The GMRT : User's Manual

version 2.3 dated March 2012.

Contents

List of Tables

List of Figures

Part I

A Brief Introduction to the GMRT

1 The Array

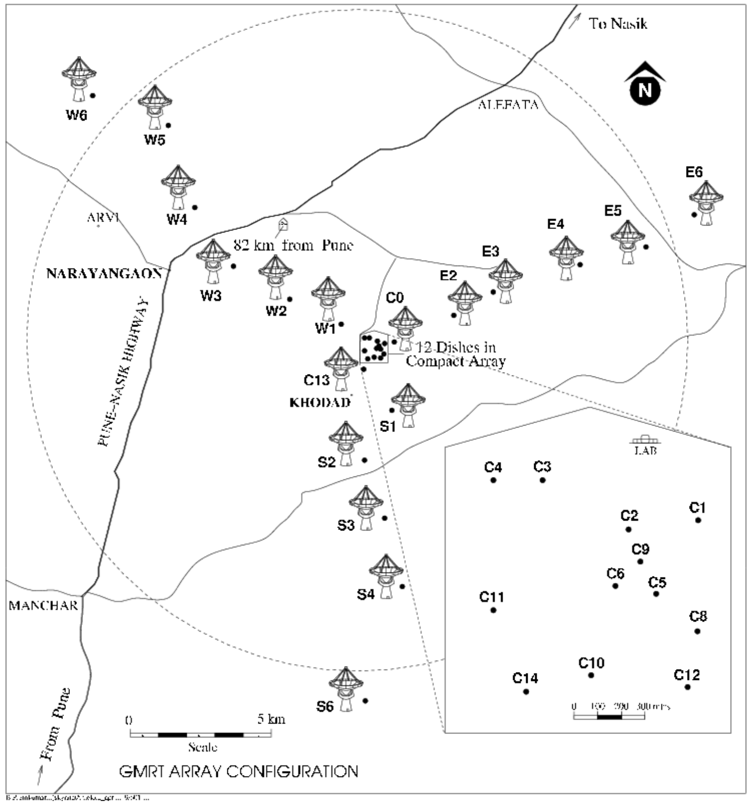


Figure 1: The GMRT Array.

The GMRT consists of 30 45 m diameter parabolic dishes spread over 25 km near the village of Khodad, about 80 km north of Pune, India. The site coordinates are:

```
latitude  = 19 deg 05 min 48 sec North,
longitude = 74 deg 03 min 00 sec East,
altitude  = 588 m.
```

The array consists of two main parts: a central array of 14 antennas which are labeled, C# (e.g. C00, C01, ..., C14), and an outer Y consisting of 14 km long East, West, and South arms (labeled E#, W#, and S#, respectively). There are 5 antennas on each of the east and south arms and 6 antennas on the west arm. Note that the numbering scheme is not consecutive and there are no C07, E01 and S05 antennas (dropped due to shortage of funds).

The elevation limit of the array has currently been set to 17 to 90 degrees (software limit), giving a declination range coverage from $-53d54^{'}$. to +90 degrees.

The telescope currently operate at 5 frequencies, 150 MHz, 235 MHz, 325 MHz, 610 MHz, and 1000–1420 MHz. There are 4 feed systems, mounted on 4 sides of a turret of which one (235/610) is a dual frequency feed.

The GMRT antenna specifications are given below.

	Specifications
Parabolic Reflector Diameter	45m
Focal Length	18.54 m
Physical aperture	1590 m^2
Sensitivity of single dish	0.3 K/Jy
Feed Support	Quadrupod
Mounting	Altitude-azimuth
Elevation Limits	Software Limit 17−90 degrees
	Hardware Limit 15−110 degrees
Azimuth Limits	Software Limit −265 to +265 degrees
	Hardware Limit −270 to +270 degrees
Slew rate	Azimuth 30 degree/minute
	Elevation 20 degree/minute
Wind speeds	Operation upto 40 km/h
Pointing accuracy	$1'$ *rms* at wind speeds

Table 1: The GMRT Antenna specifications

2 The Receiver System

The GMRT receivers are designed to operate at 5 frequency bands : 150, 235, 325, 610, and 1420 MHz. 50 MHz feed is under development. The half-power radio frequency (RF) bandwidth for 150, 235, 325 and 610 MHz respectively is 40, 40, 40 and 60 MHz. The 1420 MHz band is split into 4 sub-bands centered at 1060, 1170, 1280, and 1390 MHz, each with a bandwidth of 120 MHz. Thus, the sub-bands overlap by 10 MHz and provide continuous frequency coverage from 1000 MHz to 1450 MHz. This allows observations of the 21cm spectral line of hydrogen from local gas to a redshift of about 0.4. Higher redshift HI can, of course, be detected in the lower frequency bands. The user can also choose the full band (from 880 to 1450 MHz), by using the bypass mode of 1420 band (see Section 4.2 for more details).

RF signals are received in two polarizations (called CH1 and CH2). As shown in figure**??**, for all frequencies except the 1420 MHz band, right and left circularly polarized signals are processed, whereas for the 1420 MHz band, the linearly polarized signals are processed. The intermediate frequency (IF) is 70 MHz with a maximum bandwidth 32 MHz.

The 1st LO and the 5th LO should be specified (both for the spectral line and the continuum observations, depending on the observer's requirements). The 1st LO can be set in steps of 1 MHz for frequencies from 150 to 354 MHz and in steps of 5 MHz for frequencies from 350 to 1795 MHz (Ref : GMRT sub-systems report).

At the antenna base, after the IF conversion, an automatic level control (ALC) system is available. This adjusts for the varying signal levels at the output of the IF. For interferometric observations, the ALCs are generally on. The final bandwidth can be chosen from 0.125 MHz to 32 MHz.

3 GMRT system

3.1 The Control System

The "online" displays the status of the telescope (position, rates, reference position, time), the setup of various front and back ends, information on the procedure that is being run, and so on, on different screens. For each of the items on the control panel there would be a display of the current value (e.g. the exact position of the telescope at that instant).

The observer's inputs simply generates a setup that is sent to the online through the operator.

Presently, the control panel mode of program control is in its infancy. Soon, like other observatories, we would be able to do away with a machine-readable input file and this would update the variables. This would provide a way to design an experiment entirely as a ”real-time” operation; instead of specifying, altering various states of the control panel; *i.e.* observer submits a file generated for his/her observations.

3.1.1 Running up GSB (GMRT Software Backend) for recording astronomical data

1. **GSB Hardware Set-up :**
   The present configuration of the GSB has 1 to 50 nodes and 4 control/peripheral machines. These are split as follows, based primarily on functionality :

   RACK 1 : nodes 1 - 16 : data acquisition nodes (each hosts one 4 channel ADC card)
   RACK 2 : nodes 17 - 32 : computing nodes (quad core machines which do the main computing)
   RACK 3 : nodes 33 - 48 : compute nodes for extra computing (e.g. 32 MHz full stokes modes) and recording nodes for voltage raw dump mode.
   RACK 4 : nodes 49,50, gsbm1, gsbm2, gsbm3, gsbm4.

   nodes 49 and 50 are used for beam/pulsar data recording. node49 is for beam 1 (normally IA beam) and node50 is for beam 2 (normally PA beam).

2. **Local Oscillator Settings :**
   At present, both LO4 and LO5 need to be set explicitly for GSB observations.

   For IF BW 32MHz, LO4 = 51MHz, and LO5 = 149, 156 (in MHz).
   For IF BW 16MHz, LO4 = 62MHz, and LO5 = 138, 167 (in MHz).
   For IF BW 06MHz, LO4 = 67MHz, and LO5 = 133, 172 (in MHz).

   One can set any custom LO5 through the entry box. One need the set the corresponding LO4 also. Presently LO5/LO4 can be changed in the steps of 100 KHz.

3. **Currently Available modes of GSB** : as shown in the **Table 2**.

   Notes regarding Table 2 :.

   - (*) Released on trial basis : set lta-visibility pre-integration to 4sec and beam output 245.76 uSec.
   - (#) Regarding beam integration and beam-data-host.
   - (@) Output data is in spectral voltage form; needs one inverse FT to get voltage time series with time resolution of 15 nsec for 32 MHz mode and 30 nsec for 16 MHz mode.

4. **Decimate Mode (sub band selection)** : In case of *line observations* we need to set the sub band and custom LO5.

   As shows in the following **table 3** are the different sub-band (step no.) :

   Notes:

   - LO1 freqs from 0 to 355 MHz can be changed in steps of 1 MHz.
     LO1 freqs from 355 to 1500 MHz can be changed in steps of 5 MHz.
     LO4 freqs from 50 to 90 MHz can be changed in steps of 100 KHz.
   - IF Band-width should not be more than ACQ-BW (acquisition bandwidth)
   - Line frequency should match with the middle channel frequencies.

	Observation Type	Usage Mode	Input IF BW (MHz)	Acquisition BW or Final o/p BW (MHz)	No. of Channels	Output Time Resolution
1	Interferometry : Continuum	Total Intensity (32 MHz mode)	32,16,6	32	512,256	2,4,8...(sec)
		Total Intensity (16 MHz mode)	16,6	16	512,256	2,4,8.. (sec)
					128	0.5,1,2.. (sec)
					64,32	0.25,0.5,1.. (sec)
		Full Stokes (32 MHz mode)	32,16,6	32	512 (*), 256	2,4,8..(sec)
		Full Stokes (16 MHz mode)	16,6	16	512 (***), 256	2,4,8..(sec)
2	Interferometry : Spectral Line	Total Intensity (16 MHz and lower BW modes)	16,6	16/N (N=4,8,16..128) (viz. 4,2,1, 0.5,0.25,0.125 MHz)	512,256	2,4,8..(sec)
3	Array Beams IA	Total Intensity (32 MHz mode)	32,16,6	32	512,256	Pre : 2 (*) Post : 1,2,4
		Total Intensity (16 MHz mode)	16,6	16/N (N=4,8,16) (viz.4,2,1 MHz)	512,256	Pre : 1,2 (**) Post : 1,2,4
4	Array Beams PA	Total Intensity (32 MHz mode)	32,16,6	32	512,256	Pre : 2 (*) Post : 1,2,4
		Total Intensity (16 MHz mode)	16,6	16/N (N=4,8,16) (viz.4,2,1 MHz)	512,256	Pre : 1,2 (**) Post : 1,2,4
		Full Stokes (16 MHz mode)	16,6	16	512,256	Pre : 2 (**) Post : 1,2,4
		Voltage Beam (32 MHz mode)	32,16,6	32	512,256	15 nsec (@)
		Voltage Beam (16 MHz mode)	16,6	16	512,256	30 nsec (@)
5	Raw Dump	Raw voltages from all antennas	16,6	16		30 nsec at 4 bits per sample

Table 2: GSB Modes

BW	CHANNEL	PRE-INTEG	IFR	Beam-Stokes	Data-Nodes(Beam1-Beam2)
16.666	256	30.72 uSec	TI	IA(TI):PA(TI)	node33-34
16.666	512	61.44 uSec	TI	IA(TI):PA(TI)	node33-34
16.666	256	61.44 uSec	FS	IA(TI):PA(FS)	node33-34
16.666	512	122.88 uSec	FS	IA(TI):PA(FS)	node33-34
33.333	256	30.72 uSec	TI	IA(TI):PA(TI)	node33-34
33.333	512	61.44 uSec	TI	IA(TI):PA(TI)	node33-34
33.333	256	61.44 uSec	FS	IA(TI):PA(FS)	node47-48 with XNET
33.333	512	245.76 uSec	FS	IA(TI):PA(FS)	node47-48 with XNET

Sr. No.	IF BW	ACQ BW	Final BW	Sub Band [step no.]	Type
1	32	33.33	33.33/OFF	n=0/OFF	Continumm
2	16	16.66	16.66/OFF	n=0/OFF	Continumm
3	16/6	16.66	4.16	n=0..3	Line/Decimate
4	16/6	16.66	2.08	n=0..7	Line/Decimate
5	16/6	16.66	1.04	n=0..15	Line/Decimate
6	16/6	16.66	0.52	n=0..31	Line/Decimate
7	16/6	16.66	0.26	n=0..63	Line/Decimate
8	16/6	16.66	0.13	n=0..127	Line/Decimate

Table 3: Decimate Mode(Sub-band Selection)

5. **Beam Selection** : beam1 and beam2 are by default for sub-arrays (subar 1 and subar 2, respectively); but two beams can be formed from a single sub-array also. This antenna selection is done through GAC config.

   The following valid combinations (shown in **table 4**) are available for beam mode :

   Note : Change in post integration will reflect after the ia/pa scan is restarted and change in GAC config will reflect after restarting the IFR scan.

No.	Beam - 1	Beam - 2
1	IA	IA
2	PA	PA
3 (default)	IA	PA
4	IA	OFF
5	OFF	PA
6	OFF	VOLTAGE

Table 4: Beam Selection

	Frequency (MHz)				
	150	235	325	610	1420
Primary Beam (arc min)	186±6	114±5	81 ± 4	43 ± 3	$24 \pm 2 * (1400/f)$
Receiver Temperature (T_R)	295*	106*	53	60	45
Typical T_{sky} (off Galactic plane)	308	99	40	10	4
Typical T_{ground}	12	32	13	32	24
Total System Temperature (K) ($T_R + T_{sky} + T_{ground}$)	615	237	106	102	73
Antenna Gain (K/Jy/Antenna)	0.33	0.33	0.32	0.32	0.22
Synthesized Beam (arcsec)					
Whole Array	20	13	9	5	2
Central Square	420	270	200	100	40
Largest Detectable Source(arcmin)	68	44	32	17	7
Usable Frequency Range (MHz)					
Observatory default	150 to 156	236 to 244	305 to 345	580 to 640	1000 to 1450
Range allowed by electronics	130 to 190	230 to 250	305 to 360	570 to 650	1000 to 1450
Fudge Factor(actual to estimated time)					
Short Observations	10	5	2	2	2
Long Observations**	5	2	2	1	1
Best rms sensitives achieved so far as known to us (mJy)	0.7	0.25	0.04	0.02	0.03
Typical Dynamic Ranges	> 1500	> 1500	>1500	>1500	>2000

Table 5: Measured System Parameters of GMRT

∗ With default solar attenuator (14 dB).
∗∗ For spectral observations fudge factor is close to 1

4 Preparing for Observations

The following should be carried out before the observing session for ALL OBSERVATIONS.

1. **Check GMRT specifications** to choose the appropriate frequency, primary and synthesized beam sizes to match the source and the science.
2. **Check the latest antenna status** with telescope operators to see which antennas are available and the central square and complete Y configurations to see that the *uv* coverage is adequate.
3. **Determine the source rise/set times**. At the GMRT, Khodad, the ONLINE command 'gts' will accomplish this, provided a source file has been created and loaded (see Appendix **Z2**). Also you can use from 'GMRT home-page → Observing Help → For GMRT Observations' for finding source rise/set times.
4. **Choose IF bandwidth**, $\Delta\nu$ (see Table 2), from the available bandwidths.
5. **Determine the required time on source**, τ. This is computed *via*:

$$\Delta S \;=\; \frac{\sqrt{2}\; k\; T_{\rm sys}}{\eta_a\; \eta_c\; A\; \sqrt{(n_b)\; n_{\rm IF}\; \Delta\nu\; \tau}}$$

System Settings	
Frequency band	150, 235, 325, 610, 1060 1170, 1280, 1390, 1420 MHz
Solar Attenuator	0, 14, 30, 44 dB.and -1 for FE Termination.
Polarization swap	Swap on (1) / Swap off (0)
Noise cal Level	E-HI(0), HI(1), MED(2), LO(3) and -1 for RF OFF
LO Frequency	From 100 to 355 in steps of 1 MHz and From 355 to 1600 in steps of 5 MHz
IF Pre Attenuator	From 0 to 30 dB in steps of 1 dB.
IF Post Gain	From 0 to 30 dB in steps of 0.5 dB
IF bandwidths	32, 16, 6 MHz
IF ALC	ALC ON (1) / ALC OFF(0)

Table 6: Table showing RF, LO, and IF parameters

where ΔS is the required rms noise (Jy), $T_{\rm sys}$ is the system temperature (K), and $[(\eta_a\ A)/(2k)]\ =\ G$ is the antenna gain (K/Jy), where η_a and η_c being aperture and correlator efficiencies respectively. A is the geometrical area of the antenna, n_b is the number of baselines, $n_{\rm IF}$ is the number of IF channels, and $\Delta\nu$ (Hz) is the bandwidth of each sideband (or channel width for spectral line observations).

Here, $n_{\rm IF} = n_{\rm pol} + n_{\rm SB}$, where $n_{\rm pol}$ is the number of polarizations (2 for the GMRT) and $n_{\rm SB}$ is the number of sidebands. Note that the improvement in S/N by operating in double sideband mode applies only to continuum observations.

6. **Choose a primary flux density calibrator and phase calibrator** from the VLA calibrator manual. The VLA calibrator manual is also available at the GMRT site. The best sources for GMRT use will be those which are usable at all VLA arrays (A, B,C, and D). However, sources which are not acceptable as A array calibrators (and possibly B) may still be acceptable, provided the appropriate *uv* limits are adhered to. It is best not to use a calibrator which is not usable at D array since this will eliminate the central square of the GMRT. Decide which calibrator will be used to calibrate the bandpass. This is usually the flux density calibrator, but could be the phase calibrator for strong, low frequency sources.

7. **Create a source file**; the source file contains the names, coordinates, and coordinate epochs of all the sources to be observed. It is usually named *via* the initials of the observer (*e.g.* 'yourname.list', lower case !). Only one such file is usually necessary (a master list) since the file can contain more sources than are actually observed. The format must be exact (including spaces) and is case sensitive. Thus, it is best, when first making the file, to copy and edit one which is already in existence. The telescope operator can supply a template file (or see astro1@lenyadri/shivneri/lenyadri:'`/odisk/gtac/source/⋆.list`'). There is already a 'source.list' file in regular use which includes many calibrator sources, including the primary VLA flux density calibrators. This file also can be prepared from program 'gut' also. However, it does not contain all sources in the VLA calibrator manual. Therefore, it is likely that the phase calibrators will also need to be included in the user's master list of sources. Once the source file is created in the user's home directory, it should be copied by the telescope operator into a directory which can be read during the observing session.

8. **Create a command file** (see Appendix **Z2** in the end of this document and/or astro1@lenyadri/shivneri/lenyadri:'`/odisk/gtac/cmd/⋆.cmd`' for templates). The command file also can be created by the program 'gut'. This file contains commands for the telescope to slew to a source, track, collect data for a specified time, etc. Any of the commands in this file can also be input manually at the console during observations, but the file, when accessed, will prevent the necessity of a continuous input of manual commands. It is possible to override this file from the console; however, when started again, it will start from the beginning of the file, so some

editing might be required if this occurs. Strategically, it is best to start the observing run with commands issued manually so as to monitor a calibrator and correct problems from the console level, if they occur. Once satisfied, the command file can then be invoked. A typical example of a command file can be found in Appendix Z2. Command files are usually put in the directory, *e.g.* astro1@lenyadri/shivneri/lenyadri:'`/odisk/gtac/cmd/yourname.cmd`' (lower case !).

9. **Choose integration time**, The integration time specifies the time over which data from the source is collected, thus specifying the time interval for an individual visibility. The integration time is specified through the parameter, LTA1 while GSB configuration and LTA2 while recording. For integration time LTA1 kindly refer to table 2, and on top this integration we can give LTA2 while recording the data. For example, LTA1 is 8 which is about 2.013264 seconds and LTA2 is 8, which gives the final integration 16.106112 seconds, which we use as default integration time while observations.

10. **Choose the ACQ_BW** bandwidth (see Table 2). The ACQ_BW should be at least as large as the final IF bandwidth.

11. **Determine the frequency of the 1st LO**. $\nu_{\rm RF} = \nu_{\rm LO1} + \nu_{\rm LO4}$. where $\nu_{\rm RF}$ is the sky (observing) frequency (first channel frequency), $\nu_{\rm LO1}$ and $\nu_{\rm LO4}$ are the local oscillator frequency. $\nu_{\rm LO4}$ has default values depending on the IF bandwidth and value of $\nu_{\rm LO1}$ can be determined accordingly. For line observations both the LOs can be changed as per requirement. The user should note the permitted frequency increments (see Section 2). The user can also use the program `tune.pl` available locally. You can also use from 'GMRT home-page → Observing Help → For GMRT Observations → Frequency Setting Calculator' for calculating TPA values and also can use program 'gut' for getting the same values.

4.1 Spectral line observing with GMRT

This section is for users interested in spectral line observations with GMRT. Observer must be aware that GMRT always observes in the spectral line mode. What differentiates spectral line observations from standard continuum observations is that the local oscillator settings are important so as not to miss the spectral line which is expected at a certain frequency. For the continuum observations, one can use the default settings (see Table 8) for the desired band. Moreover, one can choose to record less than 512 channels in the case of continuum observations whereas for spectral line projects, recording data of all channels would be desirable.

For spectral line projects, the user will need to have an idea of the observing frequency and the desired bandwidths.

1. **Determining the observing frequency:** Once you know the rest frequency of your spectral line, the redshift for far Universe objects should give you the observing frequency. In case of Galactic or near Universe objects, the NRAO programs '`dopset`' or '`gut`' (available *via* usual "`source /astro/RC`") can be used to obtain the change in the rest frequency due to the earth's rotation and motion around the Sun so as to obtain the heliocentric or the local standard of rest values. Please note that online Doppler correction is not provided at GMRT - the change over an eight-hour run is $\sim$1 km/s.

2. **Determining the final bandwidth:** The available bandwidths at GMRT are in binary steps from 125 KHz to 32 MHz. Observations with bandwidths greater than 0.5 MHz are regularly made whereas the lower bandwidths are not frequently used. You will have 512 channels spread over the bandwidth that you choose. Please note that there are three choices for the IF bandwidth: 6, 16 and 32 MHz. Depending on your project, the line width will vary from a few km/s (Galactic lines) to a few hundred km/s (extragalactic lines). Select a channel width such that you have at least 2-3 channels across your expected line width. Thus '512×selected_channel_width' gives you a 'minimum' bandwidth required. The other point to consider now is the desired

velocity coverage. This is also very project dependent. If you are trying to observe multiple transitions within your band *e.g.* while observing recombination lines, it is desirous to obtain both hydrogen and carbon lines which are separated by 150 km/s within the band. Thus, this might mean compromising your channel width. This is a subjective decision. The third and last part is the available bandwidths at GMRT. You have to make your own decision as to which is the best combination for your project.

3. **Determining the LO settings:** Once you have decided on your observing frequency and the bandwidth, you need to figure out the local oscillator settings for GMRT. For Galactic and near Universe spectral line observations, fine adjustments to the local oscillator frequencies are required for the narrow bandwidths used. For the distant Universe, these settings are more coarse since the bandwidths generally employed are large. To help you with these settings a locally developed program `tune.pl` is available at GMRT. The program is user-friendly and will help you play around with the local oscillator frequencies (both for LO1 > RF and LO1 < RF). Default settings are as follows:

```
     150 MHz LO1 > RF
     235 MHz LO1 > RF
     325 MHz LO1 < RF
     610 MHz LO1 < RF
 L sub-bands LO1 < RF
```

   and visualize your observing band. It also provides you with default local oscillator settings for each GMRT frequency band used for continuum observations. Please note that LO1 (the first local oscillator in electronics) has a least count of 1 MHz for frequencies < 355 MHz and a least count of 5 MHz for frequencies > 355 MHz. This translates practically to the fact that only coarse settings are possible in the LO1 whereas the fine settings have to be implemented using LO4/LO5 LO1 and LO4/LO5 are under user control. Once you have determined all the required frequencies, you can use the `Frequency Setting Calculator` ('GMRT home-page → Observing Help → For GMRT Observations → Frequency Setting Calculator') on the GMRT web-page to determine the array of parameters `tpa` which are required by the correlator. The TPA array consists of 6 members namely as follows:

   $\mathrm{RF}_{\mathrm{freq\ in\ spec\ chan\ 1\ for\ 130\ MHz}}$,
   $\mathrm{RF}_{\mathrm{freq\ in\ spec\ chan\ 1\ for\ 175\ MHz}}$,
   $\mathrm{LO1}_{\mathrm{for\ 130\ MHz}}$,
   $\mathrm{LO1}_{\mathrm{for175\ MHz}}$,
   $\mathrm{LO4}_{\mathrm{for130\ MHz}}$,
   $\mathrm{LO4}_{\mathrm{for175\ MHz}}$

   where 130 MHz corresponds to RR and 175 MHz to LL polarizations. Please note that ($\mathrm{RF}_{\mathrm{freq}} \pm \mathrm{LO1} = \mathrm{LO4}$). If you plan on dual frequency observations ie 240 MHz on LL and 610 MHz on RR (default), you will follow the explanation discussed just above.

An example will make the above easier to comprehend. Suppose we have proposed and have been allotted time for making a Galactic HI absorption measurement using GMRT. The rest frequency of the HI line is 1421.40575 MHz. Assume that the velocity correction due to the earth/Sun motion and the source velocity (computed using `dopset`) shifts the line to a frequency of 1421.505 MHz. We would like to center our band on this frequency. The expected width of the HI line is 10 km/s translating to about 48 kHz at 1400 MHz. So we would desire a channel width of about $48/4 = \sim 12$ kHz. For a channel width of 12 kHz, the total bandwidth you can observe is (12 kHz $\times$ 512) = 6.14 MHz.

You have determined your central frequency (1421.505 MHz) and your bandwidth (Using these you have to find out the local oscillator settings. Let's use the default LO1 < RF. Then you want 1421.005 MHz in spectral channel 1 and 1421.005 in channel 512. Using `tune` will give you values of LO1 and LO4. Let's try to do the calculation here. For LO1 < RF, RF = LO1 + LO4. This will ensure that

Dual Frequency Settings	
RF	610 and 235 MHz
. Solar Attn	0 and 14 dB.
ILO	680 and 304 MHz.
IF Pre Attn and Post Gain	4 and 12 DB.
IF BW	32 and 6 MHz.
IF ALC	ON.
ACQ BW	32 MHz.
LO4	51 MHz.
LO5	149-156 MHz.
Max Channel	512
TPA	629 253 680 304 51 51.

Table 7: Table showing default dual frequency settings

your HI line falls in the center of the USB. Thus you have obtained your `tpa` as under, `tpa 1421.005 1421.005 1350 1350 71.005 71.005`

4.2 Bypass mode of 1420 MHz

A bypass mode is available for the L band so that the entire $\sim$ 500 MHz bandwidth can be accessed. This mode allows one to access frequencies ranging from 850 MHz to 1500 MHz and without choosing sub-bands (each sub-band is centered at 1060, 1170, 1280 and 1390 MHz with a bandwidth of 120 MHz). It is generally advised that while accessing the higher end of the frequency, you set the LO1 $>$ RF and for the lower frequency end set LO1 $<$ RF. This prevents the image band corrupting your band of interest. Although this allows you to use a larger bandwidth, it may corrupt your data from local radio frequency interference.

4.3 Dual frequency observations

You also may want to observe simultaneously at two frequencies. This is possible only at 235 and 610 MHz frequencies (we call it as dual frequency). The default values for dual frequency observations are as shown in table 7.

You may change LO1 for 235 MHz to find out RFI free band and also you can choose to have IF BW 16 for 235 MHz, if you could get the RFI free band (night time RFI is less!)

After the observation you can convert your data in FITS using *gvfits*. Use the "`gvfits`" program as follows:

```
astro1> listscan /rawdata/7jun/01TST01_OBJ.lta
astro1> vi 01TST01_OBJ.log
astro1> gvfits 01TST01_OBJ.log
```

For examples, editing `01TST01_OBJ.log` suggests to keep one of the stokes, say RR (also important is to choose normalization/unnormalisation !). The output 'TEST.FITS' would correspond to one of the frequency data (629 MHz) and re-run "`gvfits`" for the other stokes i.e. LL and for observed channel range for 253 MHz data.

4.4 Default parameters

The default settings used for continuum observations for the GMRT frequency bands in terms of RF, LO1, LO4 frequency settings, Solar Attn (in dB) and IF, ACQ bandwidths (all in MHz), ALC Status are shown in the Table 8. Also, you need to set LO5 corresponding to LO4.

Freq band	Solar Attn	RF_130 RR	RF_175 LL	LO1_130 RR	LO1_175 LL	LO4_130 RR	LO4_175 LL	IF BW	ACQ BW	ALC
150	14	156	156	218	218	62	62	16	16	ON
235	14	253	253	304	304	62	62	16	16	ON
325	0	306	306	255	255	51	51	32	32	ON
610	0	591	591	540	540	51	51	32	32	ON
1060	0	1041	1041	990	990	51	51	32	32	ON
1170	0	1151	1151	1100	1100	51	51	32	32	ON
1280	0	1261	1261	1210	1210	51	51	32	32	ON
1390	0	1371	1371	1320	1320	51	51	32	32	ON
dual	0-14	629	253	680	304	51	51	32-16	32	ON

Table 8: Default settings used for continuum observations for the GMRT frequency bands.

Part II
While Observing

5 During the Observations

The information which has previously been obtained during the preparation (Section 4) stage is now brought to and applied during observations. Aside from the source file and the command file which the user must prepare in advance, the other information can be provided to the telescope operators during set-up. It is the user's responsibility to ensure that the observational set-up is correct, however, so it is important to monitor and check each step of the set-up and observing operations.

As the visibilities are recorded, the user should check on the amplitude of the signals from the calibrators. For self-correlations, the amplitudes should be, the correlation coefficients, i.e.

$$A = \frac{T_{\rm ant}}{T_{\rm ant} + T_{\rm sys}}$$

where $T_{\rm ant} = S \times G$; S, the source flux density (Jy), G, the gain (K/Jy) and $T_{\rm sys}$ the system temperature (K). Refer to Tables above in Section 4 for system values. These correlation coefficients are shown on the MatMon window (see Section 5.1.1–**??** for examples of real-time display of cross-correlation outputs on a MatMon window).

Finally, information on troubleshooting is provided in the end (Appendix **Z3**).

5.1 Data quality and monitoring

The displays that have proved useful so far to review the recent history of system temperature, gain, and total power level. A few of these are outlined below.

5.1.1 Total Power:

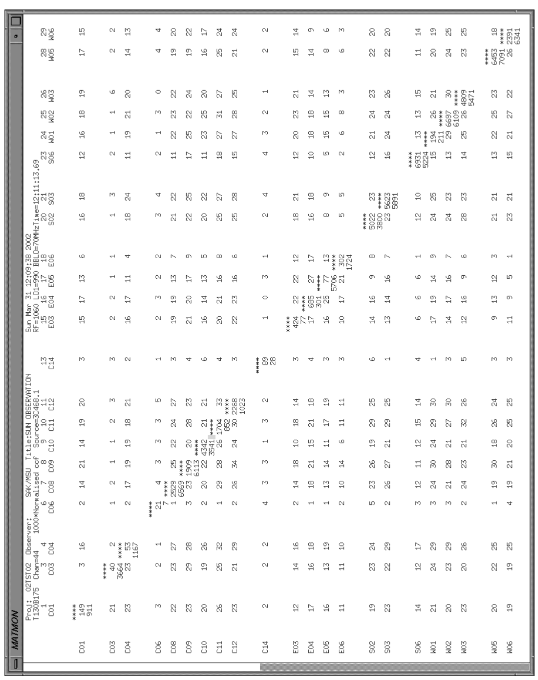


Figure 2: An example of many unhealthy antennas.

The total power (or system temperature, when ALC is off) is the single most important diagnostic of the status of the observations. It contains information on everything from elevation to interference to the weather. Display of total receiver power or system temperature is useful for all types of observing.

Several software are available to examine the data in the lta format. Some of them are discussed below:

1. `dasmon` The monitoring needed for continuum observations are largely given by the `dasmon`. `dasmon` is a snapshot mode of getting a quick health check of the system at a particular time. Following Figures (2, 3 and 4) gives examples of available healthy and poor antennas.

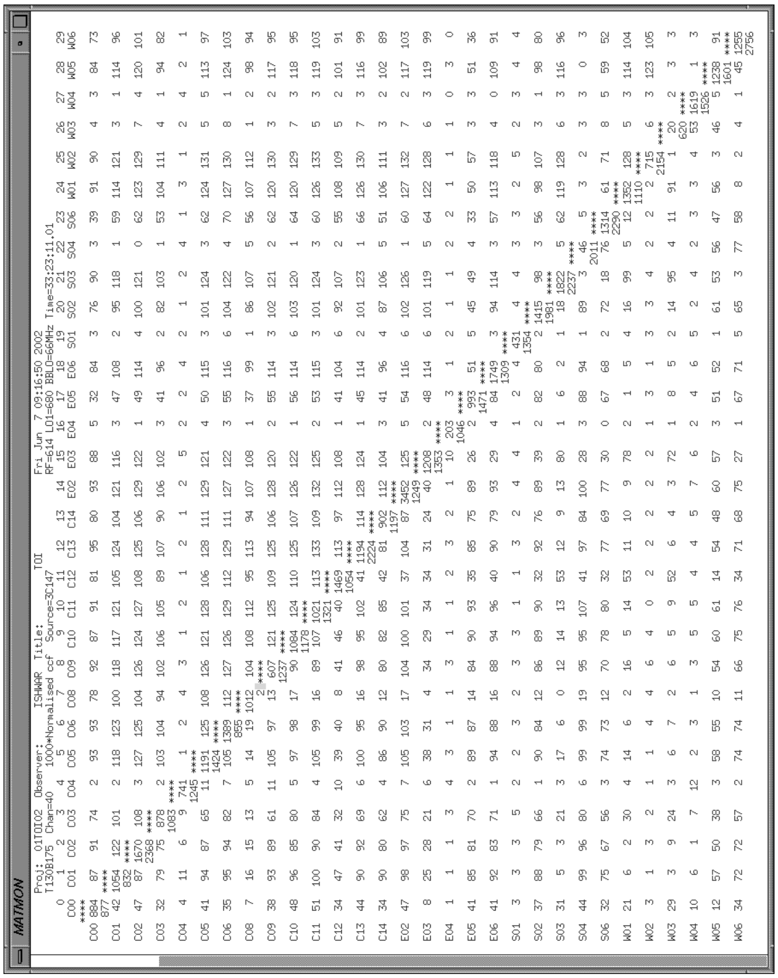


Figure 3: An example of a few unhealthy antennas.

The sensitivity in the total power mode would be

$$T_{\text{total power}} \propto \frac{2\ k\ T_{\text{sys}}}{A\ \sqrt{\Delta\nu\ \tau}}$$

and in interferometric mode would be

$$T_{\text{interferometric}} \propto \frac{k\ (T_{\text{sys}}\ T'_{\text{sys}})^{1/2}}{2\ (A\ A')^{1/2}\ \sqrt{\Delta\nu\ \tau}}.$$

Where T_{sys} & T'_{sys} are respectively the system temperatures of the two antennas, and A & A' are the corresponding effective areas of them.

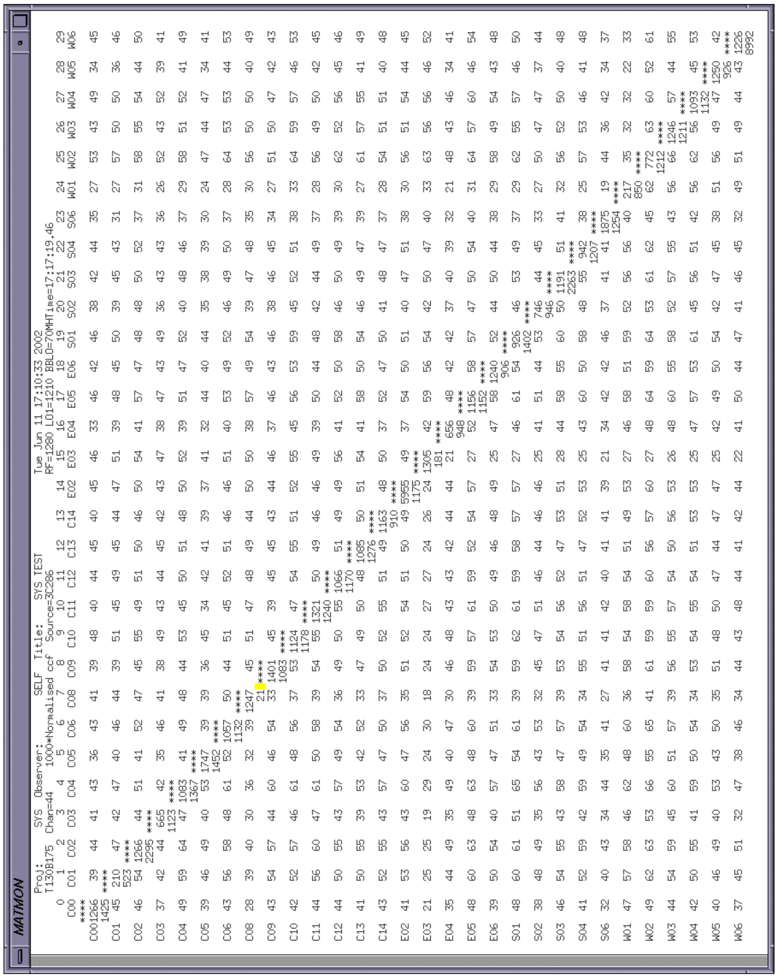


Figure 4: An example of all healthy antenna.

Cross-correlation functions displayed on the `dasmon` (Figures 2, 3 and 4) are given by

$$ccf \;\propto\; \frac{S_{(\text{in Jy})} \;\times\; K}{T_{\text{sys}}}, \qquad \text{where } K \text{ is sensitivity and is in K/Jy;}$$

with some scaling factor (usually 1000).

Following table 9 shows the expected correlation counts for the standard flux / amplitude / bandpass calibrators used at for frequency band used at GMRT.

Source Name	150 MHz	240 MHz	325 MHz	610 MHz	1280 MHz	1420 MHz
3C147	58	102	186	127	85	79
3C48	54	90	157	99	61	56
3C286	26	50	94	72	55	53

Table 9: Expected Correlation Counts.

Each Figure shows the following: (i) the diagonal elements are the self-correlation-coefficients, (ii) the upper-half elements are the 130 MHz channel cross-correlation-coefficients and (iii) the lower-half elements are the 175 MHz channel cross-correlation-coefficients. Explanations for a few examples of `dasmon` outputs is given below:

(a) Figure 2: Antennas C02, C05, C13, E01, S01 S05 and W04 were not available for observations (see empty rows and columns corresponding to these antennas in the Figure 2). The observations were made on source 3C468.1 (project 01TST01) at a frequency of 1060 MHz.

(b) Figure 3: Here all the antennas were used for the observations. The C04, E04, S01, W03 and W04 were down at both polarizations, whereas S04 and W02 (may be W01 as well !) was down in one polarization only (either 130 or 175 MHz). The observations were made on source 3C147 source.

(c) Figure 4: Something that an astronomer would love to see. This is an example where all antennas are healthy. User should compare the cross-correlation shown in this figure (Figure 4) with the one that is theoretically expected using above relation.

`dasmon` also allows (see Figure 5 below) the user to continuously monitor the amplitude and phase of the source being observed. For the sophisticated user, this is fairly useful in determining the stability of amplitude and/or phase. *i.e.* especially during scintillation and fringe winding.

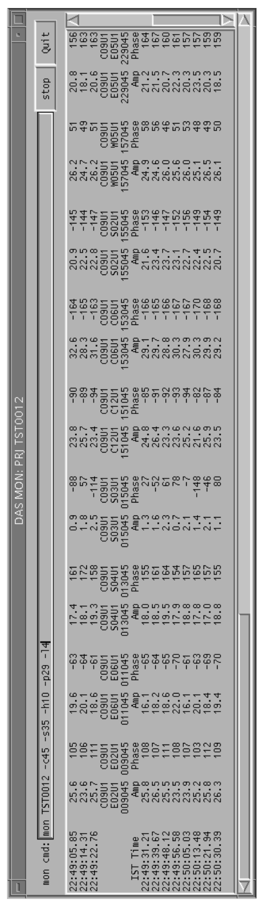


Figure 5: An example of the '`mon.tcl`' display.

2. `tax`

Task to extract data from a GMRT LTA file, with optional averaging in time and selection on time, baselines, frequency channels and on scans via the object name and/or scan number.

```
{astro0}> tax
tax> in         = /rawdata/8jun/01TST01.lta
tax> scans      = 0,1,2
tax> object     =
tax> timestamps =
tax> baselines  = C00
tax> channels   = 20
tax> antennas   =
tax> integtime  =
tax> normalize  =
tax> fmt        = ist%10.5f;base{chan{a%11.4f;p%8.1f}};\\n
tax> go
```

extracts the scans 0, 1, 2 of the '01TST01.lta'.

OR

```
{astro0}> tax
tax> in         = /rawdata/8jun/01TST01.lta
tax> scans      =
tax> object     = 3C147|3C286
tax> timestamps =
tax> baselines  = C00
tax> channels   = 20
tax> antennas   =
tax> integtime  =
tax> normalize  =
tax> fmt        = ist%10.5f;base{chan{a%11.4f;p%8.1f}};\\n
tax> go
```

would extract all scans of the two sources, 3C147 and 3C129.

You can also run `explain` and know more about it's usage. For example, `tax` can also display your data (bandpasses, scans, etc...) from 01TST01.lta file. Some of `tax` outputs are shown in the following Figures. For example:
Figure 6: Stokes RR bandshapes of C01 & E05 and W01 & W05;
Figure 7: Stokes LL bandshapes of C03 & C05 E02 & W06 and S04;
Figure 8: Amplitude and phases of Primary (first scan) and secondary (later scans) calibrators, (3C286, 1351−018 respectively) on baselines C00 & C01 and E02, E03 & W06;
Figure 9: Amplitude and phases of Primary (first scan) and secondary (later scans) calibrators, (3C286, 1351−018 respectively) on baselines S02, S03 & S06 and W03, W05 & W06.

3. `ltahdr`
   Prints header of Lta Files.
   Usage : ltahdr -i InputLtaFile [-a][-A][-b][-c][-f][-g][-G][-s][-S]

```
i Input LTA file
g Binary Global Header
G Asci Global Header
s binary Scan Header
S Ascii Scan Header
b Binary Standard Info
a Asci Standard Info
f Frequency Settings
c Source Coordinates
A Antenna Coordinates.
```

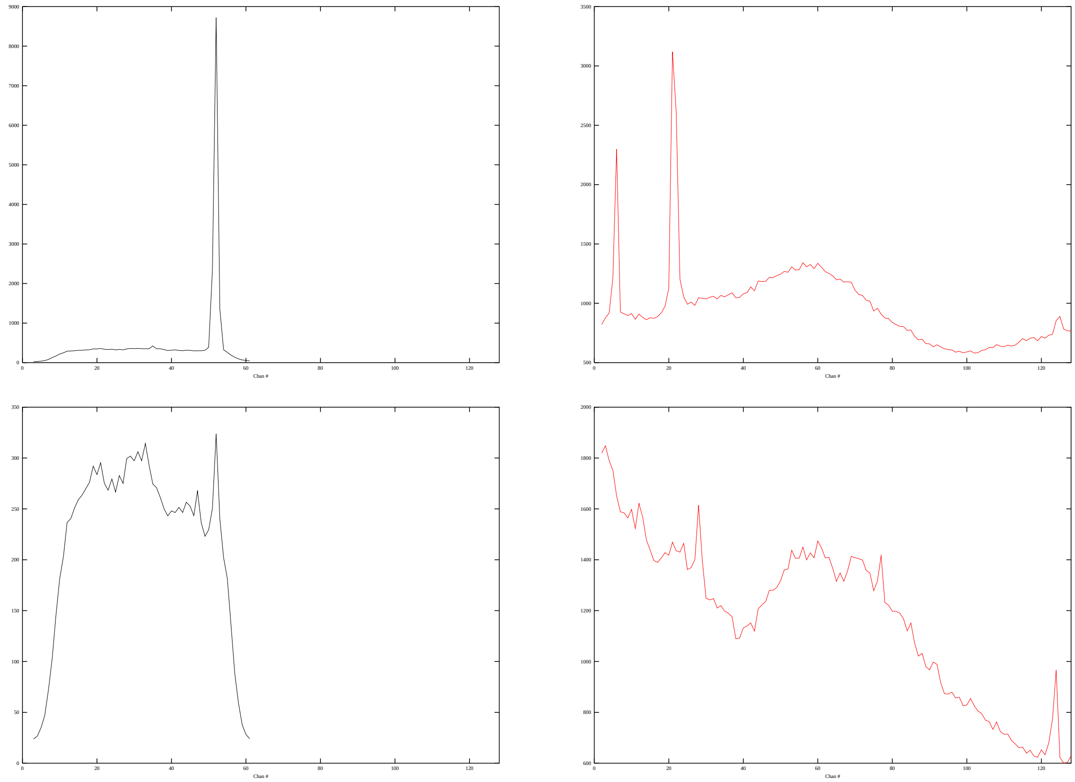


Figure 6: Stokes RR bandshapes of C01 & E05 and W01 & W05.

Stokes RR bandshapes of C01 & E05 (top two) and W01 & W05 (bottom two), the spikes seen is an effect of RFIs.

4. `ltacomb`
   Combines Lta files.
   Usage: ltacomb -i InputLtaFile1[,File2[,File3...]

5. `ltaclean`
   Cleans up format errors LTA files.
   Usage: ltaclean -i InputLtaFile [-m (maxscans)][-e (eat)][-v (verbose)]

   ```
   i InputLtaFile
   m Maximum number of scans
   e Records to Eat
   v verbose.
   ```

6. `ltaedit`
   Edits the Global and/or Scan Header of an LTA file.
   Usage : ltaedit -i InputLtaFile [-g GKW:GKV][-s SKW:SKV][-S(selscans)]

   ```
   i Input LTA file
   g Global KEYWORD to change.
   s Scan KEYWORD to change.
   S Scans to Edit.
   ```

7. `ltaprint`
   Print Selected data

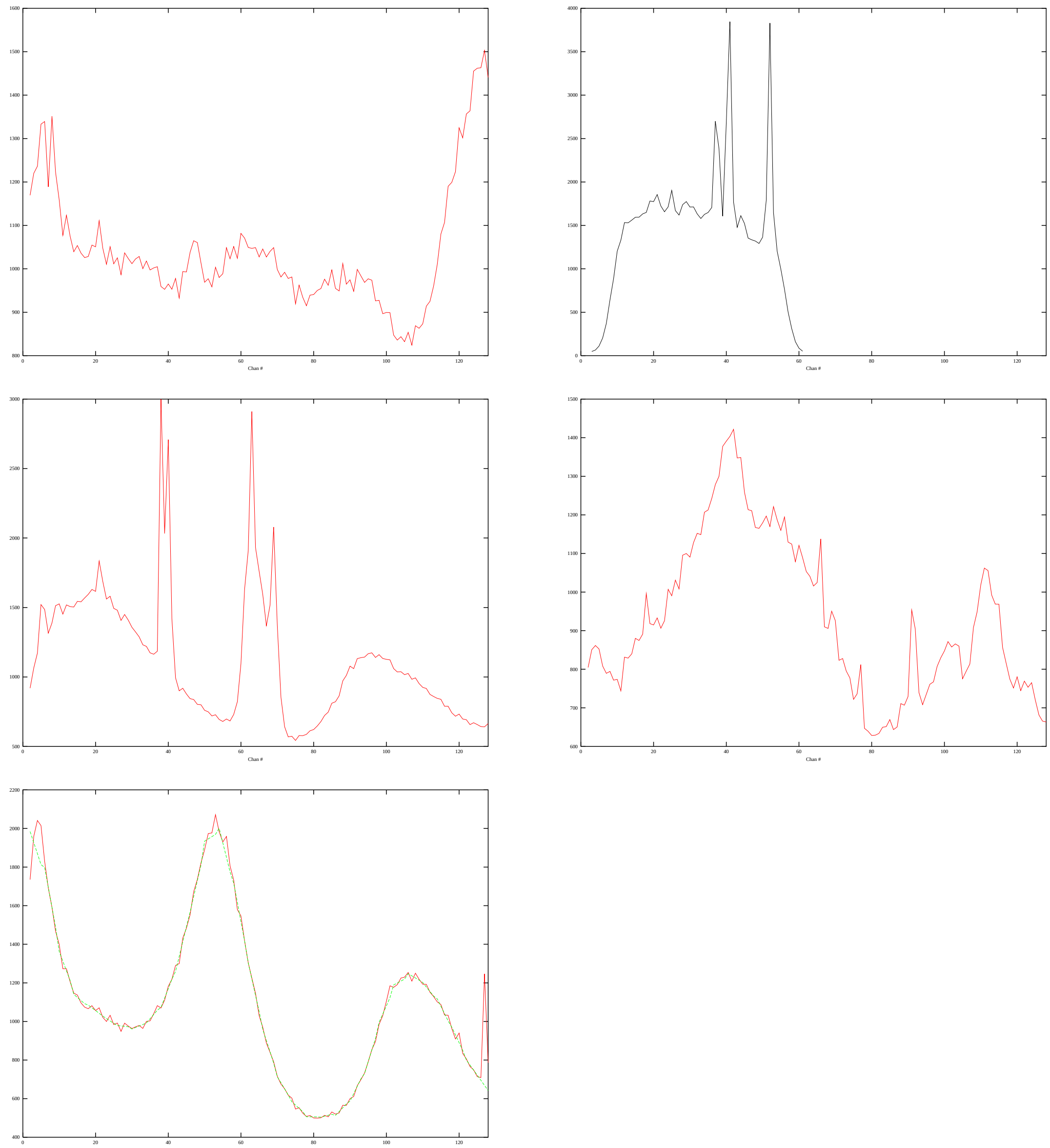


Figure 7: Stokes LL bandshapes of C03 & C05, E02 & W06 and S04; in S04, `ltaflag` program has removed the spikes.

Stokes LL bandshapes of C03 & C05 (top two), E02 & W06 (middle two) and S04 (bottom one). In S04, the FLAGing (`ltaflag`) program has removed the spikes and the bandshape is fitted with a polynomial.

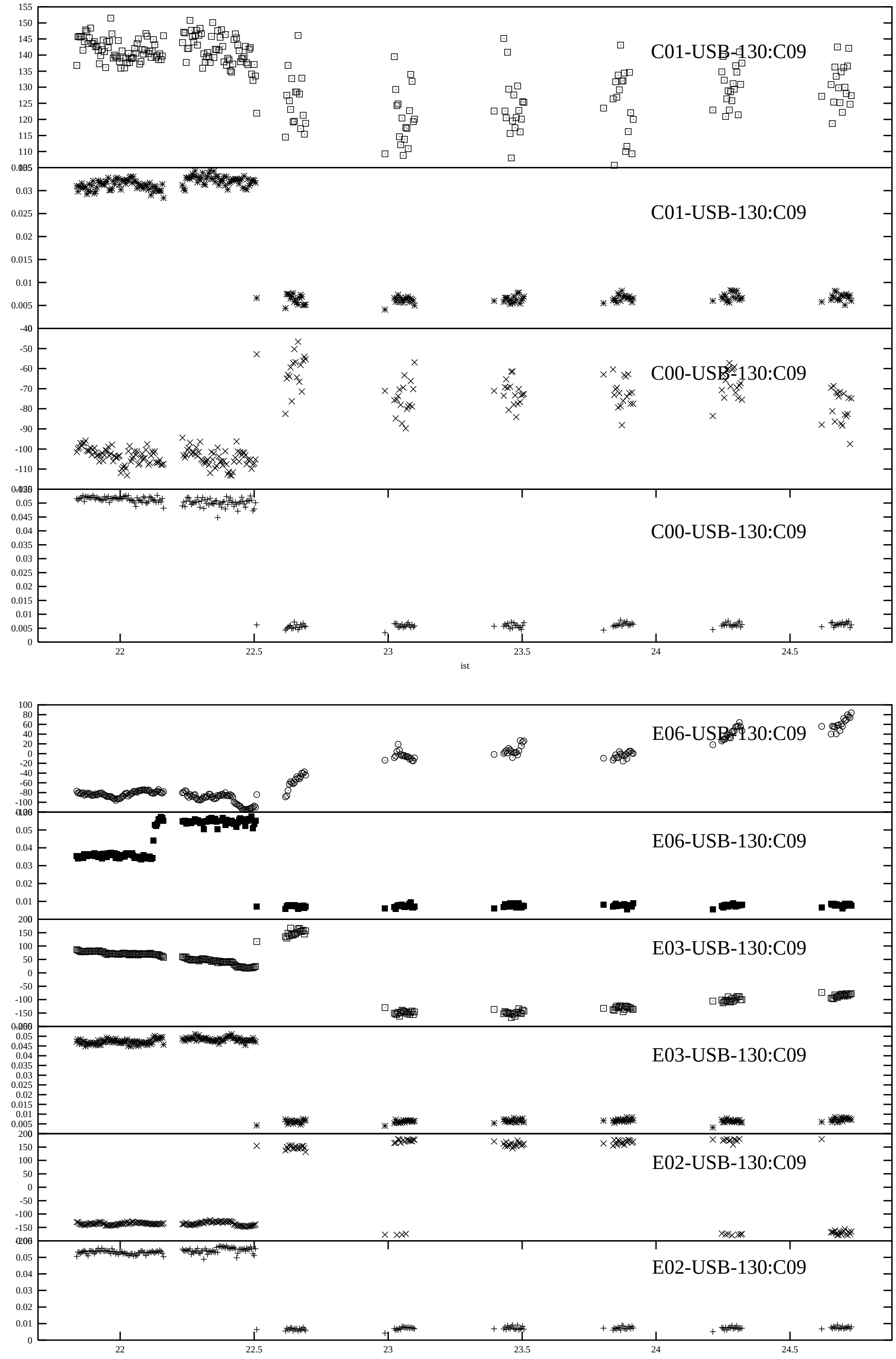
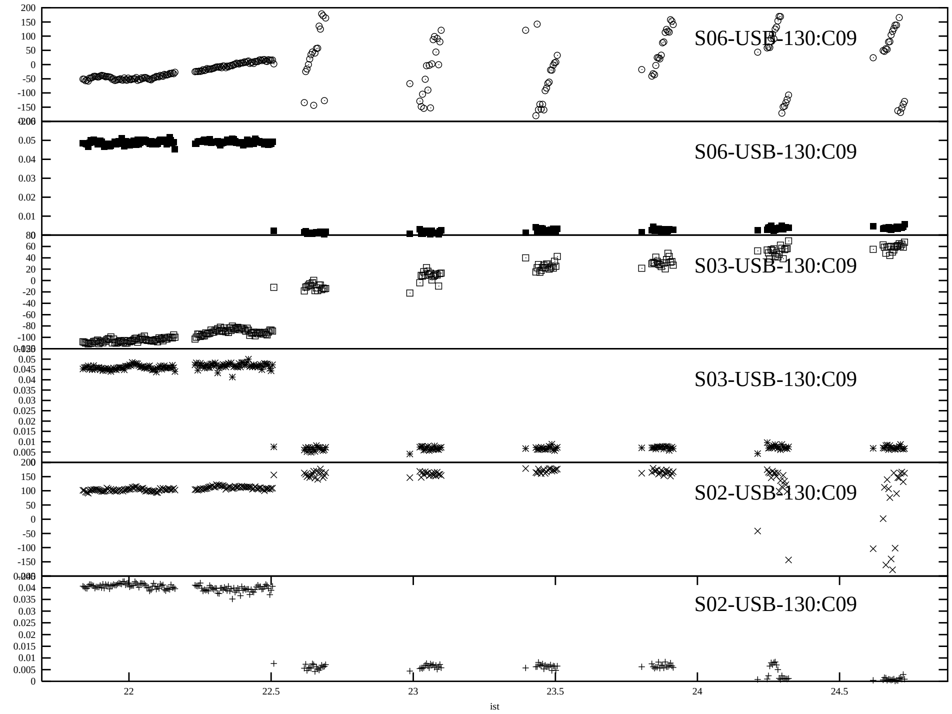


Figure 8: Amplitude and phases of Primary (first) and secondary (later) calibrators on baselines with C09 (reference) and C00, C01, E02, E03 & W06.

Amplitude and phases of Primary (first scan) and secondary (later scans) calibrators, (3C286, 1351−018 respectively) on baselines C00 & C01 (upper) and E02, E03 & W06 (lower). C09 being the reference antenna, amplitude is in arbitrary units.



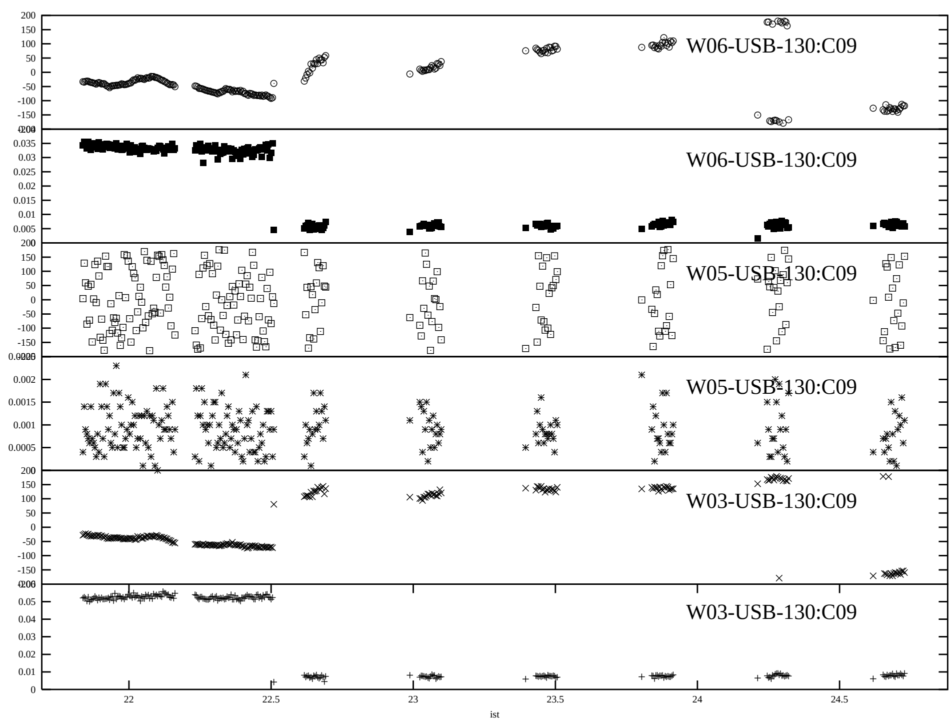


Figure 9: Amplitude and phases of Primary (first) and secondary (later) calibrators on baselines with C09 and S02, S03, S06, W03, W05 & W06.

Amplitude and phases of Primary (first scan) and secondary (later scans) calibrators, (3C286, 1351−018 respectively) on baselines S02, S03 & S06 (upper) and W03, W05 & W06 (lower). C09 being the reference antenna, amplitude is in arbitrary units.

Usage : ltaprint -i InputLtaFile [-a ant1,ant2,..][-b base1,base2,...][-c ch1,chN][-s scan1,scan2,...][-h HonourFlags][-r rec1,recN][-o Object] [-p PrintType][-x Xaxis][-B BaseNum][-S—-X—-P—-Q]

```
i Input Lta File
a Antenna List
b baseline List
c Channel Range
s Scan List
r Record Range.

S == Self, X == Cross; P == CoPol; Q == CrossPol
```

8. `ltasel`
   Selects subset of a given LTA file

   Usage : ltasel -i InputLtaFile -o OutStartChan -n OutNumChans-S ScansToCopy -m MaxFileSize (GB)-a AveChans -s StartAveChan -e EndAveChan

```
i Input Lta File
o Output Starting Channel
n Number of Channels in Output.
m Maximum Output Filesize (GB).
a Make a new channel 0.
s Start channel for Average.
e End channel for Average.
S Scans to copy.
R Record range to copy.
```

Part III

After Observing

6 Your data

Data collected on a particular date are collected into the directory, *e.g.* '/gsbifrdata(1)/date' (the disk is visible from all other PCs). These data are in LTA format and will have an extension of '⋆.lta' on the filename. A variety of software are available for examining these data in this format. These offline analysis programs can either be accessed by typing the name of the program on the command line or from the GUI by typing 'gut' (GMRT User Tool) on the command line.

6.1 Interference Monitoring

Spectrum analyzer in the receiver room shows output from the optical fiber displaying 130 and 175

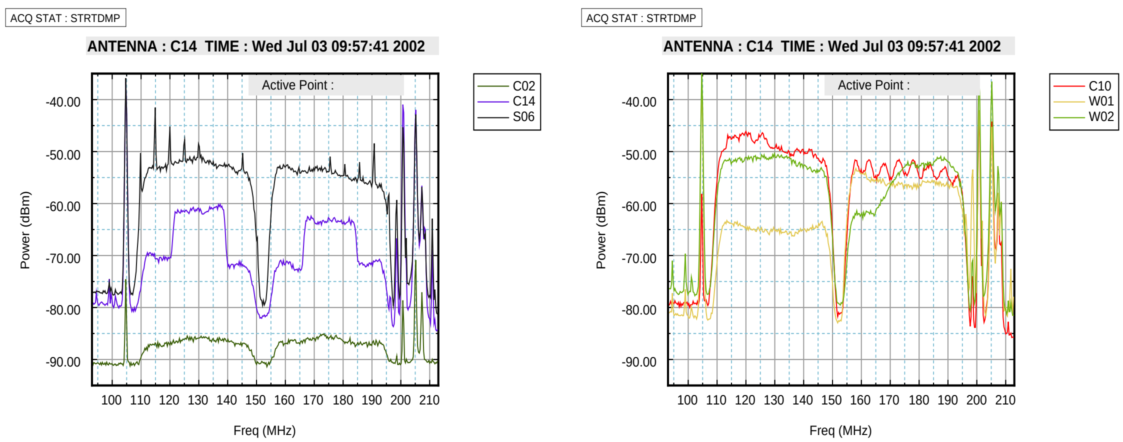


Figure 10: Spectrum analyzer output from optical fiber for a few of the antennas, each plot showing 130 and 175 MHz. S06 (in left Figure) shows spikes (RFIs) in both channels.

MHz channels as shown in the Figure 10.

6.2 Running AIPS at the GMRT

Machines gtac1, gtac2, gtac3, gtac4 are generally available for the observers on priority basis. Please get visitors login and passwd from the telescope operator or system administrative (Mr. Mangesh Umbarje) on these machines. Your data ('/gsbifrdata/6jun/yourfile.lta') is visible on all other machines at the GMRT.

6.3 Primary Beam Gain Correction

Coefficients to use in the task PBCOR in AIPS for primary beam correction of GMRT data are tabulated here. The polynomial fit to the beam is $1+(a/10^3)x^2+(b/10^7)x^4+(c/10^{1}0)x^6+(d/10^{1}3)x^8$ where where x is in terms of (separation from pointing position in arcmin * frequency in GHz). a,b,c,d are the coefficients which are required to be specified in PBCOR when using GMRT data. PBPARM(3) (=a), PBPARM(4) (=b), PBPARM(5) (=c), PBPARM(6) (=d). PBPARM(7)=0 for GMRT. More information can be found at http://www.ncra.tifr.res.in/∼ngk/primarybeam/beam.html.

Freq band	PBPARM(3)	PBPARM(4)	PBPARM(5)	PBPARM(6)	Half-power width
153 MHz	-4.04	76.2	-68.8	22.03	180'
235 MHz	-3.366	46.159	-29.963	7.529	118.5'
325 MHz	-3.397	47.192	-30.931	7.803	85.2'
610 MHz	-3.486	47.749	-35.203	10.399	44.4'
L band	-2.27961	21.4611	-9.7929	1.80153	26.2' (1280 MHz)

Table 10: Primary Beam Gain Correction.

6.3.1 Running AIPS on your data

Run `gvfits` (it provides UV data in J2000 epoch); to use `gvfits` you first need to run the program `listscan` to create "log" and "plan" files. Edit the "log" file to select normalization type, a subset of the data etc. Finally run `gvfits` on the edited log file. *e.g.*

```
astro1> listscan /rawdata/7jun/01TST01_OBJ.lta
astro1> vi 01TST01_OBJ.log
astro1> gvfits 01TST01_OBJ.log
```

This makes an output file "TEST.FITS". `gvfits` will not work on any files that have been processed by offline programs (*e.g.* `ltacleanup`, `tmac`). This is because these programs delete elements of the header that `gvfits` needs.

Begin `START_AIPS` and load this file (`01TST01.FITS`) into AIPS using `FITLD` task and follow your favorite way of reducing the data.

The `logflags` files can be used as an input in gvfits to flag bad data reported by ONLINE, while your observations were made.

6.4 Backing your DATA

The data backup facility at GMRT (Section 6.4) includes several 4mm dat tape drives for 24 GB dat tapes (DDS3) and DVD drives. These machines with corresponding tape drive (DAT-tape-drive) are as follows:

/dev/nst1	—	gtac3 machine	(4-mm DAT-tape drive)
DVD drives	–	All gtac machines	

You can also directly copy your data on another USB disks.

6.5 Your observation log

The observation log will be e-mailed to the respective user after his/her observations.

6.6 Computer Facilities at the GMRT

- There are many computers placed in terminal room for astronomical data analysis specifically reserved for GTAC observer. (also see GMRT Home-page → Facilities → Computers)
- Kindly get the relevant account name and password from the telescope operator or system administrator at GMRT, Khodad.
- In the terminal room, a network printer is available called 'npt5200'. From a Linux machine, command to print is: lpr -Pnpt5200 [files] or lpr [files].
- Default data area to get observation files is /gsbifrdata[1]/date.

- Offline analysis software developed are available. A GUI called 'gut' has also been developed under which various offline/online data monitoring programs are available. Run the software and say explain. This will give help for the software's usage. At present following software utilities exist: (also see GMRT home-page → Observing Help → Offline data analysis software).
- **kindly note : DVDs can be bought at GMRT.**

6.7 Computer Facilities at the NCRA

You can use the
(a) computing facilities at the NCRA for your data analysis, please contact Reena Shrikumar for account details. (b) many of the machines in the common computing facility are equipped with either DAT-tape (DDS3) drive and DVD drives to load and/or back-up your data.

Acknowledgments

This document involves inputs from several people, particularly those associated with the GMRT. We express our thanks to everyone of them.

- `Version 1` : Prof. Judith Irwin.
- `Version 2` : Dr. Dharam Vir Lal, Prof. Pramesh Rao, Manisha S Samble, Dr. Nimisha Kantharia.
- `Version 2.1` : Manisha S Samble & Prof. D J Saikia.
- `Version 2.2` : Sachin Sherkar, & Dr. N G Kantharia.
- `Version 2.3` : Manisha Samble.

Appendix Z1. Feedback

Please provide us feedback by filling up the `Observer/Visitor Feedback Form` available at GMRT home-page.

All publications resulting from the GMRT data should have an acknowledgment of the form

```
     "We thank the staff of the GMRT who have made these observations
possible. GMRT is run by the National Center for Radio Astrophysics
of the Tata Institute of Fundamental Research."
```

Appendix Z2. The input files

The source file: The following is the source file, specific example can be picked from '/odisk/gtac/source/yourname.list'.

```
3C286       13h28m49.66s   30d45'58.7"  1950.0
1637+626    16h37m55.31s   62d40'34.3"  1950.0
N6503       00h40m19.70s  +51d47'07.2"  1950.0
ISO1        15h36m00.00s   50d00'00.0"  2000.0
NGC1097     02h46m19.0s   -30d16'28.0"  1950.0
```

The command file: The following is a simple command file. The explanatory statements on the right are NOT in the file itself, but are used for the explanation given here. The file observes a flux density calibrator, 3C286 for 30 minutes first, then a phase calibrator, 1637+626, and then enters a loop in which the phase calibrator and the source, N6503, are observed consecutively and continuously, with 10 minutes on the phase calibrator and 30 minutes on-source. In most cases, the first part of the observing session will not be run from this file but by issuing commands from the monitor, at least until the user is satisfied that both the flux density calibrator and the first part of a run on the phase calibrator are satisfactory. Running manually also allows the user to better determine how much slewing time is required between calibrators and source. If this is the case, then lines 5 to 23 of this file would be omitted and the resulting file implemented after the first scan of the phase calibrator is found to be okay. Note that there is no allowance in this file for a flux density calibration scan in the mid-point of the observations or at the end. In order to insert such observations, the user must manually stop this file and issue commands from the console. If the file is restarted, it will start from the beginning. There is also no end to the file, since the loop, once entered, has no graceful exit. The session will stop when commands are issued from the console to stop it. If the array reaches its altitude limit (i.e. the source sets) first, then it will continue to collect data as instructed in this file while pointing at blank sky at the array altitude limit (currently 17 degrees).

```
cmode 1           Specifies that times are relative, rather than absolute.
suba 4            Specifies the subarray being used.
addlist '/online/operator/source/yourname.list'
                  Ensures that the system can read the source list.
                  This must be included in this file, even if already
                  done manually at the console.
lnkndas
gtsrc '3c286'     Gets and precesses the coordinates for the specified
                  source.
goout             Specifies the track (outer or inner) on which slewing
                  should occur. The choices are goout or goin.
                  For sources in the northern part of the sky,
                  it's generally best to use goout.
gosacout          As above, but required for the subarray controller.
                  The choices are gosacout and gosacin.
sndsacsrc(1,12h)  Slew to the source and start tracking (1)
                  for up to 5 hours (5h).
/(gotosrc 2m)     Wait for 2m until all the antennas reach on source.
                  Default is 5m.
strtndasc         Start the correlator and collect data.
time 10m          Continue to collect data for 10 minutes.
hold; stabct      Release the brakes (hold) in case minor wind gusts
                  have resulted in the brakes being applied automatically
                  at some point during the observations. For
```

```
                 strong winds, an alarm will sound in the control
                 room. And set the time at the antenna based computer
                 (stabct).
time 10m         Keep collecting data for another 10 minutes.
stpndasc         Stop the correlator (i.e. stop collecting data).
stpsactrk        Stop tracking.
gtsrc '1637+626' Get and precess coordinates for the second source,
                 here the phase calibrator.
goout
gosacout
sndsacsrc(1,5h)
/(pntmod)        Update current antenna offsets using pointing model.
run pntmod       Load the updated antenna offsets into antennas.
stabct
/(gotosrc)
time 6m

$1               starts the loop
gtsrc '1637+626'
goout
gosacout
sndsacsrc(1,12h)
sndsacsrc(1,12h)
/(gotosrc)

strtndasc
time 10m
stpndasc

gtsrc 'N6503'
goout
gosacout
sndsacsrc(1,5h)
sndsacsrc(1,5h)
/(pntmod)
run pntmod
stabct
/(gotosrc)

strtndasc
time 10m
hold;stabct
time 10m
hold;stabct
time 10m
hold;stabct
stpndasc
go to 1          returns to the beginning of the loop.
end
----------------------------------------------------------------------------
```

Appendix Z3. The trouble-shooting

The trouble-shooting

1. Fringes Disappeared ?
   (a) stpdasc; gts 'srcname'; strtdasc
   (b) are antennas tracking your source ? have they hit the azimuth limit ?
   (c) is your source extended ?
   (d) has any of correlator software crashed ?
   (e) have the front-end parameters got reset ? ask the observer.
2. Fringes are winding ?
   (a) check LO_1 and LO_4 settings.
   (b) stpdasc; tparm, prjfreq, gts 'srcname'; strtndas
   (c) check time synchronization between correlator PCs and ONLINE PC and GPS time.
   (d) ionospheric variations ? The winding will be random.
3. Some baselines record low cross-correlation on a point source ?
   (a) Is polarization swap, required on some antennas, applied ?
   (b) Are the self-correlations of problem antennas as expected ?
   (c) Are pointing offsets being loaded ?
   (d) stpdasc; gts 'srcname'; strtdasc
4. The LTA and AIPS file header shows RF=0 Hz, IF_LO=0 Hz, BB_LO=0 Hz ?
   (a) If noticed during observations, stpdasc and stpdass and start again. Don't forget to set TPARM (Frequency parameters to correlator).
   (b) If noticed after observations, forget about that data and get a fresh run.