Listening to Jupiter from 48ºN

Matt Kistner
Honors Thesis
Advisor: Dr. Stevens Johnson
Bemidji State University
Bemidji MN 56601
Spring 2007

Table of Contents

I. Introduction

In fulfillment of my research component of my Bachelor of Science in Physics, I have chosen to undertake the construction of a radio telescope in order to observe the radio signals emitted by Jupiter and the Sun. I have chosen to use the Radio Jove program sponsored by NASA as the starting point for this project. This research spanned my final three semesters of study at Bemidji State University and has included the construction of two radio telescopes and using them to collect data on the radio emissions of the Sun and Jupiter.

II. Background on Jupiter

Jupiter is named for the King of the Roman gods and rightly so. It is the largest planet in our solar system with an equatorial radius of 71,494 km and a mass 318 times greater than the mass of the Earth (Seeds 617). It comprises nearly three-fourths of all the planetary mass in the solar system (Seeds 503). Jupiter was formed from the colder gases of the outer solar nebula, which allowed it to grow very quickly to a size large enough to trap hydrogen and helium gas. Jupiter is made up of mostly liquid hydrogen surrounding a heavy-element core. The electrical conducting property of the liquid metallic hydrogen combined with Jupiter's rapid rate of rotation creates the dynamo effect responsible for Jupiter's magnetic field. Jupiter's magnetic field is approximately 20,000 times stronger than Earth's (Jupiter Lithograph).

Jupiter's large size and brightness has made it a focus of astronomical research over the last few centuries. In 1610, when Galileo first pointed a telescope at the sky, the first thing he looked at was Jupiter. His goal in observing the moons of Jupiter was to establish a universal clock with which to determine longitude at sea (North 338). It was through these observations that he was able to chart Jupiter's four largest moons, Io, Europa, Ganymede, Callisto, which are now known as the Galilean moons. Galileo recorded the orbital periods of these moons and used this data to support the Copernican model of the solar system. It was Galileo's support of the Copernican system that brought him the scrutiny of the Inquisition. Galileo published his observations on Jupiter's moons in *Narratio de Jovis satellitibus, 1611* (North 332).

In 1675, the Danish astronomer Ole Romer used Jupiter to perform the first calculation of the speed of light. He observed that the eclipse times of Jupiter's moons varied over time as the distance between the Earth and Jupiter fluctuated. His calculations determined the speed of light to be 320,000 km per second, which is just slightly faster than what we know the speed of light to be today (Tolstoy 116).

The first spacecraft to fly past Jupiter was the Pioneer 10 in 1973. The Pioneer 11 in 1974, two Voyager spacecraft in 1979, and the Galileo spacecraft in 1995 followed this first pass of Jupiter. These spacecraft provided measurements of the magnetosphere around Jupiter showing it to be 100 times larger than the magnetosphere of Earth (Seeds 506).

Io is the innermost of Jupiter's four Galilean moons and maintains an orbit just slightly larger than the orbit of the Moon around Earth. All four Galilean moons maintain almost circular orbits in Jupiter's equatorial plane (Lodders 201). Io has an orbital period of only two days compared to the twenty-seven day orbital period of our moon (Seeds 504). Io is home to a large amount of volcanic activity from its 150 active volcanoes (Seeds 519). These volcanoes emit a total of one ton of gases per second; composed primarily of sulfur and sodium ions (Stern). The gas and ash created by these volcanoes is picked up by the magnetic field and accelerated into an orbit around Io known as the Io plasma torus. The plasma torus is the strongest part within the Jovian form of the Van Allen belts. The Van Allen belts are the belts of radiation surrounding Earth (Seeds 437). They were discovered in 1958 from data collected by a Geiger counter mounted on Explorer 1, the first United States satellite (Green). Jupiter's magnetic field interacts with Io to produce a curving path of electric current known as the Io flux tube (Seeds 507). The Io flux tube is responsible for the decametric radio signals that we observe from Earth. These signals are created by electrons spiraling around the magnetic field lines and interacting with the ionosphere (Morrison 354). Another source of radio signals are the storms in Jupiter's atmosphere. The Voyager spacecraft was able to photograph lightning bolts as well as thunderheads up to 50 km high (Seeds 510). Io has remained active long after its formation because of the orbital resonance of Jupiter's largest moons. This resonance holds the moons in slightly elliptical orbits, which allows for the tidal heating of Io. This tidal heating occurs as the surface of Io is squeezed and released by the fluctuations in the strength of Jupiter's gravitational field as Io moves closer and further from Jupiter. This squeezing affect creates internal friction, which generates heat.

The Great Red Spot is a giant spinning storm that has been observed on Jupiter for the last 300 years. Robert Hooke first observed the Great Red Spot in 1664 (Lodders 200). Scientists believe that it may have originated from two smaller storms that merged together. While scientists had suspected this to be the cause of several of the larger storm systems on Jupiter, it wasn't until recently that they recorded a storm system merger with the Hubble Space Telescope. The Great Red Spot has a counterclockwise rotation period of six days (Morrison 348). The Great Red Spot was first photographed by the Lick telescope in 1890 when Jupiter was near opposition (North 455). Scientists believe that its red color may be due to the photolysis of PH_3 gas (Lodders 200).

III. History of Radio Astronomy

The early astronomer was consumed with the mysteries of the stars and galaxies as opposed to the study of the composition of the planets. However, as the age of space travel approached, the thought of traveling to other planets sparked an interest in their composition. This led to the development of radio astronomy as we know it today. Radio astronomy has been and will continue to be invaluable to researchers because it is capable of obtaining data that is unattainable by optical astronomy.

James Clerk Maxwell proposed his theory of electromagnetic radiation in 1865 (Smith 1). This was one of the most significant theories of the 19th century as it unified the theory of light with the classical theories of electricity and magnetism (North 543). Nearly twenty years later, in 1882, George Francis Fitzgerald used Maxwell's theory to claim that the energy of varying currents may be radiated into space. He then proceeded to describe the magnetic oscillator that could produce these results (North 542). In 1888, Heinrich Hertz was able to measure radio frequency waves in the laboratory (Smith 1). Hertz was able to do this by using an open circuit connected to an induction coil to produce the waves and a circular wire with a gap in it to detect them (North 543). One of the first attempts at measuring solar radio emissions was in 1900 by a French graduate student named Charles Nordmann (Smith 1). He set up his 175-meter antenna on a large glacier at an altitude of 3100 meters in an attempt to minimize the terrestrial interference (Smith 1). Nordmann was certain that there would be radio waves associated with sunspot activity, however, he was unable to collect results to confirm this. He blamed the lack of supporting results on atmospheric absorption (Smith 2).

The first detection of extraterrestrial radio signals occurred in 1932 by Karl Jansky while he was working for Bell Telephone Laboratories (Smith 2). At the time, he was studying the interference that was present in the new trans-Atlantic radio-telephone system (North 545). His telescope was located in Holmdel, New Jersey and was mounted on a rotating disc so that it could be rotated in any direction in attempts to locate the sources of interference. After Jansky first discovered the unknown signal, he spent a year carefully recording it (Smith 2). These observations led to the discovery that the point of interference traveled from east to west during the day (Smith 2). This naturally led him to the thought that the noise was coming from the Sun, however, over time the point of the noise matched the path of the Sun less and less (Smith 2). Jansky then noticed that the point was remaining stationary relative to the position of the stars and concluded that it in fact was coming from the center of the Milky Way Galaxy (Smith 3).

In 1942, while the Germans were attacking the British, Stanley Hey discovered that it was not the Germans jamming the British radar, but it was an unusual solar radio burst due to a large solar sunspot. This information confirmed the idea that Charles Nordmann had predicted forty years earlier (Smith 5). Hey is also credited with the discovery of radar reflections from meteor trails and the first radio galaxy, Cygnus A (North 544).

K.L. Franklin and Bernard Burke discovered Jupiter's radio waves in 1955. They made this discovery using a radio interferometer set up by the Carnegie Institution near Washington D.C. (Smith 69). They referred to this as decameter radiation because the wavelength was in the tens of meters (Seeds 506). It was at a wavelength of 15m, which is approximately 20MHz (Morrison 354). In the decametric band the ionosphere absorbs about 10% of the radiation, but the sporadic nature of planetary emissions of this wavelength does not require us to have extremely accurate measurements of intensity (Zheleznyakov 65). At these wavelengths Jupiter is one of the strongest emitters, second only to the Sun. After compiling a large volume of data, they were able to see that the interference they were detecting was occurring four minutes earlier each night (Smith 69). This led them to search for a star that would be in that location each night. Finding no stars to line up with their data, they heeded to a suggestion by Howard Tatel that it might be Jupiter (Smith 69). After checking Jupiter's position against their data, they found it was an almost exact match (Smith 69). They presented their discovery at the April 6, 1955 meeting of the American Astronomical Society (Garcia).

After discovering the source of this interference to be Jupiter, the Australian astronomer C. A. Shain reviewed his collection of data and discovered he had recorded Jupiter on sixty-one previous occasions (Smith 70). Using these observations he was able to pinpoint the source of the radio waves on Jupiter. He arbitrarily set a point on Jupiter's meridian to be zero degrees longitude. Using this point and assuming a constant rate of rotation, he plotted the sources of his previous recordings (Smith 72). After plotting these points he noticed that they were centered at 67 degrees. While this was important to confirming the existence of a local radio source, it did not indicate the latitude of the source (Smith 73).

On January 24, 1956, Shain and F. F. Gardner discovered the polarization of the Jupiter radio waves (Smith 86). They were followed in their discoveries by an American team only two days later. Both teams discovered that the signals had right-handed elliptical polarization (Smith 86). Right-handed elliptical polarization refers to a situation in which the rotation of the electric field vector and the direction of propagation for a right-handed screw. When studying radio emissions, polarization is one of three things that scientist look for; the others are frequency spectrum and angular spectrum (Zheleznyakov 20).

As astronomers continued to monitor Jupiter, they noticed that the Jovian signals were becoming weaker over time. Some thought that the radio emissions may be dying off. However, in 1960, when the sunspot cycle was on the decline, the radio waves from Jupiter began to increase. This led researchers to the conclusion that there is an inverse relationship between the sunspot activity cycle and Jovian emissions (Smith 90).

In 1959, at the newly formed National Radio Astronomy Observatory (NRAO), D. F. Drake hypothesized that Jupiter's microwave energy could be coming from a radiation belt around Jupiter. This was significant because of the similarity of that prediction with the Van Allen belts around Earth. Drake proved this hypothesis correct less than a year later (Smith 95). This was also confirmed in 1960 by researchers at the California Institute of Technology using two telescopes mounted on 1600ft of railroad track. This allowed them to confirm that the microwaves were coming from an area surrounding the planet (Smith 95).

Also in 1960, observers performed simultaneous recording of Jupiter at +41° and -22°, these points are located on opposite sides of Earth's geomagnetic equator. These recordings showed that Jupiter had the same polarization from both observing points. This shows that the polarization is not due to Earth's ionosphere but is proof of a Jovian magnetic field (Zheleznyakov 258).

By the mid-1980's, the NRAO had an operating budget of fifteen million dollars which was used to fund the Very Large Array (VLA) completed in 1982. The VLA is located near Socorro, NM, and is comprised of twenty-seven 25m-diameter telescopes arranged in a Y-pattern (North 553).

Today a large part of radio astronomy is focused on the design and construction of new instruments to gather data. Researchers are focusing on how the instruments function and what their limitations are. This is in part due to the fact that modern astronomers are not building their own telescopes as they were in the past. Instead they are starting with a problem and then figuring out how to use and develop technology to make the observations they need (Rohlfs 2).

The radio telescope with the largest reflecting area is located in Arecibo, Puerto Rico. It has a diameter of 305m and is built into the ground of a large valley. The telescope was originally constructed under a contract with Cornell University to monitor Soviet satellites but now is operated as a branch of the National Astronomy and Ionosphere Center (North 554).

IV. History of Radio Jove

The Radio Jove program began in 1998 as a collaboration between NASA's Space Science Data Operations Center, the University of Florida and the Florida Space Grant Consortium. It was intended as a program to expose students and amateur scientists to radio astronomy by providing them with an economical way to listen to the natural radio emissions of Jupiter and the Sun. The goals of the project include: educating people about planetary and solar radio astronomy, space physics, and the scientific method; providing teachers and students with an astronomy exercise; creating an on-line radio observatory that provides real time data; and facilitating interactions among participating schools and individuals (Brown).

There are currently over 800 teams working on the Radio Jove project worldwide. Through the online archives participants are able to access the data from all the observing sites, which provides them with the ability to confirm the validity of their results as well as look for larger patterns within the volume of data.

An interesting aspect of the Radio Jove project is that it collects data on radio emissions below 25 MHz, which is not currently being collected by the National Oceanic and Atmospheric Administration (NOAA). This means that the data collected by Radio Jove participants is crucial to our understanding of lower frequency solar and planetary activity (Brown).

Using Radio Jove to analyze Jupiter allows us to better understand the magnetic fields and plasma environment of Jupiter. The data can also provide us with insight to the interior composition of Jupiter and its moons.

In addition to examining the composition of Jupiter and its moons, we can also examine the storms present on Jupiter's moon Io. This is possible through the use of software to predict the timing of Io's storms and then recording during the periods of storm activity. The continual testing of these predictions allows researchers to better understand the Io storm systems and also create more accurate models.

V. My Project

In January 2006, the Physics Department at Bemidji State University made the decision to bring the Radio Jove Project to our campus as a research project for several of the students enrolled in the Theoretical Physics class. This group included Caralyn Flack, Mark Sandbo, and myself. We were each assigned a separate part of the project. My responsibility was for the construction of the antenna.

The Radio Jove antenna is a dipole antenna that consists of two copper antenna wires supported by two masts each. These masts can be constructed out of either PVC or metal. At this point in the project we chose to construct them out of PVC because it is lightweight and has greater portability. This involved marking and drilling a series of holes as shown on the blueprints. Next, I assembled the antenna wires. Once everything was assembled, I installed the antenna at the chosen site, the roof of Sattgast Hall.

Using the antenna that I built, Mark and Caralyn were able to record data on several occasions, and presented this at the Student Scholarship and Creative Achievement Conference in April 2006.

In September 2006, I resumed work on the Radio Jove project. After using the original antenna set up, it was decided to build a second set of antennas using the metal mast design and also a redesigned base platform in an effort to make the structure more stable under windy conditions. This also allows us to have a permanent observing station on the roof, while using the PVC antenna for remote observations. The fall semester was spent designing and purchasing the materials needed for construction. I then proceeded to construct the new antennas and position them on the roof. This process was somewhat hindered by the presence of snow on the roof, fortunately this coincided with the time when observing Jupiter was less than ideal.

During the 2006-2007 academic year I have had the assistance of Adam Dorn. He is a Science Education major and has an interest in the use of the Radio Jove project as a demonstration tool in high school science classes. We had our first listening session on March 28, 2007. During this time we confirmed that the antenna was working and were able to isolate some of the sources of man made interference. Our second listening session was an early morning session on March 29, 2007 focusing specifically on Jupiter by recording before the Sun had risen. During this session we recorded several spikes, which we believe to be originating from Jupiter. This also provided us with a good opportunity to try different tuning configurations in an effort to achieve the best signal.

Early in April we were hit with a late snowstorm, which significantly hindered our progress. During this time one of the antenna wires broke when a mast fell over. Fortunately, I had built an extra set of antenna wires and we were able to replace it rather quickly once the snow melted.

This delayed our third viewing session until April 13, 2007. During this session we attempted to record the Sun rising in order to see the effect of the solar emissions on the radio signal. I had expected to see a significant increase in the intensity of the radio signal as the Sun rose above the horizon. While we observed a slight increase in the intensity over time, it was not to the degree that I had expected. However, during this time we were able to record several unknown spikes similar to those in previous recordings and we were also able to duplicate a signal that was recorded in the observations last year. We also recorded a series of chirps, which one source stated could be caused by a satellite moving through the Ionosphere. Additional recordings are necessary before any of these hypotheses can be confirmed.

VI. Challenges

The main challenge for me in the completion of the Radio Jove project was the limited viewing time available. During the winter months the Sun rises very quickly after Jupiter so it is difficult to obtain recordings of Jupiter by itself. Another hindrance was the weather during most of the academic year. The snow combined with cold temperatures made it difficult to construct the antenna on the roof. We are also currently at the solar minimum in the 11-year solar cycle. For example, on April 14, 2007, we have not had any sunspot activity for 11 days, which is the longest streak since the last solar minimum in 1996. This limits the recording of solar emissions generated by sunspots. Also, there was no storm activity predicted on Io between the middle of March and April 22, 2007 that was visible from our location.

In addition to the complications beyond our control, another challenge was the ability to make recordings while also being in school. In order to record Jupiter, you must record it before the Sun rises. This generally means recording from 3-6 AM, which I have found difficult to do on my current class schedule. This has limited my viewing times to weekends and days off of school.

VII. Future Plans

The next steps for the Radio Jove Project include observing the Io storms that are predicted for April 22, April 28, April 29, May 7, and May 14. I would also be interested in observing Jupiter every day for a complete 8-day cycle in order to see how our recordings changed throughout the cycle. It is also necessary to compile more data in order to determine the causes of the different spikes we have observed. Once we determine which signals are indeed from Jupiter or the Sun we would submit our data to the online data archives.

VIII. Works Cited

Appleyard, Rollo. Pioneers of Electrical Communication. Freeport, NY. Books for Libraries, 1968.

Brown, James. "Radio Astronomy on the Cheap." Mercury. May/June 2004: 12-16.

Burke, Bernard F. and Francis Graham-Smith. An Introduction to Radio Astronomy. Cambridge: Cambridge University, 2002.

Cheng, David. Field and Wave Electromagnetics. Reading, MA: Addison-Wesley, 1992.

Flagg, Richard S.. Radio Jove Assembly Manual. December 2004.

Garcia, Leonard N.. "The Discovery of Jupiter's Radio Emissions." http://radiojove.gsfc.nasa.gov/library/sci_briefs/discovery.html

Green, James L.. "The Magnetosphere." http://ssdoo.gsfc.nasa.gov/education/lectures/magnetoshphere/index.html

"Jupiter Lithograph." http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Jupiter_Lithograph.html

Kreyszig, Erwin. Advanced Engineering Mathematics. Hoboken, NJ: John Wiley and Sons, 1999.

Lodders, Katharina and Bruce Fegley Jr.. The Planetary Scientist's Companion. New York, NY. Oxford University Press, 1998.

Morrison, David, and Tobias Owen. The Planetary System. San Francisco, CA: Pearson Education, 2003.

North, John David. The Norton History of Astronomy and Cosmology. New York, NY. W. W. Norton and Company, 1995.

"Radio Jove." http://radiojove.gsfc.nasa.gov

Rohlfs, K. and T. L. Wilson. Tools of Radio Astronomy. Berlin: Springer-Verlag, 2000.

Seeds, Michael. Foundations of Astronomy. Belmont, CA: Brooks/Cole, 2005.

Smith, Alex G. and T. D. Carter. Radio Exploration of the Planetary System. Princeton, NJ. D. Van Nostrand Company, 1964.

Stern, David P.. "A Brief History of Magnetospheric Physics During the Space Age." *Reviews of Geophysics*. Volume 34. 1996. pp 1-36.

"Storms Collide on Jupiter." http://science.nasa.gov/headlines/y2000/ast24oct_1.htm

Tolstoy, Ivan. James Clerk Maxwell. Chicago. University of Chicago Press, 1982.

Zheleznyakov, V. V. Radio Emission of the Sun and Planets. Oxford: Pergamon, 1970.

Appendix

Tools Required for Assembly

Soldering Iron
Solder
Wire Cutters
Utility Knife
Scissors
Lighter
Tape Measure
Black Marker
Small Flat Screwdriver
Crescent Wrench
Pliers
Drill
Drill Bits: 1/8in, 1/4in, 3/8in
1/16 in allen wrench
Sandpaper
Metal Edge Ruler

Antenna Parts

Quantity	Description
1	50ft #14 Gauge Bare Copper Wire (7-stranded)
1	95ft RG59U Coaxial Cable
4	PVC End Insulators
2	Plastic Center Dog-bone Insulators
6	Twist-on F-connectors
1	Coaxial Cable Coupler
1	2-1 Power Combiner
6	Ferrite toroid cores

PVC Mast Parts

Quantity	Description
1	300ftx3/16in Nylon Rope
4	10ftx1in PVC Sch40 Pipes
4	10ftx1.25in Non-Metallic Conduit Pipes
4	1.25in Non-Metallic Conduit End Caps
12	4inx0.25in Eye Bolts
4	4inx0.25in Bolts
16	0.25in Nuts
16	0.25in Lock Washers
4	4inx(3/8)in Bolts
4	4inx(3/8)in Nuts
4	4inx(3/8)in Flat Washers
4	4inx(3/8)in Lock Washers
6	6in Black Tie-wraps

Metal Masts

Quantity	Description
1	300ftx3/16in Nylon Rope
8	10ft 6in x1.375in Metal Fence Top Rail
8	4inx0.25in Eye Bolts
12	0.25in Nuts
12	0.25in Lock Washers
4	2inx0.25in Bolts

Constructing the Antenna

1) Cut four 12ft 4in pieces of copper wire.
2) Cut two 1-wavelength (32.31ft) pieces of coaxial cable.
3) Cut one 0.375 wavelength (12.12 ft) of coaxial cable.
4) Cut one 0.5 wavelength (16.16ft) of coaxial cable.
5) Cut four 2ft lengths of nylon rope.
6) Attach an end insulator to each wire. Thread 5in of copper wire through one of the holes in the end insulator and wrap it back on itself.
7) Attach the wires to the center(dog-bone) insulator using the same method as the end insulators.
8) Check the total length between the inner edges of the end insulators. It should be 23ft 3in.
9) Attach one of the lengths of rope to each end insulator. Each rope should extend 1.5 ft from the end insulator.
10) Strip back 4.5in off one end of each of the 1 wavelength coaxial cables. Be careful not to cut the braided copper wires.
11) Unweave the braided copper shielding.
12) Twist all the individual strands of copper shielding together.
13) Strip off 2in of the insulation off the center conductor. Be careful not to nick the center conductor.
14) Loop the coaxial cable over the center insulator and use a tie wrap to secure it.
15) Wrap the bare center conductor around one side of the copper antenna wire.
16) Wrap the twisted copper shielding around the other end of the copper antenna wire.
17) Solder the center conductor and the shielding in place.
18) Slide three ferrite cores up to the top of the coaxial cable. Secure them with a tie-wrap.
19) Remove 1in of the outer covering from the end of the coaxial cable.
20) Carefully unbraid half of the braided copper shielding and fold it back on itself.
21) Remove 0.5in of the insulator around the center conductor.
22) Twist on the f-connector. About 0.25in of the center conductor should extend past the end of the f-connector.
23) Repeat steps 6-22 for the other dipole.

Constructing the PVC Mast

Notes:

1) Drill all holes using a 0.25in diameter drill bit.
2) Drill all holes in the same plane.
3) Use hole E as a guide to drill hole D so that they match up.
4) Push the top mast section in to the stop bolt and use hole E to drill hole C so that they match up.

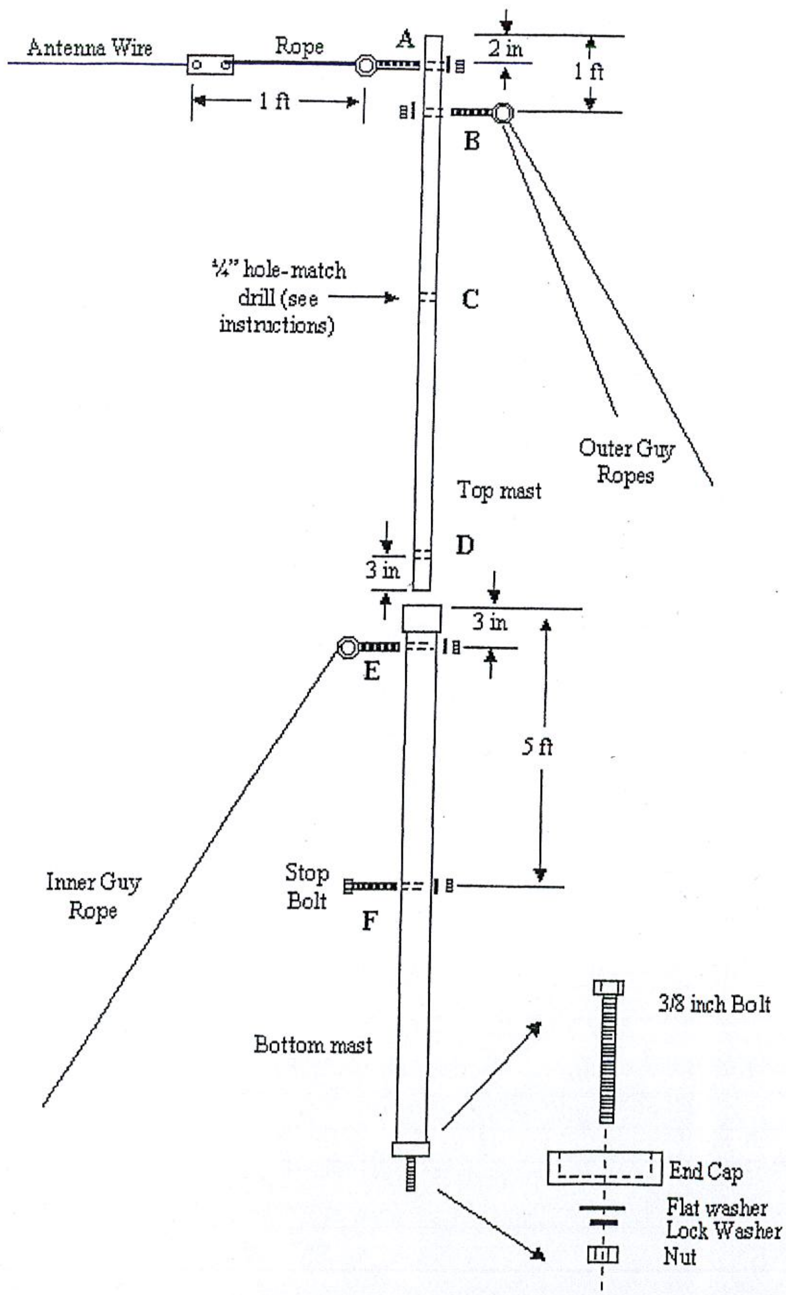

Figure 4.2. PVC Mast Assembly.

Notes:
1) Cut one of the masts so that the total assembled height is 20ft.
2) Use a 1/8in drill but to drill a pilot hole at each location.
3) Ensure that all holes are drilled in the same plane.
4) Drill hole E first and then use it to drill hole D to match.

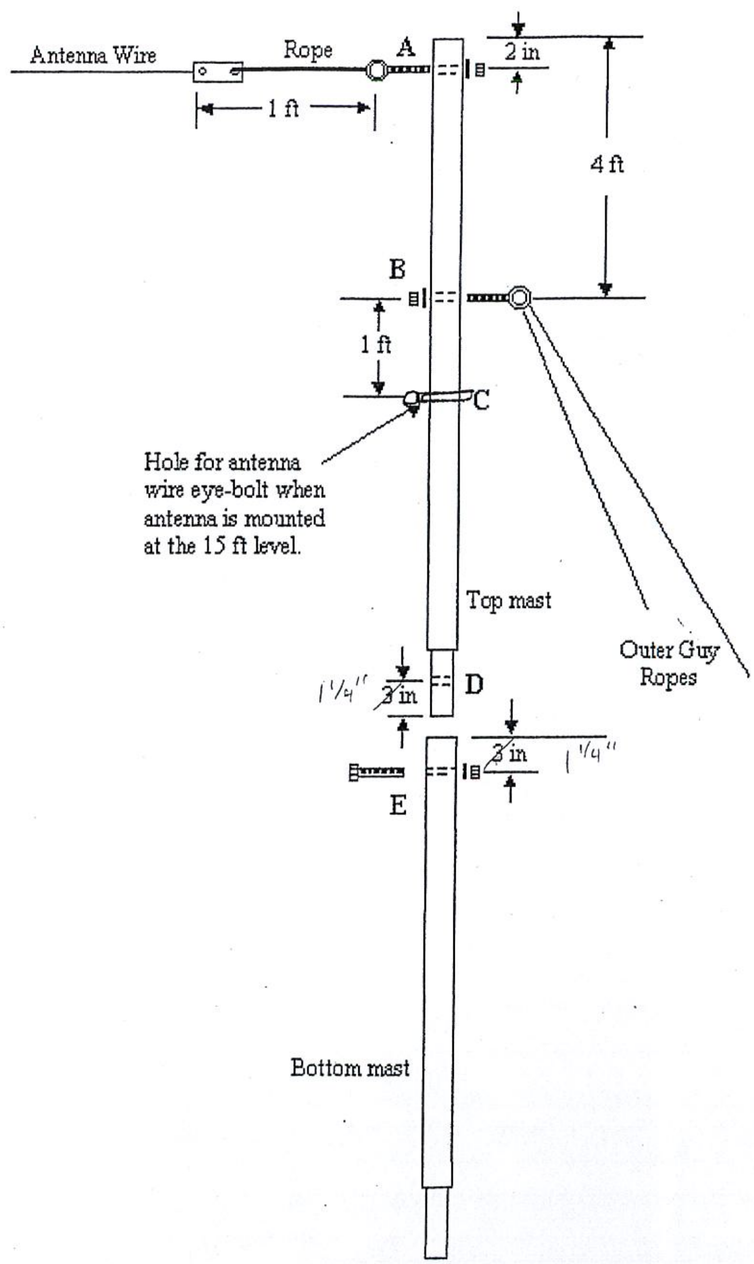

Figure 4.4. Metal Mast Assembly.

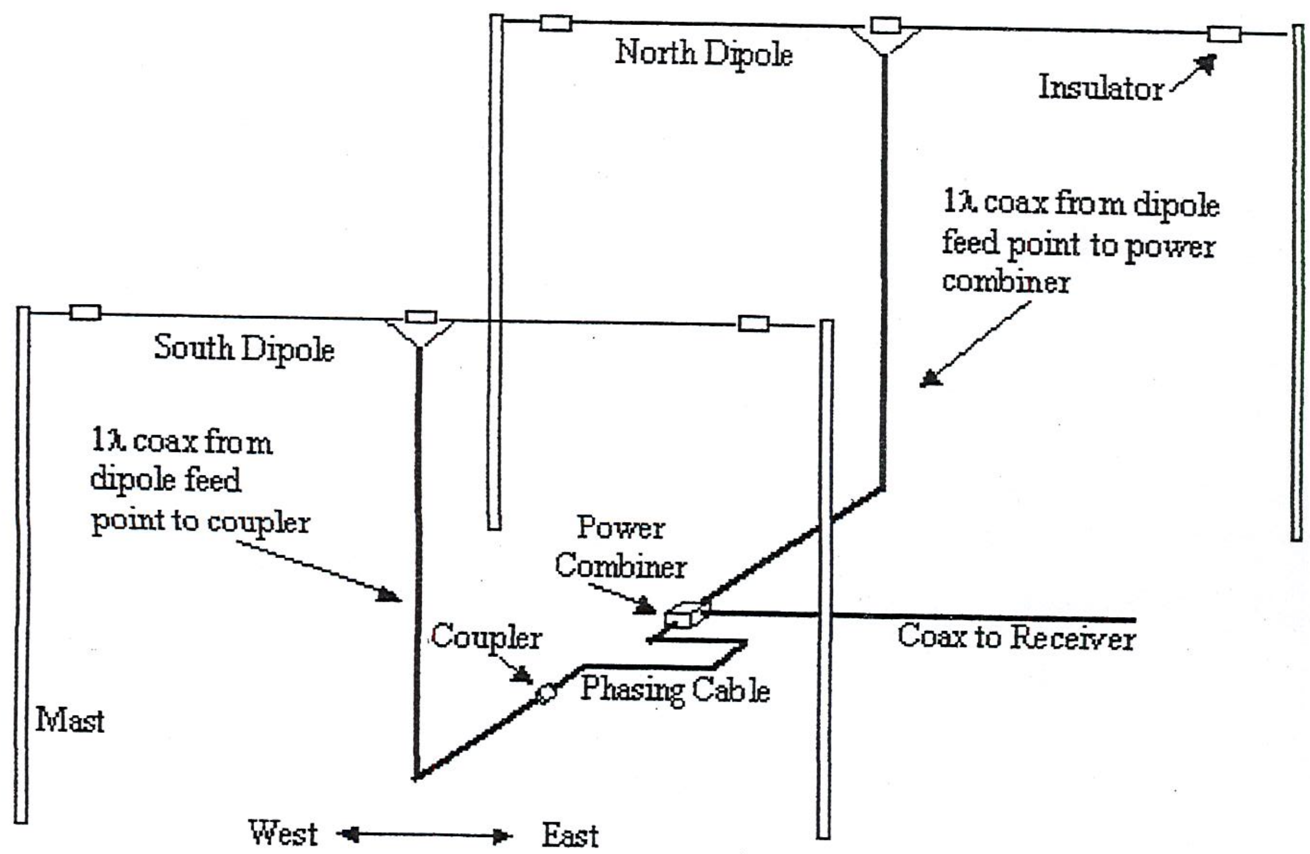

Fig. 1.3. The Jove dipole system setup with the dipole wires running East-West.

Construction of the Receiver

The Radio Jove antenna detects radio signals from Jupiter that produce less than one microvolt at the antenna terminals. These signals then pass through a bandpass filter and preamplifier in order to filter eliminate out of band interference and to amplify the signal strength. The signals are amplified by a factor of ten using a junction field effect transistor. The signals then pass through a local oscillator (LO) and mixer, which convert the radio signals to audio frequencies. This is done by mixing the RF signal and the LO signals and producing a signal that is the arithmetic difference of the two signals. This new signal goes through a low pass filter in order to focus on the desired frequencies and eliminate frequencies outside of the immediate neighborhood of the desired frequency. Then the signal is amplified so that it has enough power to drive a speaker.

1) Compare the PC board to Figure 4.
2) Install resistors R1-R27.
3) Install inductors L1-L3.
4) Install the three IC sockets so that the notch is near the pin 1 dot on the PC board.
5) Install capacitors C11, C14, C17, C18, C23, C26, C29, C34, C35, C36, C40, C41, C42, C43.
   These capacitors are not polarized and can be installed in either direction.
6) Install capacitors C16, C24, C25, C30, C31, C33, C38, C44.
   These capacitors are polarized and must be installed so that the + lead of the capacitor is placed into the hole marked + on the PC board.
7) Using the excess wire cut from the capacitors in step 6, install jumpers J1-J10.
8) Install all remaining capacitors.
   Note: Capacitors C27, C32, C39 are polarized.
9) Install inductors L4-L7. Solder all pins and mounting tabs on L4 andL5.
10) Install R7 and R15/S1.
11) Install transistors Q1-Q3 making note of their orientation.
12) Install diodes D1-D3, VD1, ZD1, and ZD2.
    Note: The band on the diode must match up with the band marked on the PC board.
13) Install the test oscillator, OSC1. Align the square corner with the hole designated pin 1 on the PC board. It is marked with a diagonal slash.
14) Install one end of each resistor, R28-R31 on the PC board. The other end will be soldered to the audio jacks later.
15) Plug the integrated circuits (ICs) into their sockets. Make sure the pin 1 mark is near the notch in the socket. Be very careful not to bend any of the pins on the ICs.
16) Carefully examine every solder joint.
17) Mount the PC board to the front panel.
18) Form the leads of LED1 so that the LED fits into the front panel hole and the leads extend through the PC board. Solder the LED leads into place.
19) Assemble one end of the enclosure as well as the four extruded channel pieces.
20) Slide the front panel into the front channel guides.
21) Prepare a two inch red wire and a two inch black wire by stripping off a ¼in of insulation from each end.
22) Install the red wire on the center pin of the antenna connector on the back panel.
23) Install the black wire on the solder lug adjacent to the antenna connector on the back panel.

24) Slide the rear panel into the rear channel guides.
25) Install the red wire from the center pin of the antenna connector to the antenna hole on the PC board.
26) Install the black wire from the solder lug adjacent to the antenna connector on the back panel to the ground hole on the PC board adjacent to the screw hole in the corner.
27) Mount the right side panel to the four channel guides.
28) Tighten all eight enclosure screws.
29) Mount resistors R28-R31. Leave a little extra lead length so that the resistor leads are not taut. Solder R29 and R31 first on the bottom tabs and then R28 and R30 on the top tabs as shown in Figure 12.
30) Install wires to the power connector as shown in Figure 13.
31) Install the spacers as shown in Figure 14 using 1/4in 4-40 screws and lock washers.
32) Attach the four rubber feet to the corners of the bottom panel.
33) Solder R32 between the center pin of the antenna connector and the adjacent solder lug.
34) Install the two knobs. Align them so the index mark is near the seven o'clock position when the knob is turned all the way counter-clockwise.

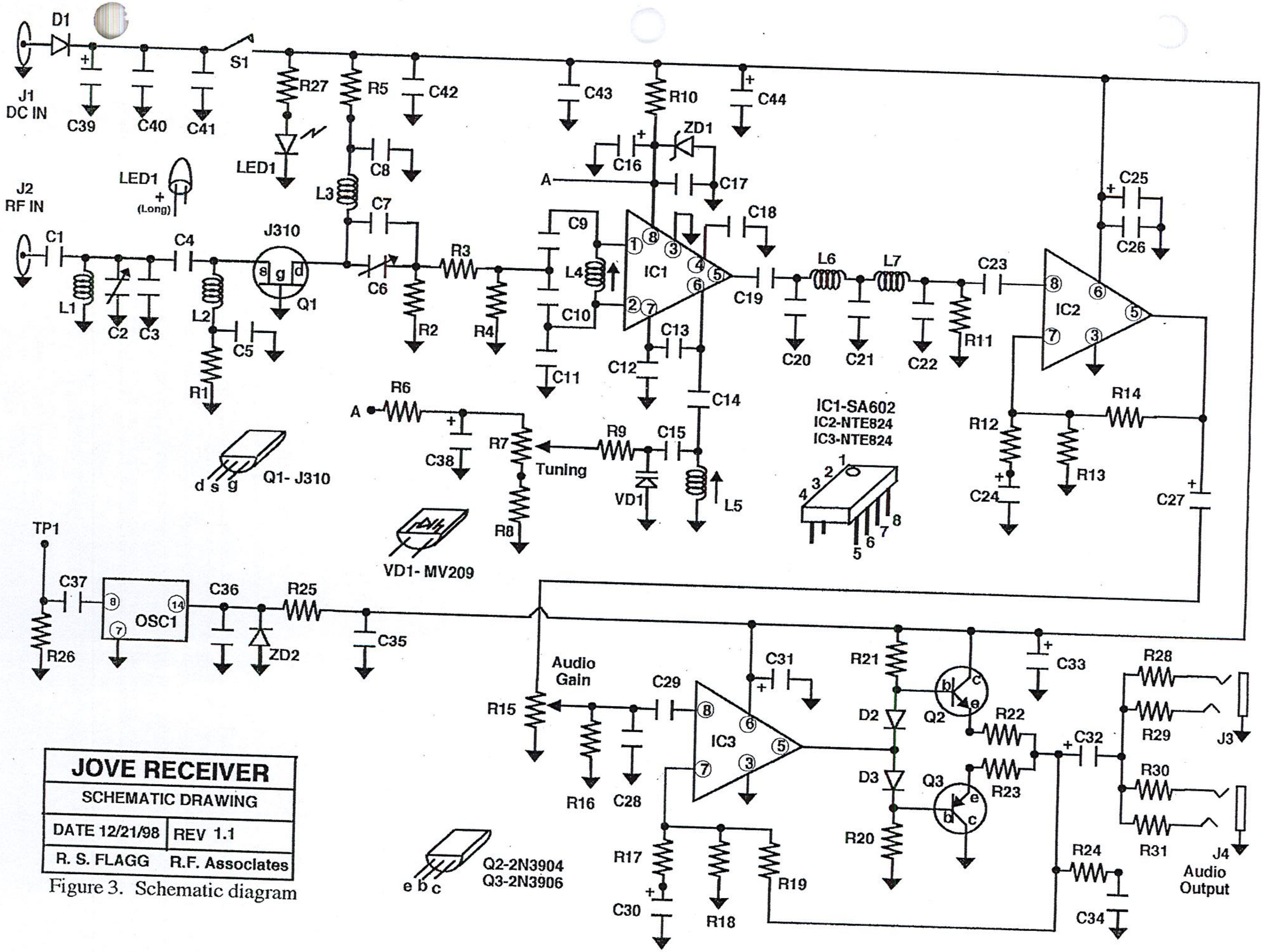

Figure 3. Schematic diagram

NOTE: On the PC board itself, IC2 and IC3 are both labeled incorrectly as LM387, the correct components are both NTE824 as indicated below

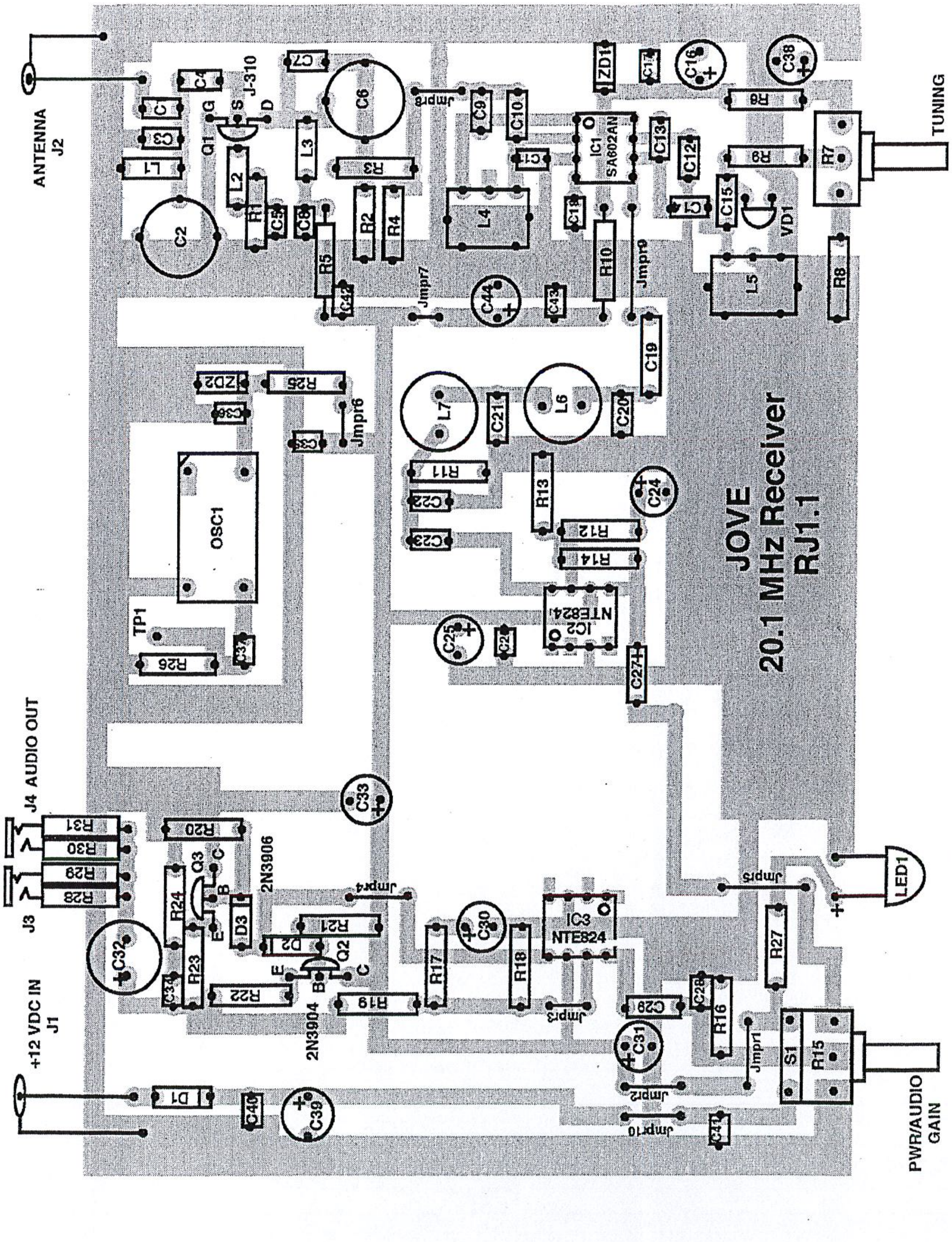

Figure 4. X-ray view of PC board from component side

Table 1
JOVE Receiver Parts List

Actual marking found on component is shown in parentheses ( ). Two columns of check-off boxes are provided: use one for parts identification, and the other, for installation.

CAPACITORS	*Note polarity on all electrolytic capacitors*		
C1	39 pF, disc ceramic (390)		
C2	4-40 pF, variable capacitor		
C3	56 pF, disc ceramic (560)		
C4	22 pF, disc ceramic (220)		
C5	.01 µF, dipped ceramic		
C6	4-40 pF, variable capacitor		
C7	not used		
C8	.01 µF, dipped ceramic		
C9	47 pF, disc ceramic (470) or (47)		
C10	270 pF, disc ceramic (271)		
C11	0.1 µF, dipped ceramic (.1K)		
C12	47 pF, disc ceramic (470) or (47)		
C13	47 pF, disc ceramic (470) or (47)		
C14	0.1 µF, dipped ceramic (.1K)		
C15	10 pF, disc ceramic (100)		
C16	10 µF, 25 vdc, electrolytic		
C17	0.1 µF, dipped ceramic (.1K)		
C18	0.1 µF, dipped ceramic (.1K)		
C19	1 µF, metal polyester (105)		
C20	0.068 µF, 5% metal film (683)		
C21	0.1 µF, 5% metal film (104)		
C22	0.068 µF, 5% metal film (683)		
C23	0.1 µF, dipped ceramic (.1K)		
C24	10 µF, 25 vdc, electrolytic		
C25	10 µF, 25 vdc, electrolytic		
C26	0.1 µF, dipped ceramic (.1K)		
C27	10 µF, 35 vdc, tantalum, stripe, long lead +		
C28	220pF, disc ceramic (221)		
C29	0.1 µF, dipped ceramic (.1K)		
C30	10 µF, 25 vdc, electrolytic		
C31	10 µF, 25 vdc, electrolytic		
C32	330 µF, 25 vdc, electrolytic		
C33	10 µF, 25 vdc, electrolytic		
C34	0.1 µF, dipped ceramic (.1K)		
C35	0.1 µF, dipped ceramic (.1K)		

	C36	0.1 μF, dipped ceramic (.1K)		
	C37	10 pF, disc ceramic (100)		
	C38	10 μF, 25 vdc, electrolytic		
	C39	100 μF, 25 vdc, electrolytic		
	C40	0.1 μF, dipped ceramic (.1K)		
	C41	0.1 μF, dipped ceramic (.1K)		
	C42	0.1 μF, dipped ceramic (.1K)		
	C43	0.1 μF, dipped ceramic (.1K)		
	C44	10 μF, 25 vdc, electrolytic		
DIODES		*Note Polarity*		
	D1	1N4001		
	D2	1N914		
	D3	1N914		
	LED1	light emitting diode (LED), red		
	VD1	MV209, varactor diode		
	ZD1	1N753, 6.2 v, zener diode, 400 mw		
	ZD2	1N5231, 5.1v, zener diode, 500mw		
INDUCTORS		*Do Not Confuse L1, L2, L3 with Resistors*		
	L1	0.47 μH, (gold, yellow, violet, silver)		
	L2	1 μH, (brown, gold, black, silver)		
	L3	3.9 μH, (orange, gold, white, gold)		
	L4	1.5 μH, adjustable inductor		
	L5	1.5 μH, adjustable inductor		
	L6	82 mH, fixed inductor		
	L7	82 mH, fixed inductor		
INTEGRATED CIRCUITS				
	IC1	SA602AN, mixer / oscillator		
	IC2	NTE824,audio preamplifier		
	IC3	NTE824,audio preamplifier		
	OSC1	20 MHz crystal oscillator module		
RESISTORS				
	R1	68 ohm (blue, gray, black)		
	R2	294 ohm (red, white, yellow, black, brown)		
	R3	17.4 ohm (brown, violet, yel, gold, brown)		
	R4	294 ohm (red, white, yellow, black, brown)		
	R5	100 ohm (brown, black, brown)		
	R6	2.2 Kohm (red, red, red)		
	R7	10 Kohm linear potentiometer		

Table 1, continued

R8	2.2 Kohm (red, red, red)		
R9	100 Kohm (brown, black, yellow)		
R10	220 ohm (red, red, brown)		
R11	1.5 Kohm (brown, green, red)		
R12	1 Kohm (brown, black, red)		
R13	27 Kohm (red, violet, orange)		
R14	33 Kohm (orange, orange, orange)		
R15	10 Kohm potentiometer /switch		
R16	10 Kohm (brown, black, orange)		
R17	1.5 Kohm (brown, green, red)		
R18	27 Kohm (red, violet, orange)		
R19	100 Kohm (brown, black, yellow)		
R20	1 Kohm (brown, black, red)		
R21	1 Kohm (brown, black, red)		
R22	2 ohm (red, black, gold)		
R23	2 ohm (red, black, gold)		
R24	1 ohm (brown, black, gold)		
R25	220 ohm (red, red, brown)		
R26	47 ohm (yellow, violet, black)		
R27	1Kohm (brown, black, red)		
R28	10 ohm (brown, black, black)		
R29	10 ohm (brown, black, black)		
R30	10 ohm (brown, black, black)		
R31	10 ohm (brown, black, black)		
R32	47 ohm (yellow, violet, black)		
TRANSISTORS			
Q1	J-310, junction field effect, (JFET)		
Q2	2N-3904, bipolar, NPN		
Q3	2N-3906, bipolar, PNP		
HARDWARE / MISC			
E1	Enclosure 5x7x2		
PCB1	Printed Circuit Board		
J1	Power Jack, 2.1 mm		
J2	F female chassis connector		
J3	3.5 mm stereo jack, open ckt		
J4	3.5 mm stereo jack, open ckt		
spacers (2)	0.375 inch spacer, 4-40 thread		
K1, K2	Knob, 1/8 inch shaft		
P1	2.1 mm plug with 72 inch cord		
Screw (5)	4-40 thread, 1/4 inch long		
Lockwaser (5)	#4		
Flatwasher (1)	#4		
Nut (1)	4-40		
Solder Lug(1)	#4		
Wire	1ft red and 1ft black		
Feet (4)	Rubber adhesive feet		
Decals (2)	Front and rear panel decals		

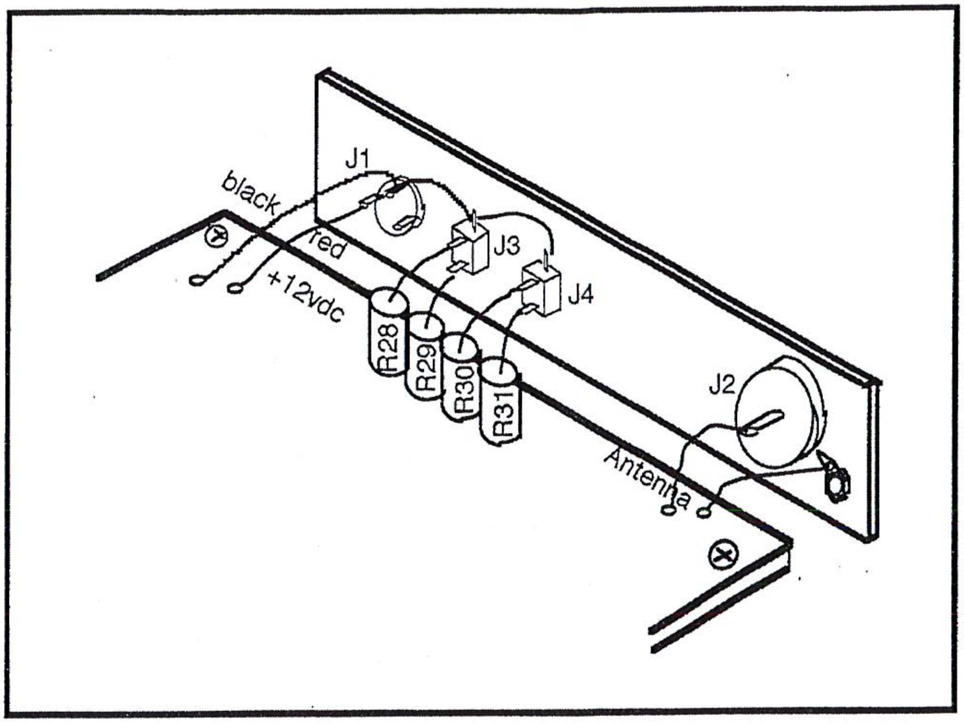

Figure 12. Rear panel wiring

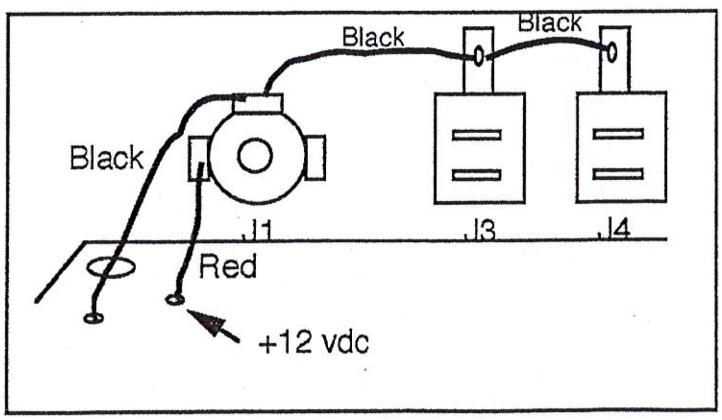

Figure 13. Rear panel power jack (J1) wiring detail

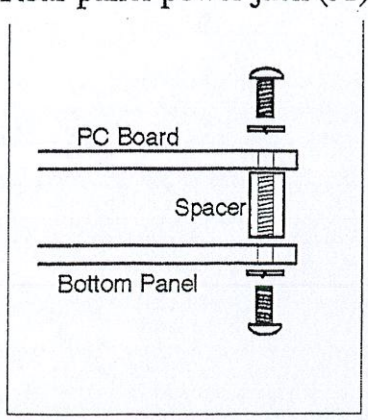

Figure 14. Mounting the spacers to the PC board and the bottom panel

Testing and Alignment of the Receiver

1) Supply the receiver with 12-volts of power. You can use a 12-volt battery or a 12-volt power supply.
2) Turn the power switch to off.
3) Connect an amplified speaker to the receiver audio output.
4) Turn on the speaker.
5) Turn on the receiver.
6) The LED should light up.
7) Set the volume knob to the 12 o'clock position.
8)Allow the receiver to warm up for several minutes.
9) Set the tuning knob to the 10 o'clock position.
10) Carefully adjust inductor L5 until a loud frequency tone is heard. This tunes the receiver to 20.00 MHz.
11) Use C2, C6, and L4 to obtain the maximum signal strength.
12) Adjust C6 for the maximum signal strength.
13) Adjust L4 for the maximum signal strength.
14) Adjust C2 for the maximum signal strength.
15) Repeat steps 12-14.
16) Turn everything off and disconnect the receiver from the power supply.
17) Unsolder and remove R32.
18) Snip jumper 6 and separate the wires by at least 1/8in.
19) Remove the right side panel. Install the top panel and re-install the right side panel.

Date	Time(hours)	Description
2/21/2006	1	Read manual Measured and cut copper wire, coaxial cable, and rope
2/22/2006	3	Connected copper wire to insulators Melted ends of rope Connected rope to insulators Remove outer covering of coaxial cable
2/28/2006	2	Strip inner layer of coaxial cable Attach F connectors to all four coaxial cables Draw straight line on PVC and conduit
3/1/2006	3	Mark and drill all 1/4in holes Soldered copper wire to coaxial cable
3/2/2006	1	Drill hole for base in endcaps Assemble hardware
3/3/2006	1.5	Enlarge holes for stop and at top of conduit Assemble both pieces together Dry run on roof
11/7/2006	0.5	Clean up lab Organize supplies
11/9/2006	1	Met with Adam Measured and cut copper antenna wire
11/11/2006	1.5	Assembled antenna wires Worked on mounting ideas
11/20/2006	1	Cut down the poles to 20ft Attempted to drill holes, drill bit dull Found a level
11/27/2006	0.5	Finished marking the poles Got new 1/4in drill bits
12/4/2006	1	Drilled all holes in poles
12/11/2006	0.5	Assembled eye hooks into masts Measured coaxial cable Got coaxial cable request to Dr. Johnson
1/22/2007	1	Discuss plans for base Clean work area/get organized
1/29/2007	0.5	Set up alternate meeting time for this week Discuss next steps
1/31/2007	1	Measured and cut 1 wavelength coaxial cable Unbraid copper wires and twist together
2/1/2007	0.5	Attach coaxial cable to antenna wire Began soldering process
2/5/2007	1	Finish soldering coaxial cable to antenna wires

2/12/2007	1.5	Assembled torroid cores Finished one antenna Still waiting for more coaxial cable Read manuals Browsed website Listened to other recordings
2/19/2007	1.5	Designed base structure Made shopping list Found RG59-U coaxial cable Assessed roof situation
2/23/2007	1	Measured and cut 2nd 1-wavelength coaxial cable Attached coaxial cable to antenna wire Began soldering
2/26/2007	1.5	Finished soldering coaxial cable to antenna wire Carried in 2x4's Applied polyurethane to 2x4's
2/28/2007	0.5	Read manuals
3/19/2007	1.5	Moved supplies to roof Began dissassembly of old antenna
3/23/2007	2	Assembled metal antenna on roof Measured guy lines Drill holes for hinges and eye hooks Test set-up
3/26/2007	1	Set up antenna Adjusted guy lines Scheduled first listening session
3/28/2007	1.5	Listening Session #1 Began 14:03 14:09 Disconnected antenna to show it worked 14:03-14:12 Adjusted tuning 14:12 Set tuning to 12 o'clock position 14:18 Set volume knob to 12 o'clock 14:38:46-14:38:49 Hard drive spinning 14:59 End recording
3/29/2007	2.75	Listening Session #2 7:57 Start recording 8:00 Turn radio knob left 8:00:49 Turn radio knob right 8:04:11 Set volume to 12 o'clock 8:04:11 Set tuning to one spot right of 12 8:18 Spike 9:04 Adjusted tuning, returned to original location Saved as 2 files, only holds 1:59 per file

4/2/2007	1	Noticed one pole had fallen Went to roof and found one antenna wire had broken
4/12/2007	1	Snow finally melted so able to fix antenna on roof Did test run, antenna worked Planned observing sessions
4/13/2007	3	Listening Session #3 Sunrise session Volume and tuning at 12 o'clock 11:14:30 Set adjustments Many spikes observed Observed ramp and drop similar to last year Series of chirps at 12"42 13:42:56 End recording
Total hours	41.25	

Jupiter Observation Table

Date	Above 15°	Above 20°	Below 20°	Below 15°	Sunrise
1/1/2007	747	857	1108	1219	807
1/15/2007	707	824	1015	1131	802
2/1/2007	618	741	909	1037	746
2/15/2007	534	703	816	949	725
3/1/2007	448	622	720	853	700
3/15/2007	359	536	625	801	633
4/1/2007	356	538	618	759	658
4/15/2007	300	438	523	703	631
5/1/2007	153	328	423	558	603
5/15/2007	1251	222	326	457	542

Data obtained using *The Sky* software program.