Observer's Guide for the 2.3m Radio Telescope

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1 Introduction

This Guide outlines the basic procedures for running the telescope and collecting data. For more advanced use consult the SRT Manual provided by Haystack observatory (http://www.haystack.mit.edu/edu/undergrad/srt/).

The 2.3m Radio Telescope is a prime focus, L-band telescope designed by Haystack Observatory to allow for continuum and 21cm spectral line observations. The design goes by the name "Small Radio Telescope." The telescope was manufactured by Custom Astronomical Support Services, Inc. (CASSI).

The computer is controlled by a PC in Robeson 307A (the "2.3m Radio Telescope Control Room"). USB flash drives can be used for data transport. The computer is not connected to the internet.

2 Basic System Specifications

- Geometric Aperture: 2.3m
- Focal length: 0.857m (f/0.375)
- Half Power Beamwidth (HPBW): ∼7 degrees
- Local Oscillator Frequency range: 1370–1800 MHz
- Preamp frequency range: 1400–1440 MHz
- Bandwidth/Resolution Modes: 500kHz/8kHz (mode 1), 250kHz/4kHz (mode 2), 125kHz/2kHz (mode 3), 1200kHz/8kHz (mode 4). Mode 4 is produced by stitching together three 500kHz bands with overlap. See Table 1 at end of this guide for more precise information.
- Intermediate Frequency Center 800 kHz
- 6 dB Intermediate Frequency range 0.5–3 MHz
- Typical system temperature: 150K (but an additional front-end filter has been added to the system, which yields a larger system temperature)

3 Start Up

Obtain the key to 307A Robeson Hall (the control room) from the instructor. The telescope is on the roof of Robeson Hall. It can be seen from the parking lot north of Robeson. It can also be seen from windows in third-floor rooms on the short leg of Robeson Hall. Access to the roof is not available.

1. In the control room, check for notes/signs on the bulletin board concerning updates to the telescope start up, shut down, or usage procedures.

2. Flip on the toggle switch on the small metal receiver box to the left of the PC. A red LED on the box should light up.

3. Login to computer. The username and password are posted on the bulletin board.

4. Double-click on the **driveX.bat** icon on the Windows desktop. This will assign a drive letter of x: to the Windows Desktop to make some things easier later on.

5. Double-click the **Run SRT** shortcut on the Windows desktop. (Other shortcuts are available. One will run only the receiver, one only the antenna mount, and one will simulate the entire operation. Simulation does not require the metal receiver box to be powered on.)

6. Wait until the telescope has reached the "stow" position at an azimuth of 92.0 degrees and elevation (altitude) of -1.5 degrees.

4 HI Spectral Line Observing

1. To calibrate the receiver, pick a location (azimuth and elevation) not on the galactic plane or on any of the displayed strong radio sources. This location should not be close to the horizon (to avoid radio interference). Click the **Azel** button on the SRT program tool bar to enter the azimuth and elevation coordinates into the text box at the bottom of the SRT program (put a space, not a comma between the two values), and hit the Enter key. A yellow cursor will appear in the virtual sky display indicating the slew target, and the red cursor (actual telescope position) will move to the location of the yellow cursor. Wait for it to do so. Once it reaches the commanded position the telescope will begin to track (as indicated by the **track** button on the toolbar becoming green, and the telescope Status reported as "tracking").

2. Click on the **Cal** button on the tool bar. The noise source at the apex of the dish will turn on for one second, adding noise power to the signal received by the instrument. Given the known noise temperature of the source, the program will calibrate the response of the receiver. The system temperature will be displayed on the right side of the SRT program window. All subsequent spectra, etc., will be properly calibrated in temperature units (Kelvins).

3. You can now click on any displayed source or location in the virtual sky display and the telescope will slew to that source, track on that source, and start taking data. A location labeled with the letter G and a number is in the galactic plane at the galactic longitude given by the number (i.e., "G180" is the location for galactic longitude 180 degrees, galactic latitude 0 degrees). Once the telescope gets to the location you requested, you should click on the **clear** button to remove the accumulated average spectrum (shown in red) and start a new integration.

4. To move to a location not specified in the virtual sky display, one must resort to input command files. See the section in Input Command Files below. Alternatively, you could compute the azimuth and elevation angle corresponding to the R.A. and Declination coordinates of your source, and the current LST.

5. Hit the **freq** button to enter the center frequency for observations, and the mode. For 21cm HI spectral observations it is best to use a center frequency of 1420.4 MHz (i.e., centered on the rest frequency of the HI line), and a bandwidth mode of 4 (i.e., the maximum bandwidth, 1.22 MHz, which should allow for acquiring all the Doppler-shifted HI features). Type the following text into the text box at the bottom of the SRT program, and hit the Enter key.

```
1420.4 4
```

Note that there is a space, not a comma, after the 1420.4 value. When you change the center frequency or frequency mode, the red accumulated spectrum automatically clears and starts anew. If you find that the observed spectrum (red accumulated spectrum) does not include an approximately flat baseline (containing noise only) on both sides of the galactic HI spectral features, you might try changing the center frequency from 1420.4 MHz to another value higher or lower than 1420.4 (by a few MHz) to see if your result is better — definitely includes all the galactic emission plus a flat baseline on both sides of the spectrum.

6. Hit the **record** button (on the Command Tool bar) and specify a filename in the text box at the bottom of the screen and hit the Enter key. The filename should have .rad as the extension. The drive letter x: is for the Desktop, so a filename such as x:\nicedata.rad will create the file nicedata.rad, put it on the Desktop, and start recording data in that file. To stop recording data, hit the **record** button again. See the Appendix for information on the format of the output data file.

7. Clicking on the red accumulated spectrum will cause it to be displayed in a new window, with frequency and LSR velocities displayed along the horizontal axis and antenna temperature displayed along the vertical axis.

8. Snapshots of the screen can be captured and saved at any moment by hitting the **Prnt Scrn** key on the keyboard and then opening Irfanview (icon on the Desktop) and pasting the image into Irfanview. Save images of the desktop as .bmp files or .png files.

5 Beam Switching Observations

Beam switching involves taking a short integration OFF the source (some distance away in the sky) then a short integration ON the source, followed by many repetitions of this cycle. The OFFs are alternated between a position to one side of the source (in azimuth), then a position to the other side of the source.

Follow the steps used for Spectral Line Observing, but

- If you are doing continuum observations select a center frequency such as 1419.0 MHz, and mode 1 (i.e., 500 kHz bandwidth), to avoid HI spectral lines.
- Then calibrate at the same elevation as the source you will be observing, but at least a few HPBWs away in azimuth. Note: at the horizon a difference in azimuth of 10 degrees corresponds to a angular distance on the sky of 10 degrees. But at a non-zero elevation, a difference in azimuth of 10 degrees corresponds to a distance on the sky of 10cos(elevation) degrees.
- After starting your record file, start beam switching by clicking on the **bmsw** button. Clicking on the **bmsw** button again will stop the beam switching observing mode. Beam switching will not stop during a move, only during the start of the next integration. (Therefore, during data analysis, you should probably drop the last OFF-ON cycle, since one of those lines is probably only a partial integration.)

The red accumulated spectrum is the accumulated difference in ON and OFF spectra. The panel showing the accumulated spectrum also shows the average ON-OFF continuum antenna temperature value, and an rms deviation for the set of ON-OFF measurements, both in Kelvins.

6 Mapping Observations

A 5x5 point mapping can be accomplished by the SRT program. One possible use is to investigate the beam of the instrument by performing such a mapping on a strong radio source (e.g., the Sun). To perform a mapping, first perform a calibration. Then, move the instrument to the source or sky location where the mapping we be performed. Start recording data (if you wish to record the data). Now, click on the **npoint** button in the SRT program. The SRT program will perform the proper pointing and integrations on 25 locations spaced symmetrically about the source. A contour plot of the resulting map (false-color image of the radio sky) will be presented by the SRT program. You can also produce your own plot/image by playing with the recorded data file, in a program of your choice.

When a mapping is peformed on a strong point source the SRT program also presents the HPBW of the telescope (in azimuth and in elevation), and point offsets (pointing errors) for that source.

7 Drift Scan Observations

To perform a drift scan observation, you must put the telescope *ahead* of the source (e.g., the Sun), turn off tracking, and let the source *drift* through the antenna beam. The **Drift** button will put the telescope ahead of the source, and turn off tracking. However, it may not put the telescope appropriately *far* ahead of the source to obtain a full drift scan. For a source on the celestial equator, the rotation of the Earth causes the source to move with respect to the telescope at a rate of about 360 degrees per 24 hours. For any source, therefore, the rate of motion is about $(360/24)\cos\delta$ degrees per 24 hours, where δ is the declination of the source. Make sure a drift starts at least 1.25 HPBWs ahead of the source (assuming an approximate HPBW of 7 degrees, this is 8.75 degrees).

To make sure you start far enough ahead of the source, determine the elapsed time for the source to move 8.75 degrees on the sky; call that time Δt. Make an input command file (see Input Command File section below) with a line

```
: radec hh:mm:ss -dd:mm:ss 2000
```

where hh:mm:ss is R.A. of the source *minus* Δt, and -dd:mm:ss is the declination of the source (and the minus sign should be either a minus or plus sign, depending on whether the declination is negative or positive). Commanding the telescope to point to this position, then turning off tracking, will enable the telescope to perform a drift scan on the source.

8 Input Command Files

It is possible to write command scripts to carry out a series of observations and recording data. To do so, create a file with a name such as myinputfile.cmd on the desktop. Edit the file, and insert your commands. Run the file by clicking on the **Rcmdfl** button in the SRT program, entering x:\myinputfilet.cmd into the textbox at the bottom of the program, and hitting the Enter key.

See the SRT Manual provided by haystack for more information.

9 Shut down

1. Click the **Azel** button in the SRT command tool bar, and enter the coordinates 92.0 90.0 in the entry text box at the bottom of the SRT program window, and hit the Enter key. A yellow cursor will appear in the virtual sky display indicating the slew target, and the red cursor (actual telescope position) will move to the location of the yellow cursor. Wait for it to do so.[1]

2. Close the SRT program.

3. Turn off the SRT receiver box (the red LED should go out).

4. Copy to your USB flash drive any record files you may have produced, and remove the flash drive.

[1] The "normal" stow position is at an azimuth of 92.0 degrees and elevation of -1.5 degrees, but to protect the telescope from wind it is better to point the instrument at the zenith.

5. Move your record files from the desktop into your desktop folder for safe keeping, where they will be kept for about one semester. If you or your group does not have a data folder on the desktop, please make one at this time.

6. Log off of the user account. Leave the PC on.

7. Call the professor's office phone number and leave a message detailing the success (or problems) of your observing session.

8. Turn out the lights to the room and lock the deadbolt on the door to 307A when you leave.

10 Appendices

Output Data File Format

The extension is .rad for an output data file. The data file can be opened in Excel. The data values are separated by spaces. Formatting information for the file is given in this Appendix.

Any comment line starts with an asterisk. The first line of an output data file

```
* STATION LAT= 37.2 DEG LONGW= 80.4
```

gives the observing site location. Calibration results produced while data are being recorded are also put on a comment line, such as

```
* tsys 215 calcons 0.98 trecvr 195 tload 300 tspill 20
```

Data lines start with a UT date and time for the line (yyyy:ddd:hh:mm:ss), followed by the the pointing information: azimuth, elevation, azimuth offset, elevation offset, first frequency of the spectrum being recorded (in MHz), spacing between frequencies (in MHz), observing frequency mode number, number of frequency bins, and then the calibrated temperature value for each frequency bin (units of K), followed by the keyword "vlsr" and a value (km/s) for the velocity component along the line of sight of the Local Standard of Rest (LSR); we will call this value V_o for use below. Thus a typical line might look like

```
2010:026:22:05:31 92.0 68.5 0.0 0.0 1419.79 0.00781250 4 156 3.6 4.7 ...  vlsr 24.80
```

You will find that the program records about one data line per second in frequency observing mode 4, but the actual integration time is less than 1 second per line. (Experience suggests the actual integration time is about 1/15 of the real elapsed time, when in mode 4 in spectral line observing. In other words, if 15 minutes have elapsed during your observation of a source, only about 1 minute of actual integration of data has been accomplished. In beam switching, mode 1, this factor is about 1/40.)

In your record file each data line corresponds to a specific integration time. Table 1 gives the integration time per line of data in a record file, for each frequency observing mode.

Table 1: Integration Time per Line of Record File Data

Observing Mode Mode	Frequency Channels	Total Bandwidth (MHz)	Channel width (kHz)	Integration Time per Line of Record Data (seconds)
1	64	0.500	7.8125	0.52488
2	64	0.250	3.90625	1.04976
3	64	0.125	1.953125	2.09952
4	156	1.21875	7.8125	0.52488

The output data file can be read into Excel. Given the data file contents, one can produce plots of antenna temperature as a function of observing frequency. It is also possible to label the horizontal axis in units of velocity with respect to the LSR. For example, consider an HI cloud at rest with respect to our telescope which will produce radiation we observe at the rest frequency of hydrogen, namely 1420.4 MHz. If the vlsr value for that line of sight is $V_0 = 30$ km/s, then the LSR is moving toward the HI cloud at 30 km/s so the cloud will have a velocity of -30 km/s with respect to the LSR. Thus the frequency 1420.4 MHz on the horizontal axis can now be relabeled as $V_{LSR} = -30$ km/s. Actually, taking account of the Doppler effect, any frequency ν on the horizontal axis can be relabeled with a corresponding V_{LSR} given by

$$V_{LSR} = -V_o - c\left(\frac{\nu - \nu_{\mathrm{HI}}}{\nu_{\mathrm{HI}}}\right),$$

where $c = 3.00 \times 10^5$ km/s is the speed of light, and $\nu_{\mathrm{HI}} = 1420.4$ MHz is the rest frequency of HI emission.