Education Notes
Rubriques pédagogiques

AN AMATEUR RADIO TELESCOPE FOR SOLAR OBSERVATION

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ABSTRACT. Building a simple radio telescope is relatively easy with a combination of persistence and the proper help. Surplus satellite television equipment can be modified to permit radio observations of the Sun and the Moon, as well as to allow the user to learn the fundamentals of radio astronomy. This article describes the steps taken by the author to assemble a radio telescope, and presents the results of his observations.

RÉSUMÉ. La construction d'un simple radiotélescope est relativement facile, pourvu qu'on ait de la persistance et de l'aide convenable. L'équipement en surplus de télévision par satellite peut être modifié afin de permettre les observations par radio du Soleil et de la Lune, aussi bien que d'apprendre les connaissances fondamentales sur l'astronomie par radio. Cet article décrit les dispositions prises par l'auteur pour assembler un radiotélescope, et aussi présente les résultats de ses observations. SEM

1. INTRODUCTION

Between December 1997 and April 1998 I assembled a simple radio telescope that was able to observe solar radiation at radio frequencies. The telescope consists of a used satellite television (TV) system in the 12 GHz (Ku) band that was constructed with guidance via E-mail from William Lonc, professor emeritus of physics at Saint Mary's University in Halifax, Nova Scotia. My experiences may be helpful to others wishing to take beginning steps in the interesting field of radio astronomy.

The exercise allowed me to rekindle interests in both astronomy and electronics that were abandoned when I was a teenager in order to pursue other career goals. Much has changed since I worked with vacuum tubes and gazed at Saturn through a 3-inch refractor. At age forty and reflecting on life at this stage of maturity, I was ready to revisit the awe I felt as a teenager exploring an unseen part of our world.

2. FAILED FM RADIO TELESCOPE

My first radio astronomy project began in December 1997 using a standard home stereo FM receiver arrangement based on a design described by David L. Heiserman in his book *Radio Astronomy for the Amateur* (Heiserman 1975). It was not successful, perhaps because of my lack of experience. The construction of a 34-foot Yagi antenna (figure 1) mounted in my backyard, and the measurement of the noise it picked up, demonstrated just how much terrestrial interference there is in the radio spectrum. Varying household line voltages to the receiver, coupled with interference, made it impossible to observe the Sun in the commercial FM band. I learned that, in addition to ambient light, ambient radio transmissions also hinder the observation of astronomical sources.

By the end of December, I concluded that I needed to try a different tack. If the FM band was not going to work, what frequency should I use? Some books I scanned and a couple of radio astronomers I spoke with via E-mail suggested various frequencies for several antenna and receiver configurations. E-mail conversations directed me to the 600 MHz or 1420 MHz (the hydrogen line frequency) bands. But there were enough options to be confusing. A couple of people suggested that I contact William Lonc and read his book *Radio Astronomy Projects* (Lonc 1996). I contacted Bill via E-mail. He told me to read the book first, then talk with him about projects. It proved to be good advice. Once I read the book, he suggested that the simplest way to get started was to adapt a satellite TV system and do solar observations. That became my goal.

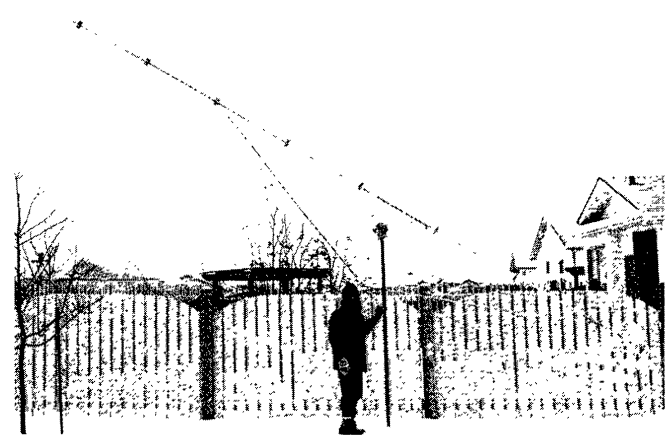

FIG. 1 — The 34-foot Yagi FM antenna.

3. A SATELLITE RADIO TELESCOPE

Finding a satellite system within my budget was the first hurdle. After telephoning a number of retail satellite TV businesses and surplus yards looking for used dishes and receivers, I reached one satellite TV business that gave me a good lead. A staff member informed me that *The People's Network* (TPN), a broadcaster selling self-help programming via satellite, had recently switched its Canadian subscribers over from

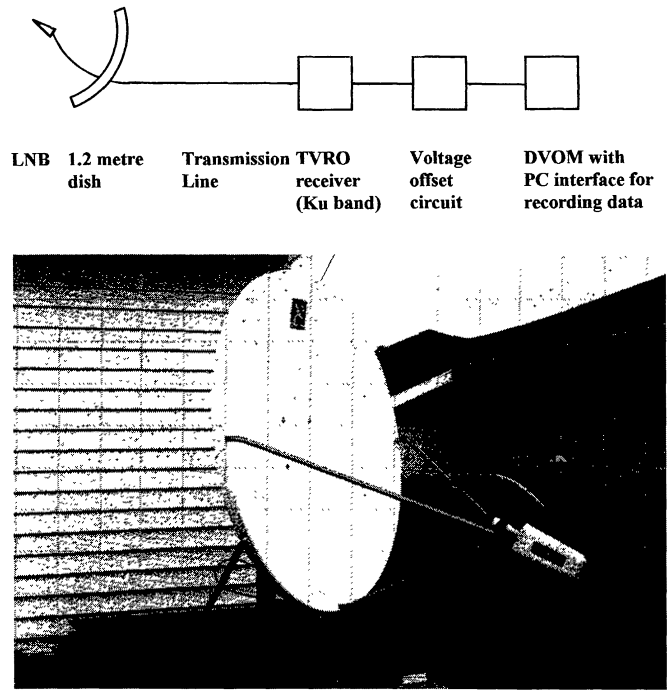

Fig. 2 — The 1.2-metre dish antenna and the block diagram of the Radio Telescope.

analogue to digital receiver systems. That meant there was a supply of relatively inexpensive used C or Ku band equipment lying around.

I contacted the local TPN representative, who was happy to give me the names of five people who wanted to sell their systems. I found one for $210. It included most of the features I needed: a 1.2-metre dish with azimuth and elevation mount, a Low Noise Block (LNB) converter at the focal point of the offset dish, transmission line, and switchable C and Ku band receiver (see figure 2).

My enthusiasm got the better of me, because I purchased the system without verifying that it had a signal strength meter or Automatic Gain Control (AGC) mechanism in the receiver. Either of the two features is necessary in order to observe signal variations from astronomical sources. Signal strength meters can be found on many FM stereo receiver systems. They are used to indicate when the receiver is tuned to a station. Most take the form of a meter that deflects proportionally to signal strength. Others can be a single LED, or a series of LEDs, that lights as the signal increases.

The receiver I purchased had a single LED that was affected by changing the channel tuning on the front of the receiver. It proved to have some other as-yet-undetermined purpose unrelated to signal strength, and was therefore of no help to me. In other words, the receiver had no signal strength meter. I had to find some other way of detecting signal strength. Sometimes satellite TV systems have a connection on the rear of the receiver that installers use to determine when they have located the satellite signal. It is called the Automatic Gain Control (AGC). Unfortunately, my receiver had no exterior AGC connection either.

That forced me to look inside the receiver itself for a signal strength connection. The receiver (Video Plus) is not a common brand, and I was unable to locate schematics or the original manufacturer. I spoke with several satellite TV suppliers, and eventually found someone who suggested that I check the tuner inside the receiver. The tuner is a small metal box fastened on the inside of the case at the back of the unit. The transmission line connects to the box from the LNB on the dish.

Satellite tuners generally have up to twelve pin connectors used for different functions within the receiver. The satellite technician suggested that I experiment with them to locate the AGC circuit. At Bill Lonc's suggestion, I first connected the system to a TV set to make sure the system was in fact able to detect a satellite signal. It was able to pick up several satellite channels, and I began the process of testing the pins using the satellite signal to evaluate the purpose of each pin.

With the TV set near the dish, I used the TV picture and sound as a way of verifying whether the dish was pointed on or off signal as I moved the dish. A voltmeter was connected between the chassis ground of the receiver and each pin in turn. I then took meter readings for each pin when the dish was pointed on and off signal. Some had no voltage, some showed constant voltage, and some varied depending on whether they were on or off signal.

Focusing on the three pins with variable voltages, I refined the investigation by connecting a digital voltmeter with a serial interface to a data-logging program on our home computer. That allowed the output from each pin to be graphed in turn as the dish was moved slowly from an off signal position, through the signal (on), past the signal to an off position again. One pin produced an erratic behaviour, another gave a strong response to the satellite, and the third produced a mild but consistent response.

Because the signal from a point source such as the Sun is known to create a bell shaped curve when passing through the beam of an antenna, I assumed that if I got a signal in the shape of a bell curve, I must have found the AGC circuit. Since the dish was moved manually, the jerky motion of the dish affected the signals produced in the first series of graphed tests. That rendered the data inconclusive. Because TV satellites are geostationary and require manual movement of the dish is required to locate the signal, satellites were not a satisfactory method of evaluating the system response on the three pins.

4. The Sun

It was time to try an observation of the Sun, which is a strong source of radio signals. There were a couple of ways to use the Sun as a signal to verify which of the three pins was the one I wanted. It also nicely coincided with my goal of observing the Sun.

Transit observations are a common and inexpensive way for amateur radio astronomers to observe celestial sources in the radio spectrum. By pointing the antenna southward along the north/south meridian at a particular elevation and allowing the sky to pass in front of the antenna beam, the observer can correlate detected signals with astronomical objects. A variation on the meridian transit method is to point the antenna just ahead of a known source and allow the rotation of the Earth to move the source through the antenna beam. With more expensive equipment it is possible to track objects across the sky, all the time observing their radio emission.

Not having a tracking system, I used the transit method to find the AGC pin on the tuner. The dish was aimed just slightly ahead of the Sun and the response on each of the three pins was recorded as the Sun passed through the antenna beam. The pin that had behaved erratically before did the same thing this time, and the one that responded strongly to the satellite showed no response. The third pin showed a stepped response, increasing as the Sun passed to the centre of the beam, then declining as it passed out of the beam. I had found the AGC, and coincidentally observed the Sun for my first time.

After the three months I spent determining a suitable frequency, finding a satellite system, and getting it operational for radio astronomy purposes, it was a tremendous thrill to finally see some results. With an optical telescope the results are immediate, and the observable sources are more or less unlimited. Someone interested in radio astronomy needs to have a curiosity for the mechanics of radio observing to stay interested.

5. Refining the Observations

The accuracy of my first observation was not very good, as evidenced by the stepped nature of the graph (see figure 3) where the voltage moved from a baseline of 2.65 volts, to 2.66 volts, then peaked at 2.67. The voltmeter was set to 20 volts dc. The next lowest setting is 2 volts. It was not possible to use the 2-volt range because the output voltage of around 2.65 volts direct current (Vdc) would have overloaded the meter. On the other hand, the lower range would have allowed better accuracy with more significant digits.

The high range setting meant the signal could theoretically have varied between a low of 11 millivolts and a high of 29 millivolts. At the

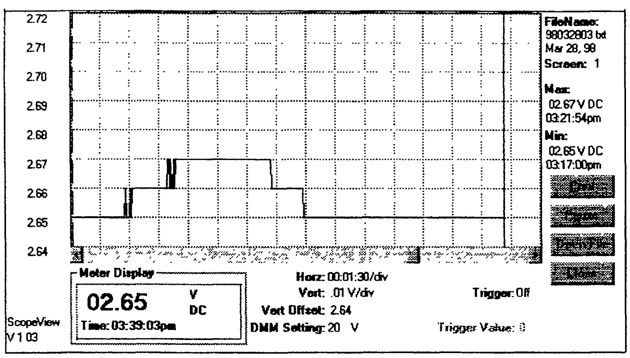

Fig. 3 — First Sun observation using 20 volts dc setting on voltmeter.

20-volt setting, the actual signal strength could have reached 29 millivolts by varying between 2.645 volts (rounded up to 2.65 because of the setting) and 2.674 volts (rounded down to 2.67). Inversely, it could have been 6 millivolts, with possible low and high readings spread between 2.665 volts and 2.654 volts. Each such reading would yield the same graphical results.

As a result, the signal strength could not be determined accurately at the setting I was using. Another uncertainty was whether or not I had pointed the dish accurately. Did the Sun pass through the centre of the antenna's beam, or through the side of the beam? If the dish was pointing off-centre to any extent, the strength of the signal would be lower. Also, the graph of the signal did not look like the nice bell curve that would be expected with a more finely graded scale at that frequency. Instead, it looked like a crooked little stile over a crooked little fence.

To solve the problem, a second observation was conducted. I attached a 100 K ohm potentiometer between the chassis ground of the receiver and the AGC pin, and read the signal between the centre-tap and ground of the potentiometer. By adjustment of the potentiometer, the baseline voltage could be offset to below 2 Vdc, making readings at the 2-volt setting significant to three decimal places rather than to the two places I was able to read at a setting of 20 volts.

The second observation showed a smooth bell curve (figure 4), but at not as strong a signal as I had expected. The circuit cut part of the total signal response off at the top end of the potentiometer. Since signals from astronomical sources are extremely small, signal loss has to be avoided at all costs.

The peak signal over the baseline voltage that I obtained using the potentiometer was 20 mV. After doing some calculations of projected signal loss at the top end of the potentiometer, I concluded that the

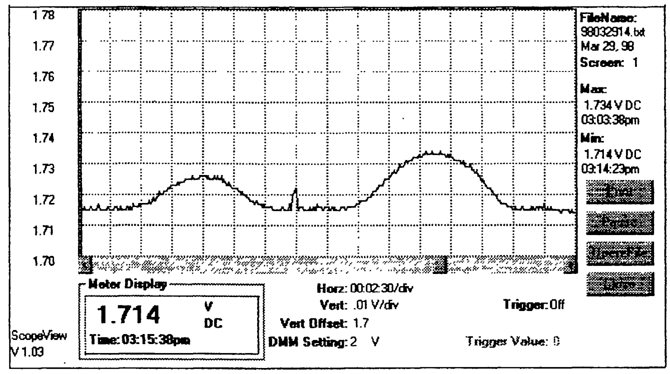

Fig. 4 — Two transits of the Sun. Note the first observation where the Sun passed off-centre to the beam. The bump between the two bell curves was made when the dish was moved manually past the Sun. The second bell curve was with the Sun passing through the centre of the beam. Note the signal strength of approximately 20 mV.

system could probably produce a maximum signal of approximately 30 mV over the baseline. For a satisfactory number of significant digits, that would require use of some other means other than the potentiometer to drop the voltage to a level readable at the meter setting of 2-volts. The results correlated nicely with the maximum signal that was possible within the limits of uncertainty associated with the first observation.

Once again Bill Lonc came to the rescue, with a simple circuit design that allowed me to drop the baseline voltage further, to the point where I was able to use the 200 mV setting on the meter, this time without signal loss. Bill's circuit uses two 1.5-volt D cell batteries and a potentiometer between the ground, meter, and AGC pin to cancel approximately 2.5 volts. The signal voltage could then be viewed against a very low baseline voltage. I was able to read a signal of 30 mV over the baseline, confirming the expected value (figure 5). Because of the voltage cancelling circuit, I was able to use the 200 mV setting on the voltmeter. At that setting the system was sensitive enough to record signal variations from vibrations of the dish as I walked across the deck while the Sun passed through the antenna beam (note the three lumps in the bell curve just after the peak shown in figure 5).

The beam of a parabolic dish antenna consists of a cone-shaped area in front of the antenna from which radio waves can be detected. The 1.2-m dish had a predicted beamwidth of 2°. Antenna beamwidth normally specifies the angular distance between the points where the signal reaches half its strength on either side of the peak signal (referred to as "half power points"). My observations had a variety of signal increases that depended largely on whether or not the Sun passed through the centre of the antenna. The first observation I could use to measure the antenna's beamwidth was done on April 5, 1998 (figure 5). The data displayed a response that lasted twelve minutes from the first noticeable increase, through the peak signal, to the baseline voltage once again. The time between the half power points was approximately 8.25 minutes.

At the equinoxes the Sun passes through 15° of arc each hour relative to the meridian of the observer. The amount decreases as a

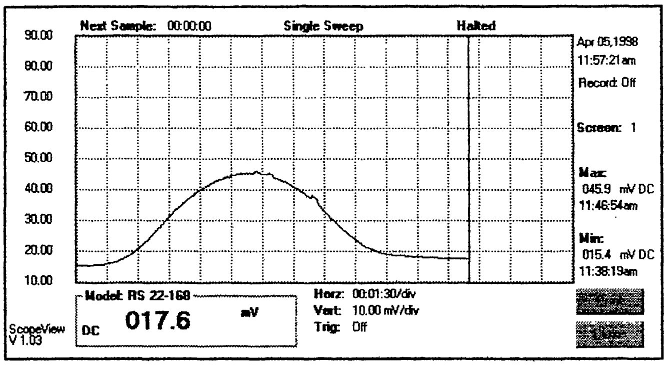

Fig. 5 — Solar observation using Bill Lonc's dc offset circuit. Note the 30-mV signal and the three bumps on the bell curve caused by vibration of the dish.

function of the cosine of the observer's declination. In other words, the arc traversed by the Sun decreases from its nominal value of 15° per hour the further the Sun is from the celestial equator.

On April 5, the date of the observation in question, the Sun's declination was approximately +6°. The half power point interval was 8.25 minutes. At the celestial meridian, the Sun traverses 1° in 4.0 minutes, but at +6° declination it takes 4.02 minutes. The calculated beamwidth of the observation is therefore $8.25/4.02 \times 1°$, or 1.9°. The antenna beamwidth is therefore close to the predicted 2°. Another observation on May 29 with the Sun at approximately +22° declination resulted in a calculated beamwidth of 2°. Further observations produced values that differed by no more than about 5% from the expected beamwidth.

6. The Moon

With successful solar observations under my belt, I decided to try looking at the Moon and other astronomical sources to see what I could detect. The Moon emits microwaves originating from its temperature. The nearly Full Moon, as observed in early April 1998, produced a signal response of 3 mV, one tenth the strength of the solar response (see figure 6).

7. Other Objects?

The dramatic reduction in signal strength between the Sun and Moon

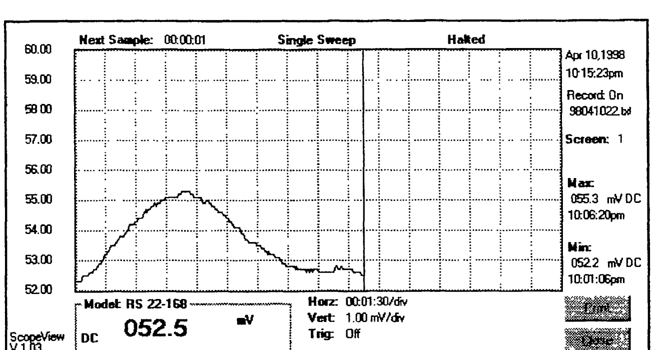

Fig. 6 — Lunar observation at nearly Full Moon on April 10, 1998. The signal strength from the Moon is approximately 3 mV.

made me wonder if I would be able to see more distant objects. Attempts to see sources known to be strong radio emitters, such as Cygnus A and Taurus A, were not successful. Reference charts showing the strength of signals from such sources compared to the signal strength of the Sun at 12 GHz, clearly showed that I was dealing with emissions so weak that I would probably not be able to distinguish them from the background noise created within the receiver system itself.

After five months of research, construction, experimentation, and successful observation, I came to the limits of what my 1.2-m satellite TV system can observe. In the end, the system was not very expensive at $210 for the used dish, LNB, mount, transmission line, and receiver. I also purchased a Radio Shack RS 22–168A digital voltmeter with computer serial interface software included for logging data, which cost $190 — but which has been on sale for about $30 off since I purchased it, of course.

For anyone wanting to try radio astronomy, I have learned a couple of things that may be helpful. Be certain that your references are current. Earlier books or articles may provide helpful general information about the foundations of radio astronomy that have not changed much over time. But technological changes have made things possible in the late nineties that were not possible in the seventies or even mid-eighties. For example, one book written in the mid-seventies before the advent of satellite television, refers to the impracticality of using parabolic dish antennas for observing. They are now quite common in amateur radio astronomy. Strip chart recorders are another example. They used to be about the only option for capturing data, aside from taking periodic visual readings from the voltmeter. Now digital technology, such as I used, permits data to be recorded in electronic files that can later be analyzed using data processing techniques.

Finally, networking is a useful way of gaining experience without having to go through a frustrating amount of trial and error in the early stages. Nevertheless, I found it worthwhile trying one thing and another even though it netted no results. It gave me time to process information gained by reading and talking with others interested in radio astronomy. Getting to know the quirks of my particular receiver and dish through trial and error helped me to understand how my equipment worked. Even with help from others, there is no doubt that the simple radio telescope project like the one described here takes a fair bit of patience. But I found it fun and worthwhile.

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