

Radio Telescope Hardware



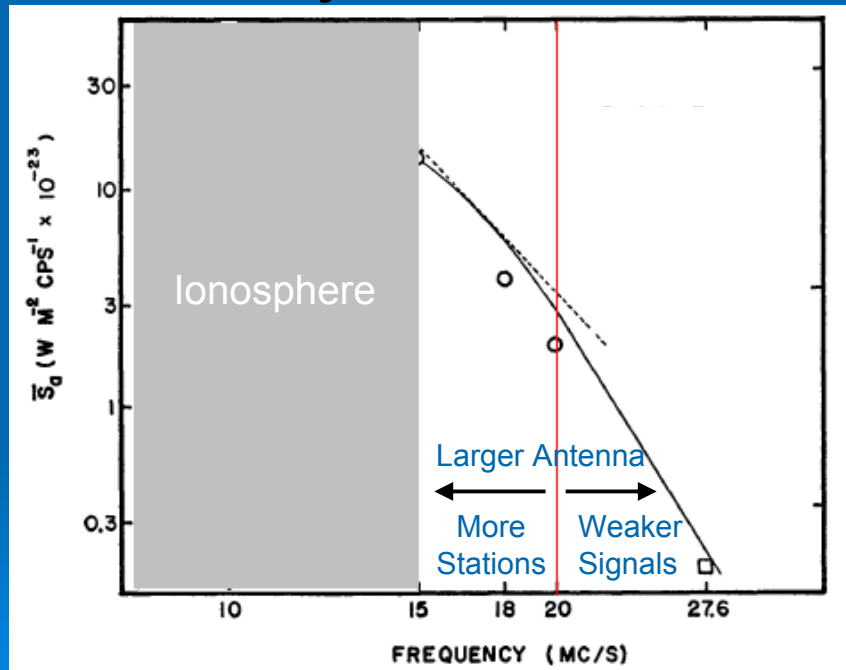
RADIO JOVE



Wes Greenman, Richard Flagg, Radio Jove Meeting, July 2, 2014, NRAO Green Bank

Good morning – my name is Dick Flagg. This morning Wes Greenman and I will be discussing the Jove radio telescope hardware. I would like to start off by answering a question I have heard several times about the radio telescope. That is - why does it operate at 20 MHz?

Why 20 MHz?



Carr et al AAS No2 , 1964

First of all the radio telescope was designed primarily for observations of Jupiter.

Here we see a curve depicting the strength of Jupiter signals vs frequency. Below 20 MHz Jovian signals are stronger but operating at lower frequencies would mean a bigger antenna. As we go lower in frequency there are more stations and also the ionosphere gets more absorptive. At frequencies higher than 20 MHz Jovian signals rapidly get weaker. To compensate for the weaker signals we would also need a larger antenna. So 20 MHz is a good compromise frequency.

Jove Radio Telescope Kit

- Receiver - components, enclosure, power supply
- Antenna - wire, insulators, coax, coax connectors, power combiner, insulators
- Software – licenses for SkyPipe and Radio Jupiter Pro
- Reference CD – *Listening to Jupiter*, etc
- Documentation – printed manuals
- Tech Support

The radio telescope kit contains all of the receiver components and most of the hardware for the dual dipole antenna. In addition, the kit includes licenses for SkyPipe and Radio Jupiter Pro as well as printed documentation.

Hardware – The Receiver

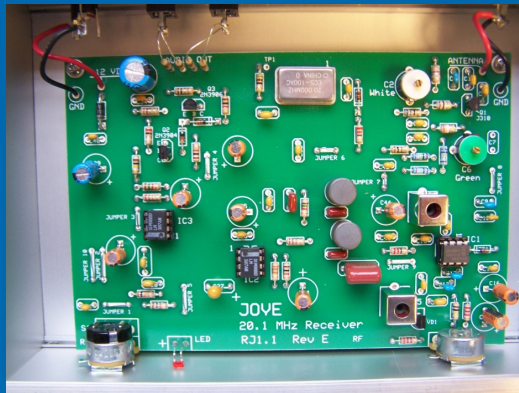


**RADIO
JOVE**

Richard Flagg, Radio Jove Meeting, July 2, 2014, NRAO Green Bank

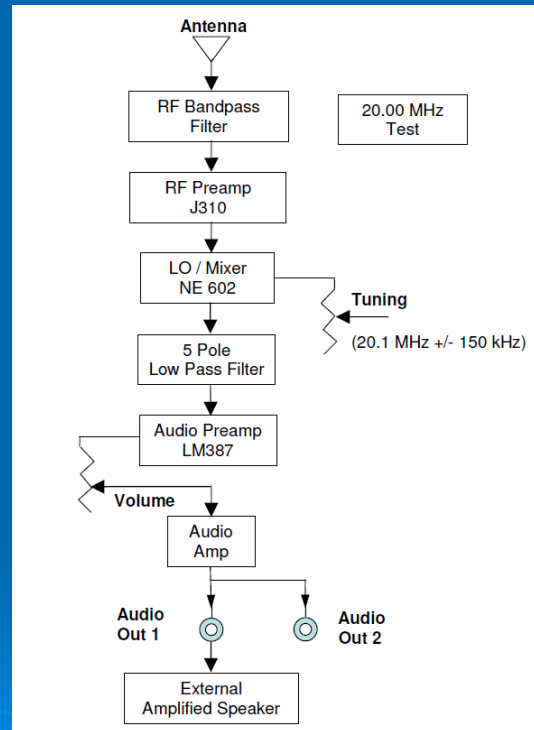
Lets dig into the receiver itself.

Jove Receiver



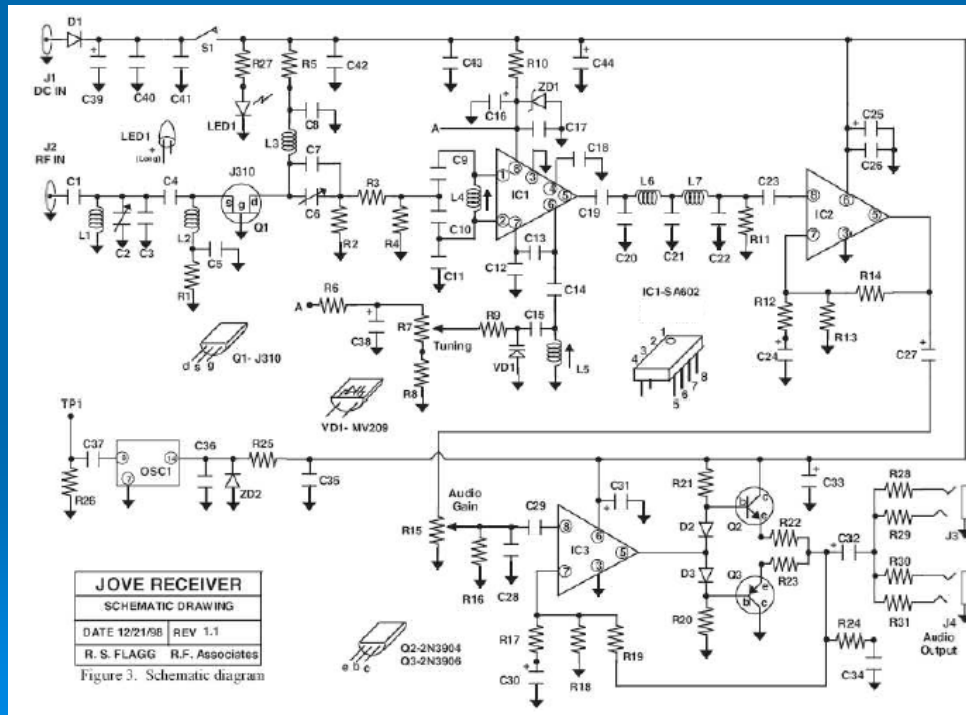
Since its introduction almost 15 years ago the Jove receiver is basically the same circuit. The PC board has been improved and the receiver front panel markings are now imprinted – a big improvement over the stick-on decals included with the early kits. The manual has also been improved with expanded tune-up and trouble shooting sections.

- Jove RJ1.1
- 20.1 MHz Rcvr
- Direct Conversion
- RF Amp
- Tuneable LO
- Mixer
- 3.5 kHz LPF
- Audio Amp
- Test Oscillator



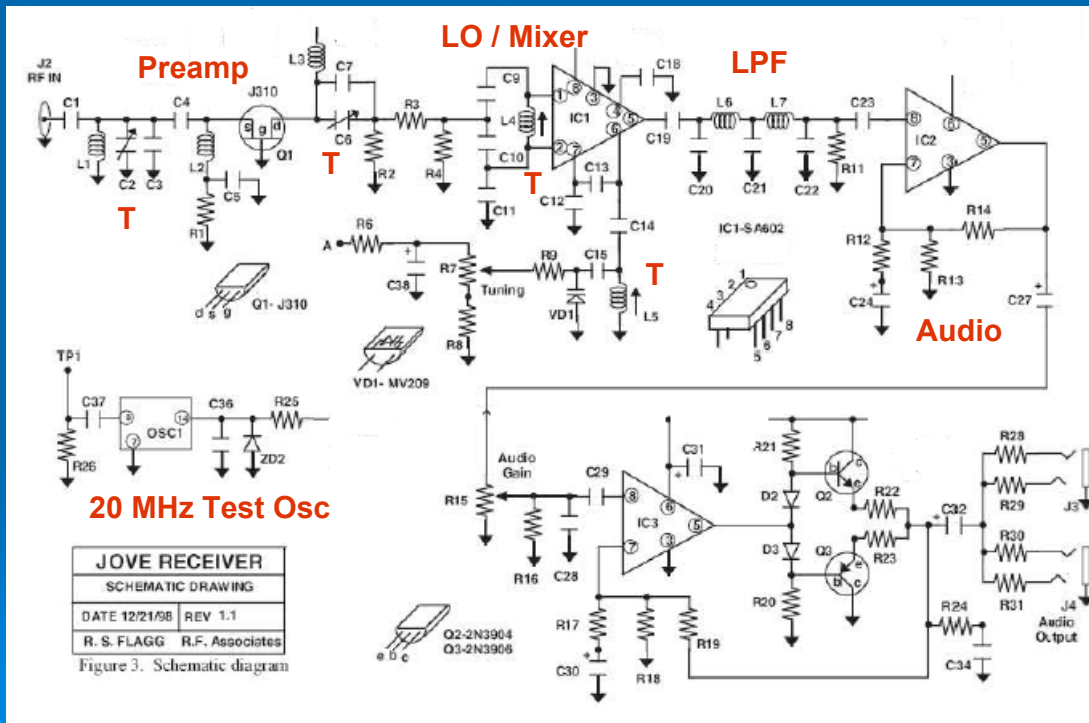
The Jove receiver block diagram. This is a direct conversion receiver – which means there is no intermediate frequency (IF) amplifier – the RF signal is converted directly down to audio. The audio output of the mixer is low pass filtered to a 3.5 kHz upper frequency limit (this filter determines the receiver selectivity). As there is no image rejection, frequencies both above and below the local oscillator are folded into the audio output band. The receiver includes a 20.000 MHz crystal oscillator used for alignment.

Jove Receiver Schematic



Jove RJ1.1 receiver schematic. Three integrated circuits, 3 transistors and 5 diodes. About 100 parts all together.

RJ1.1 Signal Flow / Tuning



The Jove receiver schematic simplified to show just the signal path (deleting the DC power distribution). The four (T) symbols represent components that must be tuned by the builder during the receiver alignment procedure. Signals from the antenna pass thru a 20.1 MHz bandpass filter/impedance matching circuit to the J310 grounded gate preamplifier. The preamp output goes thru a couple of impedance matching circuits to the input of the SA602 mixer. The SA602 circuitry includes the tuneable local oscillator, whose frequency is controlled by an MV209 varactor (a diode whose capacitance is controlled by the applied DC voltage). The audio output of the mixer passes thru a 5 pole 3.5 kHz low pass filter and then to the audio amplifier portion of the receiver. Two low impedance low power audio outputs are provided – adequate to drive headphones and a computer soundcard.

Receiver Performance Specs

- Noise Figure
- Tuning Range
- Frequency Stability
- Bandwidth
- Automatic Gain Control (AGC)
- Dynamic Range
- Gain Stability
- Kit – ease of assembly and tuneup
- Cost
- Tech Support

Several receiver parameters are important for receiving Jupiter – and some typical receiver parameters are not important for Jupiter. **Noise figure**, which is a measure of how much noise the receiver adds to an incoming signal needs to be only moderately low, as the galactic background is very hot at these frequencies. The **tuning range** is a few hundred kilohertz, adequate to find a clear spot between stations. **Frequency stability** is not of great importance as Jupiter signals are broadband – tens to hundreds of kilohertz wide. The only time this may be important if the receiver is used unattended in an environment with wide temperature variations – then the receiver could drift onto a station. The **bandwidth** of a few kilohertz is chosen so the receiver has reasonably good selectivity in a part of the spectrum where there are lots of stations.

There is no **AGC** in the Jove receiver. An automatic gain control circuit senses the strength of an incoming signal and adjusts the receiver gain so that weak and strong signals are about the same intensity at the output. This is great for listening to local and distant radio stations but it can severely distort Jupiter and solar radio bursts. The Jove receiver needs a wide **dynamic range** to accommodate a wide range of Jupiter and solar burst amplitudes without introducing distortion or saturation. **Gain stability** is important as radio astronomers hate it when the baseline drifts all over the place. In order to make the **kit** easy to assemble, thru hole components were used and a detailed assembly manual is available (although I fear it is seldom read by high school students). A built in test oscillator provides the signal necessary to tune up and align the receiver. **Cost** was a very important driver in designing the receiver – with a goal of under \$100. **Tech support** is available via a toll free phone number to India. NO – I'm kidding! Tech support is available from Jove team members thru telecons and e-mail. The receiver manual contains troubleshooting information. Receiver repair for a flat fee of \$25 is also offered so we feel that the vast majority of users can get their receivers working.

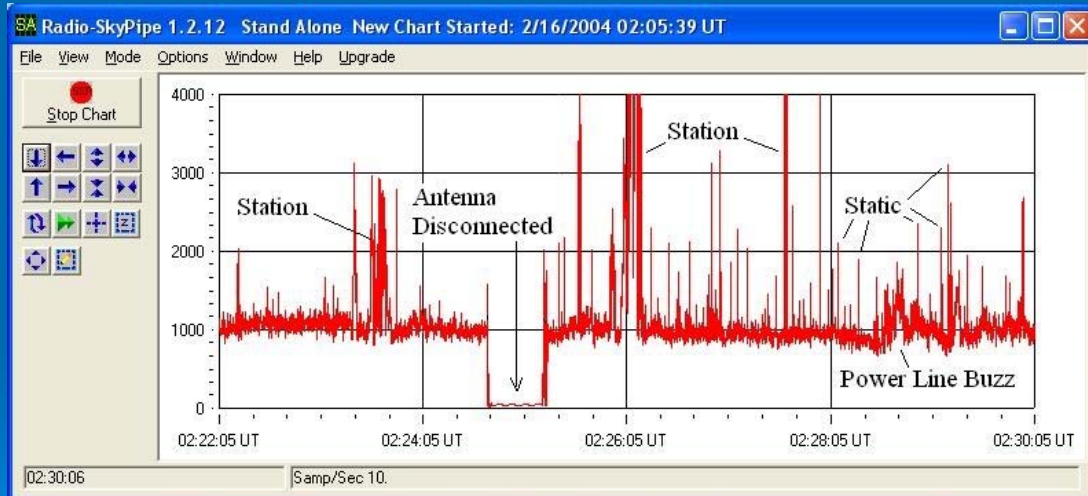
Noise Figure – what do we need

- Galactic Background temp at rcvr (20 to 50 Kk)
- Rcvr should contribute $< 1/10$ GB temp
- Noise temp of rcvr should be ≤ 2.0 Kk (NF 9 dB)
- Connect antenna : >10 dB noise rise
- Rise in dB = $10 \text{ LOG}[(T_r + T_{gb})/T_r]$

Typical Jove rcvr noise temp 1Kk (6.5dB NF)
 Get about 15 dB rise when antenna connected
 Receiver noise is insignificant

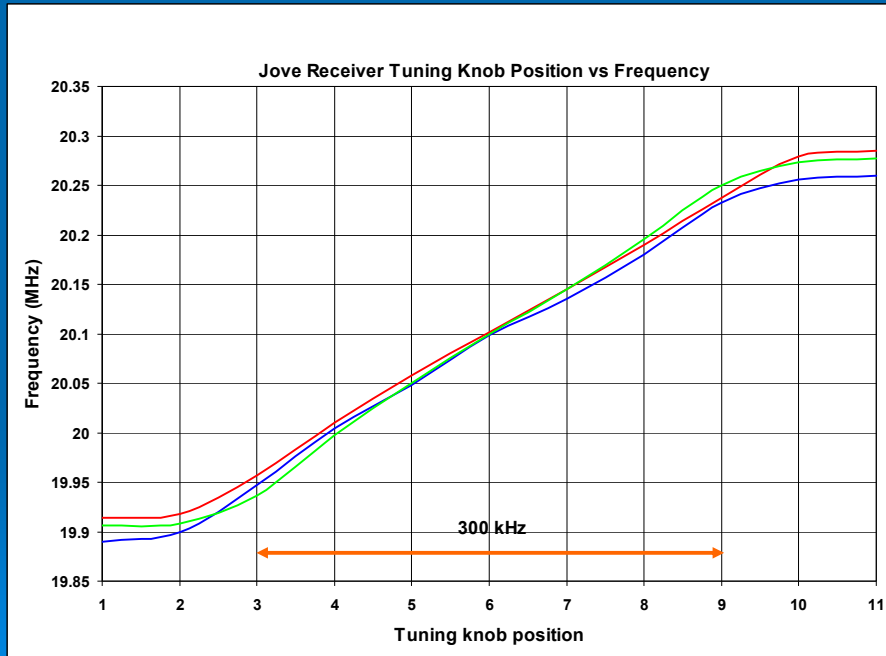
I apologize if there are any of you that aren't familiar with the term antenna temperature. We will talk more about it later. Suffice to say that when you connect your receiver to the antenna, the radio noise you receive is quite strong. This background noise comes from relativistic electrons spiraling in the galactic magnetic field and is called the galactic background. Jupiter signals are heard above this baseline noise level. If the Jove receiver added a lot of internal noise it would make the Jupiter signals harder to hear. For those of you comfortable with the terminology you can see that the GB temperature at the antenna is about 50 kK. (just to be clear a kK is 1000 kelvins). The equivalent temperature present at the receiver input, assuming a few dB of cable loss is typically 20 kK. We would like the receiver to contribute no more than say 1/10 of the level from the GB. This in fact is the case and when the antenna is connected to the receiver the level increases by about 15 dB.

Jove Receiver and Antenna



The Jove receiver audio output is usually connected to a computer running Jim Sky's SkyPipe strip chart software. In this example the vertical axis is in SkyPipe units, relative units proportional to voltage. The grassy trace around 1000 units is the galactic background. When the antenna is disconnected the trace drops practically to zero. We also see a few stations, some static and the effect of power line arcing.

Tuning Range – about 300 kHz



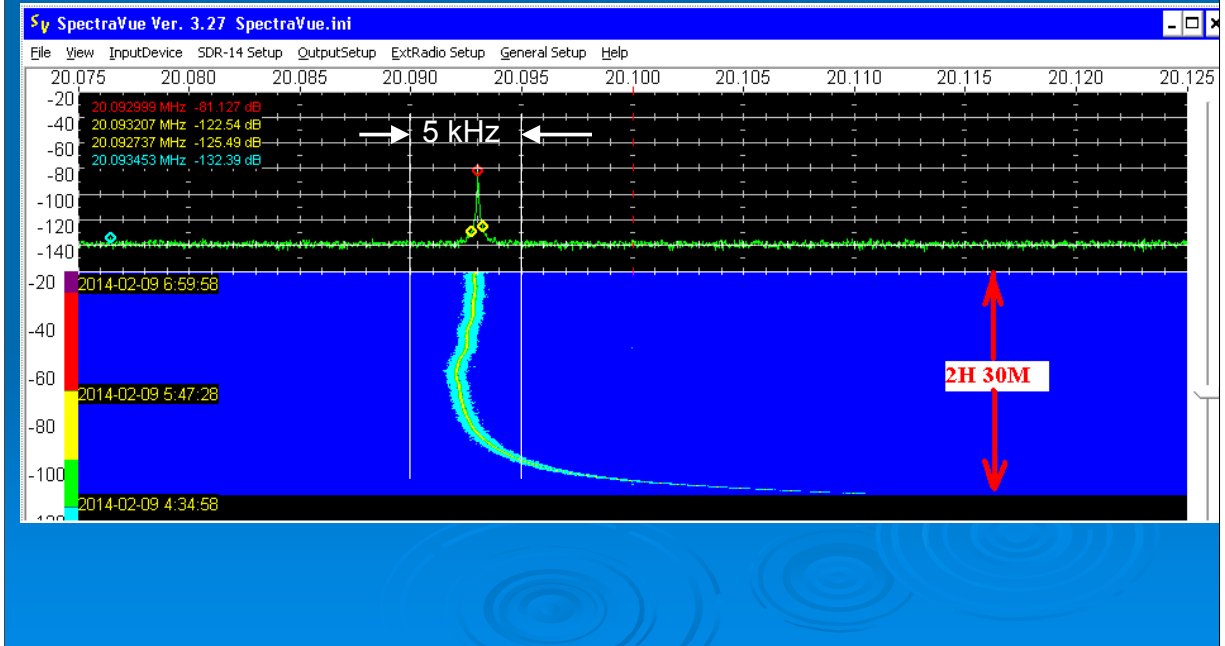
This plot shows receiver frequency as a function of tuning knob position – for 3 different receivers. The range is quite consistent and about 300 kHz

Freq Stability – what's needed?

- Jupiter and Solar bursts are wideband
- Jupiter bursts tens to hundreds of KHz wide
- Wide band noise, not like CW or SSB where 10 Hz freq stability desired
- Receiver drift rates of a few kilohertz over several minutes generally not objectionable unless receiver is unattended.

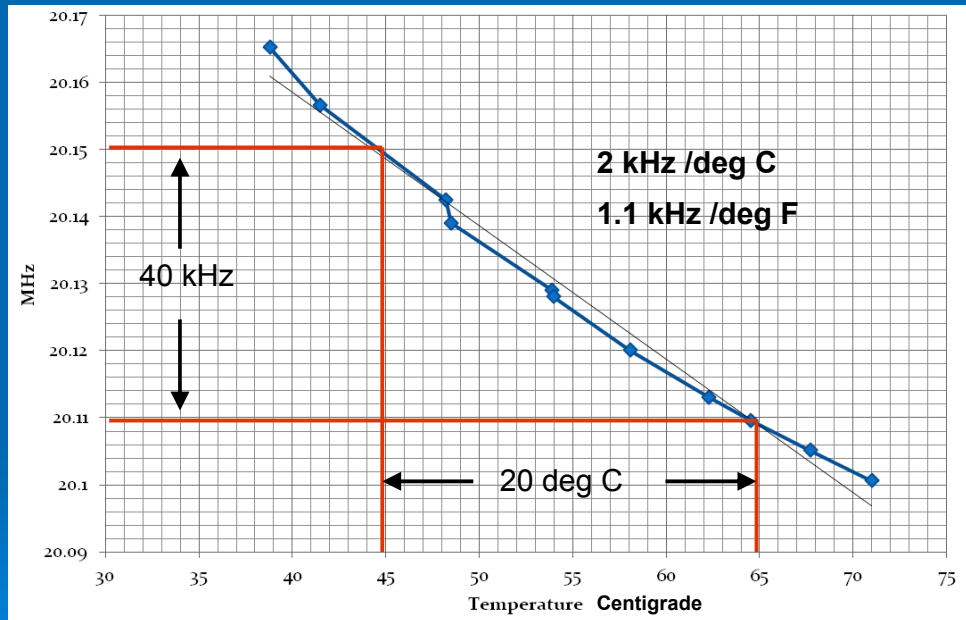
Since Jupiter and solar bursts are wideband, frequency stability is not of primary concern in the Jove receiver. This is particularly true if the observer is present to tune the receiver away from interfering stations. If the receiver is operated unattended in an environment with wide temperature swings it would be nice to be able to tune it remotely – or perhaps improve the frequency stability as a function of temperature.

RJ 1.1 Receiver LO Drift



Here we see a plot of the Jove local oscillator frequency vs time after turn-on. This plot was made by connecting an SDR-14 to the Jove receiver antenna terminal. The LO from the Jove receiver is at a level of about -70 dBm at that point. Drift is pretty severe for the first few minutes but then it settles down, just drifting a couple of kilohertz over a couple of hours. This was run at ambient temperature which likely varied a few degrees over that period of time.

Jove Receiver Drift vs Temp

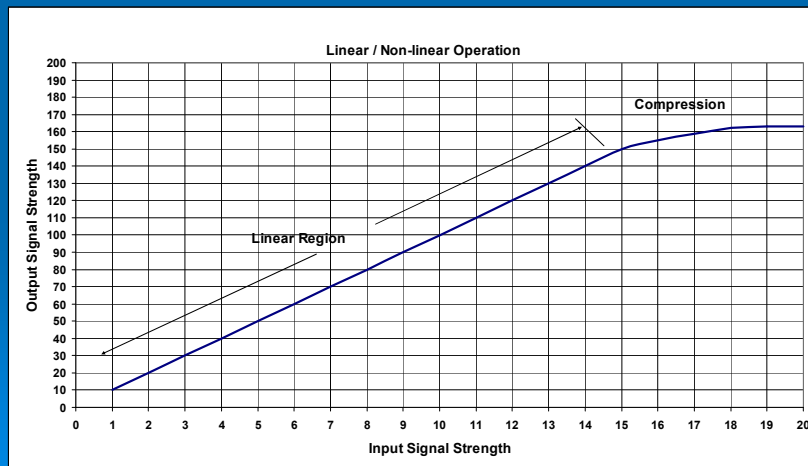


Original data from Keith Payea AG6CI SWC 2014

At the 2014 SARA Western Conference Keith Payea discussed stabilizing the Jove receiver in terms of frequency vs temperature drift for unattended operations. He stuck a Jove receiver in an oven and measured the frequency of the LO as a function of temperature. He cooked the Jove receiver – well done I think was the setting – from 100 to 160 deg F. As we see from Keith’s plot the frequency drifted downward at a rate of about 2 kHz per deg C (which is about 1.1 kHz / deg F). In an air conditioned environment the receiver drift is negligible.

Dynamic Range

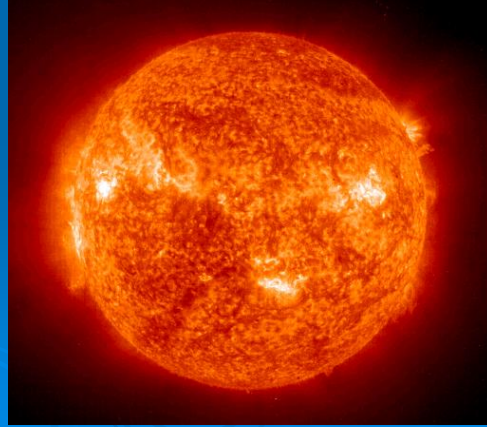
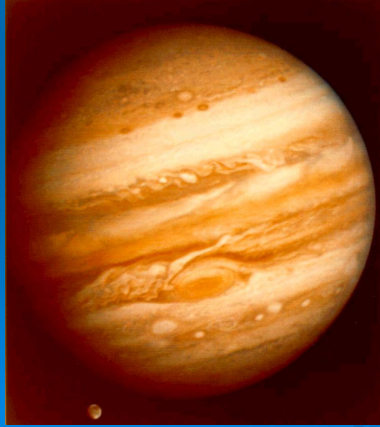
- Dynamic range is the useful range of output signal vs input signal – from the noise floor to compression.



Dynamic range is a measure of the range over which the audio output of the receiver follows changes in the RF input level. When the input signal gets too strong the receiver is incapable of providing sufficient output and goes into compression or saturation. So how much dynamic range do we need?

Dynamic Range – What is needed?

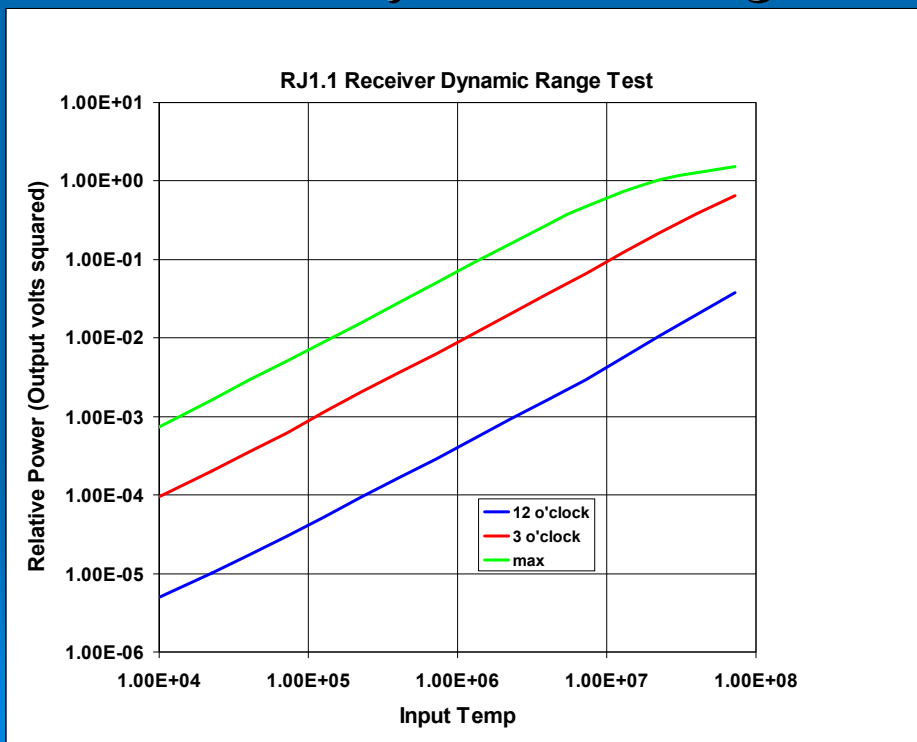
- Assuming a standard Jove dual dipole antenna
- For Jupiter: 20 dB
- For Solar :>40 dB



The first assumption is that the observer is using a Jove dual dipole antenna. If they have a bigger, higher gain antenna then signals from Jupiter and the sun would be stronger.

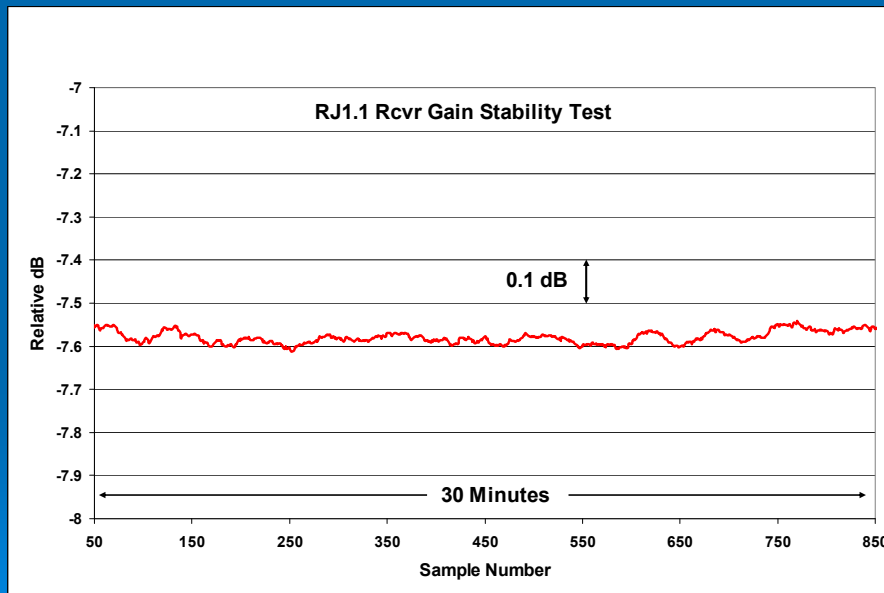
As rather rough order of magnitude estimates we can say from experience that 20 dB is adequate for the strongest Jupiter bursts and a 40 dB dynamic range will handle the strongest solar bursts.

RJ1.1 Dynamic Range



The dynamic range of the Jove receiver is determined in part by the setting of the audio gain control. The three curves represent three different settings, 12 o'clock, 3 o'clock, and full gain. The horizontal scale represents input temperature (a 40 dB range) and the vertical scale represents relative power (output voltage squared). Even at full gain the receiver dynamic range is in excess of 30 dB. At the recommended gain setting of 12 o'clock it is 40 dB or more.

Jove Receiver Gain Stability



And finally, the last performance plot – this one showing receiver gain stability.

Jove Receiver Summary

- Noise Figure: 6.5 dB
- Tuning Range: 300kHz
- Frequency stability: 2 kHz / deg C
- Bandwidth: Audio 3.5 kHz (7 kHz RF)
- Dynamic Range: 40 dB
- Gain stability: <0.1dB per hour drift at constant temperature.

In summary, these are the performance specifications of the Jove receiver.

Probably the most important performance spec is the following one:

It Works!



Hardware – The Antenna



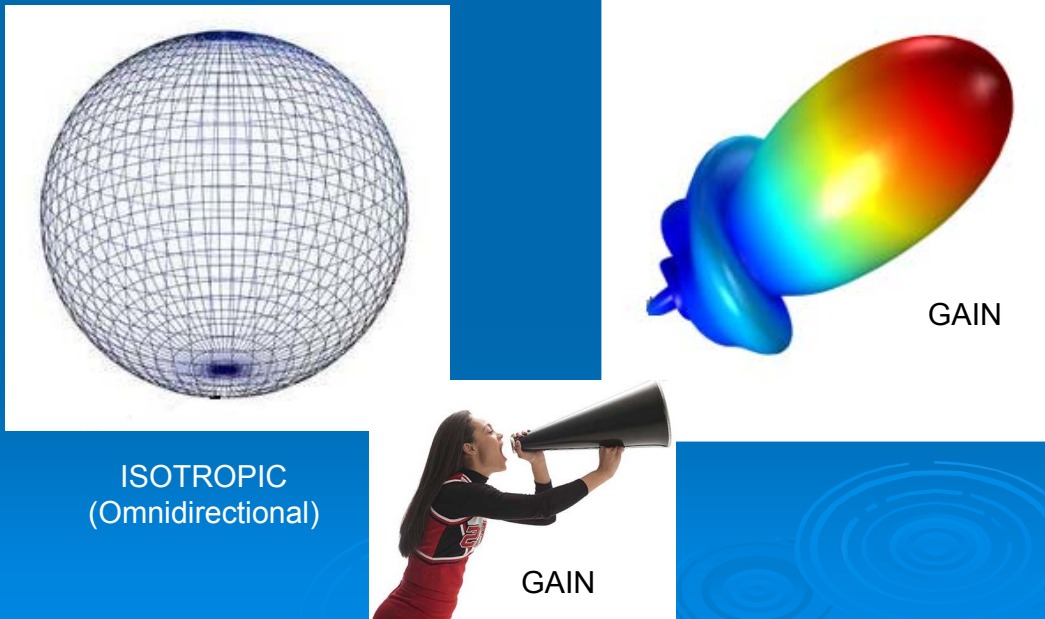
**RADIO
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Wes Greenman, Radio Jove Meeting, July 2, 2014, NRAO Green Bank

Hello, my name is Wes Greenman. My Jove site is Radio Alachua.

I will talk about the Jove dual-dipole array, such as the one (not seen) in this first slide.

Antenna Gain relative to Isotropic Radiator (dBi)



So, what exactly is an antenna?

One definition would be that an **antenna** is a device for converting electromagnetic radiation in space into electrical currents in conductors. You are surrounded by antennas such as those located on cell towers, AM/FM antennas, TV antenna's and even the old CB antennas.

There are several terms we use when discussing antennas.

1. We use the expression **dBi** to define the gain of an [antenna](#) system relative to an [isotropic radiator](#).

2. An isotropic radiator is a theoretical point source of electromagnetic energy which radiates the same intensity of radiation in all directions.

3. Gain If you hold the small end of a cheerleader's megaphone to your ear you would find that **it amplifies sounds from certain directions**. Antennas have these same properties – **the antenna has gain (it amplifies signals) and it has a beaming pattern (it amplifies signals best coming from certain directions)**. The Jove antenna beam is tens of degrees wide so when it is aimed properly Jupiter takes several hours to pass thru the beam.

ANTENNA: Definition of terms

I_{ANT} = Maximum radiation intensity from an antenna

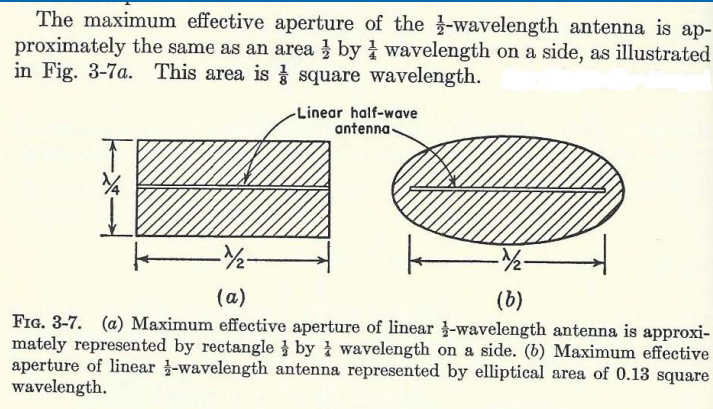
I_{ISO} = Max radiation intensity from (lossless) isotropic source with same power input

Then Gain = $G_i = I_{ANT} / I_{ISO}$

Gain = $k D$ where D is Directivity and k = antenna efficiency

Gain referenced to an isotropic in decibels = $G_{dB_i} = 10 \log_{10} G_i$

Effective Area (for any antenna) = $A_e = G_i \lambda^2 / 4\pi$ (m²)



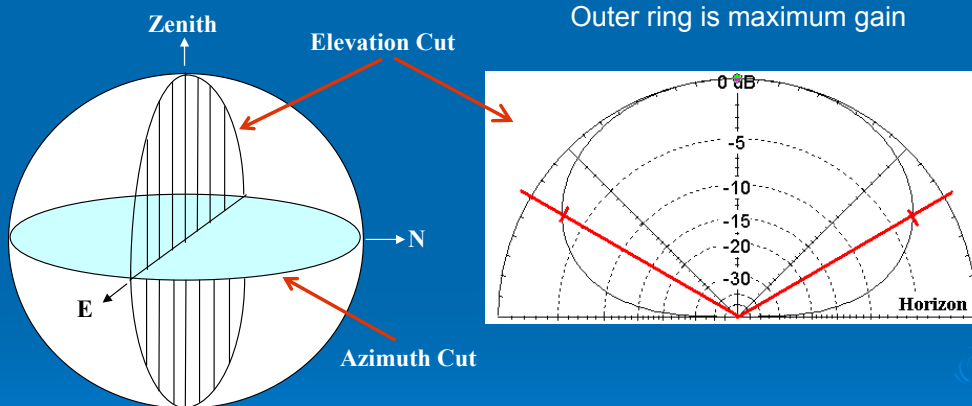
Antennas – by Kraus

Just a little bit of math – showing the important relationship between gain and effective area.

The **higher the gain the larger the effective area** and the **narrower is the beam-width**. If you want to collect lots of rain water use a wide mouthed bucket. If you want to collect lots of signals use an antenna with high gain and a large collecting area.

As seen from the dipole image, the effective area of a dipole is approximately 1/8 th square wavelength.

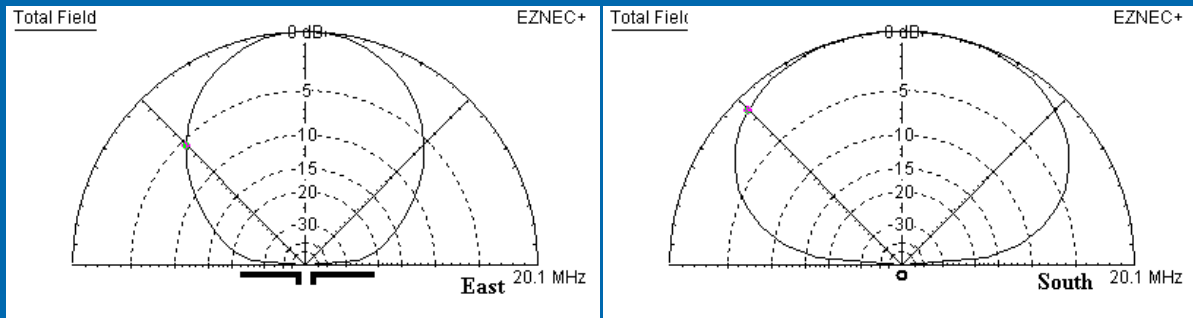
ANTENNA PATTERN OF SINGLE DIPOLE ABOVE GROUND



An antenna pattern is really a **3-dimensional beamshape with gain varying with direction**. However we often use 2-dimensional patterns, showing gain as a function of elevation angle and gain as a function of azimuth. We see these two cuts in the left hand drawing. An elevation pattern is seen on the right.

Lets pretend an antenna is transmitting. This pattern can be made by moving from the horizon to the zenith at a fixed distance from the antenna and measuring how strong the signal is at different elevation angles. We then plot those values in decibels referenced to the peak signal strength, which is normalized to 0 dB. (The maximum gain is represented as the outer ring marked 0 dB in the right hand drawing). So we see this antenna has a maximum gain straight up. The power has fallen off to half (or 3dB down) as seen by the intersection of the red lines in the antenna pattern. You can then **define the beam-width as the angular distance between half-power points**, 120 degrees in this case.

Single dipole at 10 ft



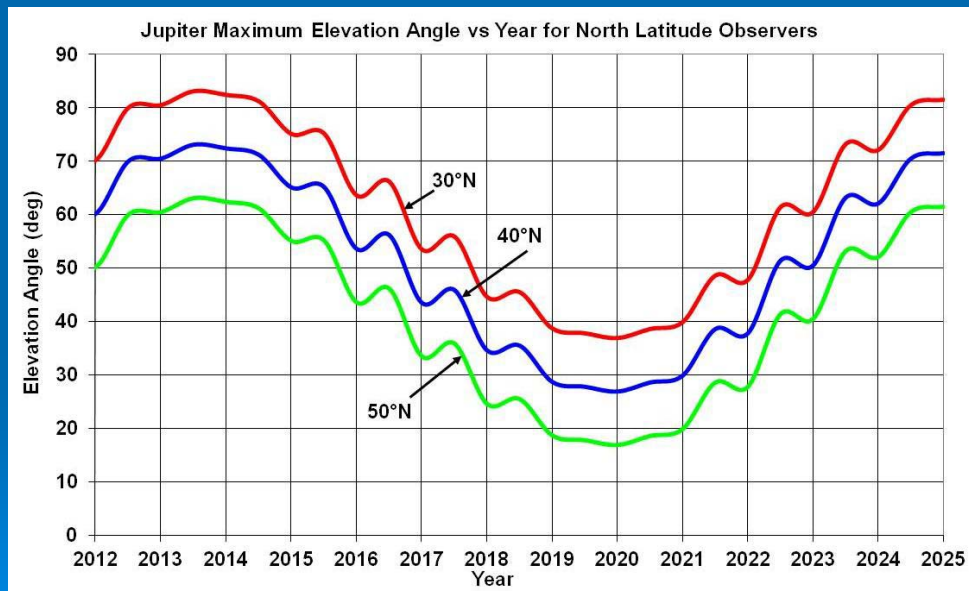
East-West Beamwidth = 67.8 Degrees

North-South Beamwidth = 117.8 Degrees

Dipole wire runs E-W

Now a look at the pattern of a single dipole. A dipole close to the ground has its beam pointing up to the zenith. In these elevation views, the dipole wire is running E-W. Note the EW beamwidth is narrower than the NS beamwidth. There are nulls off the ends of the dipole in the EW direction.

Jupiter's Max Elevation vs Year for Northern Latitudes

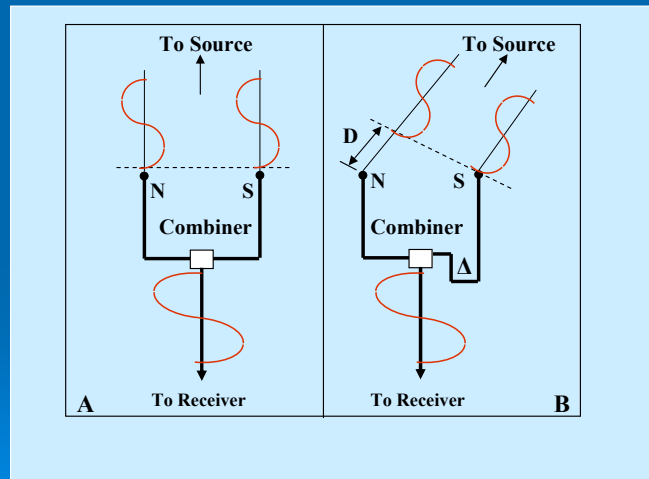


Well, Jupiter is not usually at the zenith and we need a way to steer our antenna beam to where Jupiter is in the sky. For example in 2015 an observer at 40 deg north would want to have the peak of their beam at an elevation angle of about 65 degrees (or even lower cause Jupiter is at the max elevation only at transit).

So how do we steer the antenna beam to center on Jupiter? This is the beauty of the JOVE Array. We add 2 things, a second dipole and an extra delay (coax) cable so we can steer to most elevations from 20 degrees to 90 degrees to keep Jupiter well within our beam. The second dipole doubles the gain of our array as an added bonus.

JOVE Array Phasing

2 dipoles – equal cables – beam at zenith
 2 dipoles + extra phasing cable – steer beam

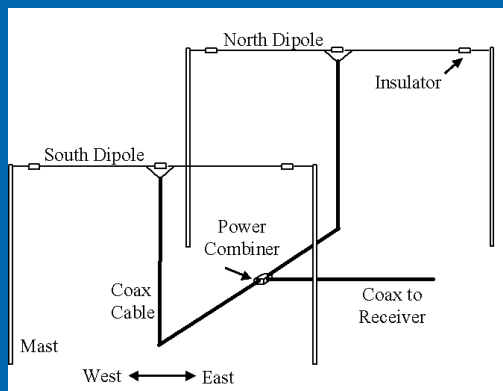


Here is how two antennas and phasing works. (This is a single frequency narrow-band solution). The example is for most of the Northern Latitudes.

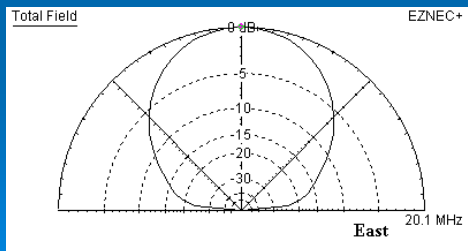
In drawing (A), if the source is directly overhead, the signal wave-front strikes both the north and south antennas at the same time. If the cables are the same length then the signals would arrive in phase to produce a maximum signal at the combiner output.

If the source is from the south, drawing (B), then the signal wave plane will hit the south antenna first, then the north antenna. This would result in a **signal delay (D)** in the north antenna. **We can express this signal phase delay in terms of electrical degrees or fractional wavelength.** If we increase the cable path length or cable delay (Δ) in the south antenna where $\Delta=D$, then the 2 signals will arrive in phase at the combiner output. **Thus, by changing the extra cable delay (Δ) we can steer the beam up and down in elevation.**

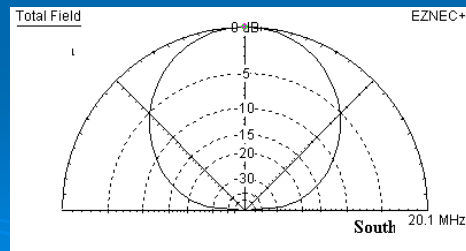
JOVE Dual Dipole Array at Transit



Height = 10 Feet



East-West Beamwidth = 66.4 Degrees



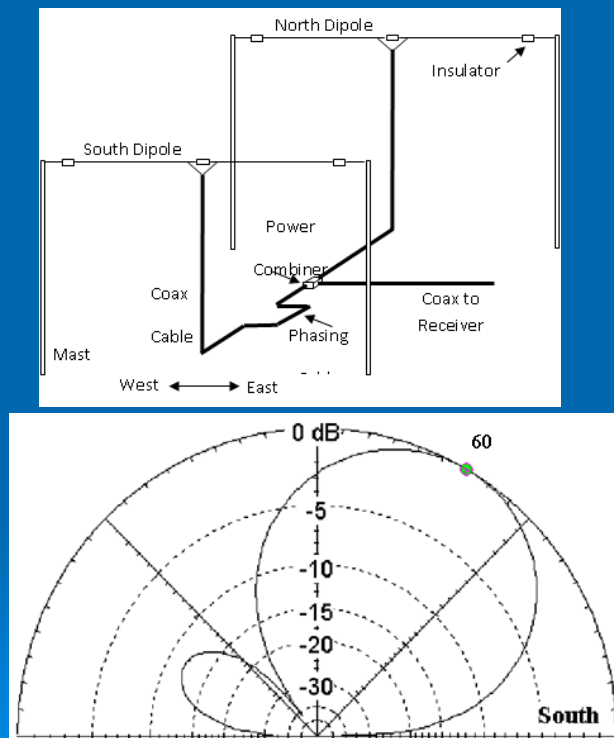
North-South Beamwidth = 69.6 Degrees

“Why did we choose the dual-dipole Array?”

1. Inexpensive
2. Easy of construction.
3. Enough sensitivity to detect many Jupiter storms.
4. Extremely easy to point the antenna beam.
5. Holds up well in bad weather.

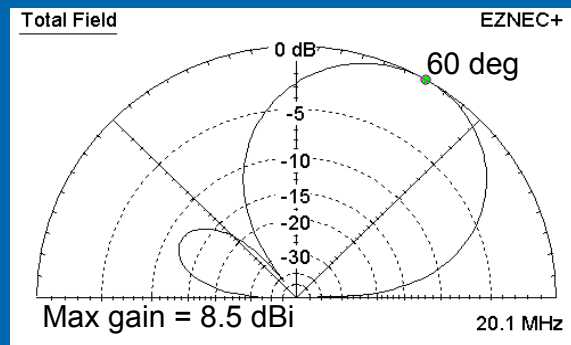
The Jove dual dipole antenna is shown with equal lengths of coax connecting each dipole to the power combiner. This is similar to the configuration of (A) in the last slide. The resulting beam is overhead (or at transit). The dual dipole array produces a narrower beam with 3 dB more gain than a single dipole.

JOVE Array with 90 degree phase cable

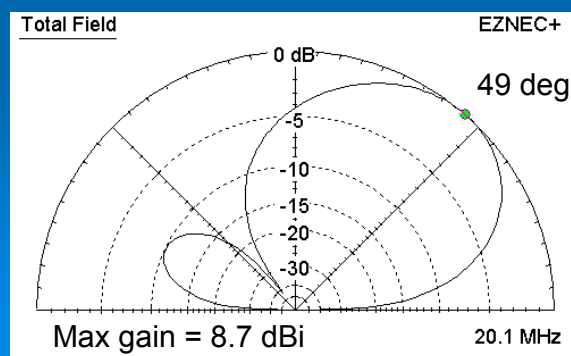


Now we look at the Jove dual dipole array with a 90 degree phasing cable inserted in the transmission line leading from the south dipole to the power combiner. You can see that the additional 90 degree phase cable causes the beam to shift 30 degrees south to a 60 degree elevation.

Antenna height: 10 ft. 90 deg phasing



Antenna height: 15 ft. 90 deg phasing



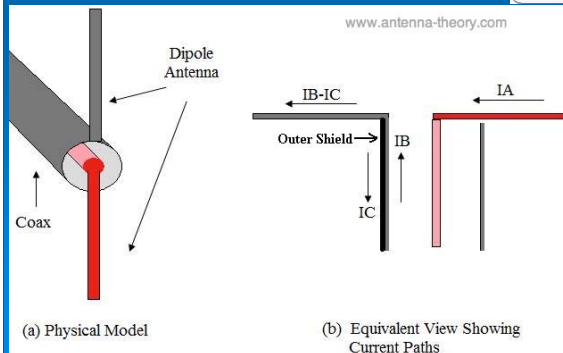
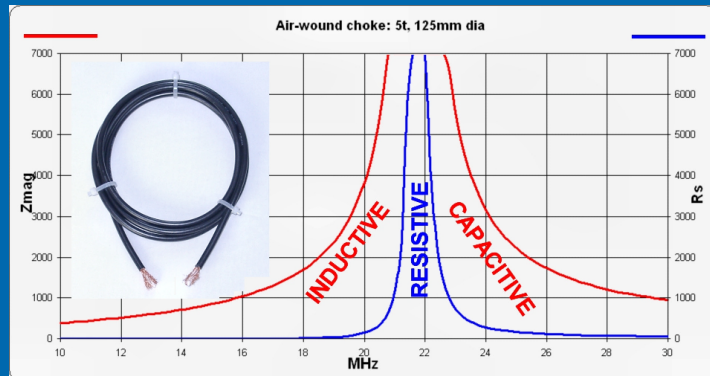
Comparison of phasing vs height. The same phasing at an increased height gives a lower beam angle. By adjusting both the height and phasing the beam can be steered over a wide range of elevation angles.

DIPOLE ANTENNA AND BALUNS

FERRITES



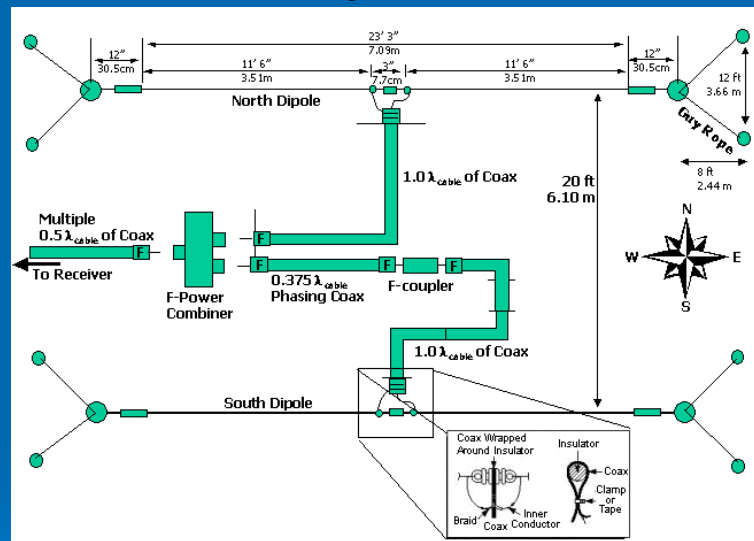
CHOKER BALUN



The dipole is inherently a balanced device. The coax that attaches to the feed point of the dipole can be considered an unbalanced device. A **Balun** is used to "balance" unbalanced systems - i.e. that's where power flows from a balanced line to an unbalanced line (hence, balun derives from *balance* to *unbalanced*). **For a dipole antenna to operate properly, the currents on both arms of the dipole should be equal in magnitude.**

The (1A) current that flows from the right dipole arm flows down the center conductor. The return current (1B) that travels along the inner surface of the coax shield (IB) has two paths: it can travel down the left dipole antenna, and down the outer surface of the coax shield (IC). **If it flows down the outside of the shield the coax becomes part of the radiating structure and it will distort the radiation pattern.** To prevent current (IC) from flowing down the outside of the shield you place a high impedance near the feedpoint, which insures all the current will flow down the left-dipole arm. **This high impedance can be in the form of ferrite chokes** which have an impedance of several hundred ohms, or you could use the coax itself in the form of a coil which has a several K ohm impedance at the resonant frequency of the coil. Unfortunately this is a narrow band approach and the impedance is dependent upon the exact dimensions of the coil. For simplicity we have opted for using ferrite beads.

JOVE Array Construction



Key Points to Remember:

1. Dipole Phasing – Solder center conductors to same compass direction.
2. Install ferrites on coax before soldering coax to the antenna feed.
3. Install Array Phase Delay cable in proper dipole line. (N or S hemisphere)

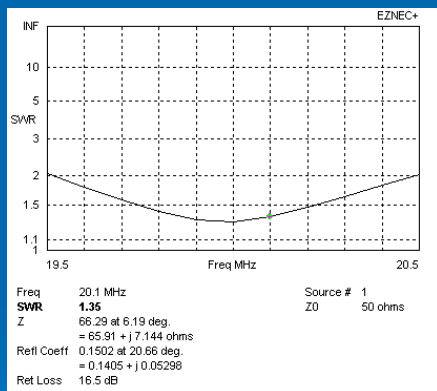
A word about the Jove dual dipole construction (northern hemisphere). When constructing the dual dipole there are several points to remember.

1. Internal Dipole Phasing: Solder the center conductors to East in both dipoles or both West in both dipoles. Not one center conductor to the east and other to the west. If you cross-wire the feedpoints it is the same thing as adding a 180 degree delay cable to the array. **Always check this before you raise your antenna.**

2. Install ferrites on the coax before soldering the center conductor and shield to the antenna.

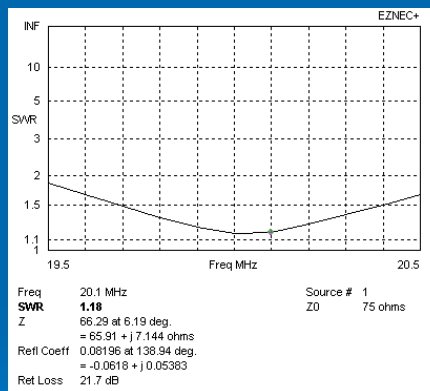
3. Install the external Phase Delay cable in the proper dipole line (South for Northern hemisphere and North for Southern Hemisphere).

SWR for single dipole at 10 ft



50-Ohm source to 66-Ohm Load
SWR= 1.35

JOVE System



75-Ohm source to 66-Ohm Load
SWR = 1.18

Standing wave ratio (SWR) is a term used to describe how effectively power is transmitted from a source to a load.

In a receiving antenna system, you want to transfer all of the power from the antenna through the coax, to the load (receiver input). If the antenna, coax and receiver are all of the same impedance, then all of the power from the antenna would be delivered to the load. In this condition the SWR is 1:1. If the antenna and receiver input are different impedances then there will be reflected power resulting in a higher SWR measurement. The Jove dual dipoles don't deliver a perfect 1:1 SWR as the antenna impedance is closer to 66 ohms than 50 ohms. But very little power is reflected in any case. We can tolerate imperfect SWR's since we have such high galactic background temperatures compared to system noise

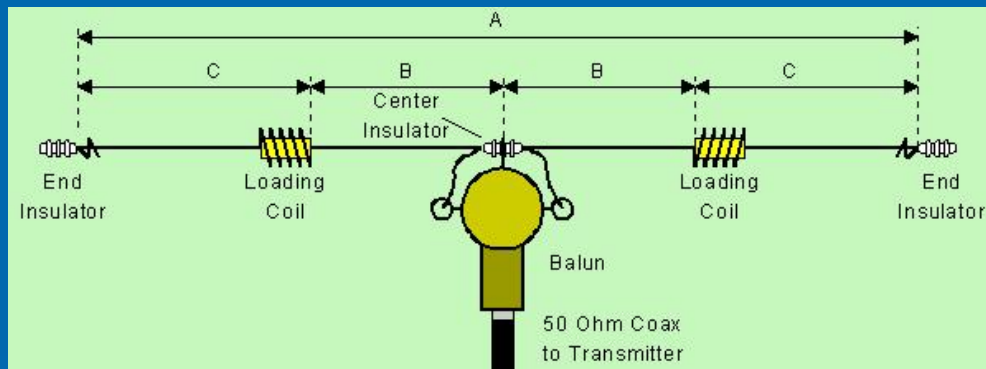
The Jove receiver is 50 ohms but we use 75 ohm coax. You may wonder why. We use 75 ohm coax because it is easy to put F-connectors on without special tools. This also allows us to use an inexpensive TV system power combiner, with 3 F-connector ports.

Except for the phasing cable, we use multiple half-wave length sections of cable leading to the receiver, which means the impedance we see at one end is the same as exists at the other end.

Other Antennas

- Smaller Antennas: (loaded dipole)
 - reduced efficiency due to impedance matching
 - Radiation resistance decreases (ohmic losses become more important)
 - Reduced bandwidth when made resonant
- Larger Antennas (Yagi, Moxon)
 - More gain
 - Narrower Beamwidth
 - Mechanical steering

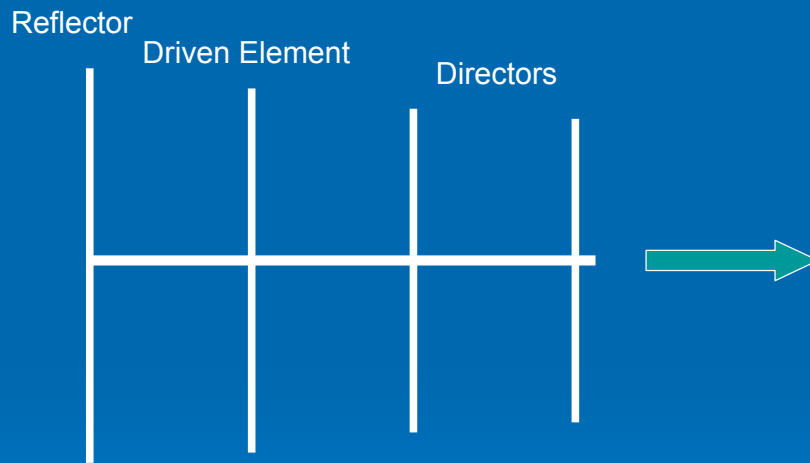
Short dipole with loading coils



k7mem.com

A dipole can be made shorter by using loading coils. As the antenna is made shorter the radiation resistance decreases and the capacitance increases. The inductance in the coils in each arm resonates with the series capacitance due to shortening. See k7mem.com for further details.

Dipole with Parasitic Elements (Yagi)



This is a Yagi antenna. The driven element is basically a dipole. By adding a longer element called a reflector behind the driven element and shorter elements called directors in front we increase the antenna gain.

➤4. YAGI ANTENNA

UPSIDE:

- ❖ Good gain
- ❖ Narrow Beamwidth

DOWNSIDE:

- ❖ Expensive
- ❖ Need Tower
- ❖ Need Tracking



Note: If used on an equatorial mount, then this becomes a very useful Antenna . UFRO used primarily this type of tracking system in the early Years. The continuous tracking motors did so at the sidereal rate (15°/Hr.) so Jupiter was always in the beam.

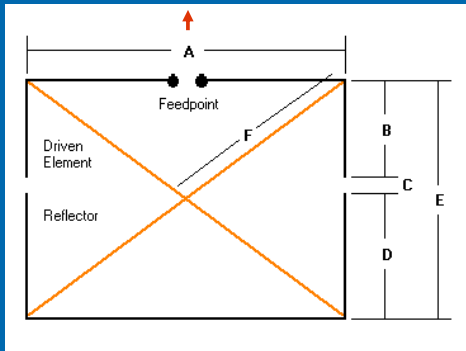
You can use an az-el mount but then you need a tracking converter to move the Antenna in small steps.

If used on an equatorial mount, then this becomes a very useful antenna . UFRO used primarily this type of tracking system in the early years. The continuous tracking motors did so at the sidereal rate so Jupiter was always in the beam.

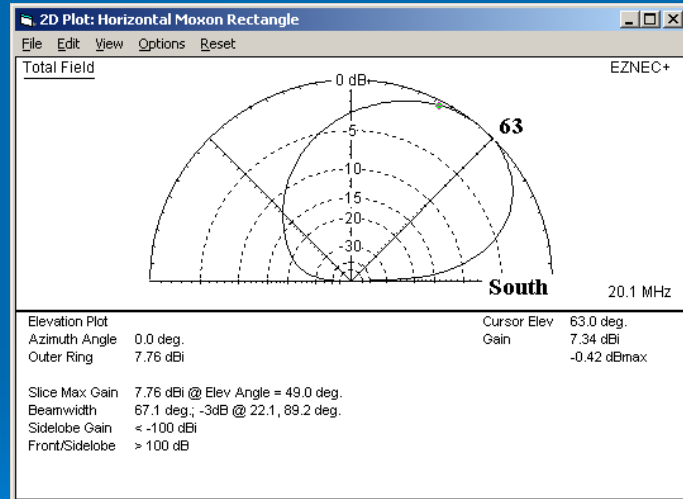
You can use an az-el mount but then you need a tracking converter to move the antenna in small steps.

MOXON ANTENNA

Top View – Feed to South



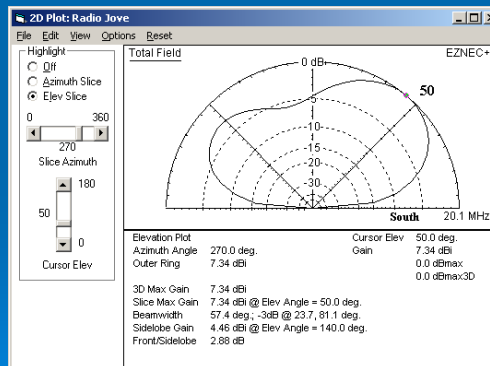
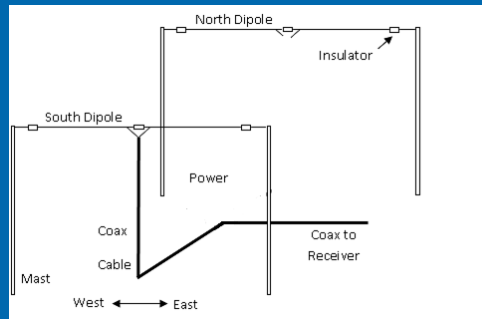
A = 17.8 ft.
 B = 2.7 ft.
 D = 3.3 ft.
 E = 6.5 ft.



Gain comparable to JOVE Array

The Moxon can be looked at as a Yagi with the driven element and the reflector folded inward toward each other. The antenna pattern above is with the plane of the Moxon horizontal, the height at 10 feet. With the plane of the Moxon vertical the beam is aimed at the zenith. The Moxon gain is comparable to the Jove Array and it takes less area. However it is a bit more complex to build and if you want to steer the beam of a single Moxon it must be done mechanically. An array of Moxons could be steered with phasing cables like the Jove array.

➤ 3. JOVE ARRAY AS 2-WIRE YAGI



R = 70 Ohms
 SWR = 1.4

Advantages: Easy hookup, no external phasing, no power combiner
 Disadvantages: Only usable for Jupiter low elevation angles, large backlobe.

I ran the JOVE array as a wire Yagi as an experiment with the coax connected to the South dipole only. I did not change the dipole lengths or the spacing. The resultant can be seen in the above elevation plot. The north dipole acts as a reflector while the South dipole acts as the driven element. Since the JOVE array was not altered either in spacing or dipole length, you must accept the pattern you get. You can experiment by changing the spacing, dipole lengths and dipole height but you must have software to determine the results.

In Conclusion

- A single dipole is adequate for the sun.
- We recommend the dual dipole phased array for Jupiter
- Feel free to experiment with different antennas – but a good starting point is the Jove dipoles.