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Amateur Radio Astronomy Projects—Total Power Radio Telescope

Build your own radio telescope and copy signals from deep space!

My final project in this series is the total power radio telescope. This was the first astronomy project I built, and the most difficult. It took me many years to finally get a unit that worked. There are now dealers that carry very good total power receivers. I chose to build a radio that received radiation from the atomic hydrogen spectral line at 1420 MHz. Since hydrogen is the primary substance in the universe, this frequency is perfect for mapping objects in the universe.

Figure 1 — My total power radio telescope system.

Background

As most of us know, when you look at light from a light bulb with a prism or diffraction grating, you see the full spectrum. If you turn that prism/diffraction grating to a fluorescent bulb, neon bulb, or sodium lamp, however, you see quite a different spectrum with bright emission lines corresponding to the element creating the light — mercury for fluorescent bulbs, neon for neon bulbs, and sodium for sodium lamps. These spectra are distinct for each element. It turns out that these spectral lines also occur in the radio region of the electromagnetic spectrum and the line for neutral hydrogen is at 1420 MHz. The 1420 MHz line was first discovered in 1951 by Ewen and Purcell at Harvard University, and their horn antenna is on display at the National Radio Astronomy Observatory (NRAO) in Greenbank, West Virginia. Since most of the universe is made of hydrogen, this is a great frequency to use to map the radio objects in the universe.

I decided that this was to be my first radio project, and I wanted to create a radio map from my backyard. As mentioned above, I started this project in the 1980s, when there were very few resources for making such a radio telescope. I am a high school science teacher and have some background in elementary electronics but this project was well beyond me. I found Bob Sickels, an amateur radio astronomer in Florida, and he helped me over the phone and also when I flew to Florida twice for help. I then received help from a Society of Amateur Radio Astronomers (SARA — **www.radio-astronomy.org/**) member, Paul Schuler, who lived near me. We worked for several years together, and I finally got the radio to work. My radio telescope was finally operational about ten years after starting the project.

Signals Detected

If you've ever taken a digital photo, you know that you can take millions of pixels with one shot. Unfortunately, radio astronomy uses a one pixel per observation instrument, and it takes a long time to compile enough data for a picture. The data in this case is a voltage that corresponds to an intensity of signal received. The receiver is calibrated with a known noise source. My final radio telescope is shown in Figure 1. Each day that I observed, I collected data at 10 second intervals at various altitudes (25° to 75°) using the drift scan method of collection; the objects in the sky "drift" by the antenna, which is pointed as close to due south as possible. Remember that I wanted to make a full sky map, so I needed data for the entire day and an entire year. Remember, also, that the sun and moon dominate any chart taken near them, and their signal swamps that data, so many charts needed to be collected to gather all the data I sought.

When and How to Observe

Radio objects are available all day and night and in all types of weather (lightning can destroy the equipment so I always packed up when a storm approached). There are lists of objects that amateurs can try to find, arranged by astronomical coordinates. One is available at: **http://adsabs.harvard.edu/full/1968AJ.....73..135G**. [Yes, that URL includes a group of 5 dots and another group of 2 dots. — Ed.]

To share information with others, a reference system must be adopted. The system used by astronomers is the celestial coordinate system. After years of teaching that the night sky is not a sphere that rotates around the earth, it is ironic that this is what we are going to envision for our coordinate system. Since both the surface of the earth and the celestial sphere are surfaces of spheres (or nearly so), we can define any point on those surfaces with two coordinates. In nearly the same way that we use Longitude and Latitude to find a point on the surface of the earth, we use Right Ascension (RA) and Declination (DEC) to find objects on the celestial sphere.

This is where we should break to make sure that everyone who is about to use this has a radio telescope in which the pointing of the antenna is precisely known. With optical telescopes, we can verify our position with a quick glance through the scope, but with our radio antenna it's much more complicated. If you need to verify your pointing, here's a way of doing it with no extra cost than the time to complete some days of solar observation.

Verifying Your Pointing Position

I learned from Paul Schuler that you could use the sun as a pretty good point source and plot the width of the solar plot (left and right of center) versus the number of degrees away from the actual/calculated declination. For this, you must be sure to capture the entire solar peak since you will need the peak to find the center line. I looked up the sun's actual RA and DEC on the Internet (there are currently many sources for this information including: (**faculty.physics.tamu.edu/krisciunas/ra_dec_sun.html**) and pointed

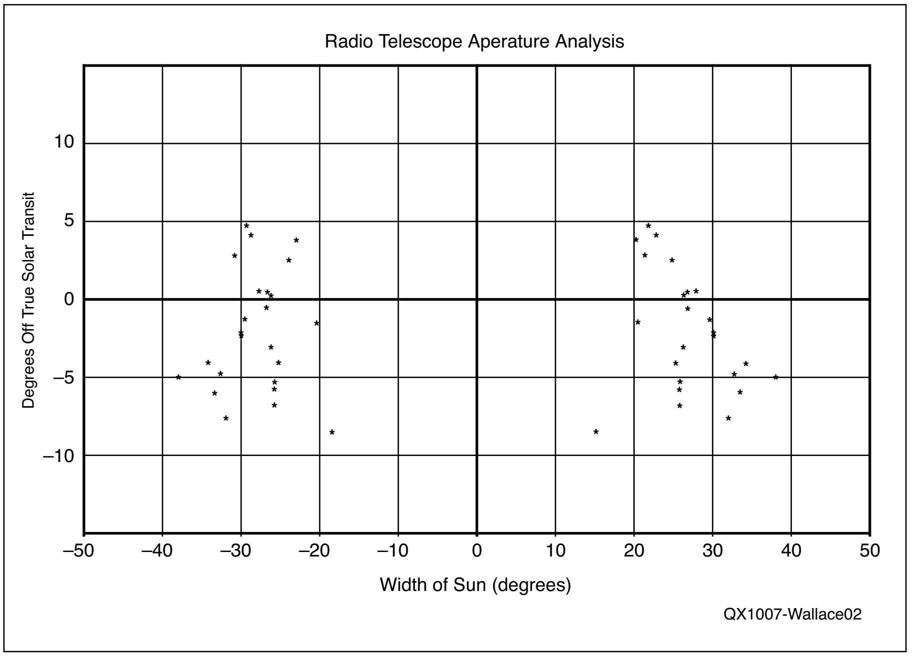

Figure 2 — An aiming chart for the 10 foot parabolic dish antenna.

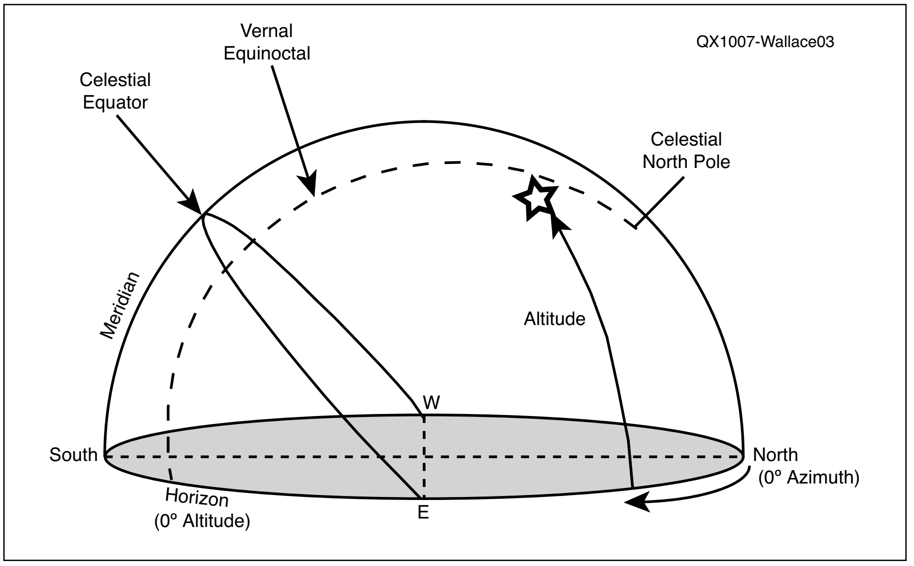

Figure 3 —Finding the altitude and azimuth for an object. (Graphic used by permission from Dr. Jim McDonald.)

my antenna directly at the sun and then progressively further away (above and below) over a period of days to get the plot shown in Figure 2. I found that my antenna is a little asymmetrical and my pointing is off by about 1.5°.

Azimuth and Altitude

If you were to go out tonight and try to show someone the "Big Dipper" you would probably point to the object and use Azimuth and Altitude. Azimuth is the angle around the horizon from due North and running clockwise. It corresponds to the compass directions with 0° representing due North, 90° due East, 180° due South, and 270° due West. Altitude is the height of the object in degrees above the horizon. Altitude can range from 0° (on the horizon) to 90° (directly overhead). A good approximation of these to use at night is your hand at arm's length. Your whole hand (thumb through pinky) is about 10° and each finger is about 2°. Although Altitude and Azimuth are useful for observing at night and showing others constellations and other objects, it isn't helpful for us. This is because none of us is at the exact same latitude and longitude, and so my altitude and azimuth information for the "Big Dipper" would be different for you. Also, as the object rises and sets, it changes position in the sky. See Figure 3.

Right Ascension and Declination

As I mentioned earlier, Right Ascension (RA) and Declination (DEC) are similar to longitude and latitude. If you picture Earth's North Pole projected into the sky, this would correspond to the Celestial North Pole. And if you project Earth's equator into the sky, this

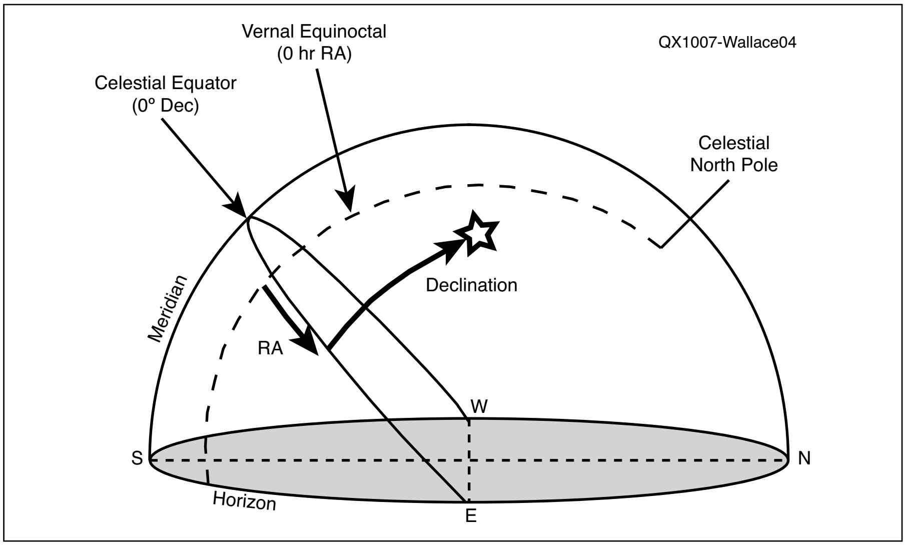

Figure 4 — Finding the right ascension and declination for an object. (Graphic used by permission from Dr. Jim McDonald.)

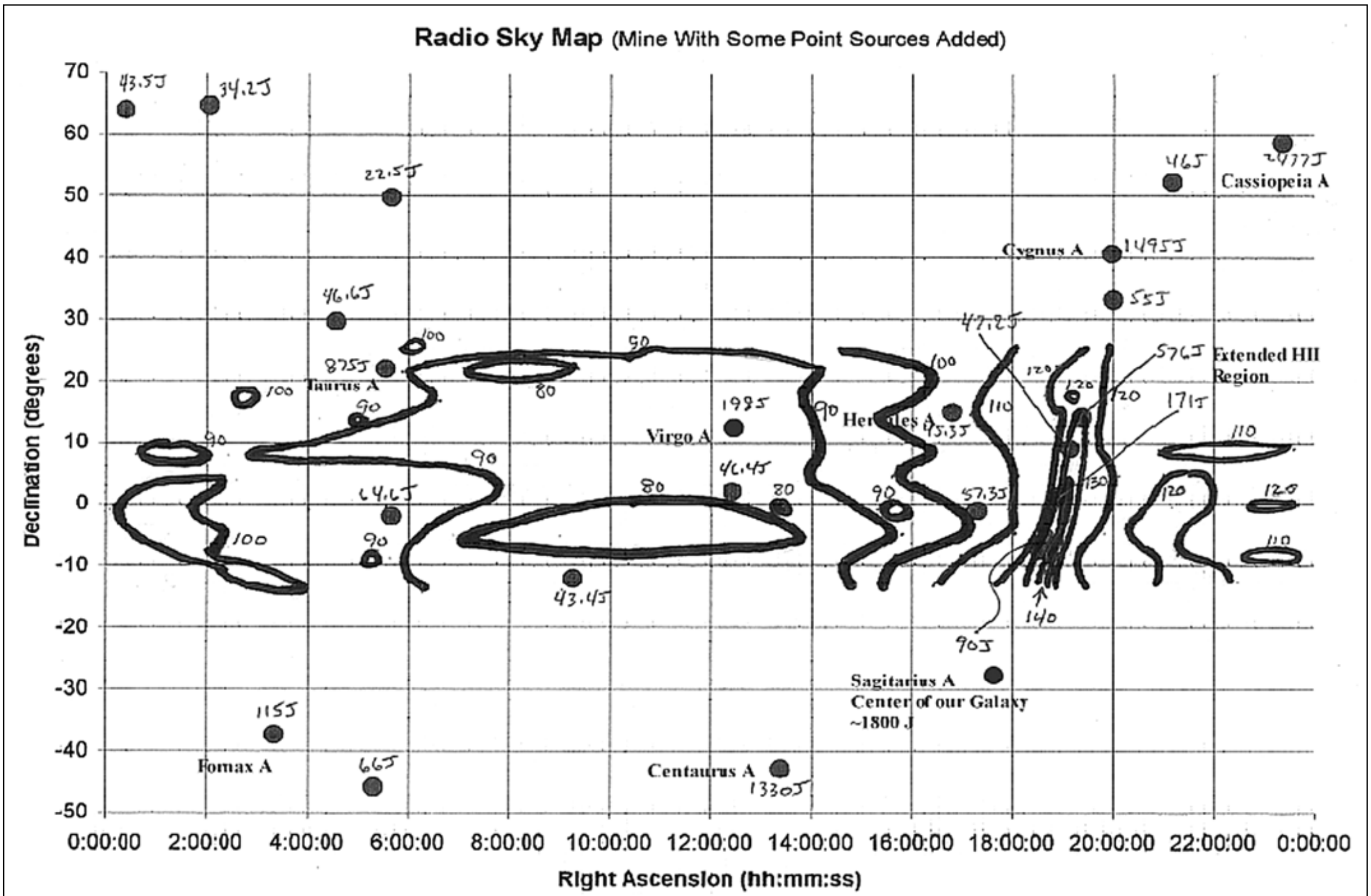

Figure 5 — This radio sky map was created from data I collected.

would correspond to the Celestial Equator. The longitude lines on a celestial sphere are called Right Ascension. Right Ascension is measured on the Celestial Equator in an easterly direction. Instead of measuring in degrees, though, it is measured in hours, minutes, and seconds. A full rotation corresponds to 24 hours, roughly the time it takes for the sphere to rotate once around. Each hour of right ascension is about 15° on the celestial sphere. The Right Ascension of 0 hours occurs on the Vernal Equinox.

Declination corresponds to latitude and is measured in degrees above or below the Celestial Equator. An object above the Celestial Equator has a positive declination; an object below the Celestial Equator has a negative declination. Since this coordinate system is relative to fixed objects in the Celestial Sphere, the Right Ascension and Declination don't change and can be shared with anyone on Earth. See Figure 4.

Radio Examples

I've included a map that I made from my observations (see Figure 5), plotted as voltages out of 255, with some point sources from charts with their flux in Janskys. (A Jansky is a measure of flux density equal to 10^{-26} watts per square meter per hertz). Try the following examples:

1) You find a large peak at 05:33:00 RA, +21:59:00 Dec — What object is this?

2) You find a small peak at 16:49:00 RA, +15:02:00 Dec — What object is this?

3) You find a large peak at 12:29:00 RA, +12:31:00 Dec — What object is this?

Answers to Radio Examples:

1) Taurus A
2) Hercules A
3) Virgo A

Equipment Needed

In Figure 6, you can see the generalized block diagram of my final radio telescope. Starting at the antenna, which was a 10 foot parabolic dish antenna, I ran a 15 foot length of the best low-loss cable I could buy (at the time this was RG-6, 50 Ω — a very thick cable) with N connectors to a temperature controlled cooler with the receiver front end devices inside. This cooler had a PID thermoelectric circuit accurate to at least 1^{O}F with two huge power resistors for any heating needed. All the components before the DC amp were housed in the cooler. See Figure 7 for a view inside the cooler. The DC amp was housed in a foam box and had offset controls as well, and fed the A/D converter to the laptop computer running the Skypipe software (Jim Sky's site is **www.radiosky.com/**) housed in a plastic bin to protect it from rain. You can see the entire system in Figure 1.

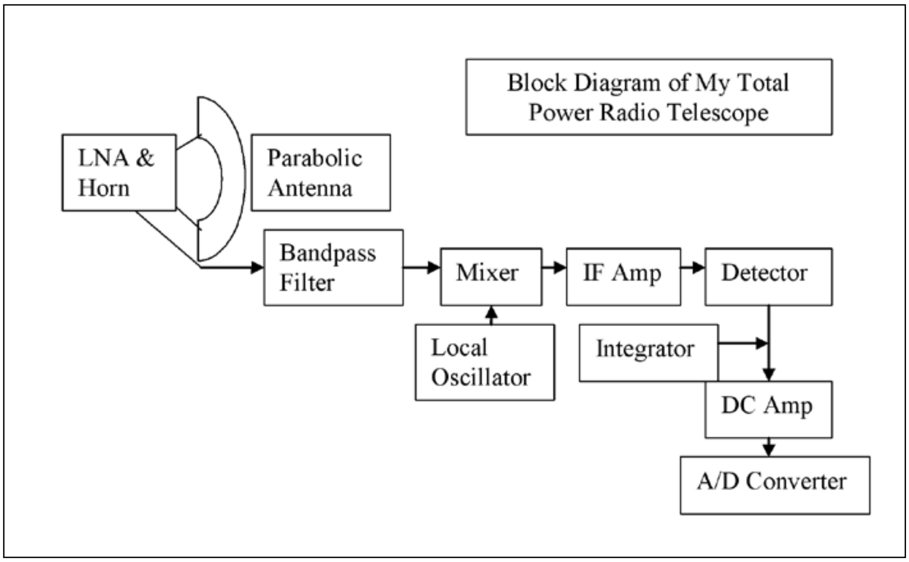

Figure 6 — Here is a block diagram of my total power radio telescope.

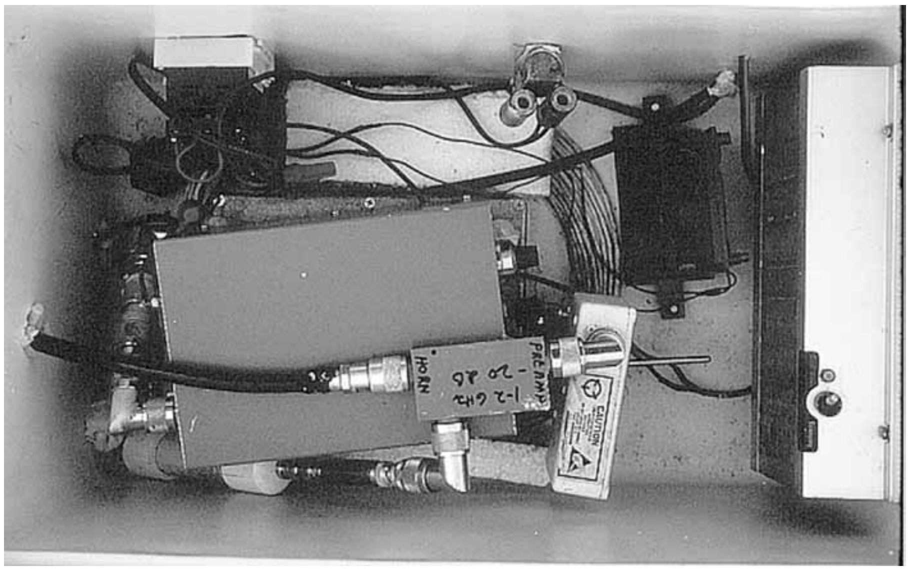

Figure 7 — This photo is a view inside the cooler, showing the front end components.

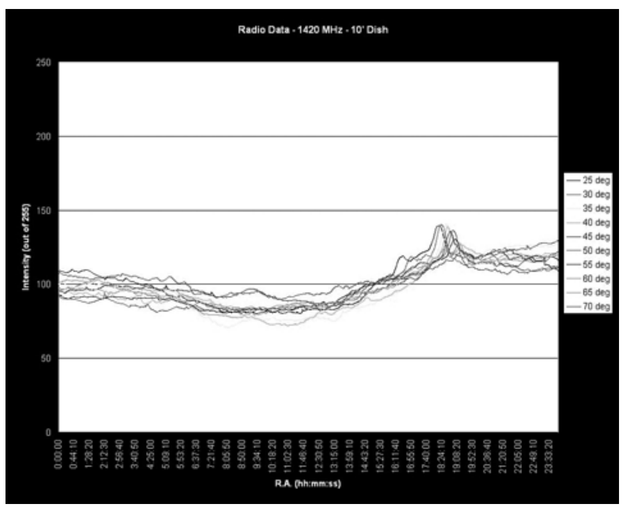

Figure 8 — This Microsoft *Excel* graph uses data I collected over 10 years of measurements.

Data Analysis

After collecting data for 10 years, I had enough charts (12 of each altitude) to create charts of each altitude from 25° to 75° in 5° increments. I averaged the charts and created the Microsoft *Excel* graph of all 11 altitudes shown in Figure 8. (The large peak is the Milky Way galaxy.) I next took the data and used *Mathematica* to create a 3-D graph of the data and thus my final picture. Ten years to get one picture!

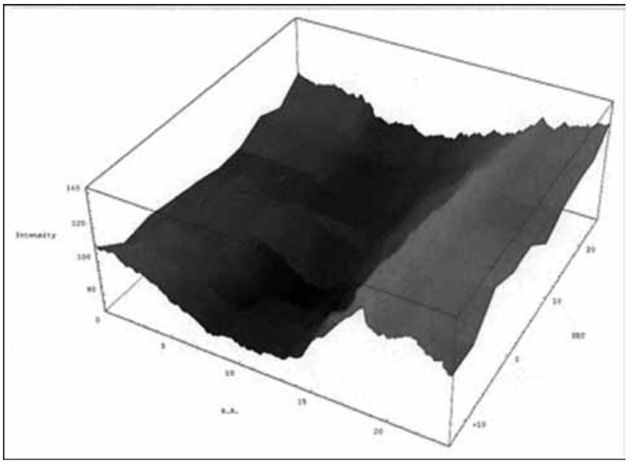

Figure 9 — I used the *Mathematica* program to create this 3-D graphic map of the sky.

Sources for Total Power Radio Telescopes and Additional Information:

SARA website:
www.radio-astronomy.org/
Jim Sky's Radio Sky website:
www.radiosky.com/
Jeff Lichtman's radio astronomy supply website:
www.radioastronomysupplies.com/

Jon Wallace has been a high school science teacher in Meriden, Connecticut for over 28 years. He is past president of the Connecticut Association of Physics Teachers and was an instructor in Wesleyan University's Project ASTRO program. He has managed the Naugatuck Valley Community College observatory and run many astronomy classes and training sessions throughout Connecticut. Jon has had an interest in 'non-visual' astronomy for over twenty-five years and has built or purchased various receivers as well as building over 30 demonstration devices for class use and public displays.

Jon is currently on the Board of the Society of Amateur Radio Astronomers (SARA) and developed teaching materials for SARA and the National Radio Astronomy Observatory (NRAO) for use with their Itty-Bitty radio Telescope (IBT) educational project. Other interests include collecting meteorites, raising arthropods ("bugs") and insectivorous plants. Jon has a BS in Geology from the University of Connecticut; a Master's Degree in Environmental Education from Southern Connecticut State University and a Certificate of Advanced Study (Sixth Year) in Science from Wesleyan University. He has been a member of ARRL for many years but is not a licensed Amateur Radio operator.