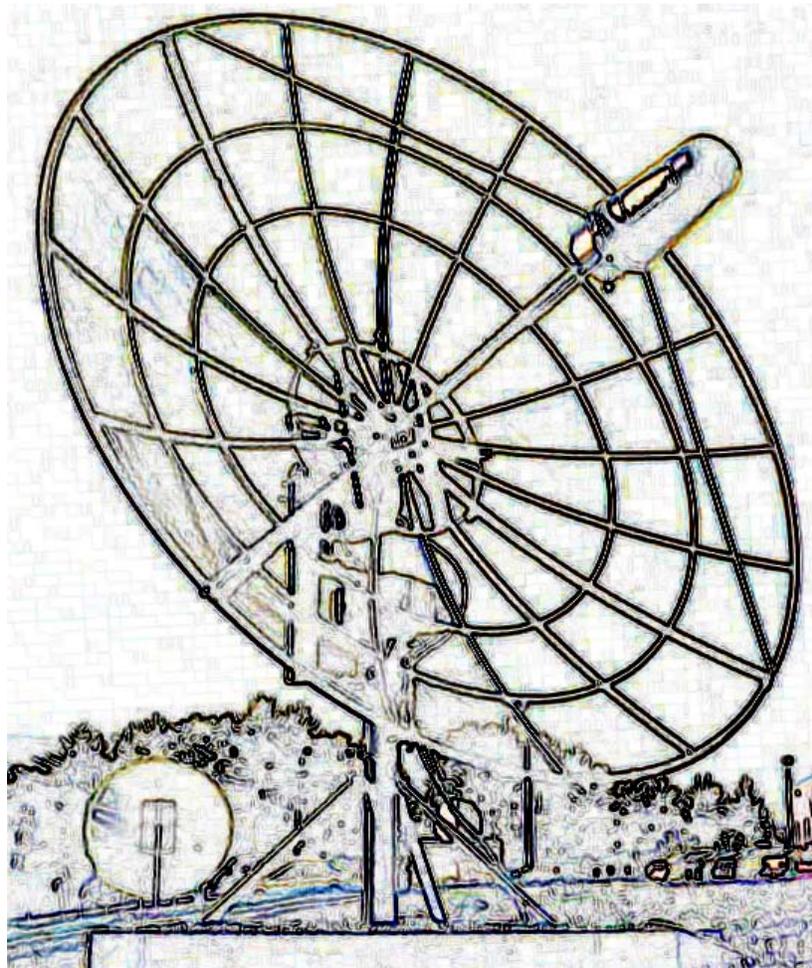# NEROC Haystack Observatory
Undergraduate Research Educational Initiative

Small Radio Telescope

Operator's Manual

Abstract

The Haystack Observatory Small Radio Telescope was developed as an educational tool to teach concepts of radio astronomy, mechanical and electrical engineering and research methods. The two-axis motorized mount allows the telescope to point from horizon to zenith with an azimuth capability of nearly 360 degrees. All sky coverage is achieved through drift-scan methods. The kit includes antenna dish, motorized two-axis mount, receiver feed, receiver electronics and JAVA-based control software. This manual is intended as a guide for the student and instructor in the operation and data collecting of the telescope.

Further information regarding observing projects and mechanical specifications can be found on Haystack Observatory website at http://fourier.haystack.mit.edu/SRT.

SRT Control Software, explains how to operate the telescope and how to read the main control panel. Also included is a discussion about data reduction methods.

SRT Control Software

Table of Contents

1.1 Overview of Capabilities

The SRT is capable of spectral line (1420 MHz hydrogen) and continuum observations using source tracking, 25-point maps and drift-scans.

Aperture	2.1	Meters
LO Frequency Range	1370 - 1800	MHz
LO Tuning Step	40	kHz
Preamp Frequency Range	1400 - 1440	MHz
System Temperature	150	K
Pointing Accuracy	1	Degree
Travel Limits (degrees)	~360 Azimuth/~0-90 Elevation	

See added capabilities of the **digital receiver** at http://web.haystack.mit.edu/SRT/receiver_1.html

1.2.1 Getting Started

The SRT control software is a JAVA-based program designed to be portable to most computer operating-system platforms. The main telescope control interface is an active window with which the user can enable the telescope functions either by a simple mouse click or by a combination of mouse clicks and text entry. Users can also construct command files (form *filename.cmd*) which will take data and calibrate the SRT automatically.

The control window can be seen in Figure-1. For the purposes of this tutorial, the explanation of the control screen will be covered in seven separate sections in section 1.3.

The Java software consists of fourteen **.java** files.

geom.java	plots.java	time.java	velspec.java
srt.java	disp.java	sport.java	hdisp.java
global.java	cat.java	map.java	
checkey.java	procs.java	outfile.java	

Also needed are dynamically linked library files (**.dll**) which are imported when the **.java** files are complied.

The user will need to import a Java Standard Edition (SDK) as well as the **javacomm20-win-32.zip** (windows OS) for the serial port communication API. *Note: Previous editions were titled Java Development Kit (JDK)*

Instructions for setting the CLASSPATH for Windows-NT and XP can be found on the Haystack Web site at http://web.haystack.mit.edu/SRT/winNTdl.html . When you have installed your Java Standard Edition and downloaded the SRT java files,

The syntax for compiling the SRT JAVA code is:

javac *.java

When you have compiled the code there are six run modes available to run the SRT software;

Run the SRT	**java srt 0**
Simulate SRT	**java srt 1 1**
Simulate Antenna	**java srt 0 1**
Simulate Radio	**java srt 1**
Simulate (speed time x 10)	**java srt 1 10**
Simulate (with 1 hour advance)	**java srt 1 -1**

The SRT window will open, ready for command input. Go to section 1.3 for the operational details of the command console.

SRT users need to access an ASCII file labeled **srt.cat**. This file contains the user source list, the telescope station latitude and longitude, telescope azimuth and elevation limits, in addition to other optional information if defaults are not acceptable

An example file is listed on the next page. The file in its current configuration will allow for commands to be properly sent to either of the three mounts currently in use or under development for the SRT

SRT.CAT file

```
* sample srt.cat file
SIMULATE RECEIVER
SIMULATE ANTENNA 10
* first word is key word
* STATION: latitude longitude west in degrees
* SAT: satellite ID then longitude west
* SOU: source ra, dec, name, epoch
STATION 42.5 71.5 Haystack
* source coords epoch 1950 unless specified
SOU 05 31 30  21 58 00 Crab
SOU 23 21 12  58 44 00 Cass
SOU 00 00 00  00 00 00 Sun
SOU 17 42 54 -28 50 00 SgrA
SOU 06 29 12  04 57 00 Rosett
SOU 20 27 00  41 00 00 CygEMN
SOU 00 00 00  00 00 00 Moon
SOU 05 40 00  29 00 00 G180
SOU 12 48 00  28 00 00 GNpole
SOU 00 39 00  40 30 00 Androm
GALACTIC 10 1 RC_CLOUD
GALACTIC 229 26 test
* AZLIMITS 92.0 265.0 /* mid az range is south */
AZLIMITS 20.0 359.0
* ELLIMITS 5.0 175.0  /*  elevation limit south - north */
* ELLIMITS 10.0 175.0
ELLIMITS 2.0 90.0
ALFASPID 1.0 1.0
* CASSIMOUNT 14.25 16.5 2.0 110.0 30.0
* CASSIMOUNT
COMM 1            /* COM 1 */
CALCONS 1.0        /* gain correction constant to put power in units of K */
BEAMWIDTH 7.0       /* 3 dB antenna beamwidth in degrees  - used to set offsets for
scans */
MANCAL 1            /* 0 or absence indicates automated cal vane */
NOISECAL 200.0     /* initial value for noise diode calibration */
DIGITAL          /* needed for digital receiver */
TOLERANCE 1        /* optional max error in counts */
* COUNTPERSTEP 50    /* optional stepped antenna motion */
* RECORDFORM TAB VLSR /* optional tabs between fields and VLSR in output */
* ELBACKLASH 3.0      /* optional correction for elevation backlash */
```

1.2.2   SRT Executable Software Package

An installable/executable version of the SRT control software is now available for MS-Windows based operating systems (95,98,Me,NT,XP). The advantages of this downloadable file are:

1. **The user no longer will need to import a large Java Development Kit.**

2. **The SRT java files are compiled and ready to run.**

3. **The win32com.dll, comm.jar and javax.comm.properties files are automatically installed into their proper sub-directories and the proper CLASSPATH is set.**

4. **An IBM JRE 1.3.0 Java Virtual Machine is downloaded as part of the Install package**

5. **The SRT console is opened by a mouse click on the installed SRT icon.**

The executable software can be downloaded from the Haystack website at http://web.haystack.mit.edu/SRT/SRTexe.html . There are three distinct download packages. One, to operate with the traditional two-piece H-180 mount. Another, to operate the AlfaSpid lightweight two-axis mount. A third to use with the new mount from CASSICorp. The CASSI version of the executable will allow operation of any of the mounts. (see the mount KEYWORDS in the SRT.CAT file)

When you have imported the file, follow these steps to install the software.

1. After you download the Install.exe file, click on "My Computer" on your desktop (or in the START menu), then find the directory where the install.exe file is located and left click on the file name.

2. An install program will open and a menu driven window will appear. SELECT C:\SRT as the directory in which to install the SRT software. NOTE: DO NOT INSTALL THE SRT EXECUTABLE IN THE "PROGRAM FILES" DIRECTORY

3. SELECT "On the Desktop" as the location for the icon

Since the executable version of the SRT software eliminates the command-line settings seen above, the switch from full operating mode (where the user can access the antenna drives and the receiver) to a simulation mode, requires the user to comment (or uncomment) the new keyword **SIMULATE** in the SRT.CAT file.

EXAMPLE: This is done easily in a Windows XP environment.

1. Click on "My Computer" on your desktop (or in the START menu)

2. Select the sub-directory in which your SRT software was installed (**C:\SRT** is best)
DO NOT INSTALL THE SRT EXECUTABLE IN THE "PROGRAM FILES" DIRECTORY

3. Click on the **SRT.CAT** icon. This should open **Notepad** or another selected editor.

4. You will find a pair of **SIMULATE** keywords in the file.

Inserting an asterisk in the first column means the SRT will run in full function mode
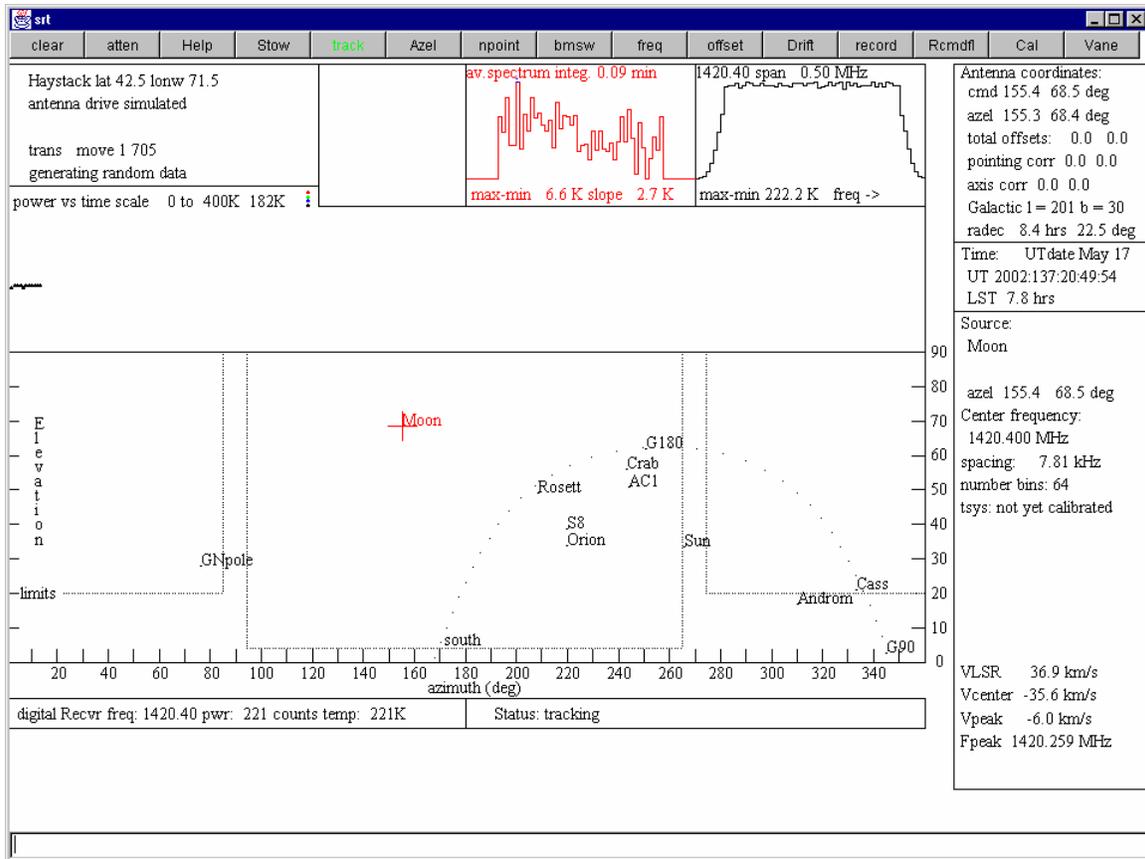
* SIMULATE RECEIVER
* SIMULATE ANTENNA

Removing the asterisks means the SRT will run in full simulation mode

SIMULATE RECEIVER
SIMULATE ANTENNA nnnn

where, nnnn = an integer time multiplier.
50 = 50 seconds of simulated time / sec of real time (Default = 1)

Comment one and not the other and you will access or simulate the related equipment.

(Figure-1, SRT Console)

1.3 SRT Control Panel

The user interface to the SRT is an interactive JAVA-generated window. The window consists of a 15 button tool-bar, a text entry command bar, an information side bar listing; times, coordinates, and source information, observing frequency and system temperatures, and a sky-map showing antenna travel limits, azimuth and elevation tick marks, as well as source plots and galactic coordinates. This section will discuss the control window in seven sections to provide the user with details about the display while allowing some easy navigation around the control panel.

1.3.1 Command Toolbar

The main command input device on the SRT Control Panel is the 15-button command toolbar arrayed across the top of the window. Pointing and clicking a mouse on any of these buttons will either initiate an automatic sequence (such as, **Cal** (calibration) or **track**) or wait on further text input from the user (**freq** or **offset**).

Figure-2 shows the toolbar as it appears on the SRT console. The following is a listing of the button functions reading left to right on the toolbar.

(Figure-2 Command Toolbar)

clear - As the label implies, the clear button will clear the control console display of accumulated spectral-line data, 25-point scan data. This function is useful if the user is accumulating multiple spectra from different sources or galactic coordinates. The system will treat new source spectra as additions to the accumulated spectrum.

atten - Enabling the **atten** (attenuation) button adds or removes a 10dB attenuation to the receiver with successive left-button mouse clicks. The **atten** will illuminate **red** while the 10dB attenuation is active. The attenuation value can also be read just above the center of the message board area to the right of the power/temperature information.

Help - Clicking **Help** opens a window titled **srthelp** that contains a 6-button taskbar.

- **srt.cat --** Contains a list of keywords available to the SRT user that can be set in the *srt.cat* file. A brief explanation of the keyword use is included.
- **srt.cmd** -- Lists the general rules and usage of command file entries with a few examples.
- **plots** -- A Brief explanation of all the plot windows seen on the SRT console
- **outputfile** -- Contains a key to reading the ASCII output of a recorded data file
- **cmdline** -- This button will show a brief list of commands used at the *MSDos prompt* or *Command prompt* to select the desired operating mode of the SRT.
- **howto** -- Contains information about adjusting pointing, checking receiver and antenna communication and possible adverse interaction between the SRT program and some screen savers.

Stow - Clicking on the **Stow** button will return the telescope to the "normal" stow position in the eastern-most, low-elevation position of the main Az/El travel zone. The travel zone is established by the AZLIMIT and ELLIMIT commands in the **srt.cat** file. (*Assuming the SRT has been setup with the travel-zone centered on 180º azimuth*)

track - The **track** button enables the antenna to slew to the selected source from clicking on the map, selecting from the source list or after typing the source information on the command entry text box. The **track** sequence will work automatically when a source is selected from a command (.cmd) file.

Azel - Action on the **Azel** button allows the user to enter a fixed azimuth/elevation position in the command entry text box (*assuming the entered coordinates are within the Az/El limits of travel of the SRT, as set in the **srt.cat** file*).

npoint - Initiates a 25-point scan/map of the source selected. The map is 1/2 beamwidth spaced and when finished displays a false-color, gaussian plot to the left of the accumulated spectrum plot. (This plot will clear when the **clear** button is enabled). The resulting *maximum* T$_{(ant)}$ (with associated offset) is displayed under **scan results** in the information sidebar. The color plot will NOT refresh if the SRT window is reduced then refreshed.

bmsw - Initiates a continuous "off/on/off " beamswitched comparison observation of the selected source at the frequency settings entered with "**freq**". The off/on/off measurements are a set and are complimentary, meaning that the two off-source positions switch sign within each set. The off-source measurements are spaced at +/- 1 beamwidth in azimuth (offset = +/- beamwidth/cos EL). "BEAMWIDTH" is set in the **srt.cat** file

A left mouse click on the bmsw button *after the scan has started* will abort the beamswitch operation.

Results of the **bmsw** observation appear in the left (**red**) spectral plot window.

freq - Sets the center frequency, number of frequency steps and the step width in MHz. Clicking on the **freq** button prompts the user to enter the desired settings in the command entry window.

Example (*for the digital receiver)*:
> To observe the hydrogen line at 1420.4 MHz, move the mouse pointer to the **freq** button. Left click the button then move the cursor to the lower text input section and enter:

> 1420.4 4   (4 = mode 4)

where:
> 1420.4 is the center frequency of an observation and **4** is the digital *observing mode*. In this case, mode 4 = 3 x 500 MHz bandwidth with a 7.81 kHz spacing.

Example (*for the old analog receiver*):

> 1420.4 25 0.04 (0.04 MHz is the default)

where:
> 1420.4 is the center frequency of an observation that is 25 times 0.04 MHz wide or spanning from 1419.9 to 1420.9 MHz.

offset - Enables the user to enter any az/el offset pair desired. Left click the offset button and enter the offsets in the command entry box.

Usage:
> Azimuth offset [Elevation offset], default sign is positive.

Drift - A left mouse click on **Drift** will offset the SRT in Right Ascension and Declination to allow the selected source to drift through the 7-degree beam of the telescope.

record - Toggles output file recording on and off. Output data files are labeled in the form:

> **yydddhh.rad**

Record also allows the user to enter a filename.

Rcmdfl - Initiates reading of the default command file (**srt.cmd**) and begins data recording. The current line number and text being read is echoed on the message board above the text entry box. To start automatic recording and reading of a file other than the default **srt.cmd**, enter the desired command file name (with the **.cmd** suffix) in the command text entry box.
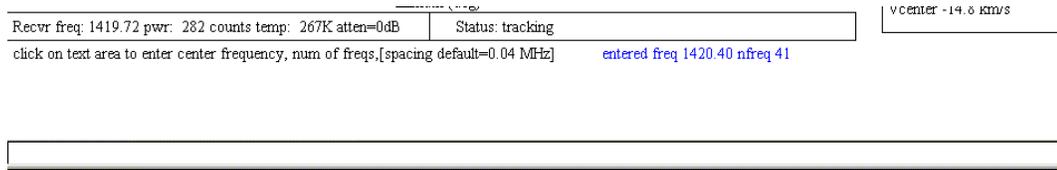
Cal - Starts an automatic calibration sequence during which a noise source, located at the apex of the antenna surface, is enabled for ~1 second. The system then takes a data sample without the noise source enabled. The resulting system noise temperature is reported in the information side bar as "Tsys".

Vane - Starts an automatic calibration sequence during which the receiver is blocked by an ambient temperature vane calibrator (motion ~20 seconds). The system then compares data with the vane in place to data with the vane retracted. The resulting system noise temperature is reported in the information side bar as "Tsys".

The actions initiated by the command tool buttons can also be listed in a command file and run automatically. See **section 1.5** for information about building command files.

Note: All input actions are delayed until the completion of any "in progress" frequency scan. A message to this effect is shaded blue and is displayed in the upper right of the message board area. (see figure 3)

1.3.2 Message Board and Text Input

Recvr freq: 1419.72 pwr: 282 counts temp: 267K atten=0dB	Status: tracking	
click on text area to enter center frequency, num of freqs,[spacing default=0.04 MHz]		entered freq 1420.40 nfreq 41

(Figure-3, Message Board and Text Input)

The command text-input box and the system message board are located at the bottom of the SRT control-panel window (figure-3). Many of the actions initiated by clicking the command toolbar are implemented by entry of parameter settings in the text box. Information regarding the correct entry is printed in a message board above the text entry area when the mouse pointer is moved over the desired command button.

Some of the buttons (**source** and **Rcmdfl**) will display more than one set of instructions if the pointer is moved away then returned to the button area. In the case of the **source** button, continuous clicking of the left mouse button will scroll through the source list on file and each source name will display in the message board.

The message board will also display the current active line command from a command file and the line number. This text will appear **green** in the form: *filename***.cmd: line nn: text command.**

To the right of the message board text area is another space used to echo information *after* a text command is entered. Printed in **blue**, it will repeat the issued command or advise the user that the issued command is waiting on some other action of the telescope.

Receiver output and telescope status can be read in two small text boxes just above the message board and below the map azimuth scale.

> In the **left box**, reading from the left is the current: frequency sweep (set in "freq"), receiver "counts" (uncorrected power level detected by the receiver), the real-time system temperature and the attenuation setting.

> In the **right box** the user can reading the current status of the telescope as a whole: Stowed, slewing, or tracking.

1.3.3 Information Sidebar

The information sidebar lists nearly all of the pertinent information the user needs to monitor real time observing with the telescope. The sidebar is illustrated in Figure-4 and displays from top to bottom:

Antenna Coordinates:

      Command (computer command)
      Azel (actual position)
      Total Offsets (User input, mapping, etc)
      Pointing Corrections (degrees)
      Axis Corrections (mechanical, user set)
      Galactic Coordinates
      RA and DEC (Hrs and Deg)

Time:

      Universal Time (UT)
      Local Sidereal Time (LST)

Source:

      Source Name
      RA and DEC
      Azimuth and Elevation

Center Frequency:

      Input Frequency (MHz)

 spacing:

      Bin spacing (MHz)

 number of bins:

      From input (Integer)

tsys: degrees K
calcons:
trec: degrees K

Scan Results:

      Max K, offset
      Az/El Widths

(Figure-4 Information Sidebar)

VLSR: Velocity Local Standard of Rest
Vcenter: Center velocity of the current observation.
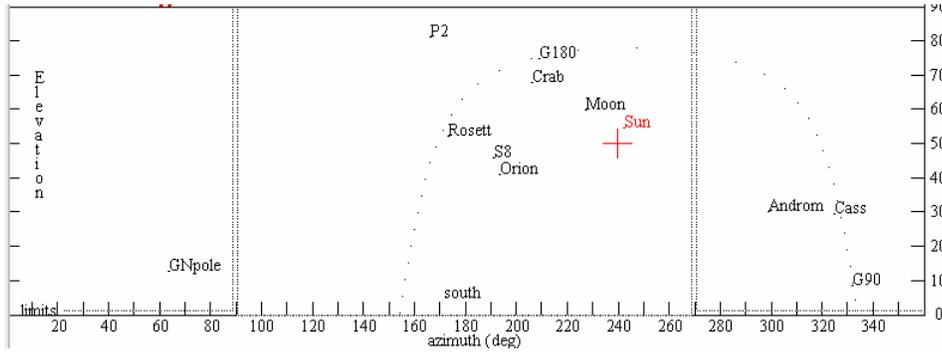**Vpeak:** Velocity of peak signal
Fpeak: Frequency bin of peak signal

1.3.4 <u>Sky Map</u>

The most obvious feature of the SRT control panel window is the sky map (Figure-5). The map shows full sky coverage in azimuth and elevation with 10-degree tick marks in both axes. The azimuth axis is labeled every 20 degrees, the elevation every 10 degrees. The elevation scale is exaggerated 33% from the azimuth scale.

(Figure-5, Sky Map)

Plotted automatically and labeled are the sources listed in the **srt.cat** file. Geo-synchronous communications satellites in the catalog are indicated by blue dots. The galactic equator is plotted. The north galactic pole and the 0, 90, 180 and 270 galactic longitude quadrants are also plotted since they have been placed in the catalog.

The user can move the pointer to any plotted source and click on that source to select it from the source list. When the source is selected, the source plot, label and the telescope "crosshairs" will be colored **red**. Selecting a source in this manner does not initiate telescope motion to the source however, only an additional action such as clicking the **track** button will engage the telescope controls.

While the SRT is slewing, the right side information box below the map will carry the message **Status; slewing**. The sky map will show the telescope "crosshairs" superimposed on the selected source and illuminated **yellow** until the SRT arrives at the source.
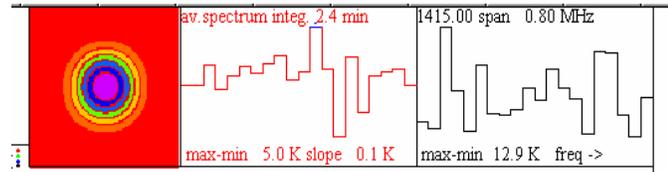
The SRT travel limits are also plotted as square boxes on the screen.

> The azimuth travel limits are set in the **srt.cat** file. In the above illustration, the limits are approximately 91 to 269 degrees. Coverage of the 271 to 89 degrees azimuth is achieved by moving the elevation axis through the zenith to the desired elevation and thus a "plus 180º " azimuth position. A total elevation travel of up to 179 degrees is possible by setting the ELLIMIT command in **srt.cat** allowing full sky coverage.
>
> Example: AZLIMIT 20.0 359.0
>   ELLIMIT 2.0 90.0

1.3.5 Spectral-line and Continuum Display

Figure-6 displays the spectral-line plotting area of the SRT control panel. There are two spectral windows.
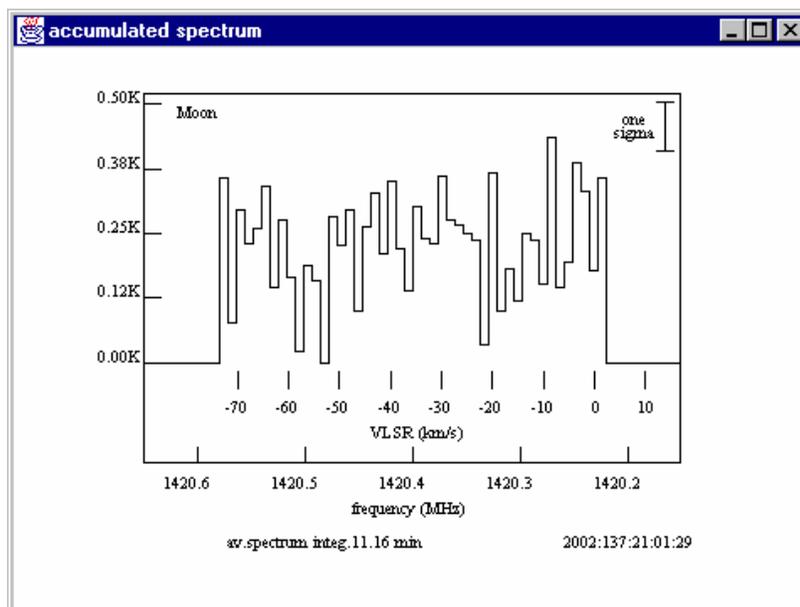

(Figure-6, Spectral Display)

Discrete Spectrum

The right side (black) is the plot of each individual spectrum as it finishes the user input span in MHz (see "**freq**" in section 1.3.1). The top of the display lists the input center frequency and the frequency step. The bottom line lists the difference of the maximum and minimum values measured during the frequency scan. There is also an arrow indicator showing the direction of increasing frequency.

Accumulated Spectrum

The left side (red) spectral-line plot shows the accumulated spectra since the selected observation began. Listed at the top of this window is the title "av. Spectrum" as well as the total "integration" time. The bottom script shows the same max-min difference and increasing frequency direction.

A "snapshot" of the accumulated spectrum can be seen in a "pull-down" window by moving the mouse pointer to the accumulated spectrum window and clicking the left mouse button. A sample is seen here:
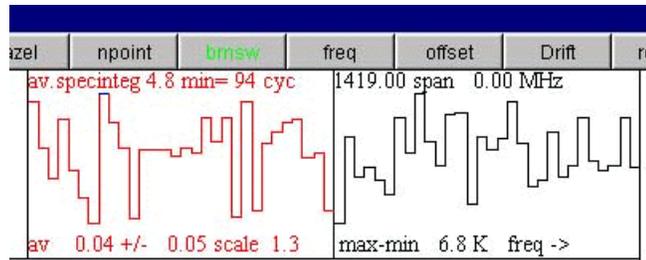
25-Point Map Display

The third window in the plot area (far left square field) is the output display for 25-point spectral and continuum maps. When a 25-point scan is complete, a false color image of the map area will automatically display.
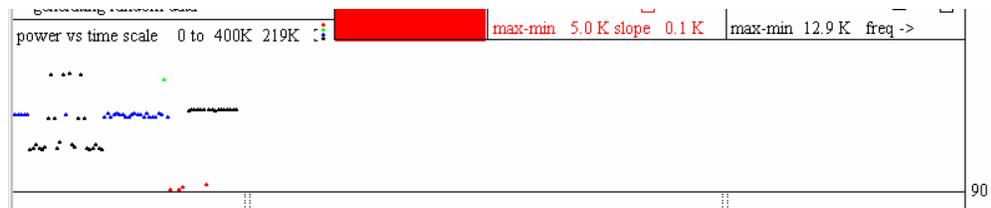
Continuum Display

Figure-7 shows the spectral display boxes as they appear during a continuum scan. The left side box now reports information showing the number of observation cycles (in this example, an off-on-off beamswitch observation) and the total integration time above the graphical output.

Below the graph, the average temperature, the RMS and vertical scale are reported.

(Figure-7, Continuum Output)

1.3.6 Total-Power Chart Recorder

(Figure-8, Total Power Chart Recorder)

The area of the SRT control console above the Sky Map is a continuously running chart recorder showing relative power of the signal received vs. time. The plot will continually overwrite as it paints from left to right and will reset to the bottom of the chart when the plot value reaches the 400K vertical scale maximum. To minimize confusion when the scale resets (400K steps), the plot is color-coded (note the color-dot icon to the right of the temperature indicator):

      black 0-400, blue 400-800, green 800-1200, red 1200-1600

1.3.7 Antenna Drive/Motion Status Display

This box, at the upper left of the control console display, (Figure-9) shows the station name, latitude and longitude as read from the *srt.cat* file. The second line lists the current antenna drive status, such as, moving, simulate, stopped …

(Figure-9, Motion Status Display)

1.4 Manual Command Entry

Most users will start SRT observations by entering text commands into the text box at the bottom of the control console. As explained in Section 1.3, most of the button actions can be duplicated with command lines or must be supplemented with manual command entries.

Example:

The user may want to conduct a simple test observation of hydrogen along the galactic equator. The required steps are:

1. Move the SRT to the intended source.
2. Calibrate.
         (The calibration can be done with the hydrogen frequency off-source (*preferred*) or, a
         non-hydrogen frequency on-source)
3. Set the observing frequency and scan width (*or observing mode for digital*).
4. Decide on a suitable integration time.

Manual commands (slow method!) (*Analog Commands in Red*)

1. Click on the desired source.
2. 1419.0 (1419 1)   (non-hydrogen frequency for cal)
3. Cal or Vane   (begins noise/vane calibration)
5. 1420.4 4 (1420.4 35)   (set observing frequency)
         Since the hydrogen line will be about 500KHz wide,
         The 3 x 500MHz digital **mode 4** is needed to display the hydrogen line with the
         digital receiver   (Analog - 35 bins times the 40 KHz default bin size should be
         enough to display the spectra correctly)

Combination Manual and Button commands (preferred!)

1. Move the mouse to the source on the map and left click.
2. Move the mouse pointer to the **track** button and click
3. Click on the **freq** button then type: **1419.0**   (in the command text box)
4. Click on the **Cal** button
5. Click on the **freq** button then type: **1420.4 4**   (in the command text box)
6. Observe the accumulated spectrum

While use of the mouse and the text box can quickly start observations or change observer settings, it can get cumbersome if the user wants to do many observations or long integration or other long-term measurements. Section 1.5 discusses the construction of automatic input command files and the recording of SRT data.

1.5 Input Command Files

The use of input command files (*filename.cmd*) will speed the entry of SRT commands as well as reduce command entry mistakes. A list of the command file syntax can be found by moving the mouse pointer to the **Rcmdfl** button. The first part of the list will appear in the message board above the text entry box. Moving the pointer *off the button then back on* will show the rest of the syntax list. The command file is ASCII and can accept instruction lines (those that are read and take some action), blank lines (they are ignored) and comment lines (also ignored by the system).

Comments: Start with an asterisk and can be any text the user wishes.

        * The following are examples of command file entries
        *2005:148:00:00:00 Cas
        *

Instruction: The line must start with a time mark (either UT or LST) or a colon.

        2005:148:00:00:00 radec 23:00:00 06:50:00   (yyyy:ddd:hh:mm:ss (UT))

        LST:06:00:00   (LST:hh:mm:ss)

        :120 azel 120 30   (sss azel position)

Rules:

: cmd	/execute the command and proceed to the next line
:120 cmd	/execute the command and wait 120 seconds, taking data, before proceeding to the next line in the schedule
:120	/wait 120 seconds, taking data, before proceeding to the next line. This is a convenient way of increasing the radiometer integration to more than one scan

Note: There is NO space allowed between the colon and a time "wait" command

LST:06:00:00	/wait until LST 06:00:00, taking data, before proceeding to the next line
2005:148:00:00:00	/wait until UT= yyyy:ddd:hh:mm:ss, before proceeding to the next line

Example Set: Instructions can be set in order to perform an observation. The following set of instructions will command the SRT to take 1420.4 MHz hydrogen spectra in 5 degree spacing along a section of the galactic equator. The user must start data recording, unstow the telescope, calibrate the receiver, set the observing frequency center and frequency scan and then repeat the spectral line observations for ten points along the equator. *Note: Allow a space between the colon and the command*

: record rotation.rad	(Start data recording of file *rotation.rad*)
: galactic 206 20	(unstow and move to calibration position)
: freq 1419	(Off-hydrogen calibration frequency)
: calibrate	
: freq 1420.4 4	(Set center frequency mode 4)
: galactic 205 0	(Move to first data point)
: galactic 210 0	(Next point)
: galactic 215 0	
: galactic 220 0	
: galactic 225 0	
: freq 1419	(Off-hydrogen calibration frequency)
: galactic 225 20	(Calibration point)
: calibrate	
: freq 1420.4 4	(Set center frequency mode 4)
: galactic 230 0	(Move to sixth data point)
: galactic 235 0	(Next point)
: galactic 240 0	
: galactic 245 0	
: galactic 250 0	
: roff	(End data recording)

If this input command file were named **galactic.cmd**, the user could initiate this observation by clicking in the command text box:

galactic.cmd

The SRT will read each line in turn and report the current line read as **green text** in the message board area. If, for example, the start time was 1400 Universal Time on March 15, 2002; and no output file name was entered, the default OUTPUT file would automatically be written and labeled **0414814.rad**.

Where the file label is: **yydddhh.rad**

Information about the output data file can be found in section 1.6

1.6 Output Data Files

The output data file (**yydddhh.rad**) is an ASCII text file. Data reduction on the raw output can be done with a spreadsheet program like *MS Excel* with some effort. The development of spreadsheet MACROS to reduce the data are desirable for large files and long integrations. Future releases or updates of the SRT software could also output certain observations in formats for other data reduction methods.

Comment lines:

Start with an asterisk and list the STATION LAT and LONG(E/W) on the first line.

* STATION LAT= 42.50 DEG LONGW= 71.50

When the output data is the result of an input command file, the next comment line could be the listing of the first command line in the input file.

* *filename.cmd*: line 1 : *command*

Calibration results will also follow an asterisk:

* tsys   215 calcons 0.98 trecvr 195 tload 300 tspill   20

Data lines:

Start with a time mark (yyyy:ddd:hh:mm:ss), then list: azimuth, elevation, offsets, center frequency, point spacing and data points.

2005:148:14:32:44 104.5 16.0   0.0   0.0 1419.75 0.00781250 1 64 …

Data points listed in the **.rad** file are multiplied by the calibration constant produced prior to the data taking.

The command file **test.cmd** starts a short calibration and hydrogen spectral-line run on the CasA. The input file listing and output file, **0514814.rad**, examples are listed below:

INPUT: test.cmd

```
: record
: azel 125 45
: freq 1419
: calibrate
: Cas
: freq 1420.4 4
:20
: roff
```

OUTPUT: 0514814.rad

* STATION LAT= 42.50 DEG LONGW= 71.50
2005:148:10:55:41 92.0 5.0 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9 10.5
20.1 40.1 70.2 107.5 154.3 218.1 219.9 223.5….…….224.5 216.5 151.1 111.2 70.2
41.9 21.1 10.3 5.8

(the data stream above actually has about 151 data points. It is truncated for this example)

* STATION LAT= 42.50 DEG LONGW= 71.50
* test.cmd: line 1 : record
2005:148:14:32:44 104.5 16.0 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9 10.5
 * test.cmd: line 2 : azel 125 45
2005:148:14:32:49 125.0 45.0 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9 10.5
* test.cmd: line 3 : freq 1419 1 0
2005:148:14:32:50 125.0 45.0 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9 10.5
* test.cmd: line 4 : calibrate
2005:148:14:32:50 125.0 45.0 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9
2005:148:14:32:50 125.0 45.0 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9
* tsys   215 calcons 0.98 trecvr 195 tload 300 tspill   20
2005:148:14:32:51 125.0 45.0 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9
* test.cmd: line 5 : Cas
2005:148:14:32:51 171.2 52.1 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9
2005:148:14:32:52 171.2 52.1 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9
* test.cmd: line 6 : freq 1420.4 41
2005:148:14:32:56 171.2 52.1 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9 …
* test.cmd: line 7 :20
2005:148:14:33:01 171.3 52.1 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9 …
2005:148:14:33:06 171.3 52.2 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9 …
2005:148:14:33:10 171.3 52.2 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9 …

2005:148:14:33:15 171.3 52.2 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9 …
2005:148:14:33:19 171.3 52.2 0.0 0.0 1419.75 0.00781250 1 64 4.7 5.9 …

Haystack Observatory - - Small Radio Telescope

Measure Antenna Beamwidth using the Sun as a Signal Source

Introduction:

The beamwidth of a radio telescope is the solid-angle measure of the half-power point of the main lobe of the antenna pattern. The half-power beamwidth (HPBW) can be measured by moving the telescope in a continuous scan across a very bright radio source. Except for the possibility of Cygnus-X or certain geo-synchronous satellites, the only source available to the SRT is the Sun.

Measurement of the beam pattern can help the user discover problems with optical alignment or aid in the determination of the antenna focus.

Procedure:

The SRT has azimuth and elevation travel limits that will constrain the user conducting the Sun scan to times close to local noon. This will allow maximum offset from the sun in order to establish a stable baseline for the scans and an off-source calibration position that will not be overpowered by the sun's brightness temperature. For the off-source calibration, an area **at least two beamwidths** (in azimuth, positive or negative) away from the sun is desirable.

A sample command file for the Horizontal (Azimuth) then Vertical (Elevation) scans might look like this (note: **commands for the analog receiver are colored blue**):

```
: record filename        /Start recording, output filename is optional
: azel 130 45            /calibration position
: 1415 5 0.0            /scan frequency, 5 bins (samples), no frequency step
: 1415.0                /center frequency with mode 1, 500MHz bw (default)
: calibrate             /calibration using vane calibrator
: noisecal              /when using noise source  (either vane OR noise)
: Sun                   /Source command
* Azimuth Scan          /Comment
: offset -30 0          /start offset commands for scan -30 to +30 degrees
: offset -29 0
: offset -28 0
: offset -27 0
: offset -26 0
: offset -25 0          /through to offset 30 0
* Elevation Scan        /Comment
: offset 0 30           /Start elevation scan (if sun El is <60 degrees!)
: offset 0 29
: offset 0 28
: offset 0 27
: offset 0 26
: offset 0 25           /through to 0 -30
: roff                  /End recording
```

Move the mouse pointer to the upper right of the control console and click the button labeled:

Rcmdfl

Move the mouse pointer down to the command line input box and type the SRT command filename you wish to open:

*Filename***.cmd**   /*example = beamsize.cmd (the suffix .cmd is required)

The software will read the input command file similar to the above example in sequence and output and ASCII text file that can be processed by a spread sheet such as MS-Excel or a hand written program to process the data in your particular form.

Output:

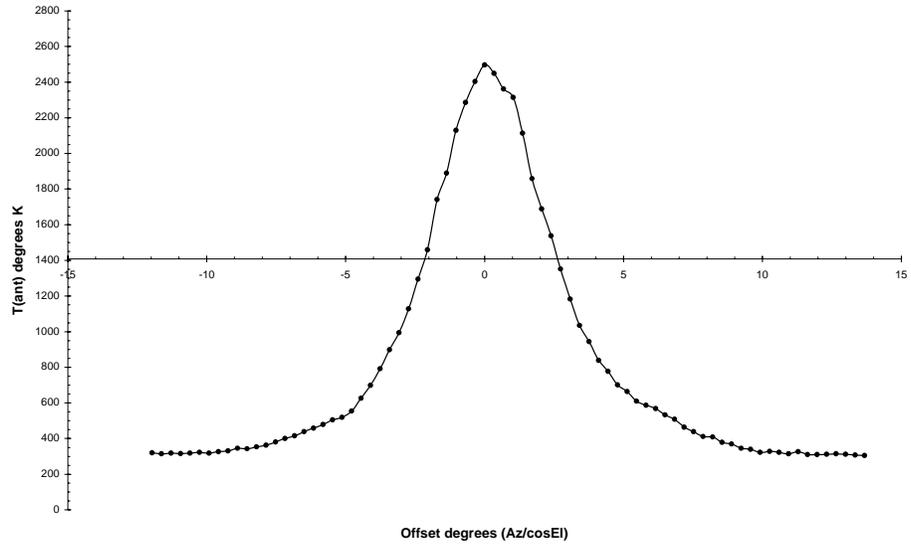Output data will default to a day/time stamp ASCII text file with the filename:

yydddhh.RAD

Where, *yy* is the year, *ddd* is the day number (UT) and the *hh* is the UT hour at the opening of the output file
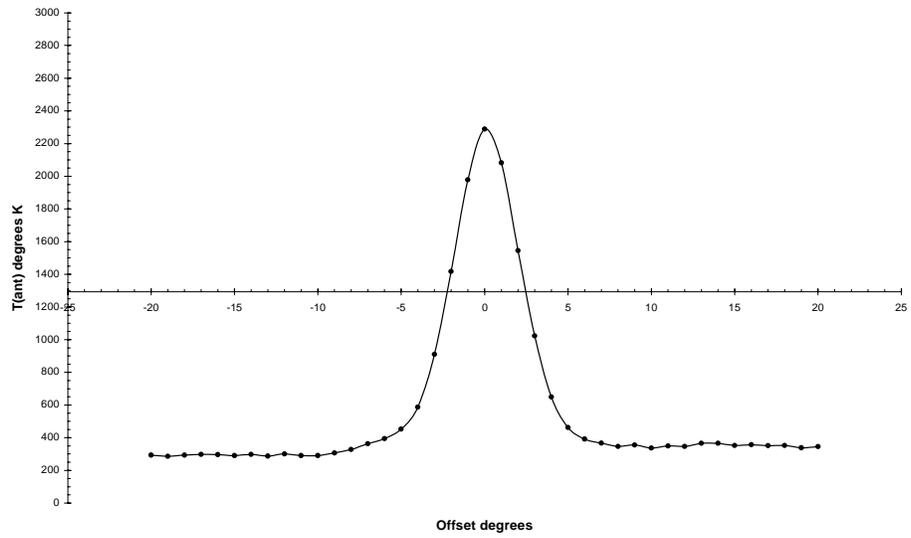
The resulting scan plots might look like the plots seen on the next page. These plots are the output from MS-Excel.

The azimuth-plot horizontal scale reflects the correction of azimuth degrees above the horizon by the cosine of the elevation angle. The horizontal scale on both plots has been drawn through the half-power points.

Azimuth Sun-scan

T(ant) degrees K

Offset degrees (Az/cosEl)

Elevation Sun-scan

T(ant) degrees K

Offset degrees

Haystack Observatory - - Small Radio Telescope

Measure Aperture Efficiency

Introduction:

Aperture efficiency η, is the ratio of the effective aperture of a radio telescope divided by the true aperture. True aperture **A**, is defined as the collecting area of the telescope surface. Effective aperture $\mathbf{A_e}$ can be defined as the losses from a perfect reflector due to such things as blockage of the surface by the feed and feed supports, over/under-illumination of the surface by the feed and other factors such as surface irregularities. Typically, total losses amount to 35%-50% of the theoretical limit. That is, 50%-65% of the power from the observed source reaches the receiver.

$$\eta = Ae/A$$

For the purposes of the use of the SRT, the aperture efficiency (η) is expressed by the following equation:

$$\eta = 2k\, T_A\, /FA$$

where, $\mathbf{\textit{T}_A}$ = the antenna temperature in degrees K, $\mathbf{\textit{k}}$ = Boltzman's constant (1.38 x 10^{-23} w Hz^{-1} K^{-1}), $\mathbf{\textit{F}}$ = the radio source flux density in Janskys (10^{-26} w m^{-2}) and $\mathbf{\textit{A}}$ = the area of the reflector in m^2

Measurement of the aperture efficiency of the SRT can be carried out on several sources: Cygnus-X, Cas-A, the Moon and even the Sun. The procedure below will use Cas-A.

Procedure:

The user should first move the telescope to an area of the sky near the source to be observed. The calibration should typically be done at the same elevation as the source but offset in azimuth by at least two beamwidths (~14 degrees for a 2.1m dish). Since this is a "continuum" measurement, the frequency setting for the receiver should be away from the 1420.4 MHz hydrogen line.

The observing mode will be beamswitching. Beamswitching involves alternate on-source/off-source observations with each off-source observation alternating in a plus/minus azimuth direction. A typical command file for a five-minute, beamswitched run on CasA might look like this (Analog receiver commands in blue):

LST 18:00:00	/select a time when CasA is at higher elevation
: record *filename*	/Start recording, filename is optional
: azel 80 45	/Calibration position
: freq 1419 20 0	/Set frequency, number of samples and sample spacing
: 1419.0	/Center frequency with 500MHz bandwidth (default)
: calibrate	
: noisecal	/When calibrating with noise diode
: CasA	/Move to CasA
:300 b	/300 seconds observing, b=beamswitch mode
: roff	/recording off

Discussion of Data Reduction:

The resulting data output file will be a succession of on-source then off-source samples. The statistical reduction to arrive at an average Antenna Temperature $\mathbf{T_{ant}}$ to use in the above Aperture Efficiency equation is as follows:

$$\mathbf{P_k = P_{on} - P_{off}}$$

Where, k = the cycle number. (On/Off pair)

$$\mathbf{For, k = 0,2,4 \quad -p_{off} + previous\ P_{on}}$$
$$\mathbf{For, k = 1,3,5 \quad P_{on} - previous\ P_{off}}$$

For N cycles

$$\mathbf{P_{ave} = \Sigma\ P_k\ /\ N}$$

Where, P_{ave} = average of N on/off pairs

$$\mathbf{P_{SD} = (\Sigma P_k{}^2 - N\ P_{ave}{}^2)^{1/2}(N - 1)^{-1/2} \qquad For\ N>1}$$

The plot of the reduced output data was generated from a program written by Alan Rogers for SRT Beam-Switched Data reduction. The program is written in JAVA and when compiled will read the output data file from the SRT beamswitched run. The syntax of the compile and run steps are listed as follows:
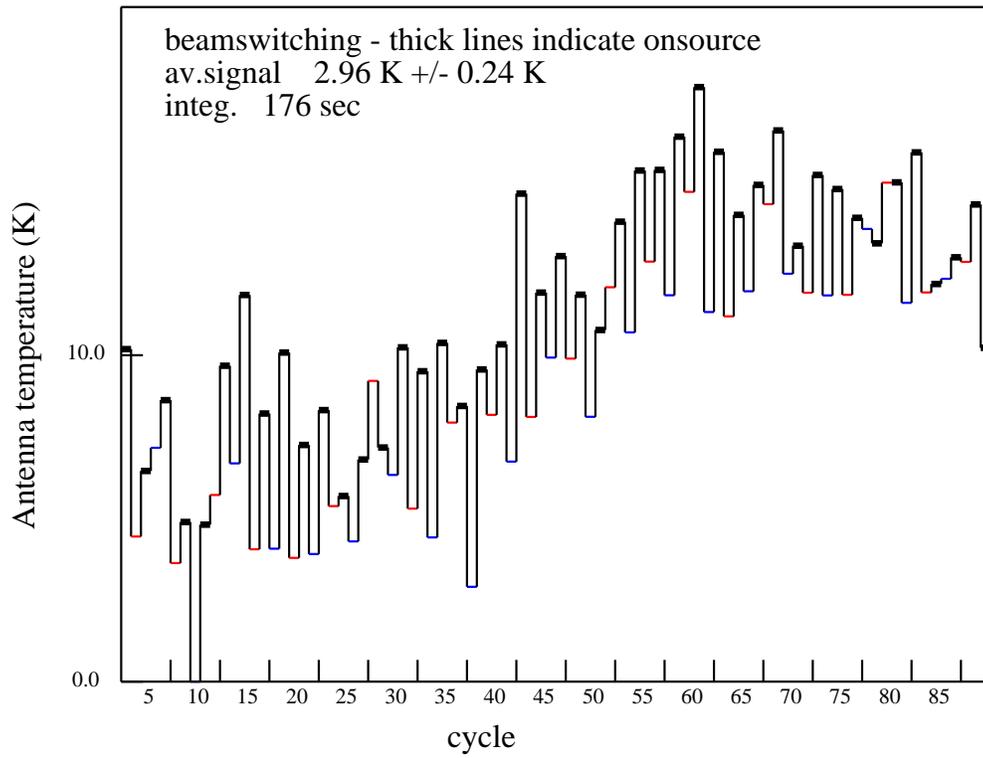
C:\ **javac bplot.java**

C:\ **java bplot** *filename***.rad**

The output data plot is in Postscript form with the default name:

C:\ **srt.pos**

This output plot is generated from *analog* receiver data.

beamswitching - thick lines indicate onsource
av.signal   2.96 K +/- 0.24 K
integ.   176 sec

Antenna temperature (K)

10.0

0.0

5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80   85

cycle

SRT