GREEN BANK OBSERVATORY

40-FOOT RADIO TELESCOPE

OPERATOR'S MANUAL

The 40 Foot Radio Telescope

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The Green Bank Observatory is a facility of the National Science Foundation.

I. INTRODUCTION

History of the 40 Foot Telescope

The Green Bank Observatory's 40-foot diameter radio telescope was constructed in 1962 primarily to determine if the intensity of certain radio sources varies with time. It had long been known that the visual brightness of some of the stars varies with time.
The radio intensity was therefore suspected to vary as well.

It was deemed impractical to tie up the large telescopes for such long periods of time as required for this type experiment, so the relatively inexpensive 40-foot telescope was constructed. The telescope was used for long term radio source variability research through 1968. After 1968 the instrument was used only occasionally as an educational tool by summer school radio astronomy students. In 1987, however, the telescope was restored to its full glory with state-of-the-art front-end equipment.

The 40-foot telescope is a landmark in an historical context alone. The feed system (dipole antenna and protective radome), for example, is the original feed used for project OZMA--the first collective scientific effort to search for communications from extraterrestrial civilizations. Much of the equipment used for our Spectrometer comes from the 300 Foot Telescope (1962-1988).

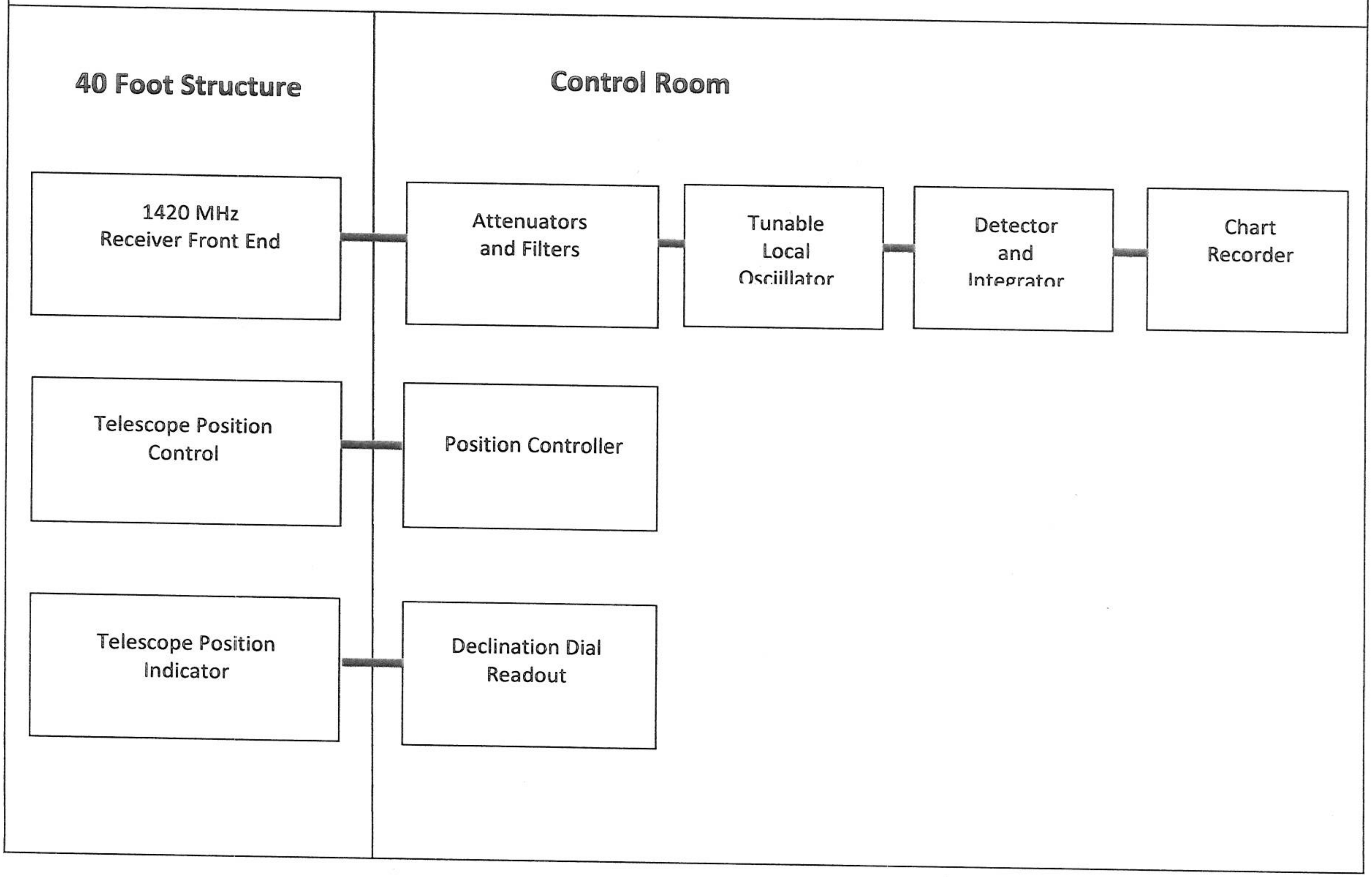
Description of the 40 Foot Telescope

The telescope's collector is a 40-foot diameter parabolic reflector constructed of steel mesh supported by a superstructure of galvanized steel. Radio energy from an astronomical source is reflected from the parabolic surface (which looks shiny at 20 centimeter wavelength) and is focused at the apex of the telescope, similar to the way a reflector type optical telescope operates.

Front end receivers and accompanying equipment are fixed at the prime focus by structural supports, where the incoming radio waves are collected and focused. The electromagnetic radiation (at selected radio wavelengths) is converted to an electrical signal via the dipole antenna. The signal is then sent to a series of electronic devices in the control room that modify it to a desired form and voltage level. A signal corresponding to the intensity of the original radio source is then displayed on a strip chart recorder or some other means of data output. (See Figure 1 for a schematic diagram of the architecture of a basic radio telescope.)

The hardware in the front end of the 40-foot telescope amplifies the signal received in excess of two million times its original intensity. Such extreme amplification is necessary due to the incredible weakness of cosmic radio signals. The radio energy collected by any telescope is inherently weak, having traversed the vast distances of interstellar space. Radio waves, like all electromagnetic radiation, dissipate according to an inverse square law--the further away the source, the weaker the signal. Incredibly small amounts of radio energy reach the earth due to

Fig 1. 40 Foot Radio Telescope Components



the immense distances involved. One can therefore understand the necessity of constructing telescopes with large collecting surfaces to focus these weak signals. It has been estimated that all the radio waves ever detected by all radio telescopes in the history of the science only contain as much energy as a falling snowflake.

Resolution and Beamwidth

The area of the sky observed by a radio telescope at any given time defines its "beam". The angular extent of the beam is called the beamwidth. The ability to discern detailed structure in radio sources depends on the beamwidth, often referred to as resolution. The beamwidth is determined by the wavelength being observed divided by the diameter of the reflector. The equation used to determine beamwidth is therefore:

$$\alpha'' = (206{,}265)\,\lambda / d$$

where:
α = smallest possible angle that can be resolved (in arcseconds)
λ = wavelength observed (in meters)
d = diameter of reflector (in meters)

Note: the constant 206,265 is the number of arcseconds in one radian; used simply to convert the numbers to convenient units. (There are 2 π radians in 360 degrees.) The relationship λ/d otherwise gives the beamwidth in radians. The beamwidth equation is, however, only an approximation. Variables such as the fact that the effective area of the reflector tends to be much less than the actual area, reduce the equation to an approximation accurate to within about 20X. The beamwidth of the 40-foot radio telescope is, therefore, calculated to be around 1.0 degree of arc.

Celestial Coordinates

The 40-foot telescope is a transit instrument--one that moves only along the celestial meridian (along the north-south direction). Such telescopes can point to any declination (within limits), but must make use of the earth's rotation to change the aiming position in right ascension. The hour angle (difference between right ascension and sidereal time) for a transit instrument is always equal to zero. The right ascension to which the telescope is pointing, therefore, is equal to the sidereal time. It is inevitable then, that at transit (when an object crosses the celestial meridian), the right ascension of the object is equal to the sidereal time at that meridian. To observe an object with a transit instrument, the telescope is positioned at the proper declination and the earth's rotation moves the beam of the telescope across the source. In such a manner the radio waves from cosmic sources are intercepted for analysis.

The amount of time that an object (assuming the object is a point source) remains in the beam of the telescope varies with the declination of the object even though the rotation of the earth is constant. If the 40-foot telescope were pointed at Polaris, it would observe Polaris constantly, since the declination would be +90 . The beam of the telescope would be parallel to the earth's axis of rotation and the rotation of the earth could not possibly move the beam away from Polaris. The earth rotates about its axis in approximately 24 hours. Since there are 360° in a complete circle, the earth makes an angular movement of 1° in 4 minutes. For an object on the celestial equator, the relationship between time and angular distance is such that one hour is equivalent to 15°.

Minimum transit times (duration times) are therefore established by the declination of the object observed. The actual time that an object remains in the beam of the telescope also depends on the angular size of the object itself. If the radio source observed is an extended source, as opposed to being a point source, then a longer deflection in the signal would be produced; one that is proportional to the angular size of the source.

II. HARDWARE

Description of Components

The heart of the hardware system in any radio telescope is the receiver system. The block diagram of the receiving system used on the 40-foot telescope is shown in Figure 2. There are two complete front end receivers at the focal point of the telescope. One receiver is called Channel A and the other, Channel B. The receivers are similar in construction and have center frequencies of 1390 MHz. The dipole feed collects energy at the focal point and channels this energy to the two receivers depending on the electrical plane of polarization.

Our receivers were originally built for continuum work. The front end amplifiers are receptive to signals within a fairly broad range of the spectrum: from 1350 MHz to 1430 MHz. This is a bandwidth of 80 MHz. Each front end amplifies the energy and then filters out unwanted energy on both sides of the desired radio spectrum window.

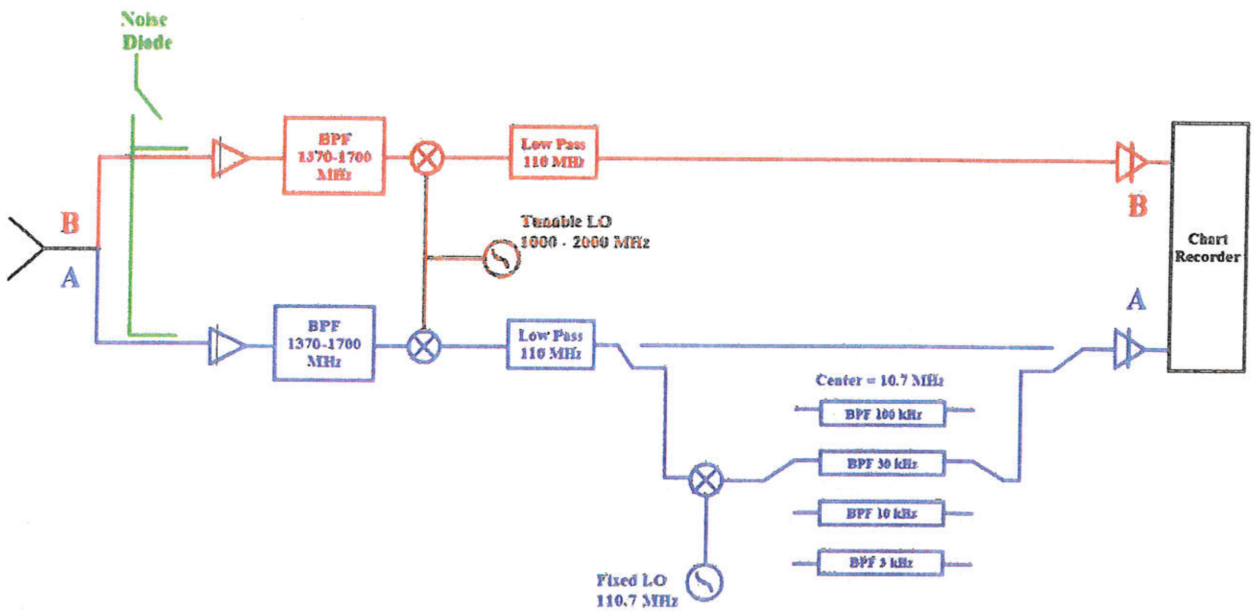
In most radio receivers, ours included, a process called mixing takes place to transform the incoming radio frequency (RF) energy to a lower frequency. Mixing creates a signal which retains all of the information contained in the high frequency spectrum, and is easier to work with. Mixing is accomplished by combining our RF (1350-1430 MHz) with another signal of known frequency. What results is the difference between the two. In the case of the 40 foot, 1350-1430 MHz is mixed with a signal at 1320 MHz (LO). The lowered frequency signal or intermediate frequency (IF) is at 30-110 MHz.

RF - LO = IF

Next, the energy is transferred to the control room by way of electrical coaxial cables. In the control room, the energy is converted to a voltage, amplified further, and averaged over a specific time known as the integration time. The integrator output voltage drives the chart recorder pens. An increase in radio energy deflects the chart recorder pens to the right. The chart is driven by a clock which can be geared to any desired speed (within reason). The amplifier gain, full scale temperature, integration time, chart recorder voltage span, and chart speed may be controlled by the user. However, as a starting point, set the controls to the following:

Continuum/Spectral Switch on Back End Rack	Set for Observing Mode
Chart recorder:	Span (located on right of chart recorder): 1 Volt/centimeter Paper Speed: 12 centimeters/hour
Square Law Detector:	Dial indicator should read between 40 and 90. If it doesn't, adjust the gain attenuation by turning the Input Attenuate and 0-3 dB knobs while watching the Square Law Detector display.
Synchronous Detector:	Full scale temp.: IOOK, Scale expand: xl, Integration time: 1 sec.
Input Level:	Adjust to get desired calibration signal height. Use the Zero Offset to reposition the chart pens .

Figure 2. Receiver Schematic



III. POSITIONING AND OPERATION

Drift Scan or "Park and Ride"

A drift scan is the simplest way to use the 40 foot telescope. You position the telescope to the proper declination, at the proper time and park it. Let the Earth's rotation do the rest.

1. First determine the transit time for the object to be observed. The right ascension of the source to be observed must first by determined (from an Astronomical Source Catalog, for example). Because the hour angle for a transit instrument is always zero, applying the equation for hour angle yields:

HA = LST - RA (LST stands for Local Sidereal Time). For HA = 0, LST = RA

The transit time (in Local Sidereal Time) equals the right ascension of the source. You must be at the telescope before the LST clock = your Right Ascension!

2. Next, the appropriate declination must be set. To set the telescope's declination, do the following:
   a) Turn the declination power switch to the "on" position.
   b) Turn the analog dial to move the telescope to the proper declination.
   c) Turn the declination power switch to the "off" position once the telescope has been positioned.
3. Next, adjust the pens for the appropriate scale deflection:
   a) Switch to Broadband on the IF drawer
   b) Turn the chart recorder power on, but disengage the pens of the strip chart recorder (using the **pen lift** on the chart recorder).
   c) Use the **"Zero Offset"** knob to position the pens to the left side of the chart paper.
   d) Check the height of your calibration peaks.
   e) To change them, with Cal switches "off", increase or decrease your amplification input level. This knob is called "**Input Level**" and is found on the synchronous detector panel.
   f) Zero your pens again with the **"Zero Offset"** knob.
   g) Fire the calibration signal. Check the height of your calibration peaks.
   h) Repeat d-f until you are satisfied.
4. Lower the pens and toggle the Drive switch on the chart recorder to engage the pens and receive a hard copy of the radio signal. Use a chart speed of **60 cm/hour**.

Peaking on a Source

Another important data acquisition procedure is known as peaking procedure. Peaking procedures are used to determine the actual declination of a radio source once the source is in the telescope beam. Once the radio source begins to transit, and you begin to see a rise on your chart, the declination may be adjusted slightly (with the strip chart recorder pens engaged) to provide peak deflection during source transit. Once the highest deflection has occurred, lock the telescope declination in place. The adjusted declination value corresponding to the peak deflection is the more accurate declination value.

Mapping Procedure

One way to quickly acquire a lot of data over a wide declination range is to move the telescope in declination as the earth's rotation changes the right ascension. You might pick two limits in declination and move the telescope between those limits over a specified time period. Be careful to devise some way of knowing where the telescope is pointing and to know when the telescope was pointing there. Each point in the sky is defined by its coordinates of right ascension and declination!

IV. SCAN PROCEDURE

In order to obtain accurate information from the telescope chart record, a radio source should be observed using the following scan procedure. A typical scan is shown in Figure 3. In this case, the declination is fixed at the desired position.

1. Starting Baseline - To begin a scan, the chart should show at least 1 minute of background radiation in order to obtain a reference line so that the calibration signal can be measured. While waiting, record the **declination** and any other pertinent data onto the beginning of the chart.

2. Pre-Calibration - The artificial calibration source is turned on for about 1 minute. This is used to check the receiver stability prior to observing a source. Record the **Right Ascension** (also called **Local Sidereal Time)** next to this calibration line.

3. Pre-Source Baseline - A baseline of at least 10 minutes should precede the time of expected source transit. This is used to obtain a reference line for source and calibration measurement.

4. Data Field - Obtain data for a specific time period. This time frame will vary depending on the desired project.

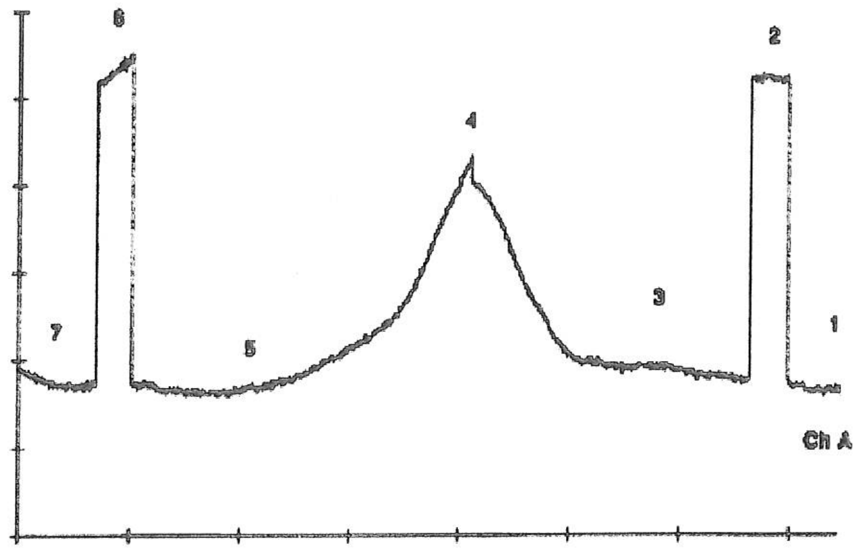
5. Post-Source Baseline - This baseline should be at least 10 minutes after the source transit. This baseline along with the pre-source baseline allows measurement of source amplitude.

6. Post-Calibration - The artificial calibration source is turned on for about 1 minute. This is used to check the receiver stability after observing the source. Again, record the LST.

7. Ending Baseline - This baseline should be 1 minute long. This is used for a reference line when measuring the calibration signal.

After the scan data is prepared in this way, the following procedure is used to analyze the data.

Fig. 3: Drift Scan, Virgo A



A. Measure the height of the two calibration signals with respect to the baseline. The average of the two measurements is taken as the calibration signal intensity.

B. Measure the right ascension of all the sources in the data field. Declination can be read from the position dial. Remember, right ascension is measured along the time axis with respect to a reference. Use the time given for the first calibration as the reference for measurement.

C. Measure the height of the sources in the data field with respect to the baseline.

D. Take the ratio of source intensity to calibration source intensity. This yields the relative brightness of the radio source.

E. If the artificial calibration signal level is known, then multiply the ratio in D by this value. The result is the measured (apparent) brightness of the radio source. Correcting for efficiency, the calibration signal = ~500 Jy.

V. USING THE HI SPECTROMETER

The Milky Way is full of neutral hydrogen atoms - especially in the plane of the galaxy - and it happens that neutral hydrogen (HI) emits radio waves at a frequency of 1420.41 MHz. This is well within our passband of 1350-1430 MHz.

But, using the telescope in normal continuum mode does not allow us to observe this narrow spectral line. The HI contribution to our received signal occurs over such a narrow frequency range that is masked by radio waves coming in at all other frequencies in our passband. In order to detect HI we need to block out all of those radio waves and just look at those coming in at the frequency of HI.

We accomplish this at the 40 foot by combining a very narrow bandpass filter with a tuner that allows us to seep over the frequencies of HI emission. The tuner is a second Local Oscillator which is mixed with our IF signal. The filter is a bandpass filter with a 10 KHz wide passband centered at 10.7 MHz. Refer back to Figure 2 to see what this system looks like. The following page shows a table to illustrate how the frequencies mix.

Observing Procedure:

1. Switch to spectral line mode on the IF drawer panel.
2. Reduce the **"Input Level"** to 0.40.
3. Position the telescope to the proper declination.
4. Set your paper speed to 60 mm/ minute on the chart recorder.
5. Set your start frequency on the Local Oscillator (LO) to 1319.8 MHz.

    Push "Frequency"
    Punch in 1319.8
    Push "MHZ"

7. Set your tuning step size. On the main LO, push the "Incr Set" button. Then select ".01 MHz".
8. Start the chart recorder: If necessary reposition the pens with the **Zero Offset** knob on the Backend. Turn drive on, pens down. Write down the **declination**.
9. Calibrate. Write down the **Right Ascension.**
10. Start the 1 second metronome (on the computer) to time your tuning steps.
11. Change the LO frequency from 1319.8 MHz to 1321.0 MHz in .01 MHz steps. Do so every 1 second
12. Push the **"Mark"** button on the chart recorder every 0.1 MHz.

Troubleshooting:

1. Check the Square Law Detector to be sure that it reads around 40. If it reads zero: Make sure that the "RF On" indicators are indicating "on" on the local oscillator (This is where you tune the frequencies). There is a second device that needs to have **RF On** as well. Is sits on the gray cart just behind the chart recorder. Find the RF on button and push it. DO NOT bother any other buttons on this device!

2. Chart Recorder not is showing nothing when you fire the cals. Pens just draw straight lines. This could be because someone has changed the switches on top of the chart recorder. Make sure that both green and red switch are on "Meas".

LO Frequency (MHz)	Sky Frequency (MHz)	IF (MHz)	LO2 (MHz)	IF (MHz)
1319.80	1419.80	100	110.7	10.7
1319.81	1419.81	100	110.7	10.7
1319.82	1419.82	100	110.7	10.7
1319.83	1419.83	100	110.7	10.7
1319.84	1419.84	100	110.7	10.7
1319.85	1419.85	100	110.7	10.7
1319.86	1419.86	100	110.7	10.7
1319.87	1419.87	100	110.7	10.7
1319.88	1419.88	100	110.7	10.7
1319.89	1419.89	100	110.7	10.7
1319.90	1419.90	100	110.7	10.7
1319.91	1419.91	100	110.7	10.7
1319.92	1419.92	100	110.7	10.7
1319.93	1419.93	100	110.7	10.7
1319.94	1419.94	100	110.7	10.7
1319.95	1419.95	100	110.7	10.7
1319.96	1419.96	100	110.7	10.7
1319.97	1419.97	100	110.7	10.7
1319.98	1419.98	100	110.7	10.7
1319.99	1419.99	100	110.7	10.7
1320.00	1420.00	100	110.7	10.7
1320.01	1420.01	100	110.7	10.7
1320.02	1420.02	100	110.7	10.7
1320.03	1420.03	100	110.7	10.7
1320.04	1420.04	100	110.7	10.7
1320.05	1420.05	100	110.7	10.7
1320.06	1420.06	100	110.7	10.7
1320.07	1420.07	100	110.7	10.7
1320.08	1420.08	100	110.7	10.7
1320.09	1420.09	100	110.7	10.7
1320.10	1420.10	100	110.7	10.7
1320.11	1420.11	100	110.7	10.7
1320.12	1420.12	100	110.7	10.7
1320.13	1420.13	100	110.7	10.7
1320.14	1420.14	100	110.7	10.7
1320.15	1420.15	100	110.7	10.7
1320.16	1420.16	100	110.7	10.7
1320.17	1420.17	100	110.7	10.7
1320.18	1420.18	100	110.7	10.7
1320.19	1420.19	100	110.7	10.7
1320.20	1420.20	100	110.7	10.7
1320.21	1420.21	100	110.7	10.7
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
1320.97	1420.97	100	110.7	10.7
1320.98	1420.98	100	110.7	10.7
1320.99	1420.99	100	110.7	10.7
1321.00	1421.00	100	110.7	10.7

VI. APPENDIX. LIST OF RADIO SOURCES

Adapted from the Invisible Universe: The Brightest Radio Sources Visible in the Northern Hemisphere (B1950).

Object Name	Right Ascension			Declination			Flux Density	Identification
	hr	min	sec	deg	min	sec	Jy	
3C 10	00	22	37	63	51	41	44	SNR- Tycho's Supernova
3C 20	00	40	20	51	47	10	12	Galaxy
3C 33	01	06	13	13	03	28	13	Elliptical Galaxy
3C 48	01	34	50	32	54	20	16	Quasar
3C 84	03	16	30	41	19	52	14	Seyfert Galaxy
NRAO 1560	04	00	00	51	08	00	26	
NRAO 1650	04	07	08	50	58	00	19	
3C 111	04	15	02	37	54	29	15	
3C 123	04	33	55	29	34	14	47	Galaxy
3C 139.1	05	19	21	33	25	00	40	Emission Nebula
3C 144	05	31	30	21	59	00	875	SNR- Crab Nebula- Taurus A
3C 145	05	32	51	-05	25	00	520	Emission Nebula- Orion A
3C 147	05	38	44	49	49	42	23	Quasar
3C 147.1	05	39	11	-01	55	42	65	Emission Nebula-Orion B
3C 153.1	06	06	53	20	30	40	29	Emission Nebula
3C 161	06	24	43	-05	51	14	19	
3C 196	08	09	59	48	22	07	14	Quasar
3C 218	09	15	41	-11	53	05	43	D Galaxy
3C 270	12	16	50	06	06	09	18	Elliptical Galaxy
3C 273	12	26	33	02	19	42	46	Quasar
3C 274	12	28	18	12	40	02	198	Elliptical Galaxy- M87- Virgo A
3C 279	12	53	36	-05	31	08	11	Quasar
3C 286	13	28	50	30	45	58	15	Quasar
3C 295	14	09	33	52	26	13	23	D Galaxy
3C 348	16	48	41	05	04	36	45	D Galaxy
3C 353	17	17	56	-00	55	53	57	D Galaxy
3C 358	17	27	41	-21	27	11	15	SNR- Kepler's supernova
3C 380	18	28	13	48	42	41	14	Quasar
NRAO 5670	18	28	51	-02	06	00	12	

NRAO 5690	18	32	41	-07	22	00	90	
NRAO 5720	18	35	33	-06	50	18	30	
3C 387	18	38	35	-05	11	00	51	
NRAO 5790	18	43	30	-02	46	39	19	
3C 390.2	18	44	25	-02	33	00	80	
3C 390.3	18	45	53	79	42	47	12	N Galaxy
3C 391	18	46	49	-00	58	58	21	
NRAO 5840	18	50	52	01	08	18	15	
3C 392	18	53	38	01	15	10	171	SNR
NRAO 5890	18	59	16	01	42	31	14	
3C 396	19	01	39	05	21	54	14	
3C 397	19	04	57	07	01	50	29	
NRAO 5980	19	07	55	08	59	09	47	
3C 398	19	08	43	08	59	49	33	
NRAO 6010	19	11	59	11	03	30	10	
NRAO 6020	19	13	19	10	57	00	35	
NRAO 6070	19	15	47	12	06	00	11	
3C 400	19	20	40	14	06	00	576	
3C 403.2	19	52	19	32	46	00	75	
3C 405	19	57	44	40	35	46	1495	D Galaxy- Cygnus A
NRAO 6210	19	59	49	33	09	00	55	
3C 409	20	12	18	23	25	42	14	
3C 410	20	18	05	29	32	41	10	
NRAO 6365	20	37	14	42	09	07	20	Emission Nebula
NRAO 6435	21	04	25	-25	39	06	12	Elliptical Galaxy
NRAO 6500	21	11	06	52	13	00	46	
3C 433	21	21	31	24	51	18	12	D Galaxy
3C 434.1	21	23	26	51	42	14	12	
NRAO 6620	21	27	41	50	35	00	37	
NRAO 6635	21	34	05	00	28	26	10	Quasar
3C 452	22	43	33	39	25	28	11	Elliptical Galaxy
3C 454.3	22	51	29	15	52	54	11	Quasar
3C 461	23	21	07	58	32	47	2477	SNR- Cassiopeia A

References for Source Lists :

1. Ohio Master Source List, Reference, Green Bank Observatory Library
2. Flux Densities, Positions, and Structures for a Complete Sample of Intense Radio Sources at 1400 MHz, A.H. Bridle, M.M. Davis, E.B. Fomalont, J. Lequeux, The Astronomical Journal, vol. 77, no. 6, pg 405+.
3. The Revised 3C Catalogue of Radio Sources. A.S. Bennett, Mem. Roy. Astron. Soc., vol. 68, pp 163172, 1962. (NB- the flux densities given are at a frequency of 178 MHz.)

Useful Websites:

Planetary data, Sun and Moon.:
http://www.usno.navy.mil/USNO/astronomical-applications/data-services

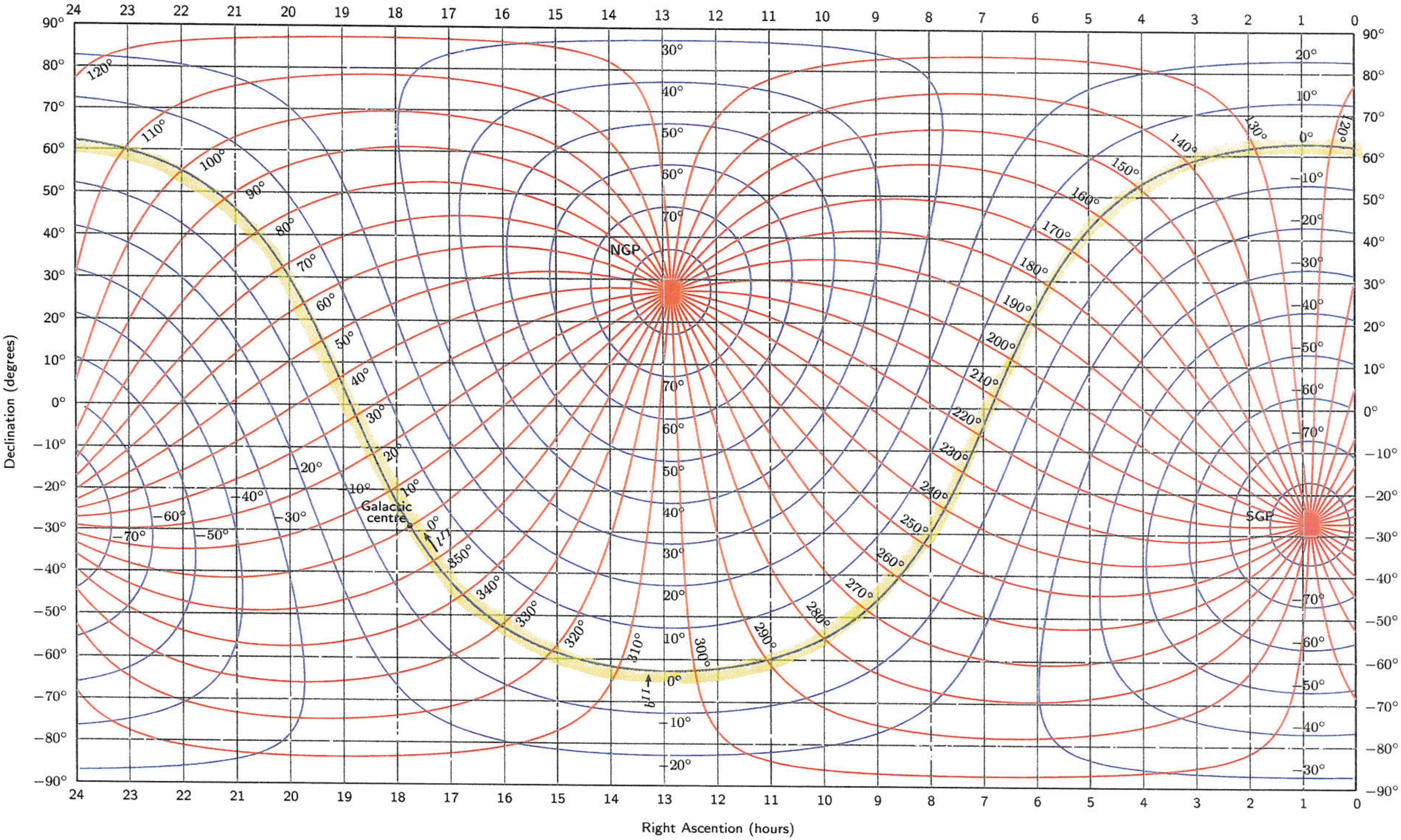
Galactic Coordinate Conversion Utilities:
http://heasarc.gsfc.nasa.gov/docs/tools.html

NED Extragalactic Database: http://nedwww.ipac.caltech.edu/

SIMBAD Astronomical Database - for galactic objects: http://simbad.u-strasbg.fr/Simbad

Astrophysics Data System (ADS): a searchable journal abstract service with lots of full articles as well. http://adswww.harvard.edu

Equatorial to Galactic-Coordinate Conversion



http://www.scrt.astro.su.se/

20 Meter Telescope User's Handout

Websites:

- **skynet.unc.edu**
- www.gb.nrao.edu/20m

Receivers: L band (1350-1700 MHz), X-band: (8,000-10,000 MHz)

For new users of the Skynet 20-meter radio telescope, here are some simple investigations and observing set-ups to try.

- Is it a radio source?
- What does it look like in radio: making radio images
- What can we learn about our Milky Way by measuring Hydrogen?

Is an object a radio source? How powerful is it?

What question are you trying to answer? The most basic one is "does this object produce radio waves?" And if it does emit radio waves, how strong are they? Here is how to find out.

When you use an optical telescope on Skynet to make an image of an object, you usually track the object. That is , you point the telescope at one position and follows your object for the length of time you specify. Light falls on all of the different pixels of your CCD camera, and you get a nice image. But this is usually not a useful observing method with a radio telescope (with one exception we'll get to later), and here's why.

The 20 Meter telescope only has one pixel, and it's "big". The telescope sees a field of view that is often much larger than the angular size of the object, so the radiation detected by the telescope comes both from the object of interest and from the surrounding background and foreground. How much radiation is from the object, and how much from the background? With a "track" scan, you cannot tell.

To find out what is coming from the object itself you need to observe both the object and the nearby surroundings, using either a "daisy" scan, "map scan" or an "on/off" scan.

Daisy Scans: The daisy scan will scan the telescope across the object several times. If the object is detected, you will see a bump in the graph every time the telescope scans across the object.

If you have set up a "daisy" scan with 4 petals, you should see 4 bumps in the graph. The height of those bumps tells you how much radiation is detected from the object. If there are no bumps, then the object has not been detected, and maybe does not emit radio waves at all.

After you click "Radio Observing" and "Add New Observation" Here is a prescription for making a daisy scan:

- Type in an object in "Target Lookup", or click on an object in the SkyViewer
- select "low resolution mode" (This is analogous to using a "clear" filter, so that you can get the maximum signal through to the detector)
- select "daisy" as the path type.
- set the radius to 120 arcminutes ***(X-band 60)***
- set the number of petals to 4
- set the integration time to 0.3 (This is analogous to exposure duration in a way)
- set the duration to 80 seconds (20 seconds per petal).

Look at the observation plots on the 20-meter web page. Look at the plot of power vs time. How much are the bumps above the baseline? That gives you the power in units of Kelvin.

Making Maps, i.e., radio images: Maps are the way to make an image of an object. For a Map to make sense, your object needs to be big-- that is it needs to take up a lot of room in the sky. Most of the objects you are observing with the optical telescopes are only a few arc minutes across. The 20 Meter Telescope can't see any detail in these objects! You need something much larger in angular size-- like parts of our Milky Way, if you want to make a good map.

Maps should be at least 6 degrees on a side (for 21 cm observations) to make a good map. **(X band 1.5 - 2 degrees, ¼ beam width for gaps)**

Measuring Hydrogen Clouds in the Galaxy. – not possible in X-band: With the radio telescope you can find out if our Milky Way Galaxy (and others) contain hydrogen atoms. Hydrogen atoms undergo an energy transition that produces energy in the form of radio waves that have a wavelength of 21cm, or a frequency of 1420.41 MHz.

These are hydrogen ATOMS mind you, not ionized hydrogen or plasma like you find in stars. These atoms reside in clouds of cold gas that will one day coalesce into stars.

To see if parts of our Milky Way contains cold hydrogen atoms, try this: click on a location near the red line on the Skyviewer. The red line is the Milky Way's equator.

Type in a name for your observation

- set the minimum elevation to 20 degrees
- select "high resolution spectral/continuum mode" select "track"
- set the duration to 60 seconds
- everything else can stay the default values.

Recombination lines (X-band): The frequency of recombination lines depends on the high energy shell and the jump from one energy level to the next. You can calculate these frequencies using this equation, where the numbers in the denominator are the energy levels:

$$\nu = 3.28805 \times 10^{15}\,\mathrm{Hz}\left(\frac{1}{109^2} - \frac{1}{110^2}\right) \approx 5.0089 \times 10^{9}\,\mathrm{Hz}$$

The 8872.565 (N 91 to 90) and 9173 (N 90 to 89) lines have been seen, and they are fairly broad, not narrow. The narrow features are RFI.

Note that the "good" channel in HIRES is the green, whereas in LOWRES its the red. I have my labelling screwed up somewhere.

Also, a caution: do not try to have the two HIRES frequencies be farther apart than 500 MHz. This crashes the spectrometer.

More info:

Recombination lines: https://www.cv.nrao.edu/course/astr534/PDFnewfiles/Recombination.pdf

"Tables of Radio-Frequency Recombination Lines, Lilley and Palmer, 1967" for a definitive list of frequencies (http://adsbit.harvard.edu//full/1968ApJS...16..143L/0000145.000.html)