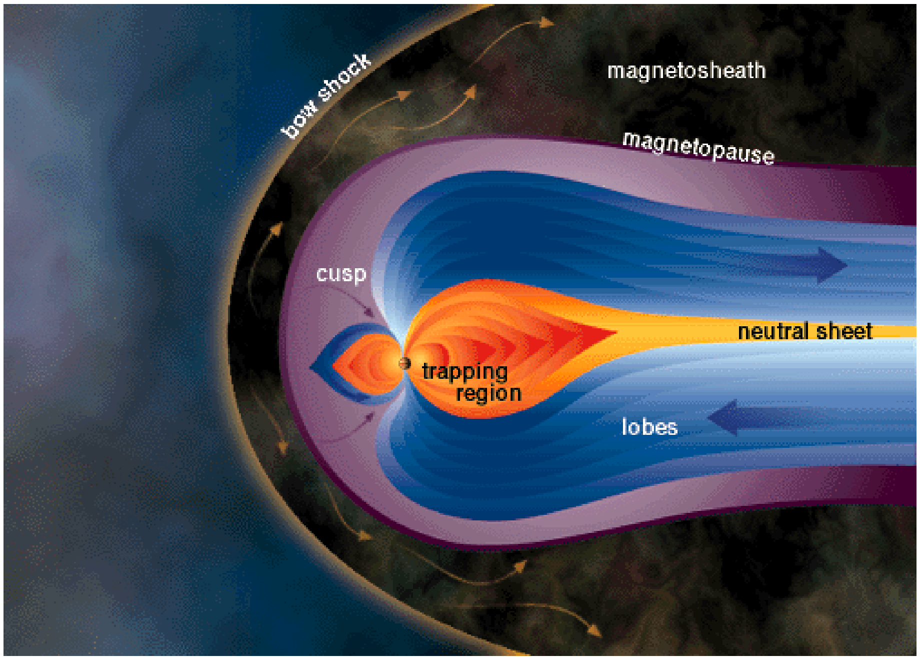


Figure 1 - Parts of a Magnetosphere [11]

Essentially, the anatomy of the magnetosphere of Jupiter works to effectively deflect solar winds. The system itself acts as an enormous magnetic field, and the byproduct of the several processes that take place within the magnetosphere are radio waves which are detectable here on earth. [11]

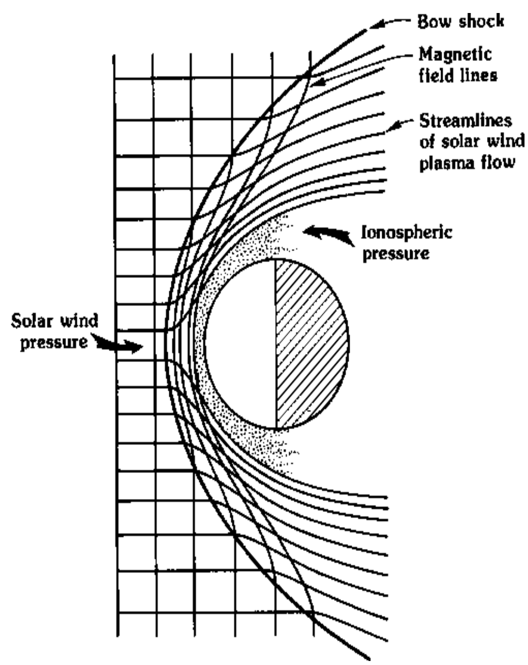


Figure 2 – Solar wind bent around planetary magnetosphere

Radio Waves from the Sun

Scientists have determined that radio waves are emitted as a result of various solar activities. Though the mechanism of many solar activities remains unknown, their results are quite significant. Some solar flares, though still mysterious, are likely a result of a magnetic sheer, due to the kinking in the sun's magnetic fields, which in turn cross each other. When this happens, radiation through the entire electromagnetic spectrum, including radio waves, are emitted. The waves we are able to detect lie in the radio area of the electromagnetic spectrum, and would appear in our data collection as a peak with a significant amplitude and brief duration.

One type of solar emission, Type III, occurs when electrons accelerate through the sun's corona, leading to both solar bursts and solar flares. [10] Consisting of protons, helium, oxygen and electrons, the zero-charge, plasma-like solar winds generate electromagnetic radiation when electrons and protons collide, entering a steadier state and emitting energy in the form of radio waves. A solar flare is created when pent up energy in the sun's magnetic field is suddenly released in an intense burst of brightness, and creates emissions that range throughout the electromagnetic spectrum. Solar bursts, caused by the violent nature of solar flares, are created when electrons given off by a solar flare interfere with radio waves and the less dense plasma of the sun's outer corona, creating radio waves with frequencies close to 20 MHz. [3]

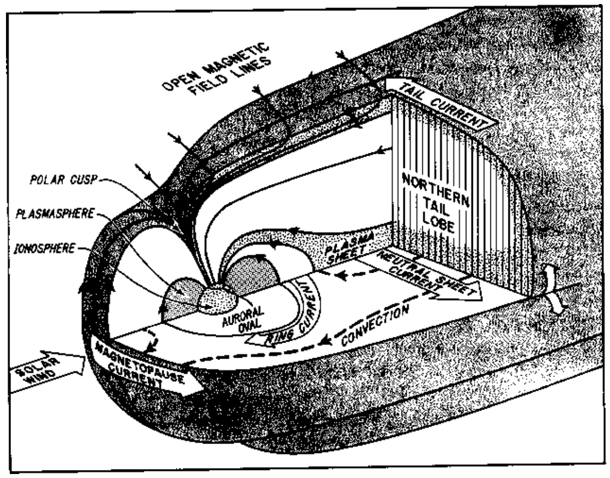


Figure 3 – Solar wind bent around planetary magnetosphere [7]

Like Jupiter, the Sun possesses a magnetic field and radio emissions that can be detected with the same receiver used to listen to Jovian emissions. Radio bursts by the sun are formed from the interaction between free electrons, traveling at speeds around 0.5c, solar winds, and the sun's corona, whose heat and magnetic field are ideal for electromagnetic emissions. Type II bursts, called "solar corpuscular radiation," occur when electrons interfere with solar winds. [10]

THE RADIO TELESCOPE

The Antenna: Components and Function

The purpose of the antenna was to intercept the radio waves emitted by the sun and Jupiter millions of miles away and translate them into an electrical current. Radio waves are optimal because they are the form of electromagnetic radiation absorbed least by our atmosphere. Thus, more of it reaches the ground level and it can be detected fairly easily. The most favorable frequency is 20.1 MHz since radio and TV do not broadcast in this range, and the sun and Jupiter emit photons at this frequency regularly. The changes in this frequency allow the observer to detect solar activity. A photon with a frequency of 20.1 MHz has a wavelength of 14.18 meters. In order to pick up these photons, our antenna had to be just less than half this length. This difference is due to resistance in the wire and end effects of each dipole. These two properties shorten the required length of the antenna to 14.18 m. Thus, the antenna is just long enough so that the photons with the desired wavelength will hit the antenna twice. The antenna, which is held up by ten feet of PVC piping is stabilized by rope and stakes and is pulled tight and parallel to the ground. This is done to receive a more accurate reading of the waves. It is in a dipole configuration, so the photons hit each pole once, as shown in the diagram below, Figure 4. [7]

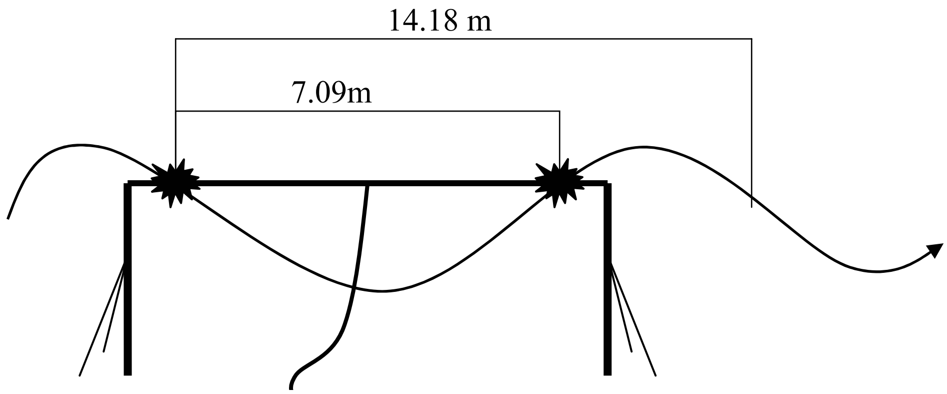


Figure 4 – Radio wavelength and antenna

When the photons hit the copper wire, electrical impulses are created. These impulses travel towards the middle of the dipole where they are joined together into a coaxial cable (constructed so that both ends of the cable have male connections). There is an insulator separating each copper wire, which allows the impulses to travel to the receiver separately. The coaxial cable was split and soldered to each copper wire in order to provide a continuous path for the electrical impulse. The inner conductor was attached to one pole, while the copper shielding of the coaxial cable was soldered to the opposite pole. The entire coaxial cable was tied around the center insulator before splitting in order to give stability to the junction and prevent the inner conductor and the outer braid of the cable from snapping. Toroids were then added around the wire to prevent current flow along the copper shielding. The current from both dipoles traveled down the coaxial cable to a junction. The velocity factor is 66%, which means that the signal is traveling down the cable at .66c**.** This imperfect speed makes it necessary for each cable to be the length of 16.15 ft, thus making the impulses in both dipoles travel at the same speed and reaching the junction at the same time at the correct point in the wave, as the wavelength shrinks as the velocity falls. The impulses are joined at a power combiner (with two female inputs and one female output) and then sent through another coaxial cable to the receiver. [7]

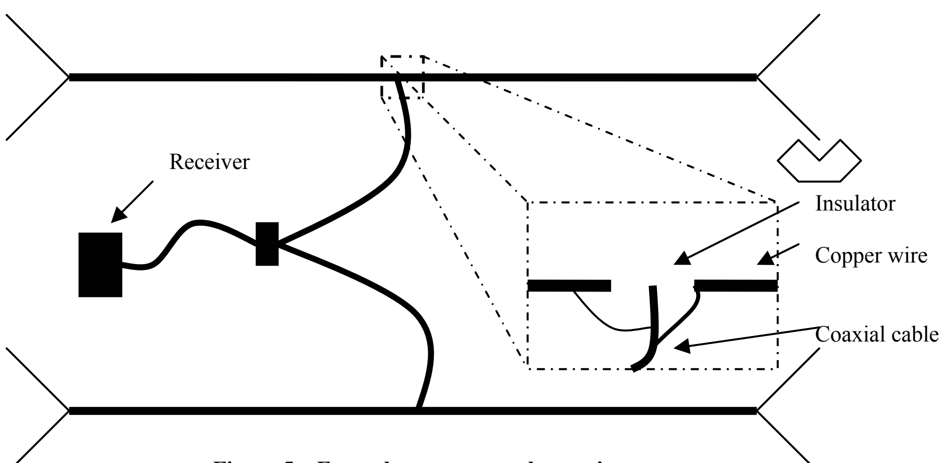


Figure 5 – From the antenna to the receiver

The antenna was oriented in order to pick up the maximum radiation from the sun. Between 11:00 a.m. and 3:00 p.m., when the sun is the highest, the antenna was situated with the poles facing east and west. Before 11:00 a.m. and after 3:00 p.m., the antenna was oriented north and south. No matter the orientation or time, the poles that are connected to the inner conductor and outer braid on the coaxial cable must be facing the same direction with respect to its pair. If this is not done, when the signals congregate, they will react as if each dipole was being hit by waves going in opposite directions, leading the impulses to be out of phase. This would render all the data to be collected completely useless.

The diagram below, Figure 6, shows the entire setup.

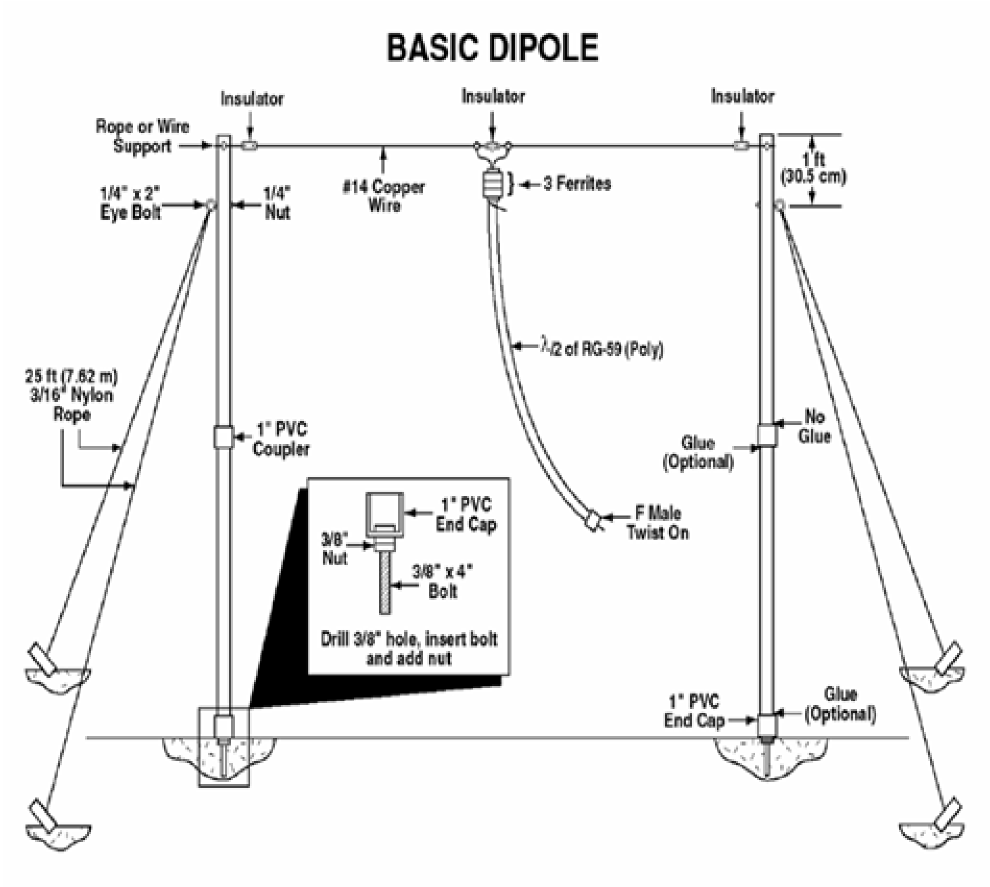


Figure 6 – Antenna setup [6]

Receiver Components

The construction of the receivers required the use of various components, each of which has its own function, and every part is integral to the circuit on the PC board. Resistors, capacitors, and inductors are three of the most important parts of the circuit. They are used to direct DC voltage and route signals to various chips, while at the same time filtering the frequencies received by the antennas.

Resistors allow current to flow, but they reduce the current by a set amount in accordance with Ohm's Law. The current is generated through the conversion of electrical energy to heat, which is given as Joules/sec (or Watts). There are two types of resistors used in this receiver--fixed and variable. Fixed resistors always dissipate heat proportional to the square of the current. Variable resistors can change their resistance and are thus useful in devices which require different degrees of current. In our receiver, variable resistors are used to control volume and tuning.

Capacitors are made of two conducting plates separated by a thin layer of insulation known as a dielectric. The insulation prevents an immediate jump of current across the plates. One plate becomes highly negatively charged as a result of being constantly bombarded with electrons. The storage of electrons in one plate increases the difference in voltage between the two plates and therefore will suspend the charge in the dielectric between the plates. The maximum voltage a capacitor can store is dependent upon the nature of the dielectric. Capacitance is measured in Coulombs per volt, or Farads (F), though most capacitors will be in the range of microfarads or picofarads.

Inductors are coils of wire that allow current to pass but resist changes in current flow. They store energy in the magnetic field surrounding the wire coils. When used in conjunction with capacitors, they form a resonance circuit which is tuned to an exact frequency. The resonance circuit acts as a filter, listening only to a limited range of frequencies while ignoring others. The circuit must be calibrated to a frequency using variable inductors and capacitors. Inductance is measured in Henrys, though most inductors are in the range of millihenrys or microhenrys.

Diodes are devices that allow current to flow in only one direction. They are polar and have an anode (+) and cathode (-) side.

Transistors are solid state devices that contain three terminals which increase the magnitude of signals. Two types of transistors are used in the receiver. One type is the bipolar transistor, which contains three terminals called the base, emitter, and collector. Signals input into the base appear amplified at the collector. The other type of transistor used is the field effect transistor (FET). The three terminals at this transistor are the gate, source, and drain. This transistor requires a constant power source and must be connected to a DC source.

Integrated circuits, known better as chips, are often made up of hundreds of interconnected transistors, resistors, and diodes all set to perform a predetermined function. The receiver uses three chips, each with eight pins.

<u>Functions of Receiver</u>

In order to keep outside radio frequencies from interfering with radio signals from Jupiter and the sun, the Radio Jove Receiver is equipped with a radio frequency bandpass. Essentially, this component serves to weaken radio signals on the earth that have the potentiality of distorting the preferred Jovian and Solar radio signals. When extraneous, unwanted signals are eliminated, the remaining signals (those broadcasted as a result of radio emissions from the Sun and Jupiter) are amplified by means of a junction field effect transistor (JFET). [4] This component proves incredibly valuable to the acquisition of data in that it amplifies the signal by a factor of ten.

When radio signals originating from Jupiter and the sun strike the wires of the antenna, travel down the coaxial cables, and finally reach the electric components of the receiver, the local oscillator converts them into audio frequencies. Almost instantly, these frequencies are sent to the mixer where they are converted into a new signal with a frequency determined by the arithmetic difference in frequency between the incoming signals from Jupiter and the sun, and the frequency at which the local oscillator is set. [4]

The low pass filter serves functional tasks similar to those of the radio frequency bandpass, and prevents unwanted signals from getting mixed into the experimentally preferred radio frequencies from Jupiter and the sun. Created by means of a resistor/capacitor combination, the filter allows for the passage of low frequencies such as those emitted by the celestial bodies, while keeping out higher frequencies. It should be noted that the filter regulates the passage of audio frequencies; frequencies up to 3.5 kHz may pass while anything higher gets blocked. [4]

Whereas the preamplifier JFET is responsible for the amplification of radio frequencies, the audio amplifier intensifies the audio signal created by the local oscillator sufficiently to drive speakers and headphones.

The following diagram, Figure 7, shows how each of these components are situated within the receiver box.

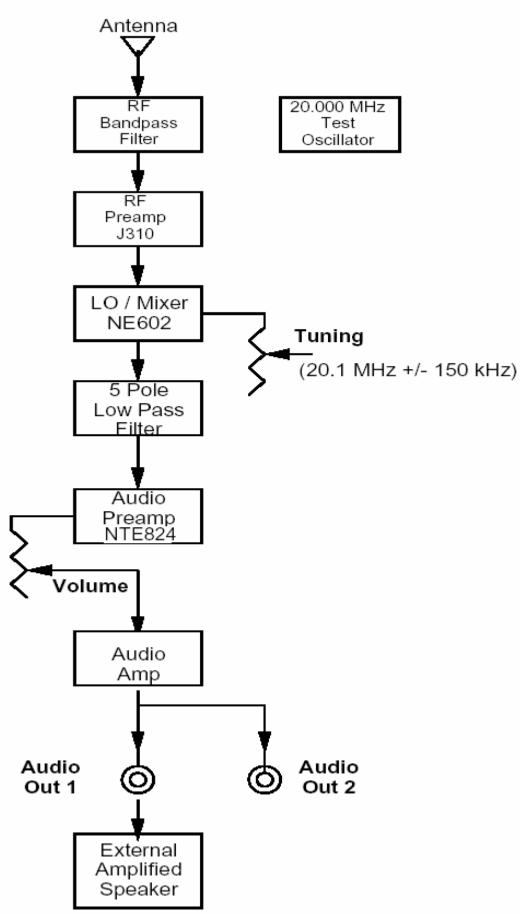


Figure 7 - Flow of signal [4]

Setup of the Receiver

In putting together the Jove receivers, our first step was splitting the eight workers into three groups, each responsible for one receiver. Our objective was to put the receivers together as quickly and effectively as possible. We were given a clear and thorough assembly manual, and the correct positions for each part were labeled both on the PC board and the layout diagram in the manual (see Figure 8). After forming groups, we proceeded to use the checklist in our manual to make sure we had all the correct parts. We identified each part with its corresponding number in the list and found that everything seemed to be in order. We also made sure to clear our work area and place the soldering iron and proper tools on the table.

We then began the assembly of the receiver. We started by mounting all the resistors in their proper places on the PC board. This was done by first locating the correct resistor and its position, bending it to fit into the holes, pushing it down as far onto the board as possible, and bending the leads down flat on the bottom of the board. After all the resistors were in their respective holes, we heated the soldering iron and carefully soldered each one onto the board. Next, each group used diagonal cutters to cut the leads away, being careful to cut close to the board and avoid protruding wire ends. We followed this same basic procedure in putting in the capacitors, inductors, diodes, transistors, and potentiometer. Unlike the resistors, orientation was extremely important in installing the capacitors, transistors, and diodes. We saved the leads from the capacitors to use as jumper wires, which we also mounted onto the board.

After completing the PC board, our next step was to assemble the enclosure that would surround the board. First, we cleaned and sanded each panel of the box and attached the decals to them. After this, the power connector, audio jacks, antenna connector, and solder lug were connected with washers and nuts. All of these parts are integral to the link between the antenna and receiver. The last step of the receiver assembly was to put the PC board and its enclosure together. This consisted of several steps. We installed the LED and connected the rear panel to the PC board with wires. We also connected four resistors to this panel. Finally, we put the panels of the enclosure together with screws, put in spacers, and added a test resistor to simulate the antenna in order to test without using the actual antenna. At that time, we were finished with assembly and ready for testing and troubleshooting, which was accomplished through the use of an oscilloscope and a digital multimeter.

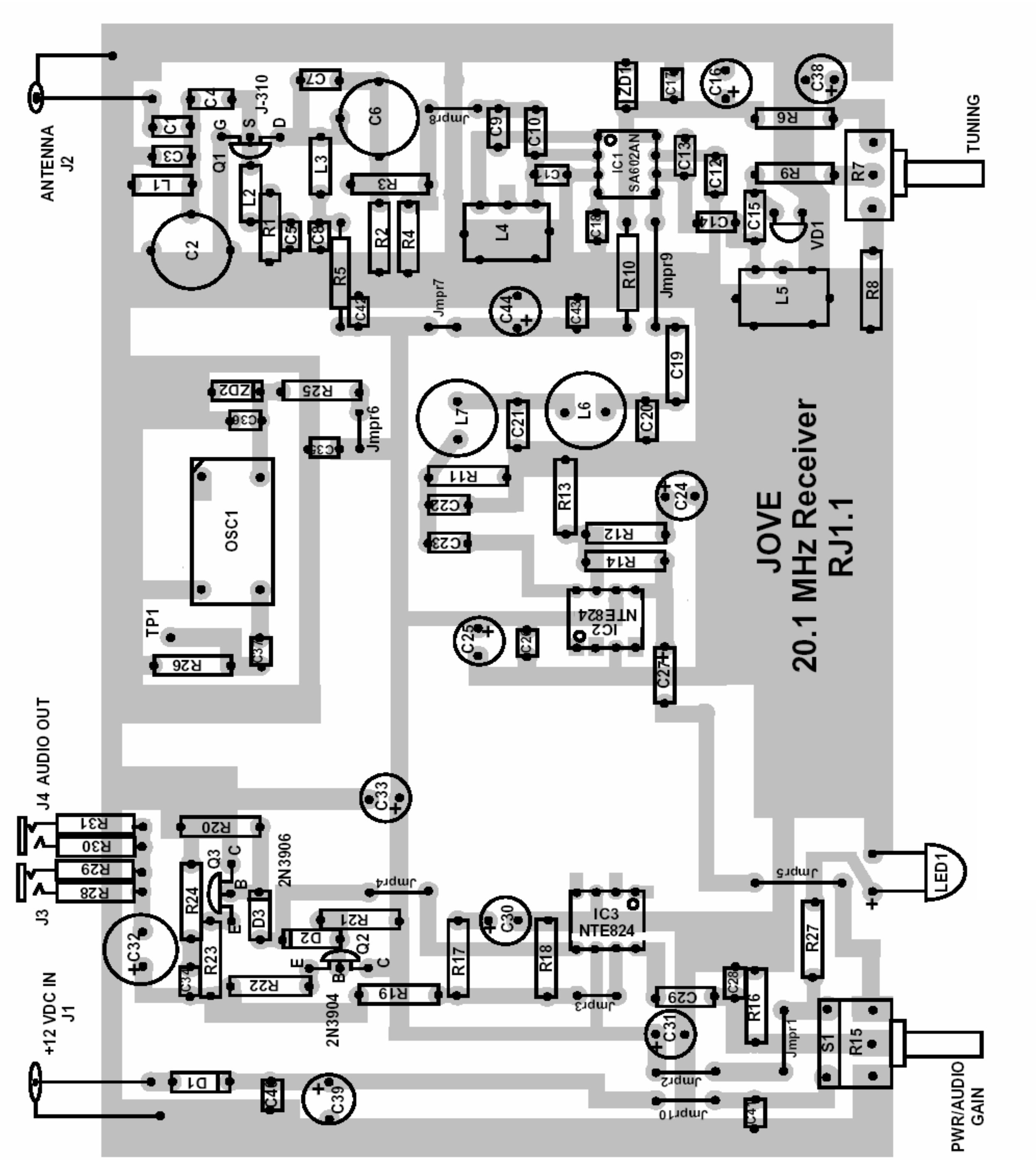


Figure 8 – Schematic diagram used to construct the receiver [4]

Setup of Complete Apparatus

The site where we set up the antennas was carefully chosen. Ideally, in order to reduce excess noise (interference), the site needed to be relatively free of metal (such as a metal roof) and electric devices (such as air conditioners). We used two antennas out of the three constructed. We ran long coaxial cables from the power combiner to the shortwave radio receiver, kept inside. Two computers, receivers, and antennas were used in order to check the data against each other and to confirm the validity of results.

We used SkyPipe™, a software program obtained from Radio Jove, which graphed the radio signals and depicted the radio data. The program plotted the output of the radio signals as a function of time. We connected the receiver to a computer and ran the program in order to view the intensity or amplitude of the waves in real time. Once the receiver produced the desirable radio wave sounds when hooked up to the antenna, we connected the receiver to the computer and ran SkyPipe™, leaving the computer on for a period of approximately 48 hours, with occasional gaps in data due to technical difficulties. We did the same to the other receiver.

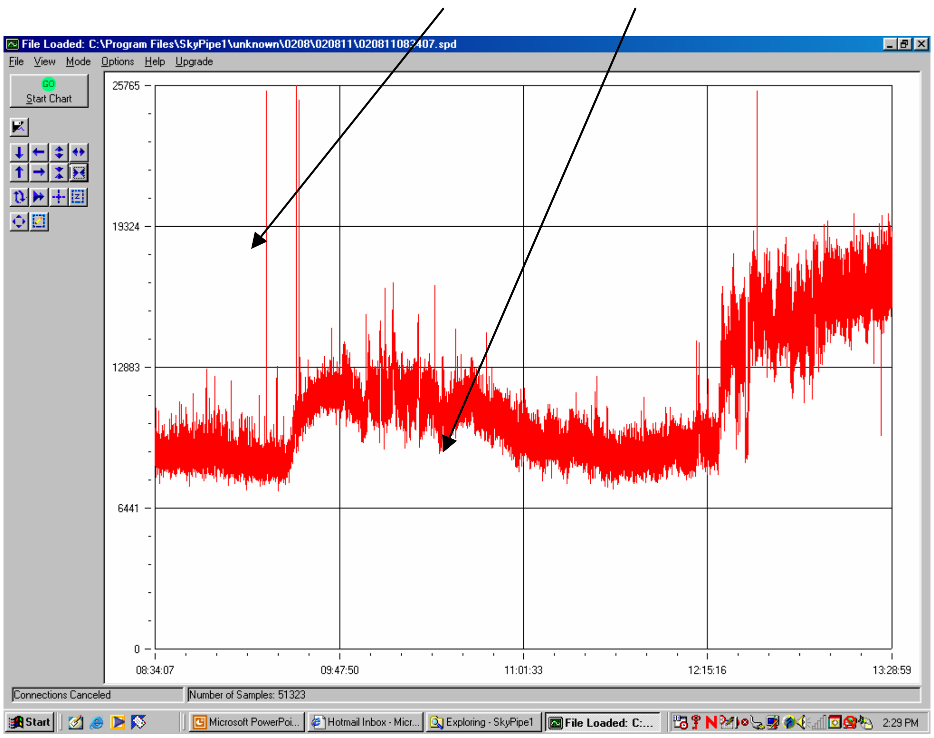
DATA AND RESULTS

Problems

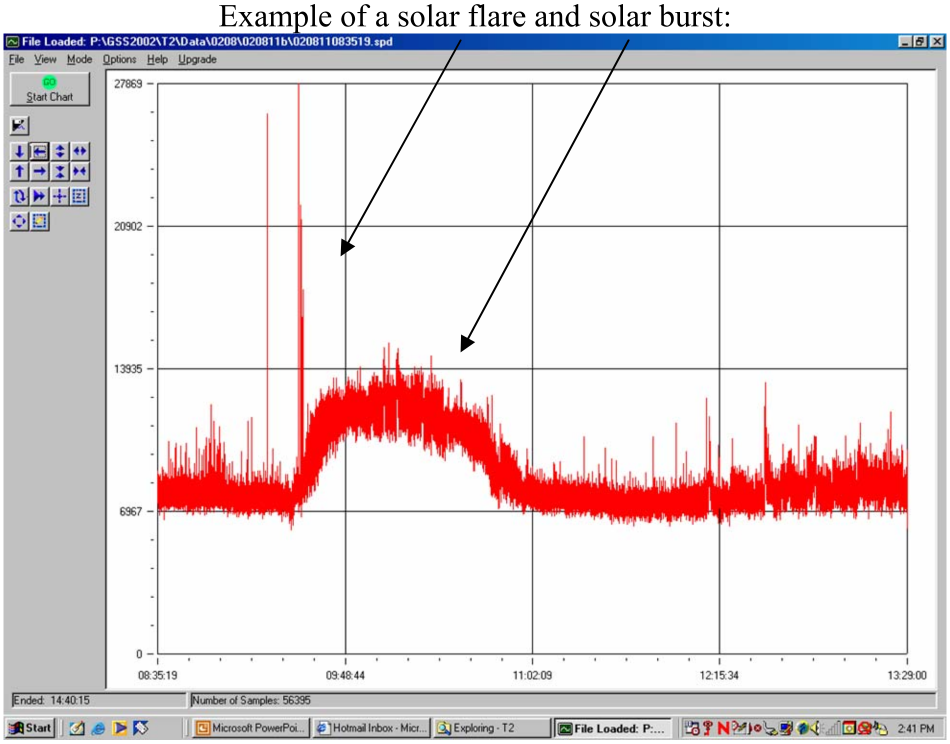
Throughout the assembly of the receiver, the team encountered numerous problems. The first setback was that one group was given the wrong set of screws and was unable to put the enclosure together. This was easily solved by obtaining new, slightly bigger screws. There was no difficulty with missing parts, so other problems were not noticed until we tested the receiver. Upon testing, we found that none of the receivers were functional. It did not take long to notice that all three groups had failed to pay attention to the orientation of the diodes, and many of the diodes were installed backwards. In removing the diodes, one of the groups mistakenly broke one and had to obtain a new one from the lab. However, after taking the diodes out and putting them back in with the correct orientation, the receivers still did not work. We repeatedly checked each section to see where the current was traveling properly, and finally discovered that we had forgotten to cut one of the jumpers. Even after cutting the jumper, the receiver failed to work. Once again, we went through each section. We finally determined that the faulty area was a chip called SA602. We were unable to determine why the current was unaffected by the chip, and we could not obtain new chips because we did not have the time to order them. Finally, in order to save time and start collecting data, we bought two pre-assembled receivers and used them instead of the ones we made. However, we continued to troubleshoot, and if time had permitted, we probably would have been able to correct the problems and use our own receivers.

Results:

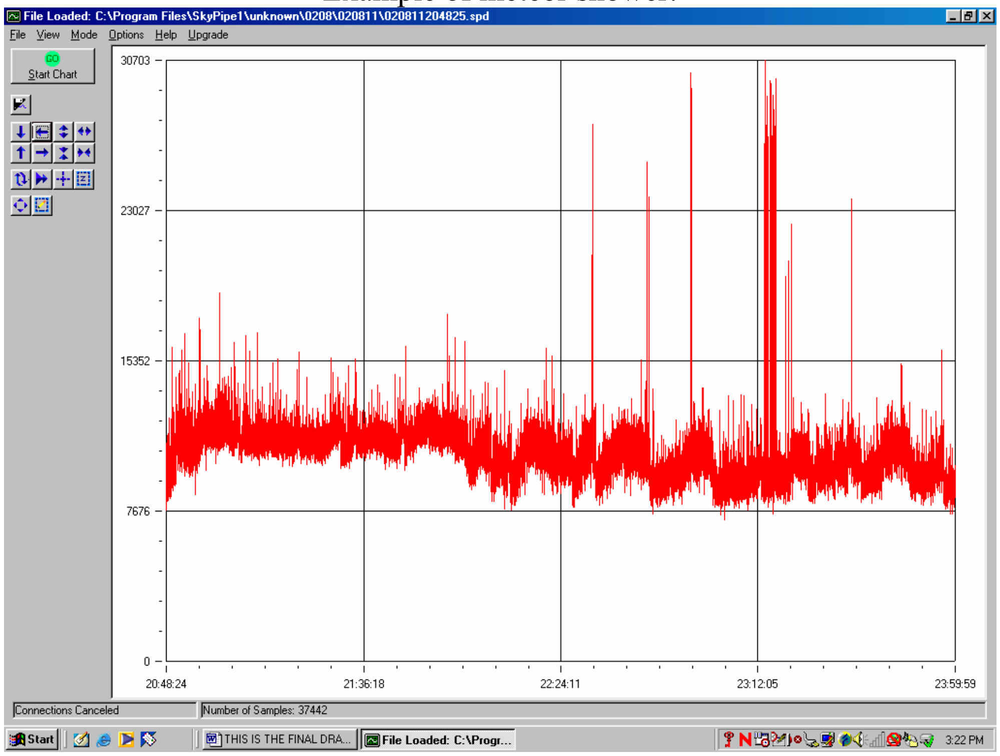
Day: 8/11/02 Tine period: 8:34 a.m-13:29a.m
Example of sunrise, solar flare, and solar burst:



Day: 8/12/02 Time Period: 8:35am.-13:29 a.m.
Example of a solar flare and solar burst:



Day: 8/11/02 Time Period: 20:48p.m. – 23:59p.m.
Example of meteor shower:



DISCUSSION

<u>Analysis of Solar Data</u>

When looking through the data files saved, we discovered numerous sharp peaks in wave amplitude, which we concluded to be solar flares. The solar atmosphere also heats and accelerates other particles, such as protons, electrons, and heavy nuclei to over 1 MeV while releasing this magnetic energy, which can total between the magnitudes of 10^{27} to 10^{32} ergs (1 erg = 10^{-7} joules). [3] In this stage, called the impulsive stage, radio waves, hard X-rays, and gamma rays are produced. The X-rays and gamma rays cannot pass through the Earth's atmosphere, so only the radio waves can be detected from instruments located on this planet. There were also several hill-like lumps throughout the data that lasted anywhere from 30 seconds to one and a half hours that we believe are be solar bursts. The sun goes through an eleven-year cycle between each solar maximum, which is the time when the occurrences of solar bursts are the highest. [9] The most recent solar maximum took place last year, so over the following several years, solar bursts happen quite frequently, as they did during the time period of our project. Intense and complex groups of bursts occur after solar flares, although the emission following the flare is often variable. The Type III bursts are caused by the flares emitting high-energy electrons that flying away from the sun at a quarter of the speed of light, and excite radio waves in the sun's outer atmosphere. [10] At low frequencies, we can detect such bursts, and our data supports the assertion that bursts follow soon after flares.

During the daytime, the most likely cause of our data possibility is radio emissions from the sun. Another possibility is lightning from a distant storm.

Analysis of Jovian Data

Scientists have compiled records of Jovian radio waves for over 40 years, and have begun to predict the likelihood of picking up radio emissions in three defined longitudinal regions, labeled A, B, and C. As Jupiter is currently on the other side of the sun, opposite to that of Earth, it is unlikely that the daytime data is from our galaxy's largest planet, but during the night, radio emissions from Jupiter are a possibility.

The data recorded over night corresponds with professional findings. The chart below, Table 1, outlines the expected time frames for Jovian radio emissions.

Table 1: Rising and Setting Times of Radio Emitting Longitudes of Jupiter (GMT) [8]

8.10.2002

	Begin	End	Begin	End	Begin	End
A	00:00	00:33	08:15	10:29	18:10	20:24
Io A	07:58	09:01				
B	04:56	08:00	14:52	17:56		
C	00:32	02:29	10:27	12:25	20:23	22:20

8.11.2002

	Begin	End	Begin	End	Begin	End
A	04:06	06:20	14:02	16:16	23:57	23:59
Io A	23:41	23:59				
B	00:48	03:51	10:43	13:47	20:39	23:42
C	06:19	08:16	16:14	18:12		

However, upon further investigation, it has been determined that the waves received during the evening are from intrinsic radio emissions from fireballs, or meteors of magnitude brighter than -4.[1] As we have just witnessed a meteor shower earlier this week, the possibility of the radio waves originating from meteors hovering relatively near the Earth is quite likely. The sound waves that we detected using SkyPipe™ electrophonic sounds are most likely generated by the transduction of very low frequency (VLF) radiation. Meteor VLF emissions are produced by one of the following two proposed mechanisms: the trapping and twisting of the Earth's magnetic field in the fireball's turbulent wake, or the rapid expulsion and subsequent relaxation of the Earth's magnetic field from a region surrounding the fireball. [2]

Overall, the data is in agreement with general characteristics for Jovian radio emissions and solar activities generated by professional astronomers over time.

CONCLUSION

Our original hypothesis beginning the experiment was that activity would be rampant during the day, beginning with a crescendo as the sun rises and peaking in activity at one o'clock, our solar noon, and declining with the setting of the sun. Because Jupiter was on the opposite side of the sun, the chances that our receivers would detect Jovian emissions were slim, thus we predicted that nocturnal data would be minimal. Diurnal data progressed as expected, showing evidence of both solar flares and bursts; moreover, activity was found to increase significantly in intensity around noon. Thus our predictions for the sun were relatively accurate; however, we found, to our surprise, that nocturnal emissions were detected. Several hypotheses, including the presence of Jupiter, were made. The most viable suspicion, however, was that the data came from the recent Perseid meteor shower. With this in mind, the project, on the whole, was a success due to the detection of extraterrestrial activity indicative of the presence and personality of both Jovian and solar magnetic fields.

REFERENCES

[1] Bagnall, Philip M. "Audible Meteors and Fireballs." Written 1996. http://www.ticetboo.demon.co.uk/audible.htm.

[2] Beech, Martin. "The VLF Detection of Fireballs." University of Regina. Last modified: August 14, 1997. http://uregina.ca/~astro/mb_7.html.

[3] Benedict, Sarah and Holman, Gordon. "What is a Solar Flare?" Last modified: January 16, 2002. http://hesperia.gsfc.nasa.gov/sftheory/flare.htm.

[4] Flagg, Richard S. "JOVE RJ1.1 Receiver Kit Assembly Manual." March 2000. NASA Radio JOVE Project.

[5] Garcia, Leonard N. "The Discovery of Jupiter's Radio Emissions." Radiojove.gsfc.nasa.gov/library/sci_briefs/discovery.html.

[6] Hathaway, David H. "The Big Questions: Solar Physics." Last modified: April 9, 2002. http://Science.nasa.gov/ssl/PAD/SOLAR/quests.hm.

[7] Higgins, Chuck et al. "JOVE RJ1.1 Antenna Kit Assembly Manual." March 1999. NASA Radio JOVE Project.

[8] Radio-Sky Publishing: Resources for Amateur Radio Astronomers, Teachers and Students; Radio Sky Engineering Services. Last modified: June 29, 2001. http://www.radiosky.com/juprpt.txt.

[9] Space Daily: "Your Portal to Space." Written March 6, 2002. http://www.spacedaily.com/news/solarstorm-02c.html.

[10] UFRO Online. http://ufro1.astro.ufl.edu/Solar-bursts.htm. University of Florida.

[11] Windows to the Universe team. "A Look at Jupiter's Magnetosphere." Boulder, CO; 2000-01 Last modified: April 28, 1997. http://www.windows.ucar.edu/tour/link=/jupiter/upper_atmosphere.html