The Carroll College Radio Telescope

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Introduction

This project began after a long series of cloudy nights and complaints about the light-polluted skies of Waukesha. We (Brian Cieslak and George Stecher) pondered building a small radio telescope. After learning of several amateur radio telescopes, we concluded, in the late fall of 1994, that designing and building an inexpensive instrument would make an excellent undergraduate research project. Brian had a strong background in amateur radio and quickly discovered that plans and materials designed by and for the amateur radio community were very useful to our project.

Brian worked on the design of the telescope in the spring of 1995 as a Physics 496 ("Special Problems and Research") project supervised by George Stecher. Brian decided that the Sun was the most interesting target and chose 2800 MHz as the frequency for our telescope. He also decided that an array of helical antennas would be effective and relatively easy to build. Meanwhile, George applied for, and received, a Carroll College Faculty Research Grant to pay for materials, starting in June of 1995. We decided on a modification of Dick Jansson's (WD4FAB) helical antenna array, written up in the 1994 *ARRL Handbook* [1], as the starting point for our telescope.

Our original goals included

- the construction of a working solar radio telescope for use in physics department research projects and as a demonstration in physics and related classes.
- learning basic radio astronomy techniques and demonstrating the advantages of multiple-antenna arrays.
- studying solar radio phenomena, including correlating solar radio activity to optical sunspot activity and perhaps auroral activity.

Late in the fall of 1995, an early form of the telescope, with a single antenna, was working. (By then we had modified our design to be a 2400 MHZ telescope.) It could detect an artificial radio source, but could not yet detect the Sun (in part because we fried the preamp and in part because it was not sensitive enough). In January of 1996, Jeff Houle joined the project and began constructing the antenna array. In early June 1996, a test run was made with the four element array. Once again, we failed to detect the Sun, but the preamp still wasn't working right. During our latest test, on 20 June 1996, we still didn't detect the Sun. The preamp was working, but we measured its gain to be 3 to 5 dB rather that 15 dB. Our project is presently halted for the summer. Brian and Jeff plan to continue working on the telescope in the fall.

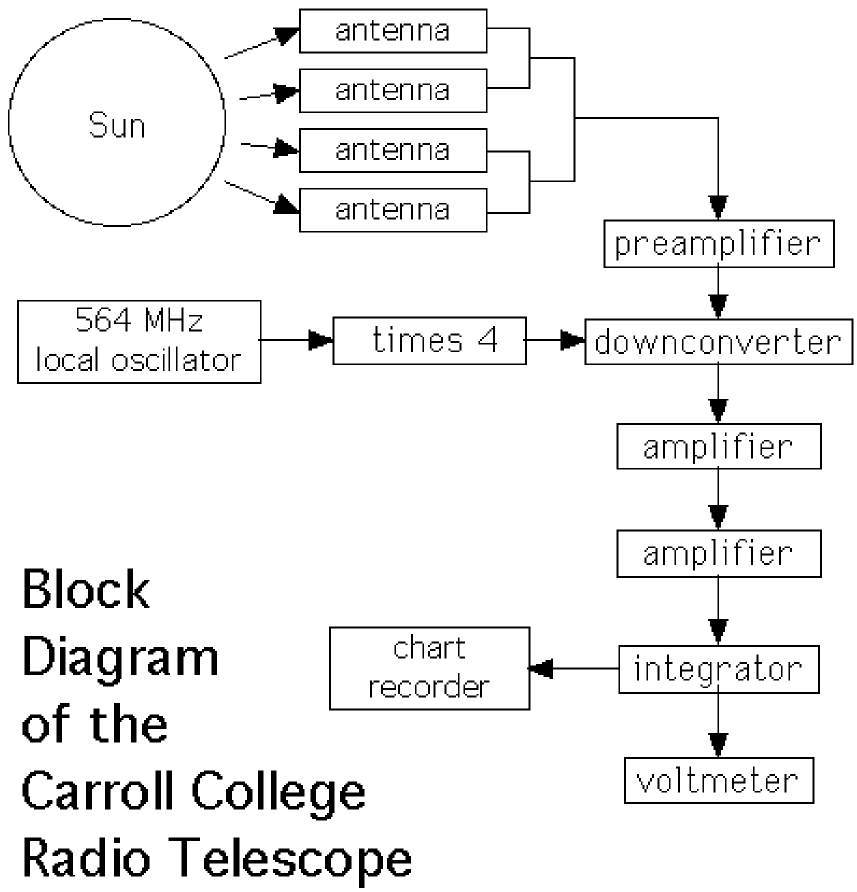
We're making this web page now for several reasons. First, George is leaving Carroll College and heading to the University of Wisconsin - Eau Claire. The Carroll Faculty Research Grant requires that the results of the grant be disseminated to the Carroll College community, and this web page partially serves that purpose. Second, we want to provide a summary of our work so far so that Carroll students can see what we've done and possibly join the project. (Interested Carroll students should see Professor Welch in Lowry 115.) Finally, just in case we stumbled into a good idea or two, we want others interested in small-scale radio astronomy to see our work, get ideas about what to do (or not to do), and improve on it.

Radio Emissions from the Sun

Our telescope is designed to measure the solar flux at approximately 12.5 cm. At wavelengths close to this, the Sun's radiation varies dramatically, and the radio flux is strongly correlated with sunspot activity.[2] The flux consists of a thermal background and a slowly varying component, or S-component, which has a peak at in flux density at around 10 cm.[3] A portion of this S-component is produced by free electrons moving in regions of high magnetic field above the photosphere. These free electrons follow helical paths around the magnetic field lines; as they spiral in the magnetic field at the cyclotron frequency--which varies linearly with magnetic field strength--they emit radiation at the that frequency. Additionally, solar flares can create broad spectrum impulsive bursts of synchrotron radiation peaked around 10 cm in wavelength.[4] We hope that our telescope will eventually measure all three phenomena: the background of the quiet Sun, the S-component, and impulsive bursts.

Design

Overview: The basics of our telescope in a nutshell

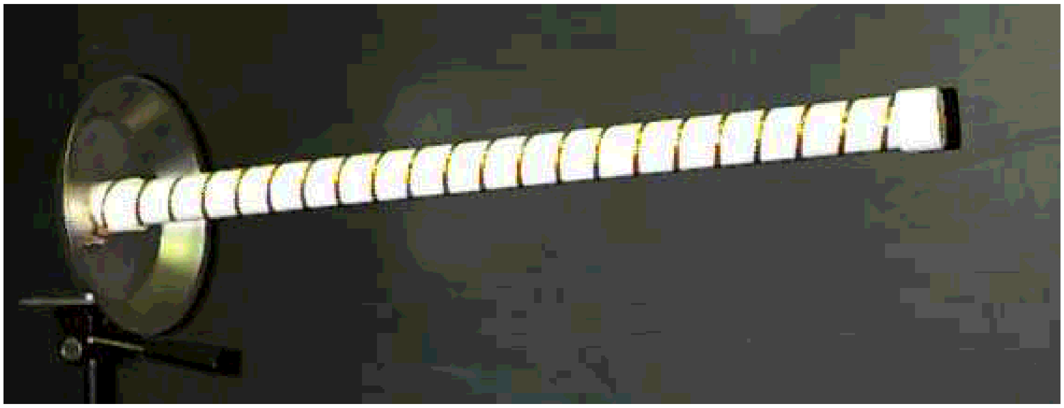


The block diagram above indicates the general path of information through our radio telescope. First, a broad spectrum of radio waves from the Sun, centered around 2400 MHz, is picked up by each of the four antennas in the antenna array. Signals from two of the antennas are combined, signals from the other two antennas are combined, and these two composite signals are then in turn combined into the four-antenna composite signal. At this point, the composite signal still contains a wide range of frequencies.

The signal then enters the preamplifier, where its power is raised approximately 15 dB, and is then fed into the downconverter. The downcoverter contains two bandpass filters and more amplifiers, which eliminate most of the signals outside the range 2400 MHz to 2404 MHz and increase the power of the signal by another 15 dB. The remaining signal is then mixed (i.e. multiplied) with a signal at 2256 MHz, which was created from the frequency quadrupled signal of a 564 MHz local oscillator. For each frequency f in the filtered solar signal, new frequency components of (f + 2256 MHz) and (f - 2256 MHz) are created, each proportional to the original solar signal. We use the lower set of frequency components, which for our input range of 2400 MHz to 2404 MHz, go from 144 MHz to 148 MHz.

The output signal of the downconverter containing the range of frequencies from 144 MHz to 148 MHz is sent through two amplifiers. The signal is then integrated and recorded by a digital voltmeter and/or a chart recorder.

The Helical Antennas



A picture of one of our helical antennas

The theory of the helical antenna, the most fundamental component of our telescope, is described by John D. Kraus in his book *Antennas*.[5] Our antennas were constructed from PVC pipe (outer diameter = 4.25 cm, nominal size 1.25") wrapped with a helix of 0.65 cm wide copper tape, were 77 cm long, excluding the top PVC cap, and contained 22 turns. Successive turns were separated by a distance of 3.5 cm. Because of our construction technique--using a PVC pipe cap on each end of the antenna--the turn closest to the ground plane had a slightly larger diameter, 5.05 cm, for part of its path. All of our antennas were wound with the same chirality, so that all the antennas would pick up the same circular polarization of radio waves.

For ground planes we used inexpensive metal pie tins. A BNC connector was mounted in the pie tin 4.93 cm from the central axis of the antenna. A small brass strip 0.65 cm in width was soldered to both the copper tape and the center conductor of the BNC connector (see picture). This strip of brass could be bent with needle-nose pliers to adjust the capacitance between the antenna and the ground-plane.

The antennas were supported mechanically by a .25"-20 bolt. The head of the bolt stayed inside the antenna and was potted in 5-minute epoxy. The threads ran through the endcap and then the ground plane. The remaining threaded portion--that part sticking out of the antenna--was used to secure the antenna in its desired location.

The Antenna Array

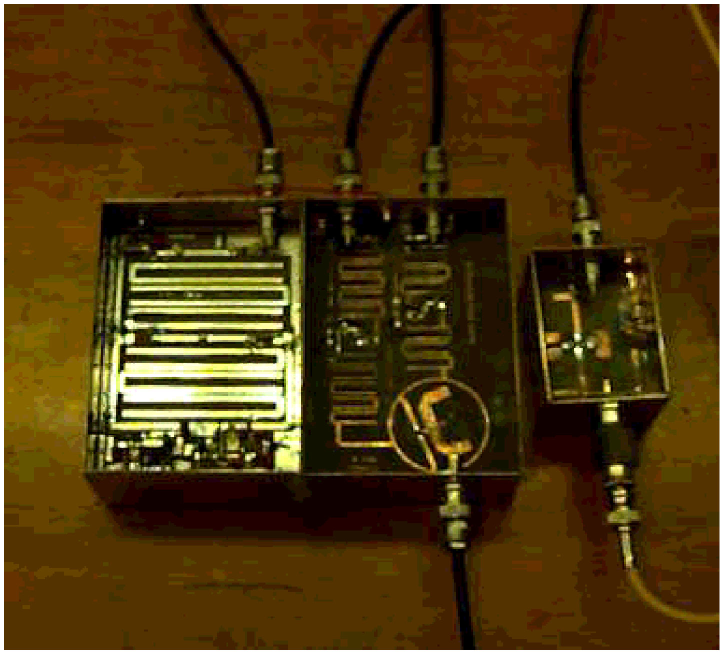
Our four antennas were positioned on the corners of a 1 m by 1 m square. A support structure made of PVC pipe (outer diameter = 4.25 cm) held the antennas in place. The antennas were connected electrically by coaxial cables which ran inside the pipes. The support structure was made of four PVC elbows, three PVC tees, six 45.3 cm lengths of PVC pipe, and two 95.5 cm lengths of pipe. When assembled, the pieces of pipe made a 1 m by 1 m square (center to center) with a central crosspiece.

Coaxial cables ran from each antenna into shorter lengths of pipe on either side of the square. Two cables met in of the side tees. A third cable from each tee ran inside the central crosspiece and met at the central tee, where a coaxial cable left the structure carrying the composite signal. In other words, the coaxial cables inside the structure formed an H, with antennas at each end and the output signal leaving the center of the H. (In the picture above, the H is tilted and looks more like an I, if you are using a font with serifs). There were no cables inside the long lengths of pipe. All of cables inside the structure were 50 cm long (excluding the length of the pin at each end of the cable) RG-58A/U 50-ohm BNC coaxes.

To allow for easy disassembly and maintenance of the cables, none of the PVC joints were glued. The entire PVC assembly was held together by four bungee cords under tension. A 1 m square of light, clear plastic (actually made to protect door frames) was attached to the ends of the antennas to provide additional support.

We attached antenna array to an old, unused German equatorial mount that originally belonged to an Edmund Scientific 6" reflector. The equatorial mount was overkill, but it was available and saved us the trouble of having to build our own.

The Electronics



The above picture shows the local oscillator (left), the downconverter (center), and the preamplifier (right).

The preamplifier was built from a Model 13LNAK 2.3 GHz GaAsFET preamplifier PCB kit from Down East Microwave and based on a design by Al Ward, WB5LUA. [6] The cost was approximately $40.

The local oscillator was an SHF Systems Local Oscillator running in mode S. This oscillator was based on a design by Richard Campbell, KK7B, modified by Al Ward, WB5LUA and Jim Davey, WA8NLC. The downconverter was an SHF Systems 2400 (K) Mode S Downconverter designed to receive signals from OSCAR satellites by Jim Davey, WA8NLC. The local oscillator and downconverter were purchased together in kit form from Down East Microwave (Model SHF2400K, cost approximately $155).

The amplifiers between the downconverter and the integrator were Radio Shack VCR-TV-FM Variable 20 dB Amplifiers, catalog number 15-1113B. The amplifiers were generally used at their maximum gain settings (20 dB each) and the FM trap attenuation was turned off.

The integrator circuit was built as follows:

```
            IN34A      330 K ohm
            diode      resistor

IN -------+--|>|--------/\/\/----+----- OUT (to voltmeter)
          |                      |
          |                      |
          -                      |
          ^ IN34A               --- 10 uF
          - diode               --- capacitor
          |                      |
          |                      |
         /// ground             /// ground
```

Performance

Is our telescope sensitive enough to detect the quiescent Sun? In theory, yes. The Sun emits approximately 6 x 10^{-21} W/(m^2Hz) at the wavelengths we are interested in.[7] Our telescope has bandwidth of 4 MHz and an effective aperture of about .23 m^2. Multiplying these, we see that our antenna array should be picking up about 6 x 10^{-15} W of power from the Sun. The preamplifier, downconverter, and two amplifiers provide a total amplification (in theory) of 70 dB, of a factor of 10^7 in power. This implies that about .06 microwatts of power makes it to the integrator. Assuming we lose half the power in rectification, and that the output impedance of our integrator is close to 330 K ohms, the final output signal should be around .1 volts. This is high enough above the typical noise in the system (around 10 millivolts) to be detectable. As of our last test run, however, we still hadn't detected the Sun.

Concluding Comments and Future Plans

Our project is not yet finished, but it has already helped the three of us learn a great deal in the areas of antenna theory and practice, transmission lines, electronics, high frequency design and construction, solar physics and related atmospheric phenomena, and simple mechanical design, and has provided the opportunity for students to design and conduct an experiment primarily on their own. We almost certainly could have built a better instrument by copying an existing design, but that was outside the spirit of the project and we wouldn't have learned as much. As a teaching exercise for us, it's already been a great success. (Some of us have also learned to dislike GaAsFETs with tiny leads and others have learned to dislike winding and rewinding copper tape.) Nevertheless, we encourage everyone interested to give small-scale radio astronomy a try, even if they don't know what they're doing!

Our telescope works--it detects an artificial source just fine--but still doesn't work well enough to pick up the quiescent Sun. We think it works well enough to pick up an active Sun, but aren't quite sure yet. Unfortunately for us, the Sun is just coming out of a minimum in the sunspot cycle and isn't very active right now.

Future plans include improving the gain of the telescope with better or more amplifiers, especially the preamp, cutting down on noise through better shielding, making the telescope more portable by making all of the electronics battery operated, and using the telescope to record the 12.5 cm solar flux and correlate it with optical sunspot observations. We may need a wider bandwidth, which would require changing the downconverter. We hope that the telescope will be used as a demonstration in next year's electricity and magnetism and astronomy classes, and possibly other classes as well.

Acknowledgements

We gratefully acknowledge the support of a Carroll College Faculty Research Grant, which paid for the materials used in this project. We also thank William Lonc for very helpful advice. He has a book out on undergraduate projects in radio astronomy that we wish we had discovered earlier.[8] Further thanks to Chris Houle for electronics help, John Symms for help with some of the test runs, and Bill Welch for agreeing to supervise the project starting next fall.

Notes

[1] The American Amateur Radio Relay League, *The ARRL Handbook for Radio Amateurs 1994* (Newington, Connecticut: The American Amateur Radio Relay League, 1993), 23.35-23.41.
[2] Alex G. Smith, *Radio Exploration of the Sun* (Princeton: Van Nostrand, 1967), 82-84.
[3] Alex G. Smith, *Radio Exploration of the Sun* (Princeton: Van Nostrand, 1967), 82-88.
[4] Alex G. Smith, *Radio Exploration of the Sun* (Princeton: Van Nostrand, 1967), 88-92.
[5] John D. Kraus, *Antennas* (New York: McGraw-Hill 1950): 173-216.
[6] Al Ward, WB5LUA, "Simple Low-Noise Microwave Preamplifiers," *QST* May 1989: 31-36.
[7] Ken Tapping and James Dean, "Solar Activity," in *Observer's Handbook 1996*, ed. Roy L. Bishop (Ontario: University of Toronto Press, 1995), 67.
[8] William Lonc, *Radio Astronomy Projects* (Louisville, Kentucky: Radio-Sky Publishing, 1996). This book is a good starting point for anyone looking for an inexpensive undergraduate research project in radio astronomy.

Bibliography

- The American Radio Relay League. *The ARRL Handbook for Radio Amateurs 1994*. 71st ed. Newington, Connecticut: The American Radio Relay League, 1993.
- Kraus, John D. *Antennas*. New York: McGraw-Hill, 1950.
- Lonc, William. *Radio Astronomy Projects*. Louisville, Kentucky: Radio-Sky Publishing, 1996.
- Smith, Alex G. *Radio Exploration of the Sun*. Princeton: Van Nostrand, 1967.
- Tapping, Ken and James Dean. "Solar Activity." In *Observer's Handbook 1996*, edited by Roy L. Bishop, 67-70. Ontario: University of Toronto Press, 1995.
- Ward, Al, WB5LUA. "Simple Low-Noise Microwave Preamplifiers." *QST* May 1989: 31-36.

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A radio telescope is a specialized antenna and radio receiver used to receive radio waves from astronomical radio sources in the sky. Radio telescopes are the main observing instrument used in radio astronomy, which studies the radio frequency portion of the electromagnetic spectrum emitted by astronomical objects, just as optical telescopes are the main observing instrument used in traditional optical astronomy which studies the light wave portion of the spectrum coming from astronomical objects Carroll College, located in Montanaâ€™s state capital Helena, is a private, four-year, Catholic diocesan college providing undergraduate education to nearly 1,500 students. Founded in 1909, Carroll has distinguished itself as a pre-eminent and award-winning leader in academic programs including pre-medical, natural sciences, nursing, engineering, mathematics, the social sciences.Â Let us help you find other ways to experience a little bit of what it means to be part of the Carroll College family - join us online! View more. Honors Convocation. Carroll College holds its Honors Convocation to recognize the academic accomplishments of Carroll students. Read more. 3. Times Carroll teams awarded highest ranking in the International Math Contest in Modeling. #1. A radio telescope is like a radio receiver except that the signal is much weaker and must be recorded for processing. Basically a radio telescope requires 8 stages as followsÂ The resolution of a radio telescope is linked to the frequency by the this formula. We immediately see that the dish diameter becomes rapidly huge if we want a resolution similar to optical telescopes. We can work at a few GHz but here silicon components are useless.