Build a Homebrew Radio Telescope

Explore the basics of radio astronomy with this easy to construct telescope.

Mark Spencer, WA8SME

There are many ham radio related activities that provide a rich opportunity to explore and learn more about the science of radio. One of those opportunities is radio astronomy.

All matter emits radio frequency (RF) energy dependent on the temperature and makeup of the matter, including the matter in space. The foundation of radio astronomy is to study the heavens by collecting and analyzing the RF energy that is emitted by bodies in space, very much as optical astronomers use light energy collected by telescopes. It sounds complicated. While professionals use very sophisticated and expensive equipment, you can, with some simple equipment and a little investment, build a radio telescope that will allow you to learn and explore the fundamentals of radio astronomy.

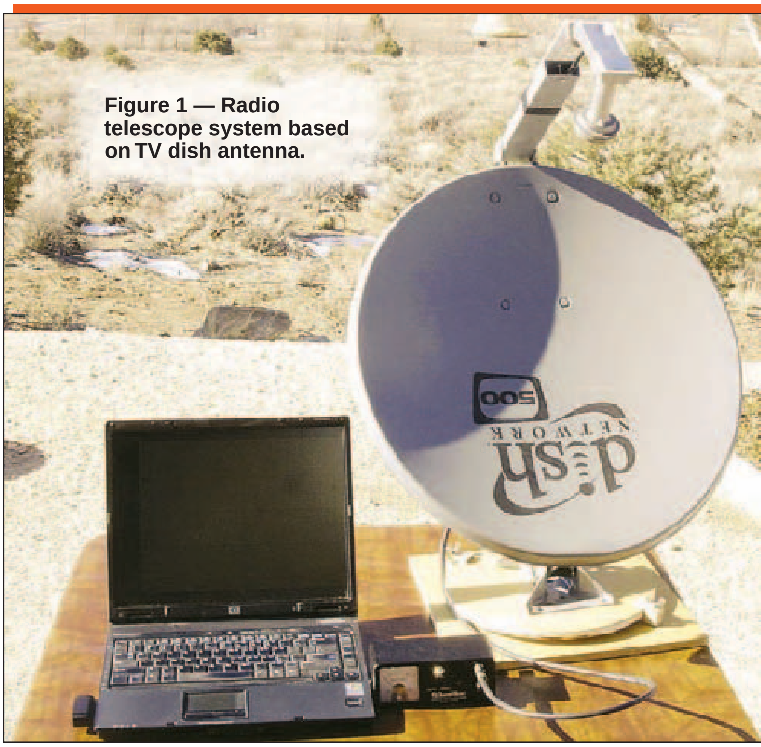


Figure 1 — Radio telescope system based on TV dish antenna.

A Homemade Radio Telescope

In this article, I will build on an existing design of a radio telescope made from one of those ubiquitous TV dish antennas that you see around your neighborhood. The radio telescope (RT) project described here can easily be reproduced. Although this is not a fully capable RT, it can provide a wonderful learning opportunity for you, or perhaps students in your local school.

Figure 1 shows the radio telescope set up. The major components include a modified TV dish antenna mounted on a wooden support structure to allow pointing the antenna, a commercial satellite signal strength detector that displays the signal strength of signals collected by the dish on a meter and an interface that converts the signal strength into a amplitude modulated tone. The tone is fed into a computer sound card and finally a computer and software graphically displays the signal strength as a function of time.

The TV dish modifications are structural, and any available TV dish system can be used. The signal strength detector costs between $40 and $65 and is widely available from Web retailers. The interface circuit, which will be described shortly, is easily duplicated and costs approximately $20. Finally, the display software is free.

Figure 2 — Dual LNB mount. Note two coax connectors.

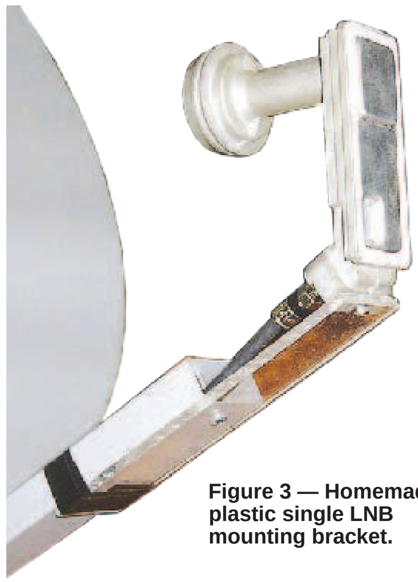


Figure 3 — Homemade plastic single LNB mounting bracket.

What it Can Do

The following is just a sample of what you can do with this simple RT:

- Use the sun to study and determine the beamwidth of the dish and verify the mathematic formula that is used to predict dish antenna performance.
- Measure the radiation intensity of the Sun and perhaps detect changes in solar activity.
- Measure the relative changes in the surface temperature of the moon.
- Learn about and explore a common radio astronomy collection technique called the *drift scan*.

Figure 4 — Dual coax connector configured LNB. Terminate one connector with a dummy load.

- Explore the fundamental principle of energy emission as a function of temperature by detecting the relative differences between the temperatures of emitting bodies.
- Detect satellites parked along the Clarke Belt in geosynchronous orbit and illustrate how crowded space has become.

Figure 5 — CM satellite signal strength meter.

- Detect the Earth's rotation around the Sun and the Earth's spin on its axis by comparing daily drift scans of the horizon.

Antenna Subsystem

The basic RT system is based on the "Itty-Bitty" design that is described in two Web pages.[1,2] The TV dish is an offset 18 inch dish that has down converter(s) mounted at the focal point of the dish. The down converter is called a low noise block (LNB). The LNB is a preamplifier/down converter that converts the satellite signals from around 12 GHz down to around 2.4 GHz. Most modern dishes have two or more LNBs to access more than one TV satellite at a time without changing the pointing of the dish

[1]Notes appear on page 45.

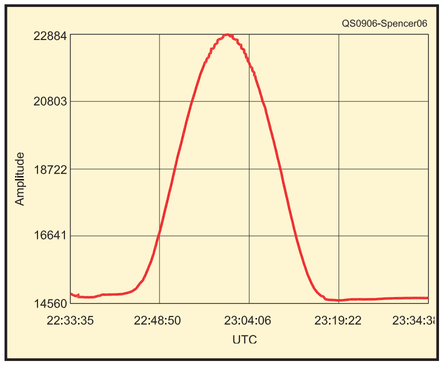


Figure 6 — *SkyPipe* screen showing antenna response.

(Figure 2). The LNBs are mounted to share the focal point of the dish. Since only one LNB is required for the RT, I made a minor adjustment to the published Itty-Bitty design to position the single LNB at the dish focal point. Mounting the single LNB at the focal point really helps in pointing the antenna.

I used the existing LNB housing and mounting bracket as a template to determine the distance between the edge of the mounting arm to the mounting hole of the LNB. I then used a piece of plastic to fabricate a new mounting bracket for the LNB as shown

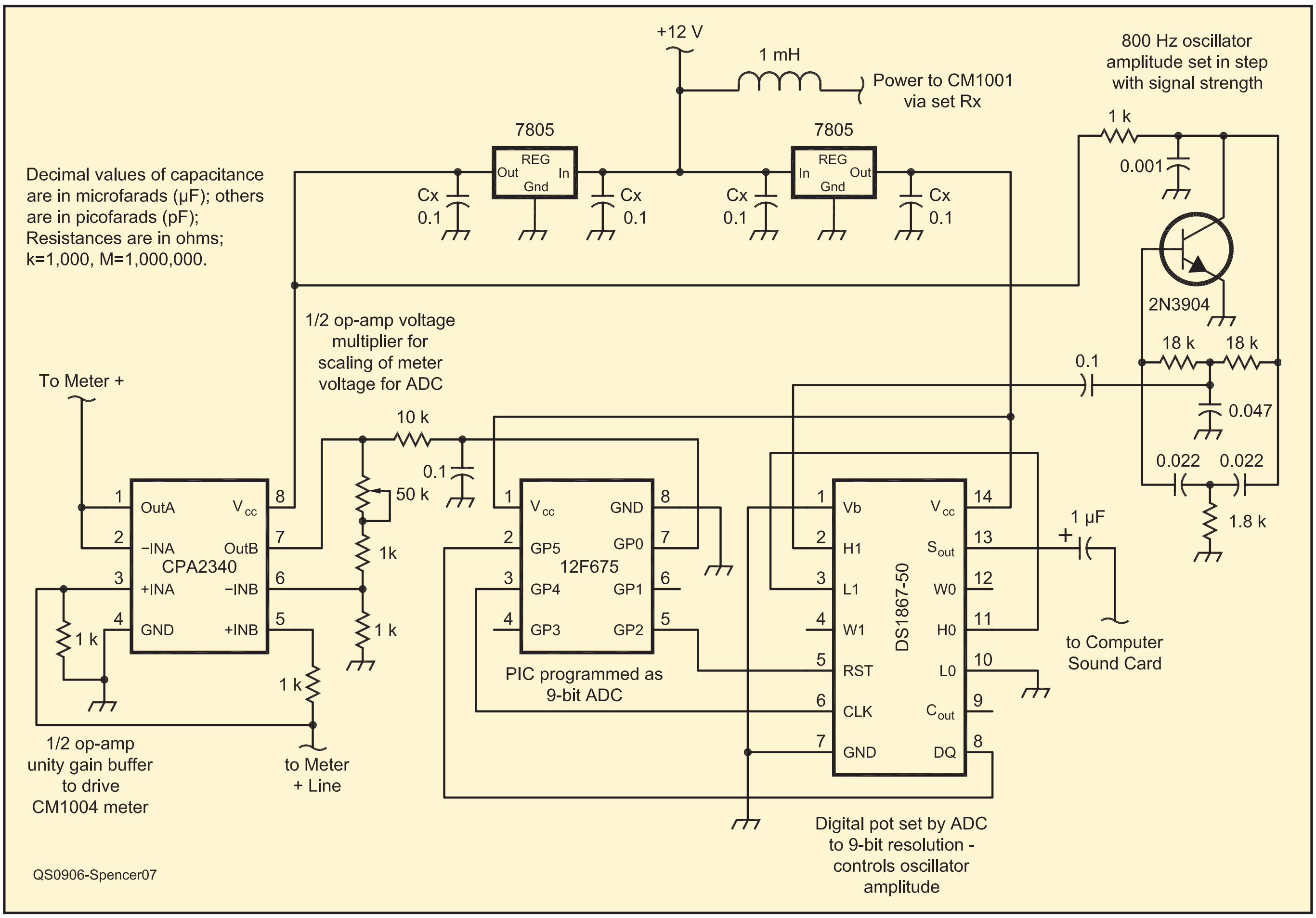


Figure 7 — RT Interface circuit diagram.

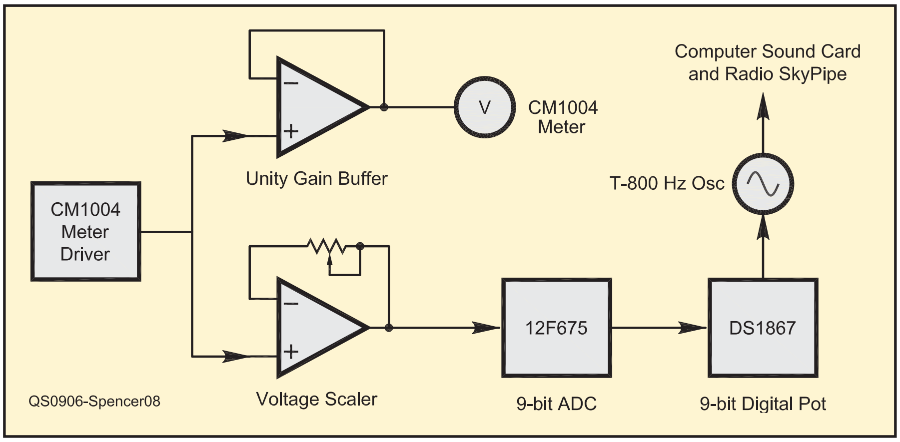


Figure 8 — RT Interface block diagram.

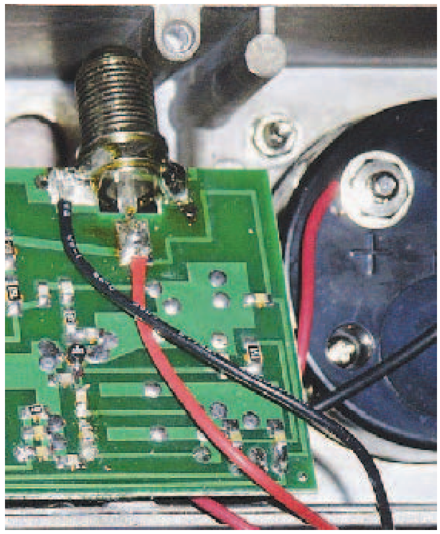


Figure 9 — Power and ground connection to CM board.

in Figure 3. The dimensions are not super critical, but careful placement certainly will improve the RT performance.

Some LNBs have two coax connectors. Only one will be used in the RT (Figure 4). It is a good idea to terminate the extra coax connector with a 75 Ω dummy load plug to balance the load on the LNB. The dummy loads for F type TV coax connectors are readily available from electronic parts retailers.

Note that the dish is mounted upside down. Though this orientation is not ideal for receiving satellite signals, this arrangement helps with pointing the dish in its radio telescope role.

Satellite Detector

The detector used in this project is the Channel Master (CM) satellite signal level meter model 1004IFD (Figure 5).[3] The CM is connected to the LNB. Power is supplied to the LNB through the coax connection from the CM. The CM detects the signal coming from the LNB and gives a meter indication of the signal strength and also varies the frequency of an audio tone to help technicians point the dish at the desired satellite. As you move the dish through the beam coming from the satellite, the meter indication will increase and then decrease coincident with the pitch of the audio tone.

The Itty-Bitty plans detail how to connect power to the CM and in turn connect power to the LNB (this power connection is handled by the interface in this project). Though somewhat effective, the CM meter and variable frequency tone indications provide limited utility in detecting changes in signal strengths required for radio astronomy.

Display

To really study the signals received by the RT, you will need to see them displayed graphically on a strip chart. There is an excellent software package called *Radio-SkyPipe* that is posted on radio astronomy Web sites.[4] The free version of this software is a good place to start. *SkyPipe* uses the computer sound card to measure the incoming signal strength and graphically displays the signal strength as a function of time. Figure 6 is illustrative of a signals detected by the RT. *SkyPipe* is very easy to use but some study of the HELP files will make it easier for you to fully tap into the capabilities of this software.

SkyPipe requires audio signals to be fed into the sound card MICROPHONE jack. The output of the CM detector is either an analog meter reading or a frequency modulated (constant amplitude) tone that is not really compatible with *SkyPipe*. An interface is required.

Interface

What is required to make the CM output work with *SkyPipe* and a sound card is to convert the signal level into an amplitude varying audio tone. The interface designed to do this is shown in Figure 7 and as a block diagram in Figure 8. Refer to the block diagram during the description of the interface function.

The unity-gain op-amp is used as a buffer between the CM meter driver circuit and the analog meter. The other op-amp is used as a voltage multiplier to scale the CM meter driver output voltage to match the 5 V reference voltage of the following analog to digital converter (ADC). The variable resistor in this voltage multiplier circuit is used to calibrate the CM to *SkyPipe*. The voltage from the multiplier is fed to a programmable interface controller (PIC) that is programmed as a 9-bit ADC to covert the analog voltage that is a function of received signal strength to a 9-bit digital word that is used to control a digitally controlled variable resistor. The interface includes a simple Twin-T audio oscillator circuit that provides a tone of approximately 800 Hz that is fed to the computer sound card. The amplitude of this audio oscillator is varied by the digital pot that is being controlled by the PIC. The result is the audio amplitude being varied in step with the signal strength detected by the CM.

The circuit provides power to the CM and the LNB. A 12 V source in the CM is tapped through an RF choke and this is connected to the LNB coax connector inside the CM (Figure 9). The 12 V is also regulated to 5 V to provide power to the interface. Though probably not required, there are two 5 V sources, one for the digital components of the interface, and the other for the analog components with one common ground point. This arrangement is used to isolate potential digital and analog noise sources within the circuit.

The interface is built on a circuit board and mounted right inside the CM box

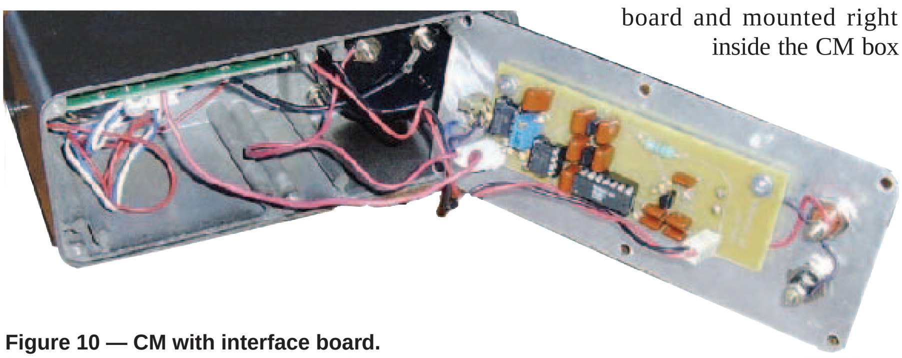
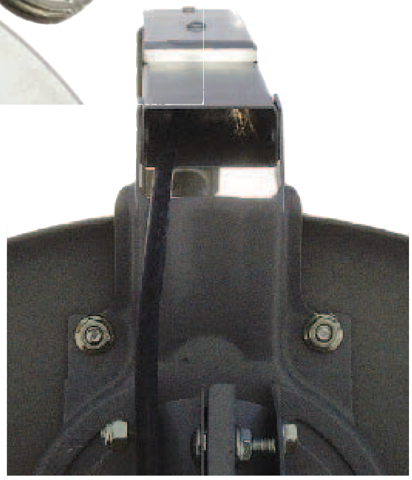


Figure 10 — CM with interface board.

Figure 11 — Aiming the RT at the Sun, note LNB shadow location.



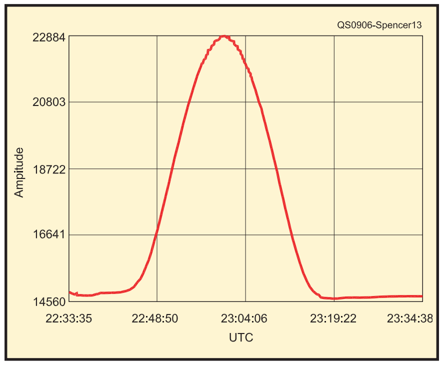


Figure 13 — Drift scan of the Sun indicating antenna's azimuth pattern.

(Figure 10). Though I made an etched circuit board for the circuit, the hand wired prototype worked equally well for those who would rather roll their own. The PIC firmware is available on the *QST* Web site.[6]

RT in Action

The first thing you need to do is learn how to point the RT antenna. The best place to start is to connect the CM to the antenna and point the antenna at the Sun. *Caution*: Do not look into the Sun as you do this, or at any time. Adjust the pointing angle and elevation until you get peak signal strength as indicated on the CM meter or hear the highest pitch audio tone. With the antenna pointed directly at the Sun, take note of the position of the shadow of the LNB on the surface of the dish (left in Figure 11). If you look from behind the dish, along the LNB

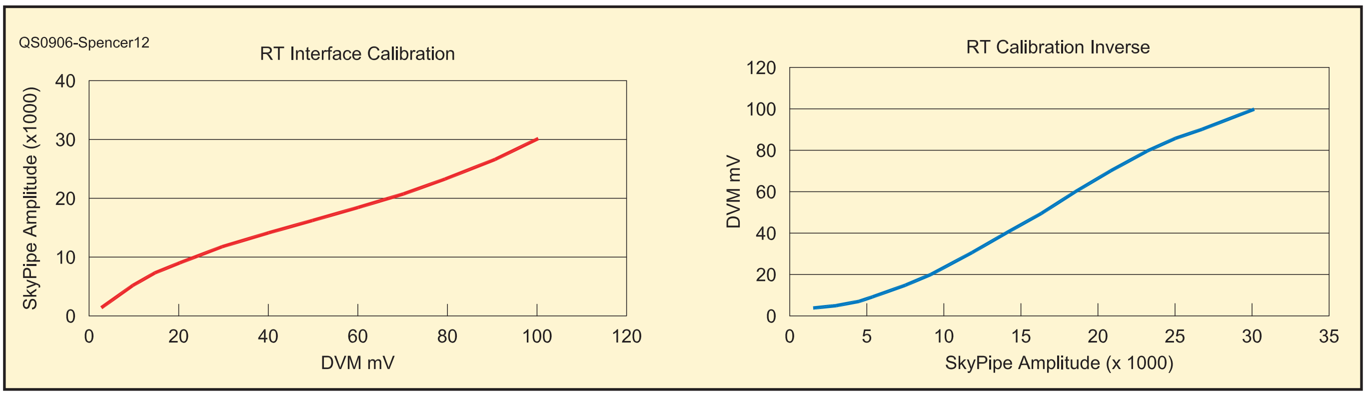


Figure 12 — Example calibration curves.

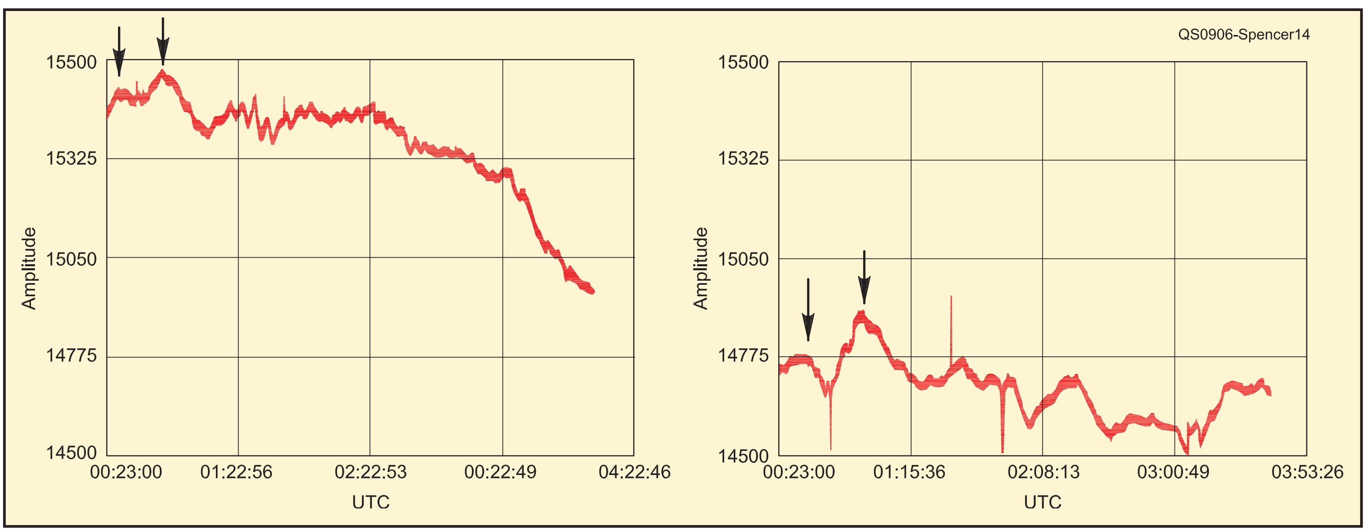


Figure 14 — Sequential drift scans. Note the time offsets between the peaks.

supporting arm (between the arm and the rim of the dish), you will see the Sun being blocked by the LNB.

Once you have the RT set up, it needs to be calibrated to match the output of the CM to *SkyPipe*. I have developed an *Excel* spreadsheet template to help with the calibration and a few of the other activities that you can accomplish with the RT (also available from the *QST* Web site). Turn the RT to a signal source, the Sun, or the side of a building would work. Turn the gain control of the CM to set the meter to maximum. Run *SkyPipe* and adjust the variable resistor on the interface board until you get a reading on the *SkyPipe* graph vertical (y) axis of approximately 32,000. With the maximum value set, adjust the CM gain control through the voltage range (0 to 100 mV) in 10 mV steps and record the corresponding y axis value on *SkyPipe*. This data is entered into the *Excel* spreadsheet to compute the calibration curve between voltage and y axis value. Both voltage and y axis values are used in analyzing recorded signal strength data (Figure 12).

A good first activity is to do a drift scan of the Sun. A drift scan means that you set the antenna azimuth (AZ) and elevation (EL) to some fixed pointing angle and allow the Earth to serve as the rotator to drag the antenna across the sky. To do a drift scan of the Sun, first set the elevation and azimuth to point directly at the Sun (maximum signal) and then move the azimuth toward the west

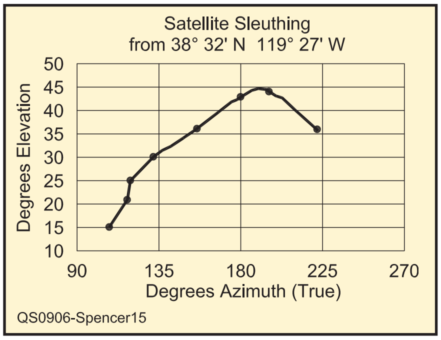


Figure 15 — Clarke Belt plot — tracking down satellites.

(leave the elevation set) until you are off the peak signal. Now start *SkyPipe*. In about 15 minutes, the Sun will pass through the antenna pattern beam width and the result will be as illustrated in Figure 13. You can also use this collection technique to explore the antenna performance parameters.

A good second activity is to do two drift scans of the night sky on two consecutive nights (beginning the scans at the same time each night) using the same fixed antenna azimuth (AZ) and elevation (EL). Figure 14 shows two such drift scans. Although at first glance they may not seem similar, there are some interesting features that are pointed to by arrows. If you compare the time that these two peaks occurred, the time difference is about 4.5 minutes. This shift is the result of the distance the Earth had traveled during the 24 hours between collections. This illustrates that the Earth's rotation as well as its travel in orbit needs to be considered when comparing drift scans. Enough to make your head spin (pun intended)?

A final good starting activity is to point the antenna toward the Clarke Belt and find all the satellites in geosynchronous orbit transmitting on 12 GHz. If you record signal strength peaks and AZ and EL for each peak, you will develop a graph of the Clarke belt as illustrated in Figure 15.

I have only scratched the surface, and the sky is the limit of this little project. The RT project can certainly broaden your horizons and expand your understanding of our universe. If you would like more detail than can be presented here, please contact the author.

Notes

[1]**www.setileague.org/articles/lbt.pdf**.
[2]**www.aoc.nrao.edu/epo/teachers/ittybitty/procedure.html**.
[3]**www.pctinternational.com/channelmaster/0612/satellite.html**.
[4]**radiosky.com/skypipeishere.html**.
[5]**en.wikipedia.org/wiki/Geostationary**.
[6]**www.arrl.org/files/qst-binaries/**.

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The Penticton Solar Flux Receiver

Here's where we get the solar flux data for predicting HF propagation.

John White, VA7JW, and Ken Tapping

The attraction and challenge of HF communications, especially DX operations, comes from the need to deal with the vagaries of the ionosphere. Although much of the underlying physics is understood, there are complexities in ionospheric behavior that make the ionosphere's most effective use a combination of science and art based upon extensive experience.

Two of the factors contributing to this complexity are the total amount of ionization and how that ionization is distributed with height. Generally the higher the degree of ionization, the higher the maximum usable frequency (MUF), which is of critical importance as it opens up the higher frequency bands (20 through 6 meters) and greatly enables amateurs to work worldwide paths.

HF Propagation and the Sun

The upper atmosphere, in the region of 50 to 400 km above the Earth, is primarily ionized by the ultraviolet (UV) radiation produced by the Sun. For two reasons it is our very good fortune that the upper atmosphere absorbs this solar UV. First, if this radiation were to arrive at the Earth's surface unattenuated, life on Earth would be untenable. Second, the absorption of the UV in the upper atmosphere leads to ionization and the production of free electrons. This complex layer of ionization is known as the ionosphere.

Ionospheric Refraction

The electrons in the ionosphere move with the electric fields in the radio waves, extracting energy from them, and then as they move, they re-radiate the signals. Gradients in electron concentration with altitude, and the effect of a negative index of refraction, have the ability to refract radio waves, thus bending upward propagating electromagnetic radiation back down to the Earth's surface.

On the other hand, too much ionization will result in ionospheric absorption which can render the communications path useless. X-rays will enhance the level of ionization throughout the ionosphere, however, they are more penetrating than the UV. The X-rays get down to *D region* heights boosting the electron density in the lower ionosphere. This is bad, because the actual percentage of ionization compared with the particle density is relatively low, and the electrons that extract energy from the radio waves collide with the neutrals. This renders the motions of the electrons incoherent so that when they re-radiate the radio emission, the contributions are randomly phased and cancel out.

We call this *collisional absorption*. It's not a critical frequency issue; it is a dissipation issue. Amateurs operating HF will recognize this phenomenon as a blackout, which is well correlated to solar X-ray flares and results in the sudden loss of signals on the band.[1] Since the Sun is the engine driving the ionosphere, understanding the ionosphere and attempting to predict its behavior starts with keeping a stethoscope on the Sun.

[1]Notes appear on page 45.

Not a New Idea

Back in the 17th Century, Galileo Galilei, Christoph Scheiner and others noticed spots on the Sun. Over most of the time since then, people have counted them. One thing that

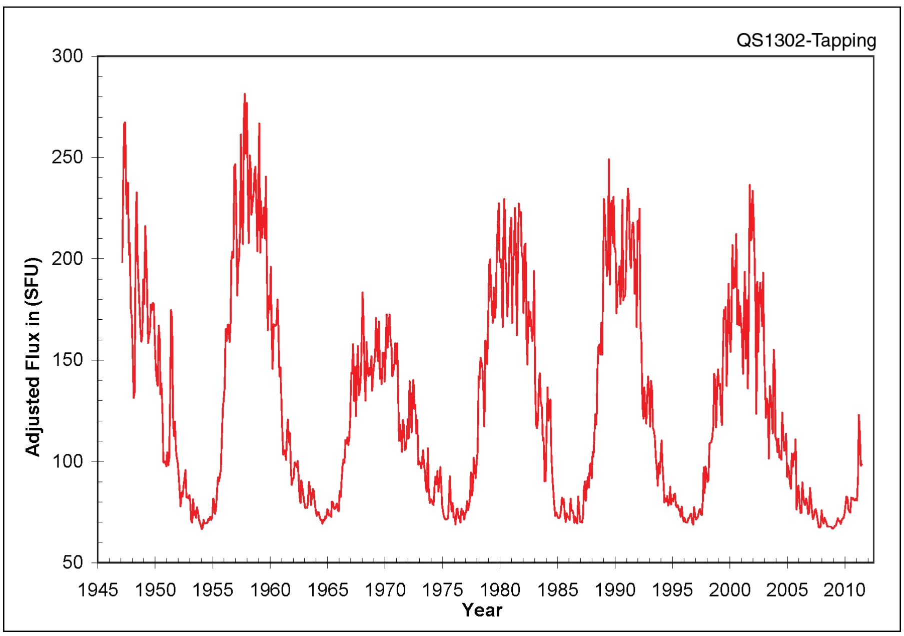

Figure 1 — Historical solar flux data.

appeared very soon is that the counts of sunspots visible on the Sun rise and fall over a 10 to 13 year cycle. We now know that the rise and fall of the sunspot number is just one manifestation of what is now known as solar activity. This rhythm of solar activity, together with intervals of high-amplitude short-term activity, affects radio communication. This is because the changes in activity level produce changes in the flux of ionizing radiation sustaining the ionosphere. This cyclic activity is important because the peak of solar activity is when the ionosphere is most highly ionized, and HF propagation opens up worldwide possibilities. At the solar minimum, things get pretty quiet on HF, as we have lately experienced.

Taking the Ionospheric Pulse

It would be a great advantage if we could directly measure the UV flux as it varies during the solar activity cycle, because this would be a direct indicator of what is driving the ionization. Such measurements, however, have to be made in space — consistently and accurately over decades. It is very difficult to do this. Therefore we fall back on proxies — ground-based measurements that can be used as indicators of the UV flux.

We use these proxies to predict when, and at what frequencies, HF path openings are likely to occur. Fortunately there are a number of such predictive tools available to amateurs just for this purpose.[2] These predictions are based upon solar activity information that is consistently available, and of consistent quality. This in essence means measurable from the ground.

The Solar Flux Index — What is it?

The *Solar Flux Index* (SFI) is known more widely as the 10.7 centimeter solar radio flux, or *F10.7*. It is a measurement of the total amount of solar radio emission in a 100 MHz wide band, centered on a frequency of 2800 MHz (a wavelength of 10.7 centimeters). This is just a sampling of the strength of solar electromagnetic emission at one part of the spectrum.

The UV emissions do not reach the ground, but there are other emissions that do, such as the solar radio emissions in the centimeter wavelength range. Fortunately these emissions are unaffected by the ionosphere and penetrate down to the ground level. Radio signals with wavelengths in the range of 6 to 12 centimeters respond most strongly to changes in the level of solar activity.

The program of monitoring the solar radio flux at 10.7 centimeter wavelength arose quite serendipitously. In 1946, Arthur Covington made Canada's first radio telescope out of bits of old radar equipment, which happened to operate at a frequency of 2800 MHz — a wavelength of 10.7 centimeters.

The only cosmic radio emission that this crude (by modern standards) and relatively insensitive radio telescope could detect were the emissions given off by the Sun. So Covington and his colleagues concentrated on those, and discovered the emissions varied with the level of solar activity. These measurements, which have now been made for more than 60 years, are an effective index of the general level of solar magnetic activity. Since that time, records of solar flux have been kept as shown in Figure 1.

Solar UV flux measurements suffer from two problems. First they have to be made above the atmosphere from spacecraft. This leads to the second problem: a long time-series of absolute measurements is very hard to make from satellite platforms. An unexpected failure or a launch delay with the next satellite is enough to render the data much less useful. If we plot the available UV flux measurements against F10.7, however, we see the two quantities are highly correlated.

This does not mean they are necessarily physically connected, just that they are both similarly affected by the rise and fall of solar activity. We can fit some easily used equation to the plot. Then by putting the current value of F10.7 into that equation we can get an estimate for the UV flux we would observe at that time. This in turn can be used to calculate the rate of ionization in the ionosphere

Flux Monitor System Requirements

The need to provide accurate and consistent measurements of the solar radio flux and CR data with the minimum of human intervention imposes severe requirements on the system. The detailed requirements are listed below.

- *Antenna Tracking Accuracy*. The antennas have beam widths of about 4°, in order to "see" the solar disc with uniform sensitivity. The antenna bore sight has to remain within 0.05° of the solar disc center from sunrise to sunset.
- *Linearity and Dynamic Range*. To measure solar flux with high accuracy and to record strong solar bursts imposes significant restrictions on the receiver design including 40 to 50 dB of dynamic range without automatic gain control (AGC). The problem with AGC is the exact nature of the gain compression is not known well enough to get back to the original signal value with sufficient accuracy for the flux determination.
- *Stability*. Each flux determination takes an hour, and the gain of the system must remain essentially constant during that time. Over a day the situation is a little less stringent, but not much.
- *Calibration*. The system needs to be calibrated sufficiently often to monitor any system performance changes, and needs an external standard.
- *Availability*. The requirement is that the system be available 24/7/365. Availability is increased by duplication. There are two receivers on each flux monitor. There are two independent flux monitors and two duplicate data distribution systems. Each flux monitor has its own uninterruptible power supply that can keep the instruments running for 15 to 20 minutes, which is far more than is needed for the observatory's backup generator to automatically start up.

Figure 2 — The solar radio flux monitors at Dominion Radio Astrophysical Observatory near Penticton. Flux monitor 1 is on the left; flux monitor 2 is on the right.

and thence the degree of ionization (electron density).

The other highly used index of solar activity is the *sunspot number* (SSN, also known as *Z* and *R*). These are counts of sunspots made using appropriately equipped optical telescopes. Sunspots were probably first observed by the Chinese more than 2000 years ago but it was Galileo who started observing the Sun with his invention of the telescope, from about 1610 onward. These data have been collected over more than 300 years. Using some partially empirical procedures to deal with sunspot groups and the inevitable differences between observers and observatories, the result has been a remarkably consistent and durable index of solar activity.

Sunspot number and F10.7 are highly correlated with one another, so one can be a proxy for the other. For example, F10.7 can be estimated from sunspot number using the relationship F10.7 = 73.4 + 0.62 N. This produces poor values at low levels of solar activity, however, such as those we experienced during the last solar minimum. This article focuses on the 10.7 centimeter solar radio flux and how it is measured.

Measuring the SFI, or F10.7

The 10.7 centimeter solar radio flux was originally measured in the Ottawa area, first at sites south of the city. This is how it got the name *Ottawa Flux*. Later measurements were made at the Algonquin Radio Observatory in the province of Ontario in Canada. The closure of the Algonquin Radio Observatory and the transfer of the Herzberg Institute of Astrophysics (the organization responsible for the solar flux measurements) to British Columbia led, in 1990, to the Solar Radio Monitoring Program at the Dominion Radio Astrophysical Observatory (DRAO). DRAO is located near Penticton, in the southern interior of British Columbia. The site is exceptionally radio quiet. The two solar radio telescopes called *flux monitors* are shown in Figure 2.

The Penticton Hardware Suite

The measurements are made using these two small radio telescopes. Both flux monitors operate simultaneously, with one acting as a hot backup for the other. The primary instrument, designated flux monitor (FM) 2, is located on the tower on the right. FM1, on the left, is operated as backup. Each instrument is autonomous. Each flux monitor has additional redundancy by being fitted with two independent systems. The receivers, backends and control arrangements are in the hut between the antennas.

Each day, as soon as the Sun is high enough above the horizon, the two flux monitors acquire it and track it, recording the total strength of the solar radio emissions. In addition, three times each day (noon –3 hours, noon, and noon +3 hours in summer, and noon –2 hours, noon, and noon +2 hours in the winter), precision measurements of the solar flux are made. These measurements are the distributed values of the SFI, or F10.7. The recordings of the solar emission from sunrise to sunset are stored as *continuous record* (CR) files, and are used for the detection of radio bursts (such as those from flares). On average, the errors in the flux determinations are 1% or one solar flux unit, whichever is the biggest.

The need to provide accurate and consistent measurements of the solar radio flux and

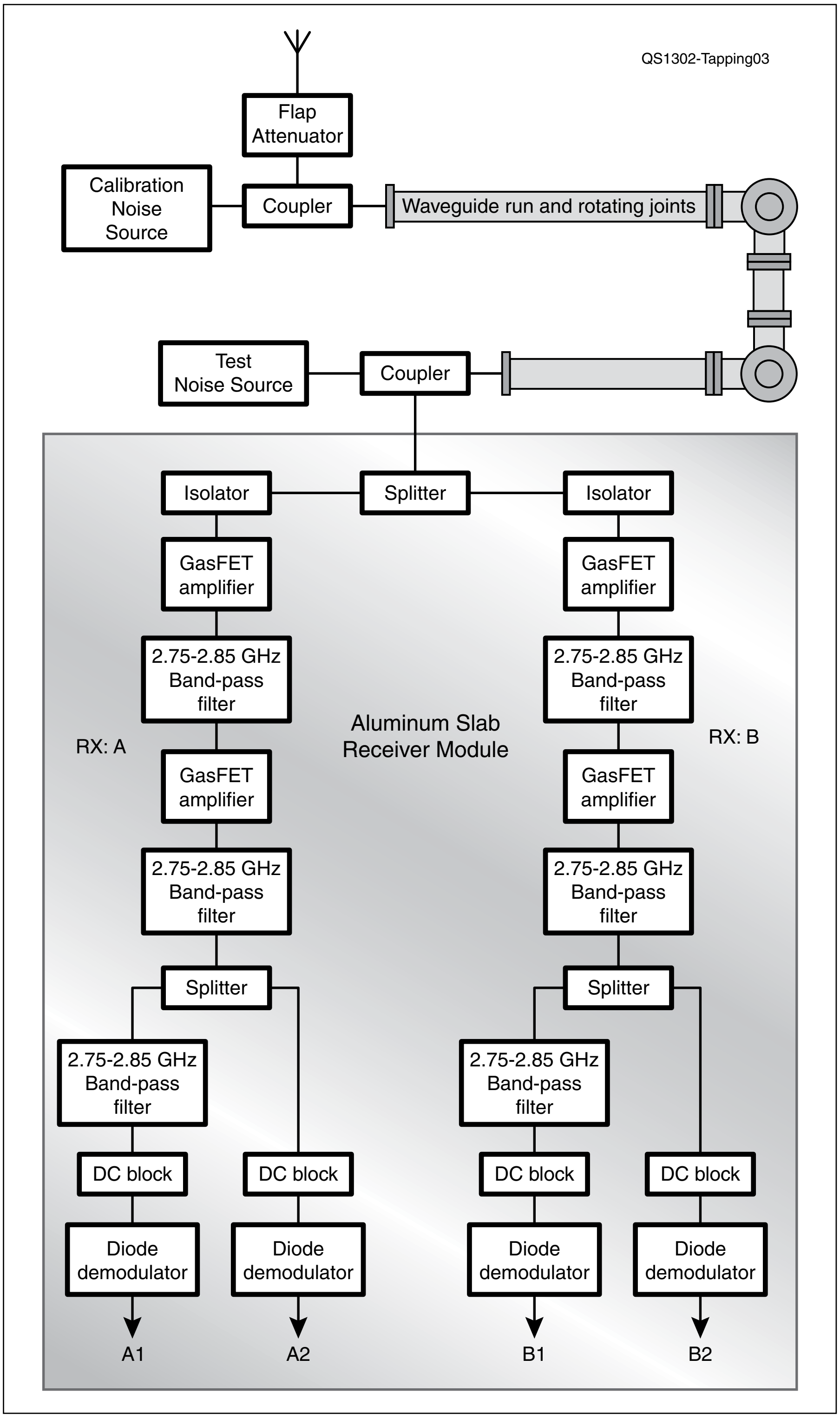

Figure 3 — Block Diagram of RF components.

CR data with the minimum of human intervention imposes severe requirements on the system. The detailed requirements are listed in the sidebar, "Flux Monitor System Requirements."

Antenna System

There are two parabolic dish antennas each 1.8 meters in diameter, pointing and tracking the center of the solar disc to better than 2 arc-minutes. The antennas are on polar (also known as *equatorial*) mounts, commonly used in astronomy. Imagine an az-el (azimuth-elevation) mount tilted back so that the azimuth axis points at the Pole Star, that is, it is parallel to the Earth's axis of rotation. This offers two huge benefits. First, tracking an astronomical object across the sky requires only driving the antenna in one plane (using just one motor), and second, it only needs to be done at a constant rate. The antennas are driven by stepping motors with drive belts that are meant to sacrifice themselves if anything jams. The antenna positions are monitored using 14-bit absolute position encoders.

The dishes each have gain of about 30 dB and a corresponding beam width of about 4°. Since the Sun has an apparent angle of about 0.5°, the antenna sees the complete solar disc with almost equal gain. It also sees the dark cold sky surrounding the solar disc.

The feed is a simple pyramidal horn. There is no preamplifier at the antenna. A run of WR284 waveguide with two rotating joints provides reasonably low loss transmission from the antenna to the receivers in the shack, about 10 meters away.

The biggest problem is snow on the antennas, which reduces their gain and makes garbage of the flux measurements. During the working week it is no problem to ensure that snow is promptly removed. In the winter, when the site might be unattended or only used by research astronomers (who are not qualified to climb on antennas), we use a webcam that can be accessed from home. This is essential, because the weather in the Okanagan Valley maybe very different from that in the White Lake Basin, which is where DRAO is located.

Receiver

The receiver is known as a *TRF*, that employs tuned radio frequency stages that simply amplify signals within a defined passband of 2.75 to 2.85 GHz, as can be seen in Figure 3. It is not a superheterodyne as might be expected, as the problems with local oscillators, mixers and down conversion complexities outweigh any advantages for this application.

The RF section of the radio employs three stages of amplification at 2800 MHz with 100 MHz band-pass filters at each stage. The amplifiers are microwave devices available from Miteq. Each one has about 35 dB of gain for an overall RF gain of about 105 dB. The noise figure of these individual amplifiers is about 1.8 dB and the point at which linearity begins to degrade, that is, 1 dB of compression, is about +10 dBm.

Each flux monitor has two receivers, designated A and B. The signal from the antenna is split between them. There are two outputs,

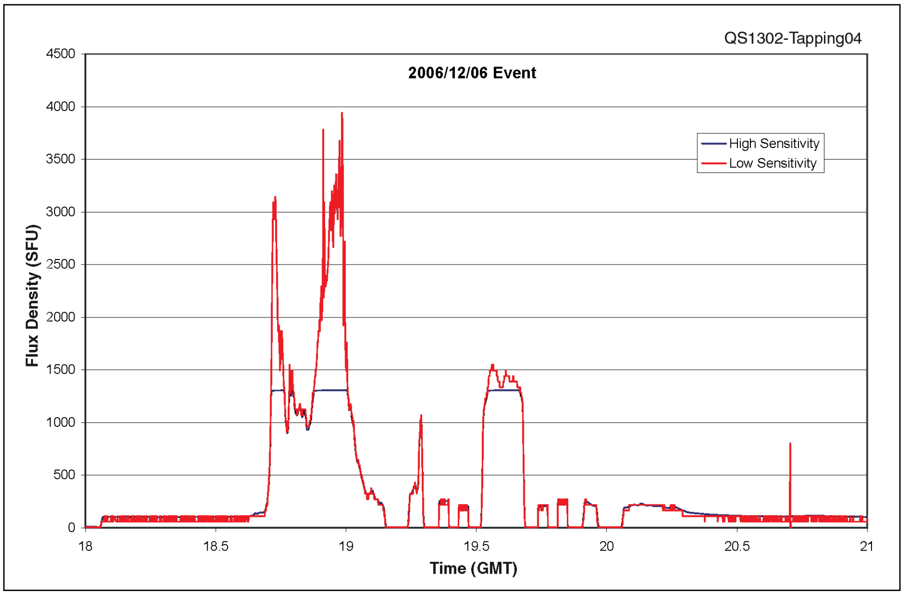

Figure 4 — Dual channel requirement for large solar flare bursts.

Figure 5 — The aluminum boxes contain the RF components for the A and B receivers.

Figure 6 — A view in through the door of the solar hut. The FM1 rack is on the left, and the FM2 rack is on the right.

one taken before the last amplifier stage and the other after. This provides a high sensitivity output and a low sensitivity output that is about 20 dB less sensitive than the other. The low sensitivity output provides a means to accommodate large bursts without overloading. Figure 4 illustrates this requirement.

The Figure 4 recording shows the radio emission from a large solar burst that occurred on December 6, 2006. This measurement involves moving the antenna on and off source and firing calibration devices. The measurement was rather messed up by a large solar flare, which started around 1840 GMT. The high sensitivity channel (dark line) overloaded, whereas the low sensitivity channel did not. The two records correspond extremely well up to the overload point.

Large dynamic range can be obtained using logarithmic detectors. The outputs would have to be delogged before processing, however. Errors in the log law could create bigger calibration issues than using a conventional diode as an approximation to square law detection, so conventional diodes are used. HP microwave detectors were chosen, and have now worked without any problems at all for more than 25 years. The dc output is filtered with a circuit having a 2 second time constant so that the random noise fluctuations are attenuated to a level suitable for processing.

Stability is obtained by embedding the components for both receivers in a 60 × 60 × 8 cm aluminum slab. Holes and slots are machined for the receiver components and cables. This puts the receivers within a waveguide way below cutoff, which reduces feedback. The large thermal mass cannot vary in temperature very quickly. To further reduce temperature variations, the slab is in an enclosure to minimize drafts and in a temperature regulated building. The components run on isolated grounds.

There are great advantages in keeping the receivers in one unit. Figure 5 shows the aluminum slab containing the RF and demodulation components for FM2. The gray box above it contains its power supplies. Note the plastic sheet so that there is no electrical contact between the power supply box and the receiver slab. The wooden box with Perspex® (Plexiglas®) windows is for suppressing drafts resulting in a very large thermal time constant.

A directional coupler and noise source provide a test signal for testing for degradation of the waveguide run and the rotating joints. The receiver output for this noise source is compared with the receiver output produced by the primary calibration noise source, which is close to the antenna feed.

Figure 6 shows the view looking directly in through the door of the solar hut. The rack for FM1 is on the left and the rack for FM2 is on the right. Directly in front, on the floor are two computers, both in aluminum cases to stop them radiating RF and causing interference. FM1, visible in Figure 7 is the original rack, dating back to chart recorders and vacuum tubes. The rack contains power supplies, antenna control equipment and post demodulation signal processing equipment. The chart recorders are not used any more, but removing them would leave unsightly holes in the rack. The FM2 rack is similarly equipped.

Demodulation

At the time these receivers were built (1980s), digital demodulation for such a high frequency was not an option, and down conversion would complicate the design and invoke more subtle linearity and dynamic range issues.

Calibration

The amount of power appearing at the input to the receiver is easily calibrated using a solid state noise source. Because the solar emission is broad band noise that is filtered by the passband of the RF section of the receiver, and the calibration noise is similarly

Figure 7 — The original rack, dating back to chart recorders and vacuum tubes.

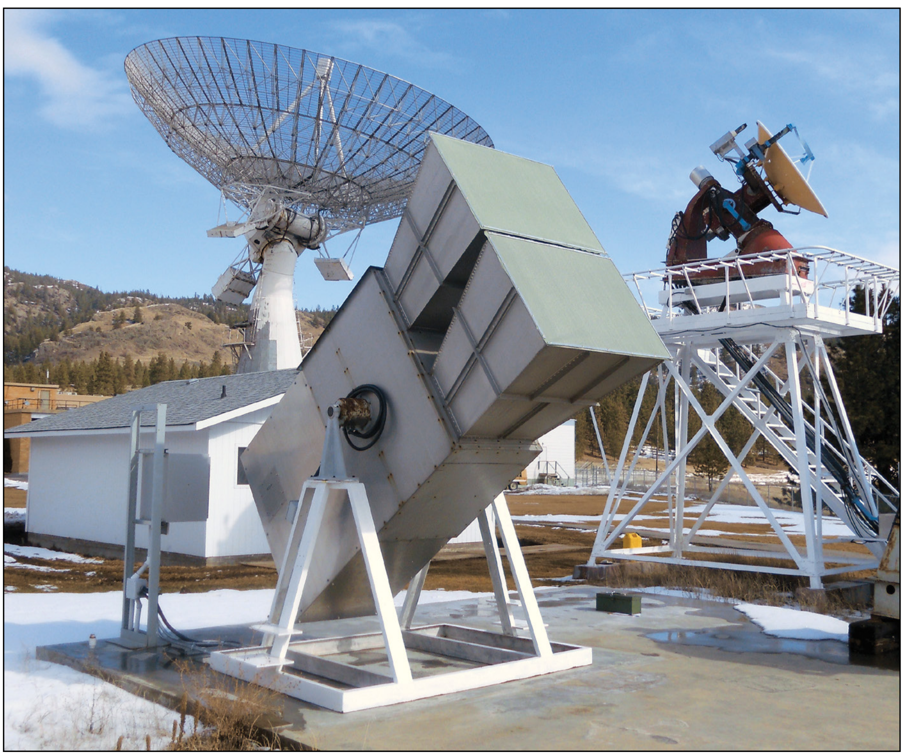

Figure 8 — The dual horn calibration antenna in the foreground.

filtered, we know that the calibration signal has the same character as the received signal. This would not be the case if we were to use a signal generator producing CW, or a narrowband modulated signal.

The difficulty is relating the signal strength collected by the antenna to what is measured at the receiver output. This requires that we know the precise gain of the antenna, or, as expressed in radio astronomy, the effective collecting area of the antenna in square meters. The relationship between effective collecting area and gain (expressed as a pure ratio — not in dB), is $A_{EFF} = (\lambda^2/4\pi) \times G$, where G is the gain of the antenna.

The gain of a parabolic dish is dependent on several factors making the absolute gain difficult to determine. These factors include the beam width of the feed, the quality of the dish surface and whether the phase center of the feed is precisely at the focus and that the bore sight direction of the feed lies exactly on the bore sight of the antenna. What is done in the case of the flux measurements is to position the feed as precisely as possible, and to fix it there as rigidly as possible, and then calibrate using an external standard.

Large horns are not used very much as stand alone antennas because there are ways to get similar gains using smaller antennas of other types. From the measurement point of view, however, they have a very important property, particularly for horns that taper gently — you can calculate the precise gains of these antennas from their physical dimensions, using basic electromagnetic theory.[3] Because the horns are large and unwieldy, however, parabolic dish antennas are used for making the F10.7 observations, and the horns used as calibration standards.

As shown in Figure 8, two identical F10.7 horns are used, mounted piggy back on the same mount. The horns have apertures of 3 × 4 feet and are about 12 feet long to the probe used to pick up the signal. The horns are mounted on an elevation only mount that makes it possible to scan the horns up and down the meridian. The antenna to the right is one of the flux monitors (FM 2), and in the background is the 26 meter radio telescope dish.

Calibration runs are made by doing a series of horn measurements over at least several days, usually in the summer while the Sun is at a higher elevation and clear, cloudless days are common, and then comparing the horn measurements with the measurements made by the flux monitors.

At a more superficial level, indications of data quality are obtained by comparing the measurements made by the two receiver channels on a given antenna, and then comparing the data between the two flux monitors. Since these are independent systems they provide a data check, although when the numbers differ, unless one set of measurements is clearly wrong, other work is needed to find out which values are correct.

Data Management and Distribution

The 10.7 centimeter solar radio flux shares with sunspot number the distinction of being the most widely used indices of solar activity. Values of F10.7 are to be found in databases around the world, and many users need data promptly. This imposes serious requirements on the program and the data handling arrangements.

Since the first commandment is to make sure the data gets out, we have two autonomous data distribution systems. The primary one tells the secondary one if it is not needed. When this NOT NEEDED signal does not arrive, the secondary system can take over. The data are e-mailed out to the high priority users, such as the Space Environment Center. The data are also copied to data services centers, such as the Data Portal of the Canadian Geospace Monitoring Programme and the **www.spaceweather.gc.ca** website.

Because of the duplication of the data among many databases, and the need to keep all these data in step, changes are minimized. For example, even though we can now calculate the gain of a horn antenna far more accurately today, we retain the model we have always used.

Summary

You now have a much better knowledge of what the solar flux is, where it is measured and how it is received and processed. Measuring the absolute value is not easy, but Penticton DRAO and Dr Tapping do a fine job. Think of them the next time you look at your SFI index along with the *A* and *K* solar activity indices, hoping for a DX opening.

Notes

[1]One of many sources of real time solar information is at **http://dx.qsl.net/propagation/propagation.html**.

[2]Some popular applications are *W6EL*, the *DX Atlas* suite, *IONCAP* and others.

[3]Jasik, *Antenna Engineering Handbook*, Chapter 15-1.

[4]J. Kraus. W8JK (SK), *Antennas*, Second Edition, McGraw-Hill, New York, 1988, Chapter 17, p 775.

Photos courtesy of the authors.

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For updates to this article, see the *QST* Feedback page at www.arrl.org/feedback.

Feedback

- In "The Penticton Solar Flux Receiver" [Feb 2013, pp 39-47] the lead map incorrectly shows Lake Sakakawea in Montana. It should have been shown in North Dakota.

- In Figure 3 of "The Penticton Solar Flux Receiver" [Feb 2013, pp 39-47], the block labeled "2.75-2.85 GHz Band-pass Filter" in both the A1 and B1 paths should read "GasFET Amplifier."

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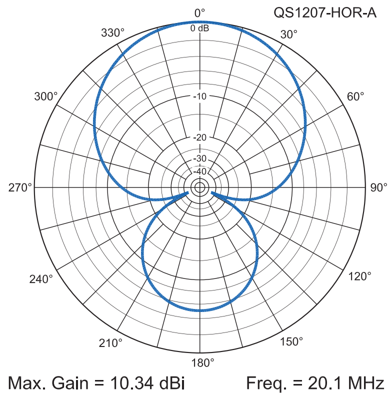
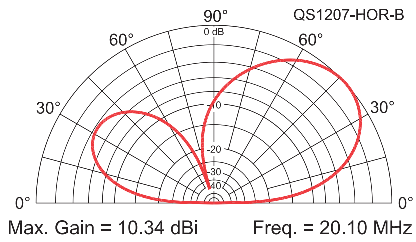
Experiment 114

Recording Signals

In Hands-On Radio Experiment 112, we went on the hunt for a cure to my sufferin' stove for RFI caused by my transmitted signal.[1] As hams know, however, RFI works both ways — a ham can receive interference from external sources, too. Tracking down the source of RFI to your operating can be at least as difficult as solving an RFI problem to an appliance in your home. This month, we'll do a neat science experiment with a free software tool you can use not only for RFI hunting but for other jobs as well.





Figures 1A and B — The two-dipole array pattern is quite broad with a beamwidth of 92° at an elevation angle of 42°. As a result, the antenna does not need to be precisely aligned. See the Radio Jove project documentation for construction and installation instructions. The patterns were computed by *EZNEC*'s free demo package (**www.eznec.com**) — an *EZNEC* model for the antenna is available on the Hands-On Radio website.

Noise Signatures

When you are receiving an interfering noise signal, one of the first steps in identifying the source is to determine its *signature* — the signal's combination of amplitude and frequency that is almost always unique to that particular noise source. When you tell your tale of woe to your friends, the first question will almost always be, "What does it sound like?" Is it a buzz, a tone, a wide-band rasp…or what? This gives important clues as to what is causing the noise. The frequencies on which you hear the noise are also clues.

Another part of the signature that can be just as important is the signal's behavior in time. For example, does the noise pulse regularly or is it present all the time? Does it appear throughout the day? Does the amplitude vary? All of these are also important clues. For example, HF operators in rural and suburban areas are often quite familiar with the pop…pop…pop… of an electric fence charger.

Sitting at the radio for hours listening to noise is not very exciting, despite what is depicted in the movie *Contact*. Yet it might be very important to learn that your noise comes and goes at regular hours — such as when a local street lamp turns on and off at dusk and dawn. The solution is a data recorder.

By Jove, You've Got It!

I found out about this month's software gadget in the course of helping the St Charles High School Radio Club, (KDØQLW), set up their Radio Jove Project equipment to listen to noise from the planet Jupiter.[2] This experiment involves building a two dipole array for 20.1 MHz (see the digital edition for a photo of the antenna and club members), connecting a radio, and listening to the receiver's output noise as Jupiter moves through the beam of the array while the Earth rotates. If you have a directional antenna for 15 meters (or can build the two dipole array) you can hear the noise, too. Figure 1 shows the *EZNEC* azimuth and elevation pattern of the array.

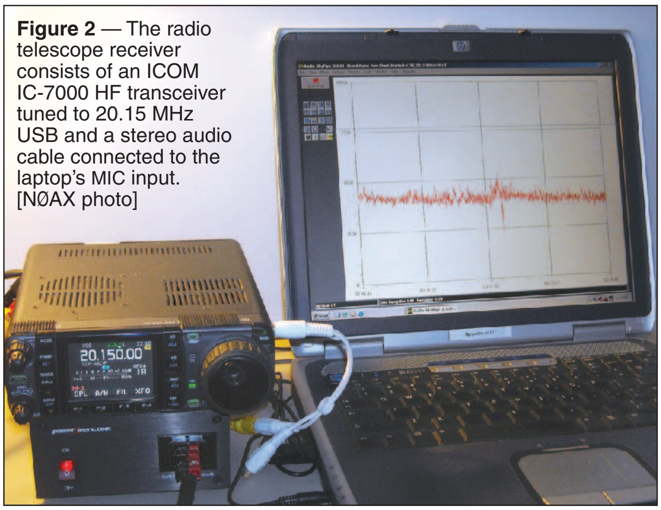


Figure 2 — The radio telescope receiver consists of an ICOM IC-7000 HF transceiver tuned to 20.15 MHz USB and a stereo audio cable connected to the laptop's MIC input. [NØAX photo]

Jupiter is a powerful source of noise at HF and was one of the first radio sources identified in the sky by radio astronomers. The noise can be received below 35-40 MHz down to frequencies below 15 MHz, at which the signals are either absorbed or reflected by the ionosphere. Frequencies around 20 MHz are usually recommended — just tune your receiver to a clear frequency around 20 MHz and…then what?

Jovian noise is just like terrestrial noise — crackly pops and crashes that you might hear from any thunderstorm. Listening by ear, there is no obvious signature of either amplitude or frequency so you must use time as your meter stick. The Radio Jove project directs the experimenter to a free program called *Radio-SkyPipe II* (**radiosky.com/skypipeishere.html**) that uses a PC sound card to record the output of a receiver, graph it on a strip-chart like display, and save the data to a file. Once the data is

[1]All previous Hands-On Radio experiments are available to ARRL members at **www.arrl.org/hands-on-radio**.

[2]**radiojove.gsfc.nasa.gov**

recorded, you review it to find the slow rise in noise level from Jupiter passing in front of your antenna.

Taking Measurements

Radio-SkyPipe II couldn't be easier to set up and install. Download and run the self-installing package from the website — you're ready to go. You will be prompted to enter your location (this is an astronomy tool, after all) and select your sampling rate and signal source. The default settings worked fine for me. I purchased the upgrade to the *Pro – Home Use* version so that I could work more easily with the data files. I'm using a slow, old laptop for recording and it seems to handle this simple task just fine.

Connecting the radio is also quite simple — use a plug-to-plug stereo audio cable from the headphone jack to the sound card's MIC input jack. Most readers will have a radio that can receive near 20 MHz or just outside the 15 meter band. Tune to a clear frequency free of local carriers or birdies and plug in the audio cable. Click the START CHART button and the red trace will begin crawling across the display at 10 samples/sec. In the OPTIONS menu, select the STRIP CHART tab and un-check Y AXIS AUTOSCALE. Right-click on the Y axis and click SET YMIN TO 0. This fixes the vertical scale at 0 to 10000, which is convenient for displaying noise measurements.

Adjust the receiver volume so that the background noise level is around 4000. You'll see the trace move up and down as the volume is adjusted so that the system looks somewhat like that in Figure 2. Point your antenna due south and wait for Jupiter to pass slowly by.

The time at which Jupiter crosses the north-south meridian over your location — called the *transit* — can be found on the Naval Observatory's website (**aa.usno.navy.mil/data/docs/mrst.php**). If you have a medium-to-low local noise level and your antenna is not completely blocked to the south, you'll see a gradual rise and fall in the noise level. After Jupiter passes by, click STOP CHART and save the file to your hard drive. After the file is saved, you'll see the entire session on the display. Maximize the window and use the control buttons at the left to move around. There are extensive on-line Help files available to get you started viewing data. Congratulations — you're a radio astronomer just like Grote Reber, W9GRZ back in the 1930's![3]

Figure 3 shows a portion of the strip chart I obtained on April 11, using the student's dipole array. It covers approximately 2 hours centered on the observed transit time. The 2 hour time period corresponds to 30° of the Earth's daily rotation. (360° × 2 hours / 24 hours = 30°) The Naval Observatory transit times (see Table 1) put the actual transit time at 14:33 (2:33 PM), which is 1933 UTC at my location in St Charles, MO. The slight rise in noise level was observable for a little more than an hour (≈16° of rotation).

The peak of the noise was later than predicted, however. I took data for several days — stopping and starting the chart twice a day — and saw a similar increase in noise level about the same time, shifting a little bit earlier each day, so I am confident that the noise was from Jupiter. I attribute the timing skew to partial blockage of the antenna beam by the house so that the signals were received best after the planet's transit. An open site with no obstructions and lower background noise would allow better observations but this was fine for a first run.

Table 1
Jupiter Transit

ST. LOUIS, MISSOURI
Location: W 90°15'00.0", N38°37'48.0", 100m
(Longitude referred to Greenwich meridian)

Time Zone: 5h 00m west of Greenwich

Date	Rise Az	Transit Alt.	Set Az.
2012 Apr 10 (Tue)	07:43 69	14:36 67S	21:31 291
2012 Apr 11 (Wed)	07:39 69	14:33 67S	21:28 291
2012 Apr 12 (Thu)	07:36 69	14:30 67S	21:25 291
2012 Apr 13 (Fri)	07:33 69	14:27 67S	21:22 291
2012 Apr 14 (Sat)	07:29 69	14:24 67S	21:19 291
2012 Apr 15 (Sun)	07:26 69	14:21 67S	21:17 291
2012 Apr 16 (Mon)	07:23 69	14:18 67S	21:14 291

Each column contains time and azimuth angle for rise and set or elevation angle and S for South for transit.

RFI Sleuthing

As you sort through the charts you collect, you'll no doubt notice other interesting phenomena. You'll see large static crashes and periods of high noise levels. You may see bursts of noise and on/off patterns, as well. In my data, it's clear that noise in my neighborhood builds quite a bit in the late afternoon and early evening as folks drive their cars home from work and begin to run their appliances and gadgets. A neighbor's motorcycle leaves a distinctive peak on the trace from ignition noise, for example.

I've been chasing a loud noise source that seems to appear only in the evenings and nearly wipes out 40 meters. My mobile rig is on my workbench listening and recording so that I can find out when it appears and when it goes away. Maybe that will help me determine what is generating it.

The *Radio-SkyPipe II* software can be used to record any audio signal your sound card can accept as input. You can adjust the sampling parameters to record faster or slower, set up automatic sampling, and so forth. The *Pro* version has a squelch-like option to log only when the input signal is above a specified level. Once you get this software running, I am confident that you'll find it a valuable addition to your electronics and radio toolbox!

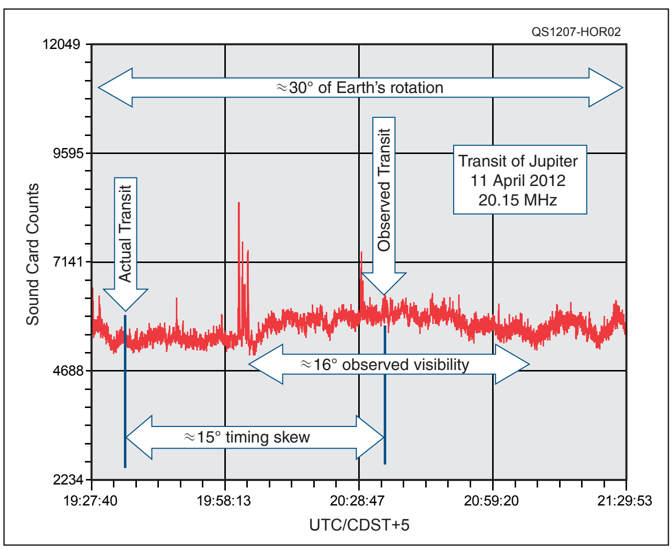


Figure 3 — This portion of the 11 April strip chart clearly shows the gentle rise in background noise as Jupiter passes by in the early afternoon. Blockage from buildings to the south and southeast results in the shift of the received peak later (westerly) in the day.

[3]**en.wikipedia.org/wiki/Grote_Reber**

And Now for Something You'll Really Like

The noise reported as Jovian in Experiment #114 turns out to have considerably more mundane terrestrial origins. The noise from Jupiter looks rather different as it happens — tune to the Hands-On Radio website (**www.arrl.org/hands-on-radio**) for more information and links to sound files of the *real thing*. Thanks to Whitman Reeve and Dave Typinski, AJ4CO, for the correction.