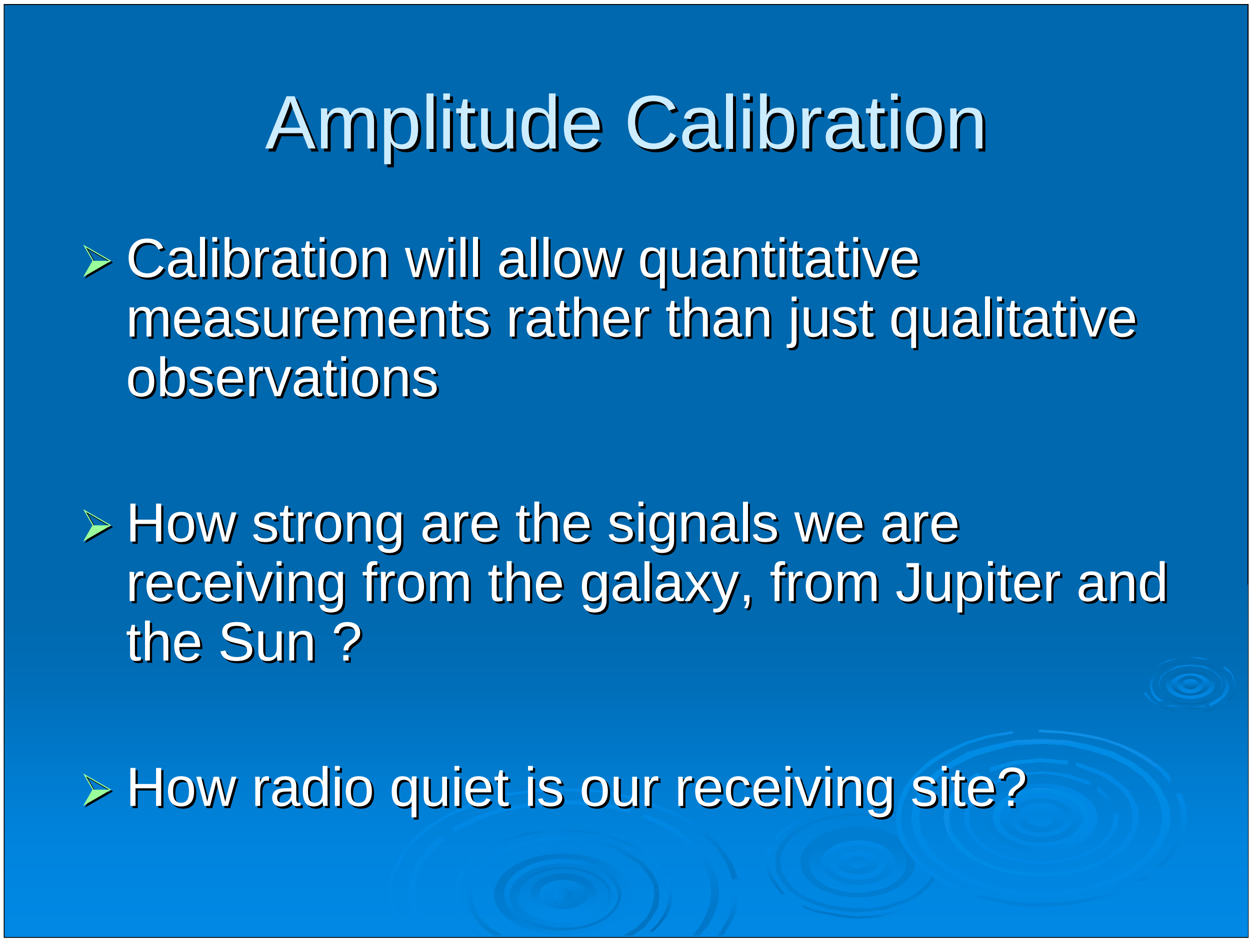
Calibration

RADIO JOVE

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



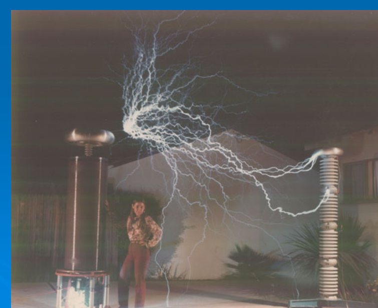
Building a receiver and setting up the antenna allows an observer to hear signals from the galaxy, Jupiter, and the Sun. Add a computer running Skypipe and they can see a strip chart record of what was received. But until the system is calibrated it’s a qualitative experience. Amplitude calibration of a Jove receiver allows the observer to make quantitative measurements. If the system is calibrated then you can make valid comparisons of results with other observers, determine the received strength of celestial signals and also evaluate how radio quiet is your receiving site.

Background Noise

- Galactic Background

Good Noise

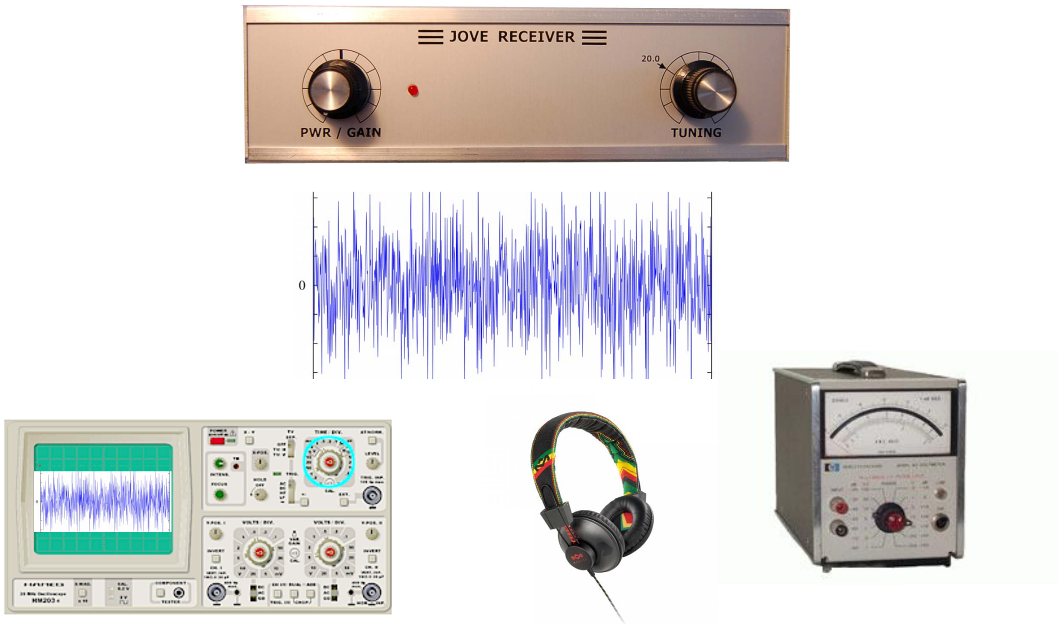
- Terrestrial Noise Sources
  - Arcing power lines
  - Automobile ignition
  - Lightning
  - Electric motors
  - Computers



Bad Noise

Consider the signals that go to make up the background – there is “good noise” from the galaxy, and “bad noise” coming from a variety of terrestrial noise sources. Signals from Jupiter and the Sun are observed against this background. If the background is too high then we won’t see Jupiter or the Sun against this background of “bad noise”. Its important to know how noisy (or radio quiet) our observing site is. If the site is devoid of terrestrial noise then we will see only the galactic background. By actually measuring the signal level from our antenna we can determine how much is galactic and how much excess terrestrial noise is present. To do this we will discuss absolute units of measurement – and convert our RSP vertical scale so it is calibrated in absolute rather than relative units.

Jove Receiver Audio Output



The Jove receiver output is audio, containing frequency components from a few 10s of hertz up to about 3.5 kHz. You can listen to it, observe its strength on a meter or look at the waveforms on an oscilloscope.

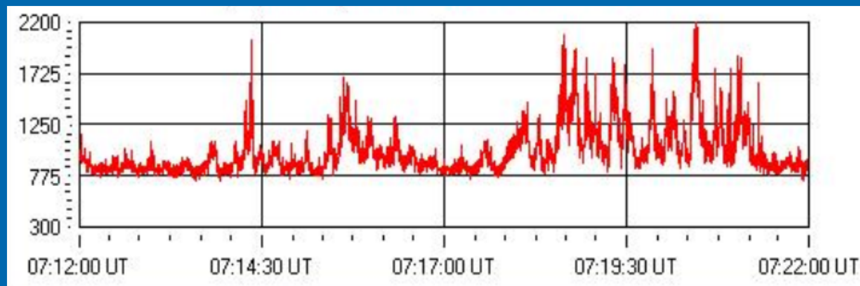
Jove Audio Processing

Jove audio is digitized by the computer sound card and processed by Radio Skypipe.

Skypipe display is proportional to signal voltage but is a relative scale, Not absolute scale units like volts or watts.

Or you can feed the audio to a computer sound card and display signal strength in graphical form using Radio Skypipe software. The sound card is an analog to digital converter typically capable of digitizing sound at a rate of 96 ksamples per second with 24 bit resolution. Radio SkyPipe normally uses 16 bit samples at an 11.025 kHz rate.

Amplitude Calibration

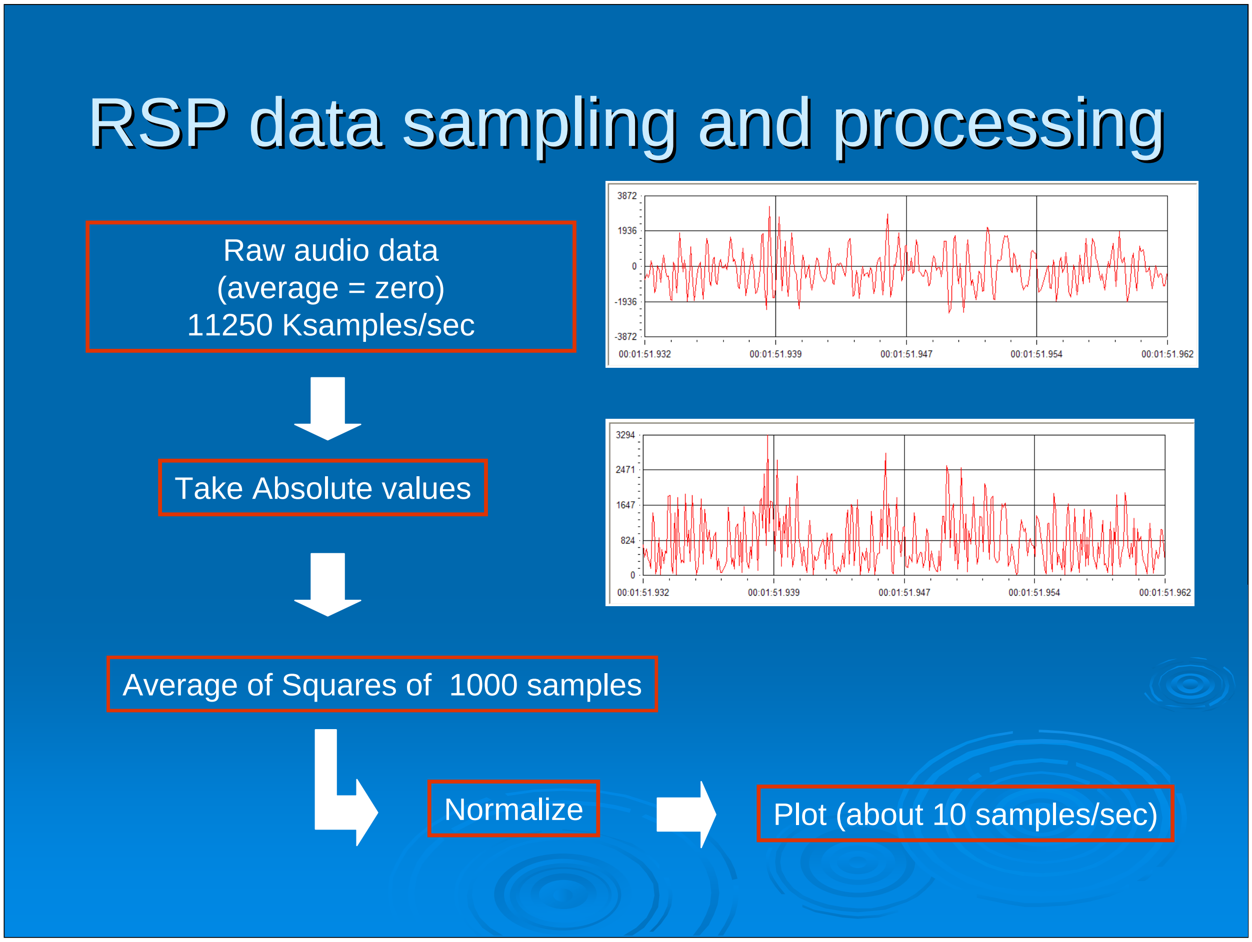


SkyPipe Units

- Vertical Axis - SkyPipe Units (SPU)
- Relative, unit-less numbers
- Proportional to voltage
- Trace adjusted with receiver and software gain controls

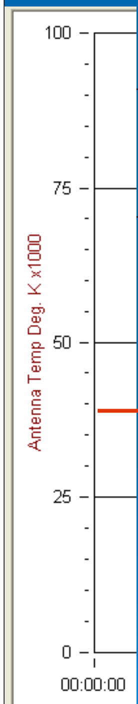
We just learned a lot about SkyPipe during Jim's talk. I want to focus on just one aspect of Skypipe - the vertical axis.

Out of the box, Skypipe does not provide an absolute scale like volts or watts – this means that data plots are qualitative. Adjusting the receiver and computer audio gain controls will move the SkyPipe trace up and down. Looking at a record one cannot tell if the signals were strong or if the gain controls were cranked wide open.



The receiver audio swings both positive and negative about zero volts as we see in the top panel view of an audio .wav file. The average value is zero. SkyPipe first takes the absolute value of the raw data points, generating a set of positive values as seen in the bottom panel. The **Power** detection method attempts to determine how much power is in the signal by taking the average of the squares of several samples. Typically, RSP plots one point every tenth of a second so over a thousand sound card samples are processed to obtain the value of each data point. The result is then divided by a normalization factor called the **Power Detection Factor**. If the input power to the sound card is known then the system can be calibrated and the vertical axis becomes an absolute rather than a relative reading.

Amplitude Calibration

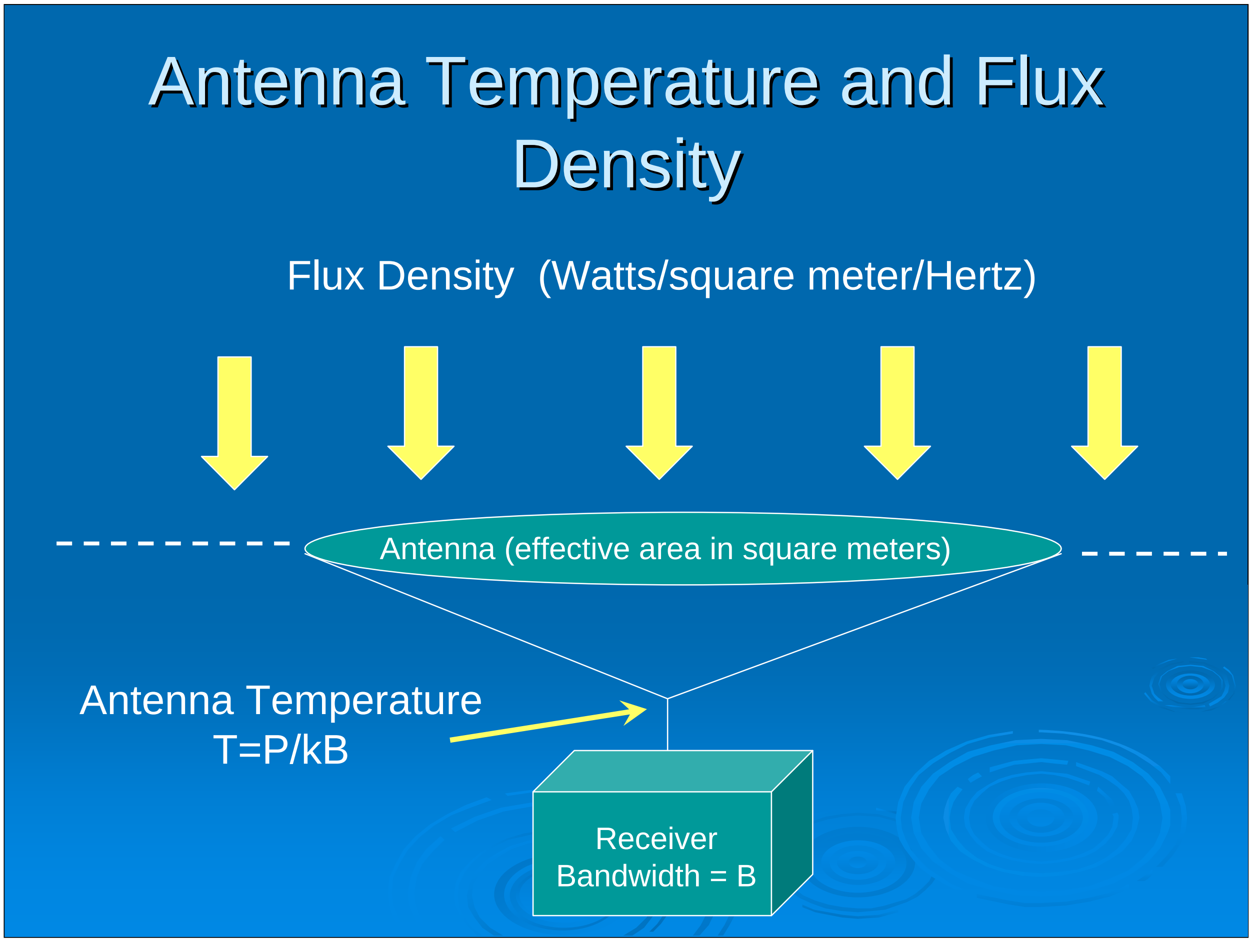


Use absolute rather than relative units for amplitude with a common reference point

Convert SkyPipe Units (SPU) to
- Antenna temperature
- Flux density

- Determine if observing site is radio quiet
- Measure burst intensities
- Compare records from different observers

The absolute unit we will use to measure signal level is antenna temperature. In the future we hope to make even more meaningful measurements in terms of flux density.



Antenna temperature is a measure of power received on the receiver side of the antenna, whereas flux density is a measure of signal strength on the space side of the antenna aperture. The antenna aperture (or collecting area) is dependent upon the antenna gain in the direction of the celestial target. If we know the beaming pattern of our antenna and the location of the source within the beam we can compute the flux density once we have measured the antenna temperature at the antenna terminals. Lets back up a bit now to understand the term antenna temperature.

Antenna Temperature (1)

P = kTB

P = power in watts
K = Boltzmann's constant
T = temperature (kelvin)
B = predetection bandwidth (Hz)

If B = 7 kHz and T = 290 kelvin
Then P = 3E-17 watts
= 37 nvolts across 50 ohms
= -135 dBm

Lets hook a 50 ohm resistor to the end of a zero loss coax running to the receiver antenna terminals. Electrons are moving about in the resistor due to thermal energy at room temperature. At any given instant there are different numbers of electrons at each end of the resistor-so a small noise voltage is developed. The amount of power delivered to the receiver is given by P=kTB. Where T in this case is ambient temperature. If the receiver has a 7 kHz bandwidth then the amount of power from the resistor at room temperature (290 Kelvin) is about 3E-17 watts. That is about 37 nanovolts across 50 ohms or -135 dBm.

Antenna Temperature (2)

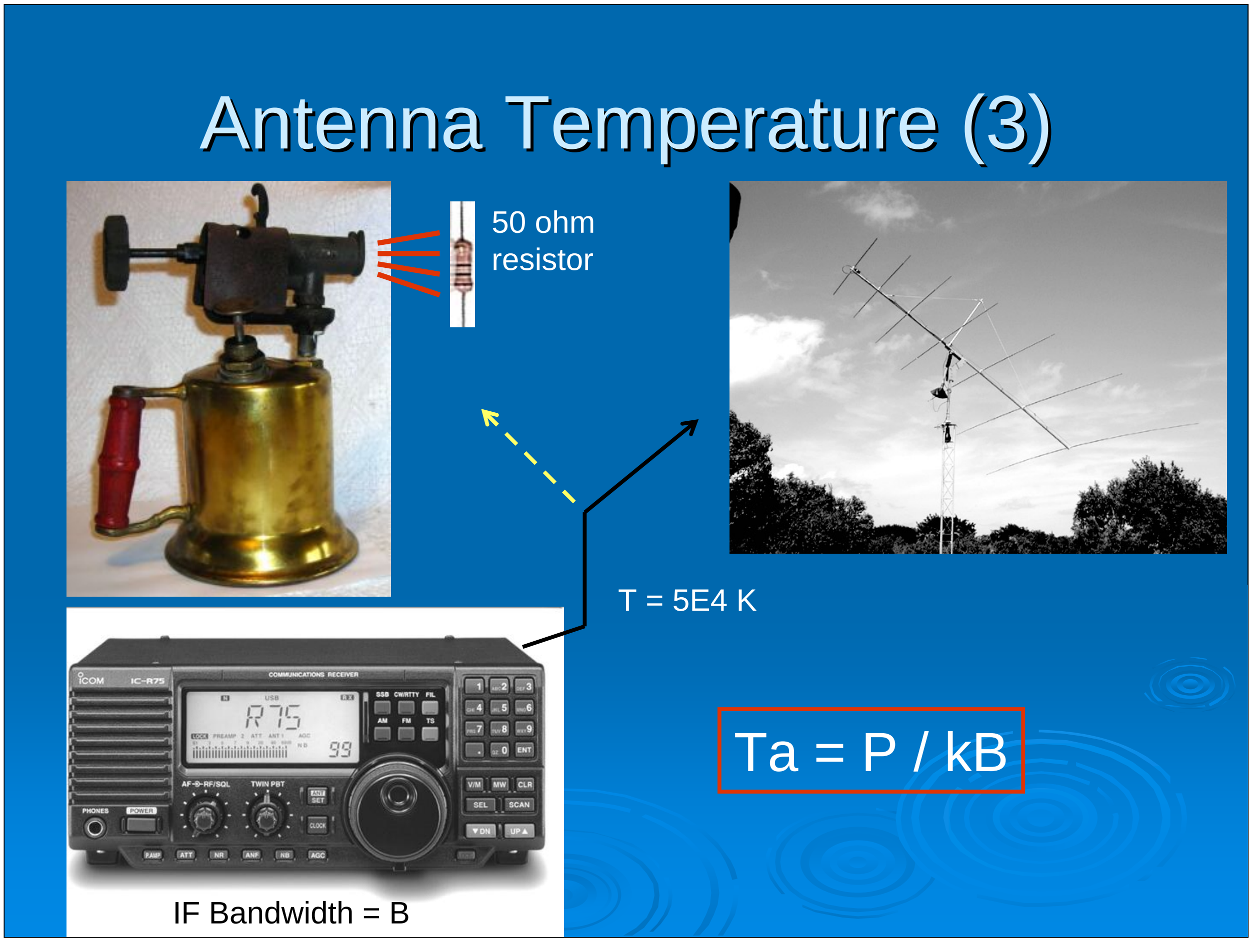
50 ohm
resistor

$$P = kTB$$

If B = 7 kHz and T = 5E4 kelvin
Then P = 4.8E-15 watts
= 0.5 uvolts across 50 ohms
= -113 dBm

IF Bandwidth = B

Well, lets have a bit more fun and heat the resistor up to 50,000 Kelvins. Now those electrons lazing around in the resistor get a good shot of energy and the voltage increases. The power delivered to the receiver is now about 4.8E-15 watts (-113 dBm) which equates to a voltage of 0.5 uv.



Lets assume that our observatory is at a perfectly radio quiet site – only galactic noise present. If we now disconnect the resistor and connect our lossless coax to the antenna we will receive about the same power level as we got from the hot resistor. The equality between the hot resistor and the power delivered from the antenna allow us to say that the antenna temperature is also 50,000 Kelvins. We can use antenna temperature to describe the signal level at the antenna terminals. Conceptually this is how we calibrate the radio telescope. Fortunately we don't need to use a blow torch– there is an easier way.

Calibration Wizard

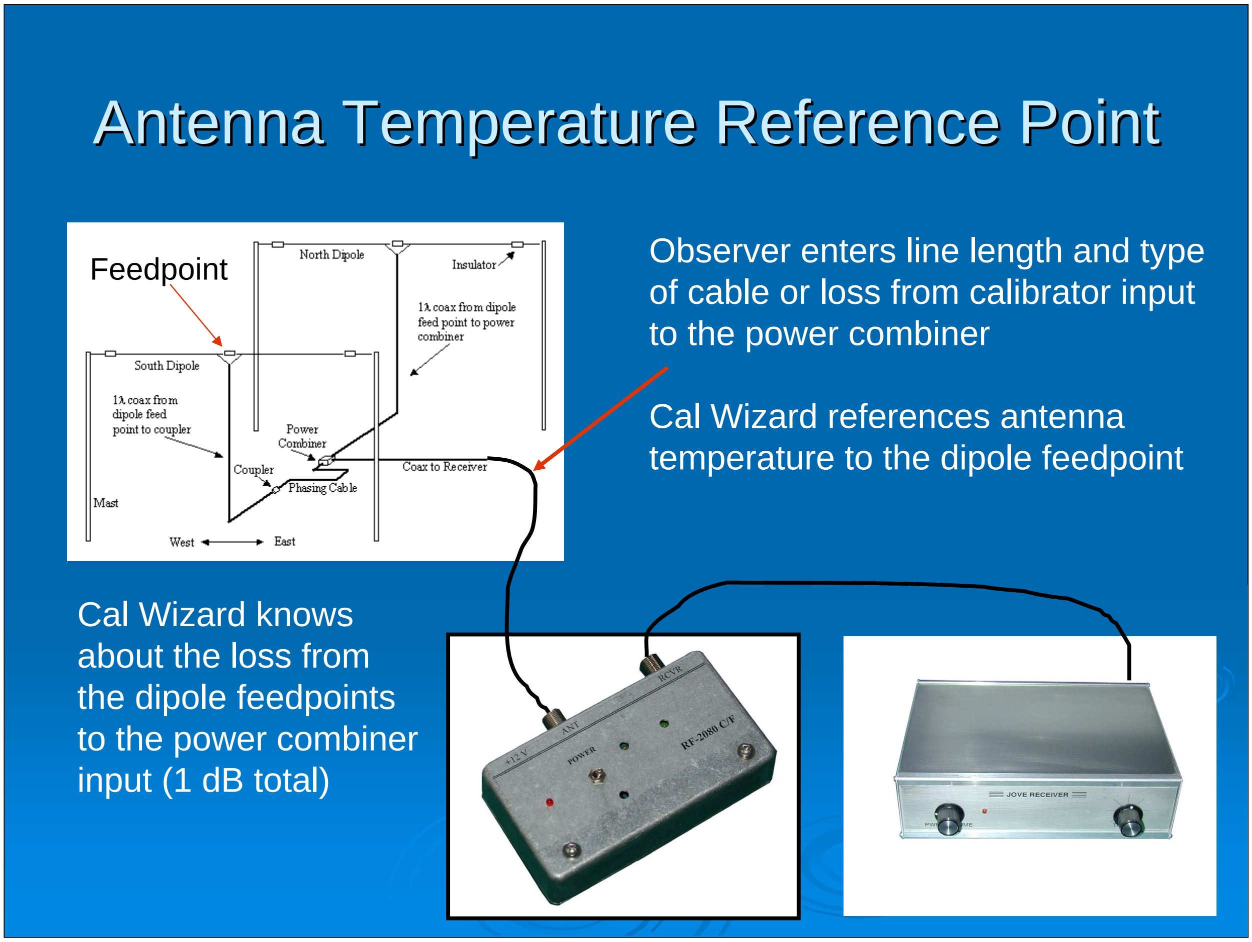
Radio-SkyPipe 2 feature

Requires a calibrated noise source

Convert SPU to Antenna Temperature

Reference point is the antenna terminals

You guessed it – it's the Cal Wizard in SkyPipe 2 – and an inexpensive calibrated noise source. The wizard steps the user thru a sequence of steps which ends up with the vertical axis of SP being calibrated in terms of antenna temperature – as referenced to the antenna terminals.



Here you see a typical Jove set-up with the dual dipole antenna. A calibrated noise source (the RF2080) has been added – between the antenna and the receiver. The cal wizard is run once –the noise source is turned on at the appropriate time – providing a known noise level to the receiver (and SkyPipe). The observer must enter the cable type and length from the calibrator to the Jove power combiner (or the loss in that cable if it is known). The cal wizard knows about the 1 dB of loss from the dipole feedpoints to the output of the power combiner and rescales the SkyPipe vertical axis in terms of antenna temperature as referenced to the antenna terminals. The Jove radio telescope is now calibrated and will remain so unless the receiver or computer audio gain controls are changed.

Calibrated Noise Sources

- RF-2080 C/F 25Kk noise source with 20.1 MHz BP Filter

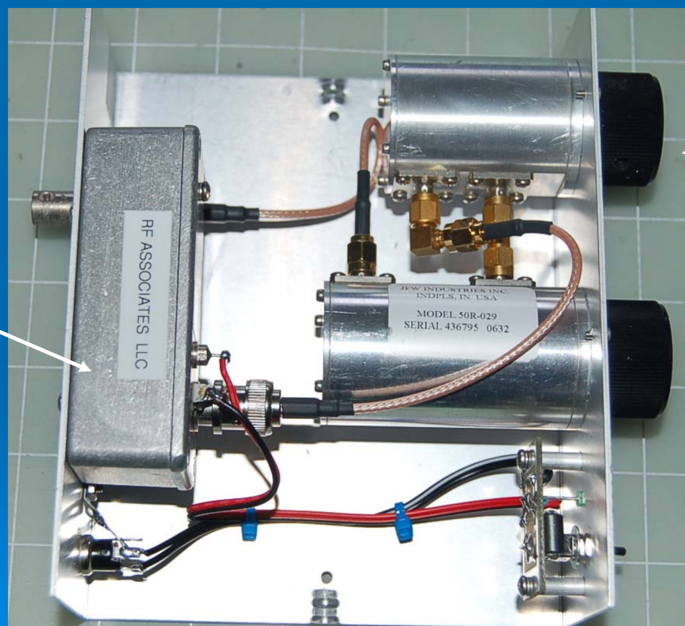
The one-step RF2080 noise source is available on the Jove website. The internal noise source generates 25kK. The unit also contains a bandpass filter to help reject strong out of band signals that sometimes overload the Jove receiver.

HP 461A

The HP461A wideband amplifier by HP is an excellent high temperature noise source. Several of these units have been measured to have output temperatures of between 70 and 90 million degrees. This is hotter than the hottest solar bursts. When used with a step attenuator it is possible to develop a wide range of temperatures for testing and calibration.

RF Assoc 20MK Variable Noise Source

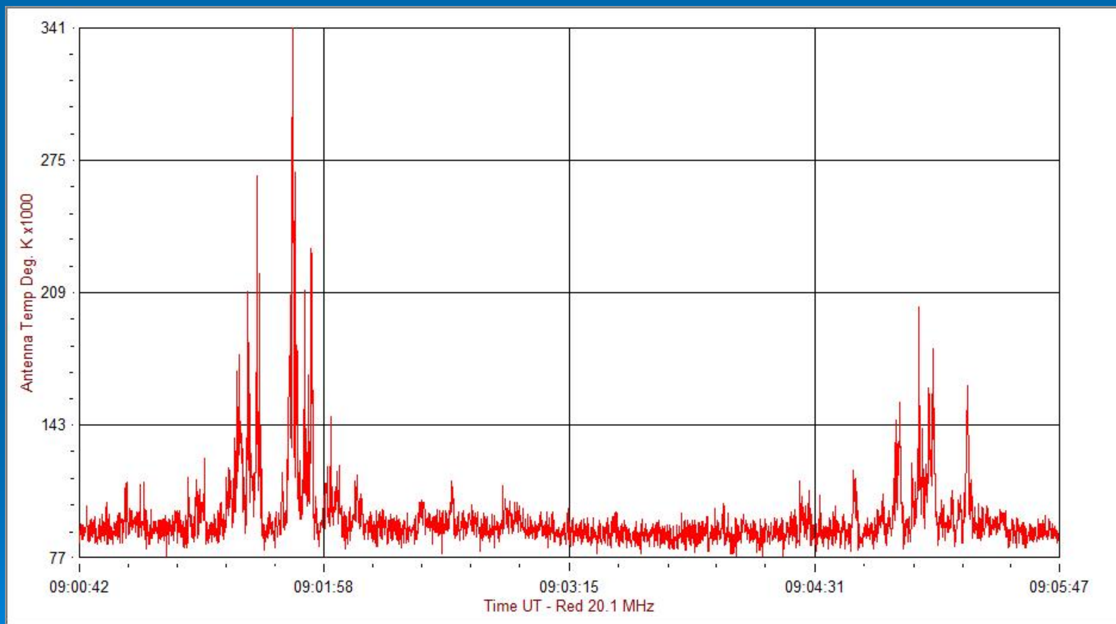
20 MK noise source



Step attenuators

RF Associates 20 M kelvin noise source and step attenuators.

Calibrated Io-B Storm



HNRAO 10/1/13 Io-B

On this calibrated SkyPipe record by Jim Brown we see that his galactic background was running at about 85kK – suggesting some local noise in addition to the normal galactic background temp. Jupiter bursts exceeded 250 kK around 0901 UTC and were somewhat weaker – around 160 kK in the second group four minutes later.

This SkyPipe calibrated record now yields a useful measure of signal strength and can be compared with similar records from other observers.