The Penticton Solar Flux Receiver

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

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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.

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

[1]Notes appear on page 45.

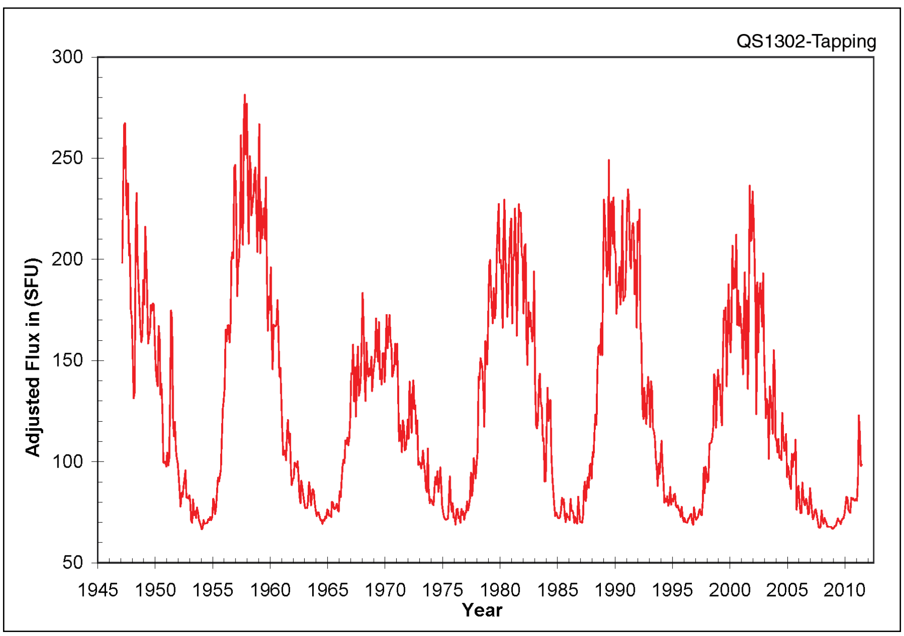

Figure 1 — Historical solar flux data.

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

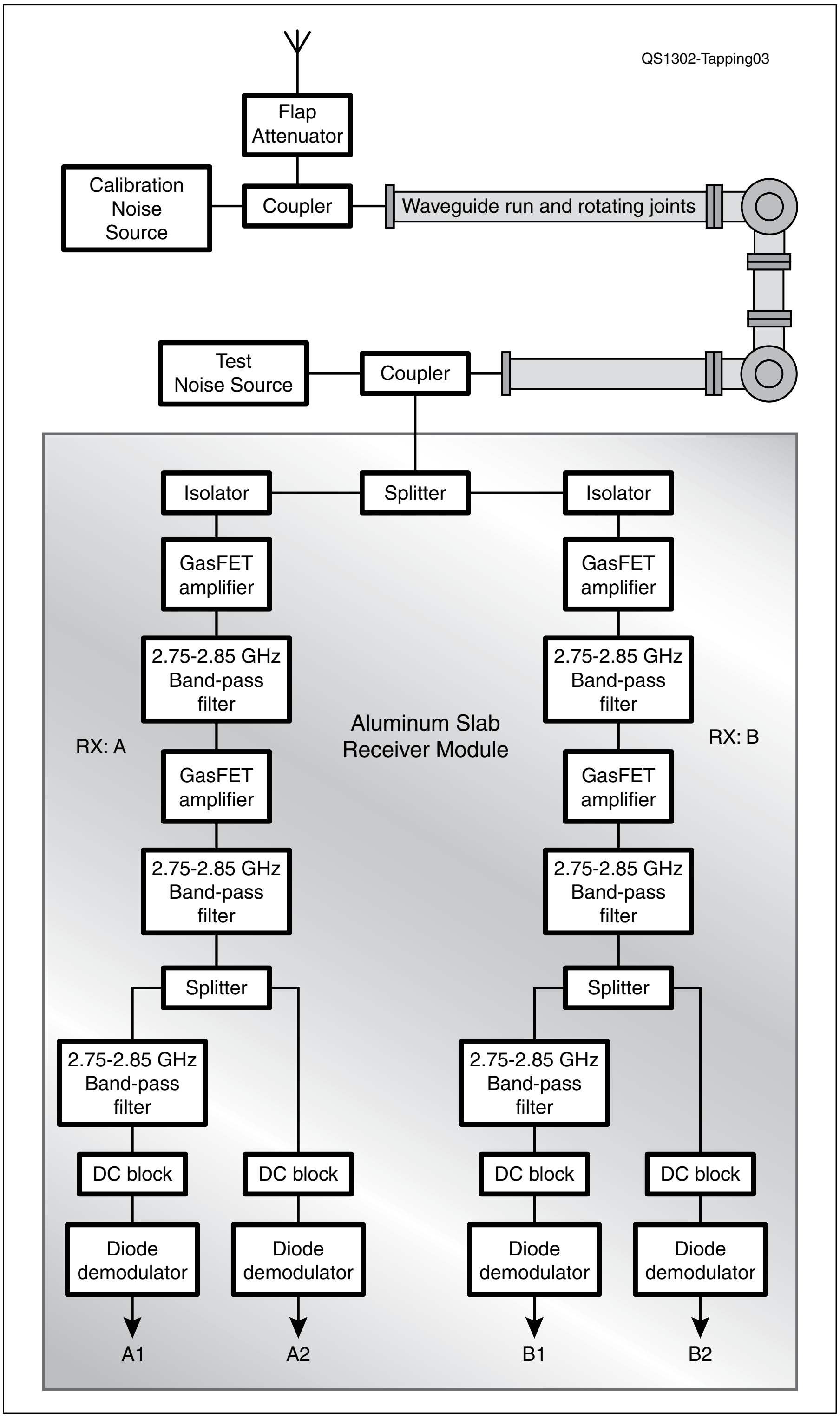

Figure 3 — Block Diagram of RF components.

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,

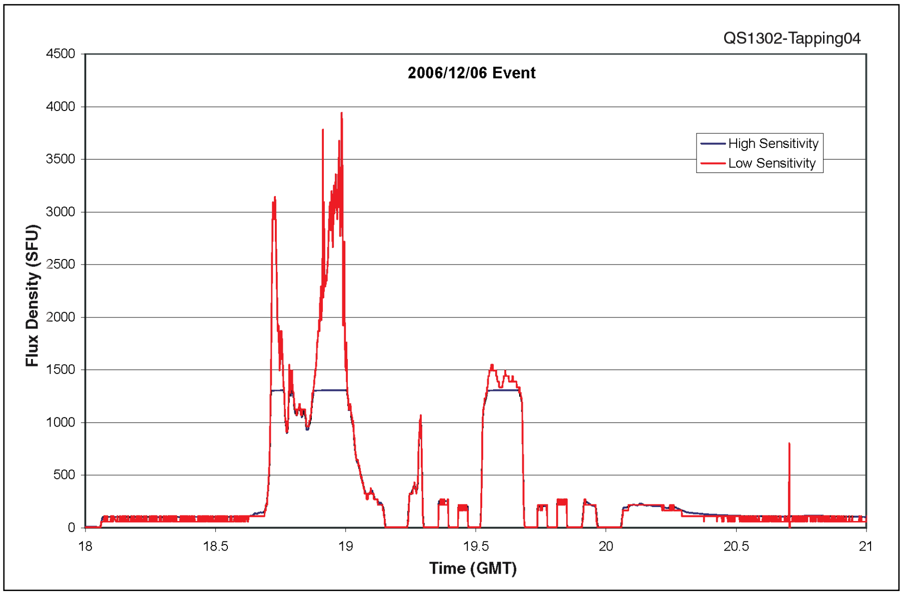

Figure 4 — Dual channel requirement for large solar flare bursts.

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.

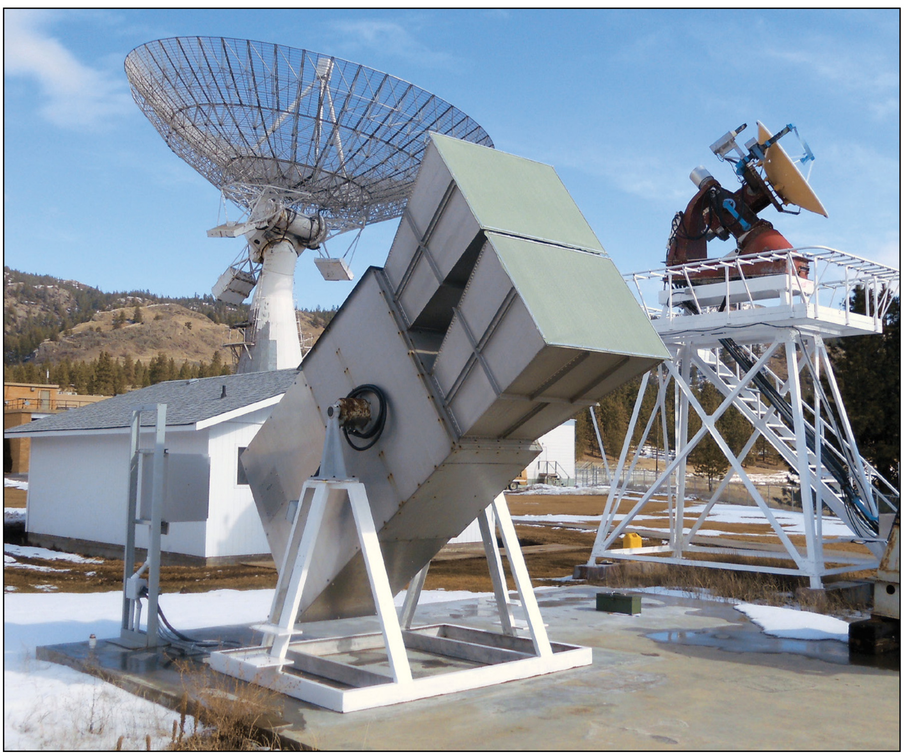

Figure 8 — The dual horn calibration antenna in the foreground.

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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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."