The GMRT: System Parameters and Current Status

Last updated : 15 June 2014

Contents

This document gives an overview of the latest status of the GMRT and some relevant system parameters. Section 1 gives the background and an overall description of the GMRT, including features under development or being planned. Section 2 gives the current status, and is the part directly relevant to those planning an observation.

1 General Overview

The GMRT consists of thirty 45 m diameter antennas spread over a 25 km region. Half the antennas are in a compact, quasi randomly distributed array with a diameter of about 1 km. The remaining antennas are on 3 arms of length $\sim$ 14 km (NorthWest, NorthEast and South) with 5 or 6 antennas on each arm. The longest baseline is about 25 km and the shortest is about 100 m without foreshortening. The array configuration is shown in Fig. 1.

The telescope (Latitude=$19.1°N$, Longitude = $74.05°E$) is located near Khodad village, which is about 80 km north of Pune. The telescope site houses laboratories, guest house, library and canteen. The observatory can be reached using the daily shuttle service starting from NCRA, Pune at 7 AM in the morning (all days including holidays and weekends), or by direct taxi from Mumbai or Pune. The closest town, Narayangaon, is about 14 km from the observatory and is connected to Pune and Mumbai by public bus transport system. If advance information is given, arrangements can be made to transport observers from the Narayangaon bus stand to the observatory. See http://www.ncra.tifr.res.in for more details on various general aspects about observing at the GMRT, including a road-map for travel to the observatory.

1.1 Antennas & Feeds

The GMRT antennas are 45 m alt-azimuth mounted parabolic prime-focus dishes. While the dishes can go down to an elevation of 16°, at present, the elevation limit has been set at 17°, giving a declination coverage from $-53°$ to $+90°$. The usable hour-angle range for different declinations is shown in Fig. 2. The slew speed of the antennas is 20°/min on both axes and they are not operated when winds are higher than 40 km/h. There is a rotating turret at the focus on which the different feeds are mounted. The feeds presently available are the 151, 325, 610/235 and the 1000-1450 MHz feeds. The reflecting surface is formed by wire mesh and the efficiency of the antennas varies from 60% to 40%, from the lowest to the highest frequency. Both the orthogonal polarisations are brought to the control room from each antenna. The polarisations are circular for all feeds except the 1420 MHz feeds, which are linear. The 610 and 235 MHz feeds are coaxial, allowing simultaneous dual frequency observations to be carried out at these two frequency bands, albeit for only one polarisation per band.

1.2 Electronics

At the focus of each antenna, each feed has 2 low noise amplifiers (one for each polarisation), with a noise injection facility where the user can select one of 4 levels of injected noise power. The two signals from each feed go to a common box (also on the feed turret) where the user can select which feed frequency signals appear at the output of the common box, since only 2 RF cables go down to the antenna base. The common box has facilities for the user to select solar attenuators (0, 14, 30 or 44 dB), enable/disable noise and Walsh modulation, and swap the two polarisation channels.

At the antenna base, the RF signals are mixed with a pair of coherent local oscillator signals (the 1^{st} LO) to give two 70 MHz IF signals. The user can select the 1^{st} LO frequency (1 MHz steps upto 350 MHz and 5 MHz steps from 350 to 1700 MHz), IF attenuators (0 to 64 dB in 0.5 dB steps) and the IF bandwidth (6, 16 or 32 MHz) independently for each IF. The IF signals from each antenna go to the Central Electronic Building (CEB) through an optical fibre. There is a facility at each antenna to turn on or off an Automatic Level Controller (ALC) before the optical modulator.

At the CEB the IF signals for the two polarisations from each antenna are converted to corresponding baseband signals. In the present arrangement, the signals are first converted to a common 70 MHz IF (using a different 3^{rd} LO for each polarisation), and then to baseband using a single oscillator (the 4^{th} LO), which the user can set from 50 to 90 MHz in steps of 0.1 KHz. For simplicity, for each polarisation, an effective value of the LO signal down conversion is specified (called the 5^{th} LO).

1.3 Software based back-end

The main back-end for the GMRT is the GMRT software back-end (GSB) which has been released for observations since GMRT Observing Cycle 20. The GSB handles the full 32 MHz baseband signals from each of two polarisations for all 30 antennas, which are digitised and sent to a networked cluster of PCs that performs all the operations needed to realise a correlator and a pulsar receiver, in real time. The standard processing features include gain equalisation, integer and fractional delay correction and fringe stopping for the signals from each antenna. The GSB implements a FX type correlator, with user selectable number of spectral channels across the band. Operation over narrower bandwidths is supported by use of a digital filter followed by desampling to the required Nyquist rate, inside the GSB. Though the GSB works for 32 MHz input bandwidth (with an exact sampling rate of 66.666 MHz and 4 bits per sample), it can also run in 33.333 MHz sampling rate (with 8 bits per sample), which is useful for cases where the input bandwidth is limited (at the IF stages) to 16 MHz or less. These two modes of operation of the GSB are referred to as “32 MHz” and “16 MHz” modes. In both these modes, the GSB can be run either in total intensity mode or in full polar mode. In the latter, the GSB provides the intensity for each polarisation and the real and imaginary parts of the cross-term. The visibilities are output from the GSB cluster at a nominal rate of 2 seconds and are further processed by a software chain which allows real-time monitoring of the data products, before recording to disk with a default integration time of 16 seconds.

The GSB also has a beam former, running concurrently with the FX correlator, which produces incoherent array (IA) and phased array (PA) beam outputs for a user selectable set of antennas, which can be chosen independently for the IA and PA modes. The input signals to the beam former are the outputs of the Fourier transform stage of the FX correlator, for each of two polarisations from each antenna. Whereas the IA beam former provides only total intensity samples, the PA output can be either total intensity or full polar. In the latter case, 4 terms are available – the intensities for each polarisation and the real and imaginary parts of the cross-product – from which the complete Stokes parameters can be reconstructed. The GSB includes the facility of phasing the array by observing a point source calibrator in interferometric mode to estimate the phases for both polarisations of each antenna, and correcting for these phases of the signal path after the FFT. The intensity products from the GSB beam former can be output from the GSB cluster at a fastest sampling rate of 30 μsec, when there are 256 spectral channels across the band. For larger number of channels, the fastest rate is correspondingly slower, e.g. 60 μsec for 512 channels. Down stream software provides options for further time integration (in powers of 2 times the input rate) and frequency integration, dedispersion and synchronous folding for pulsar observations. The final, reduced rate data can be recorded on hard disks and then backed up on SDLT or LTO tapes. The final time resolution achievable in the recorded data is a function of these various operations, in combination with the disk recording rate. The GSB beam former also has the capability to produce the raw, full time resolution phased array voltage beam output for each of two orthogonal polarisations.

The GSB also has an offline mode, where the raw voltage data from all the antennas can be recorded on an array of SATA disks attached to the GSB cluster, for offline processing. In this mode, the GSB can record data samples at reduced bit resolution, typically 4 bits or less per sample (for the "16 MHz" mode) and 2 bits or less per sample (for the "32 MHz" mode).

The entire operation of the GSB is controlled by a set of user friendly functions implemented in a graphical user interface (GUI). The GSB is interfaced to the main control and monitor software of the GMRT. The output data of the GSB are compatible with the existing data formats at the observatory, for the interferometry and beam modes.

1.4 Control System

In addition to issuing commands to slew and track the antennas, one can issue commands to set the parameters of the electronics. The control system also provides facilities for monitoring a range of parameters. In practice, the array is controlled by the telescope operator on duty and the role of the user is to create an OBSERVE file and ensure that the data quality is satisfactory. A web-based tool to prepare this command file is available on the NCRA home page (http://www.ncra.tifr.res.in/ncra/gmrt/gtac). Also available are a facility for calculation of source rise and set times and a frequency settings calculator for help in selections of the local oscillator values.

1.5 GMRT Upgrade

A major upgrade of the GMRT is currently underway. The main goals of this upgrade are to provide (i) as far as possible, seamless frequency coverage from 50 to 1500 MHz (ii) improved sensitivity with better quality receivers (iii) a maximum instantaneous usable bandwidth of 400 MHz (iv) a revamped and modern servo system (v) a new generation monitor and control system (vi) improvements in the antenna mechanical structure and (vii) matching improvements in infrastructure and computational facilities. The upgrade will result in significant changes to almost all aspects of the GMRT receiver chain and other systems. However, full care is being taken in the design of the new systems to ensure that the performance of the existing GMRT is not affected as the upgrade is implemented.

In feeds and front-end electronics, the existing 325 MHz feed will be replaced with a broadband feed operating from 250 to 500 MHz, along with a broadband low noise amplifier with improved noise temperature. A new feed operating from 550 to 900 MHz will replace the existing 610/235 MHz co-axial feed, also with a matching LNA with an improved noise figure. Due to this, the 235 MHz band will not be available in these antennas. The 150 MHz feed will also get replaced with a wider bandwidth feed. As far as possible, it is being ensured that the new feeds will cover the frequency range provided by the existing narrow band feeds that they are replacing, with similar or better level of sensitivity. The optical fibre link to each antenna will be modified to provide additional wavelengths to bring back the broadband RF signals directly to the receiver room, without disturbing the existing narrow bandwidth path that brings back the two IF signals. In the receiver room, a separate and parallel signal path will convert the broadband RF signals to baseband signals with a maximum bandwith of 400 MHz, which will be processed with a new digital back-end system (correlator + beamformer + pulsar receiver) that can handle the full 400 MHz bandwidth. This entire chain will run in parallel with the existing 32 MHz bandwidth receiver chain, without affecting its performance in any way. A new brushless DC motor system along with a new servo computer will replace the existing servo system in each antenna. A modern monitor and control system with improved hardware at each antenna connected to the central station via ethernet will come up in parallel with the existing system. It will be supported with improved high level software at the central control room. Several improvements to the mechanical structure and reflecting surface of the antennas are also being undertaken. Matching enhancements in computing resources and data archiving capabilities are being implemented.

Many of these upgrade activities are now past the prototype development and testing stages and are entering mass production and comissioning stages, which are expected to go on for the next year or so.

2 PRESENT STATUS (June 2014)

2.1 Interferometric Observations

From GMRT Observing Cycle 20 onwards, the GSB is the only back-end available at the GMRT. The older, hardware back-ends have been decomissioned. All 30 antennas are in use and feeds for all frequencies are available, except for some disturbances due to upgrade activities (see section 2.4). Programs that critically depend on the short spacing antennas (C05, C06 and C09, with $\sim$ 100 m separation) must indicate this in the observing proposal. Rotation of the feed system to change the frequency of observation is now possible fairly routinely, and requires about 1 to 2 hours time for rotation and for set-up at the new frequency of operation, including antenna pointing. A pointing model has been in use since GMRT Observing Cycle 15, which can be applied online during the observations; it updates the antenna pointing offsets at the start of source scan during an observing run, using commands included in the user's observe file. If a user does not want to apply the dynamic pointing model, the control room should be informed before the start of the observing run.

The radio frequency interference (RFI) environment can be bad at 150 MHz and is also sometimes a problem at 235 MHz; the situation is usually better at night, than during day time. For these two bands, it is recommended to use the solar attenuators in the common box, to minimize the possibilities of saturating the downstream electronics chain due to RFI. Observations at 325 MHz can be hampered sometimes due to RFI from nearby aviation related activity, especially during day time. Due to increasing interference from mobile phone signals around 950 MHz, the all-pass mode at L-band is no longer supported as an official mode, and consequently observations below 1000 MHz in this band are not supported. Even for the lowest of the 4 sub-bands of the L-band (covering 1060 ± 60 MHz), the user is advised to check for effects of RFI. Due to proximity to the Solar maximum, night time scintillation is common, even at 1400 MHz, and the probability of scintillation is higher closer to the equinoxes. Winds can stop observations in the pre-monsoon months of April − June and also sometimes in October − November. During the monsoon months of June − July the antennas on the arms sometimes fail due to power outages.

The GSB back-end supports a maximum bandwidth of 32 MHz. However, users should consult the observatory regarding usable RF bandwidth at the lower frequencies because of RFI. For 150 MHz and 235 MHz, the recommended IF bandwidth is 6 MHz; however, 16 MHz is also usable, albeit with some caution. Polarisation observations are now routinely possible, though the user has to take some care about calibration issues. Walsh and Noise Cal modulation for real time Tsys measurements are currently not supported and hence, absolute flux calibration in regions where the system temperature varies (like the galactic plane) is not automatic. All observations are in the spectral mode and users should include a bandpass calibrator, even if doing continuum observations. Normal integration times used are 8 or 16 s but more rapid sampling (down to 2 s) can be done, subject to the availability of enough disk space for recording the larger data volume. Users wanting such modes should consult the operations group at the observatory (contact person : C. H. Ishwara Chandra, ishwar@ncra.tifr.res.in). Mosaicing with the GMRT has not been fully debugged.

Various tools have been developed to look at the data in quasi real time. Some of the most used tools are `mon` (displays real time snapshots of cross correlations, self-power, antenna bandshape, phase and amplitude etc), `tax` (gives offline plots of cross correlations, self-power, antenna bandshape, phase and amplitude etc), `ggdp` (gives information on non-working antennas, bad baselines, phase jumps, delay jumps etc). These tools are available for all users and can be run with some help from on duty telescope operators.

A GMRT User Tool (GUT) has been released for users. It is a graphical interface to several existing GMRT software that are regularly used before observations (e.g. command file maker, rise and set time calculator), during observations (e.g. ondisp for monitoring the antenna status etc) and after observations (e.g. tax, gvfits) and includes a few other useful utilities.

The data from the GMRT can be converted to FITS files using locally developed software, and analysed in standard packages like AIPS. These can be backed up on DVDs or external hard disks, written by Linux machines. Users should bring their own media for backing up the data. Facilities for analysing GMRT data are available both at the Observatory and at NCRA, Pune. Users wanting extensive computing facilities or large amounts of disk space for data storage or analysis should make their requirements known well in advance (contact person : C. H. Ishwara Chandra, ishwar@ncra.tifr.res.in).

Table 1 gives the measured system parameters of the GMRT antennas and some useful numbers for estimating the required observation time. Additional information can be found at the GMRT subsection of the NCRA home page (http://www.ncra.tifr.res.in).

2.2 Pulsar observations

The GSB beam former and pulsar receiver allows incoherent and phased array mode observations using all the 30 antennas, with a maximum bandwidth of 32 MHz. For incoherent array mode observations, the actual number of antennas that can be gainfully added depends on the quality of the signals from the antennas, including effects of receiver instabilities and

RFI. Besides varying with time, these effects also vary with the radio band being used and from central square to arm antennas. The final multi-channel data from the IA beam output can be recorded either on disk or on tapes (SDLT or LTO). Due to the current limitations of the data acquisition system, the fastest sampling achievable in the incoherent array mode is 60 μsec for the 256 channel, 16 or 32 MHz modes of the GSB. This becomes 120 μsec for the 512 channel, 16 or 32 MHz modes. Faster rates are possible at the expense of reduced spectral resolutions.

For the phased array mode of observations, there is an algorithm that can phase any selected number of available, working antennas using interferometric observations of a point source calibrator. The phasing for central ($\sim$ 14) antennas works well for time scales ranging from one hour to a few hours, depending on the operational frequency and the ionospheric conditions. For arm antennas, the de-phasing can be more rapid. Polarimetric pulsar observations are possible with the GSB, but instrumental polarisation effects for the GMRT are not fully characterised and observers will therefore need to carry out their own calibration.

The phased array data from the GSB can also be recorded on disk or tapes (SDLT or LTO). Either the total intensity signal or the 4 polarisation terms can be recorded. For total intensity, the fastest sampling rate currently supported is 60 μsec for the 256 channel, 16 and 32 MHz modes of the GSB, and is 120 μsec for the 512 channel, 16 and 32 MHz modes. For the polar mode, the fastest sampling times are slower by a factor of 2 than these numbers, for the corresponding GSB modes. Both IA and PA mode data are available with a time tagging facility that is accurate to $\sim$300 nanosec with respect to GPS and timing observations can be carried out using these. The format of the beam data from the GSB is identical to that provided by the older pulsar back-ends.

The PA mode of the GSB also includes capability for recording the full time resolution voltage beam data, which can be used for applications such as off-line coherent dedispersion. The GSB also allows a mode where the single IA and PA beams can be replaced by two IA beams or two PA beams, with indepedent antenna selections for each. This facilitates simultaneous dual-frequency observations of pulsars using the sub-array mode of the GMRT. Users should note that such observations involve special scheduling considerations, due to feed rotations and related overheads.

2.3 Observing modes with the GSB

The GSB presently supports the following modes of observations : (i) full bandwidth, non-polar and full polar interferometric observations in the “16 MHz” mode, with a choice of 256 or 512 spectral channels across the full band, with integration times 2 seconds and larger. (ii) full bandwidth, non-polar and full polar interferometric observations in the “32 MHz” modes, with a choice of 256 spectral channels for both non-polar and full polar interferometric observations and 512 channels for non-polar interferometric observations across the full band, with integration times 2 seconds and larger. (iii) spectral zoom modes (for spectral line observations) where the input band is filtered and decimated by factors 4,8,16...128, while keeping the number of spectral channels across the reduced bandwidth fixed at 256 or 512 – this mode will only work within the “16 MHz” mode; (iv) IA and PA beam modes with total intensity output, with fastest sampling time of 60 μsec, at present (resolution in the final recorded data subject to constraints described in section 2.2); (v) PA beam mode with full polar output at correspondingly reduced time resolutions (as described in section 2.2); (vi) variable spectral resolution, with a choice of 64,128,256 or 512 spectral channels across the band of observation. Reduced spectral channels will allow for correspondingly faster dump times for the visibility data; (vii) full time resolution voltage beam data for "16 MHz" and "32 MHz" modes; (viii) multi-subarray beam modes (IA or PA) with full bandwidth, for upto 2 sub-arrays, with independent GAC antenna selection control for each sub-array; (ix) raw voltage recording of the digitised voltage signals from each antenna (4 bit samples) for "16 MHz" mode, followed by limited capability for offline playback and correlation / beam forming – the frequency of usage of this mode of operation will be restricted by the total volume of disk space available for recording, as well as the time taken for the offline analysis; the observatory will be able to offer very limited capabilities for long-term back-up of the raw voltage dump data and the user will be responsible for clearing the large volumes of data from the disks within a stipulated time, typically a week or less. Users wanting to use this mode should check with the observatory well in advance (contact person : Yashwant Gupta/Sanjay Kudale, ygupta/ksanjay@ncra.tifr.res.in). Current status and latest news about the GSB can be found at the GMRT home page under the "Subsystems" section.

2.4 Upgrade activities and science observations during GMRT Observing Cycle 27

The GMRT is now in an active phase of the upgrade of the various subsystems, which demands additional downtime of antennas and facilities involved in the upgrade. As mentioned, the attempt is to minimise the disruption of the existing GMRT system while implementing the upgrade, and also to ensure that the existing system and modes continue to be supported as much as possible, even as the upgrade proceeds towards completion. During Cycle 22 (April to September 2012), in order to meet both the requirements, i.e, upgrade activities and smooth running of science observations, the observatory tried out a new model for science operations. In the first half of the cycle (18 April to 30 June 2012), science observations were scheduled only during night times (while day times were used for upgrade activities), from Monday to Friday. During the week-ends (Saturday morning to Monday morning) observations were scheduled round the clock. In the latter half of the cycle (1 July to 15 September 2012), observations were scheduled through the week, as per the practice in previous cycles.

After reviewing the performance of this scheme and estimating the upgrade requirements for Cycle 23, it was decided to extend the new scheme i.e. use day time slots from Monday to Friday for upgrade activities and science observations during the night time on weekdays and round the clock on weekends, for the entire Cycle 23. It was also decided to extend the GMRT Observing Cycle by two more weeks, to cover a total duration of five and a half months. The GMRT Observing Cycles 24 to 26 were also run in the same manner viz, use day time slots from Monday to Friday for upgrade activities and science observations during the night time on weekdays and round the clock on weekends. The GMRT Observing Cycle 27 will also follow the same model. The maintenance breaks on Wednesday and Thursday will continue throughout the cycle as per the present practice. This model of operations will result in certain LST ranges having less slots available for scheduling during Cycle 27, and we request users to bear this in mind when preparing their observing proposals. The available IST/LST slots in Cycle 27 can be seen in a dummy schedule at http://www.ncra.tifr.res.in/ncra/gmrt/gtac. As can be noted, there are fewer time slots available for scheduling in the LST range 16 to 24 hrs.

Some of the existing observation modes and available flexibilities of settings for observations may be partially affected by the changes implemented as part of the upgrade activities. These include the following : (i) A few antennas might not support the dual frequency mode and 235 MHz observations due to installation of the upgraded broadband feed operating from 550 to 900 MHz. (ii) For some observing frequencies, the choice of 1^{st} LO $>$ RF might not be possible in antennas where the 250 to 500 MHz feed is installed. At the time of writing this document, 15 antennas are already outfitted with this new feed, and this is expected to increase to cover 10 more antennas during Cycle 27. These antennas can be used for regular 325 MHz observations with other antennas which have the existing 325 MHz feed. (iii) The upgrade of the servo system will result in downtime of one month, of one antenna at any given time. (iv) Antenna structure and surface improvement activities may result in up to 2 antennas being down during the night time for a week to 10 days. (v) Upgrading of optical fibre link require one antenna down for four continous days once a month. (vi) Installation of new electrical systems will also result in one antenna not available at night, one antenna at a time.

The GMRT Observatory will try its best to minimise the number of antennas down at night, by coordinating across the groups. To ensure good data quality after day-long upgrade activities, extensive testing is put in place before the system is released for science operations. The observatory will try its best to maintain the availability of 26 antennas for all the science observations. Due to the upgrade of 610/235 MHz feed, the number of antennas for 235 MHz band observations will be less than 26.

For further details and clarifications please contact

N.G. Kantharia or C.H. Ishwara Chandra (for interferometry) [ngk@ncra.tifr.res.in or ishwar@ncra.tifr.res.in] or

Y. Gupta (for pulsars) [ygupta@ncra.tifr.res.in]

with a copy to [gtac@ncra.tifr.res.in].

Table 1: Table 1 : Measured System Parameters of the GMRT

	Frequency (MHz)				
	151	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
Synthesised 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)					
For Short Observations	10	5	2	2	2
For Long Observations#	5	2	2	1	1
Best rms sensitivies achieved so far as known to us (mJy)	0.7	0.25	0.04	0.02	0.03
Typical Dynamic Ranges	> 1500	> 1500	>1500	>2000	>2000

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

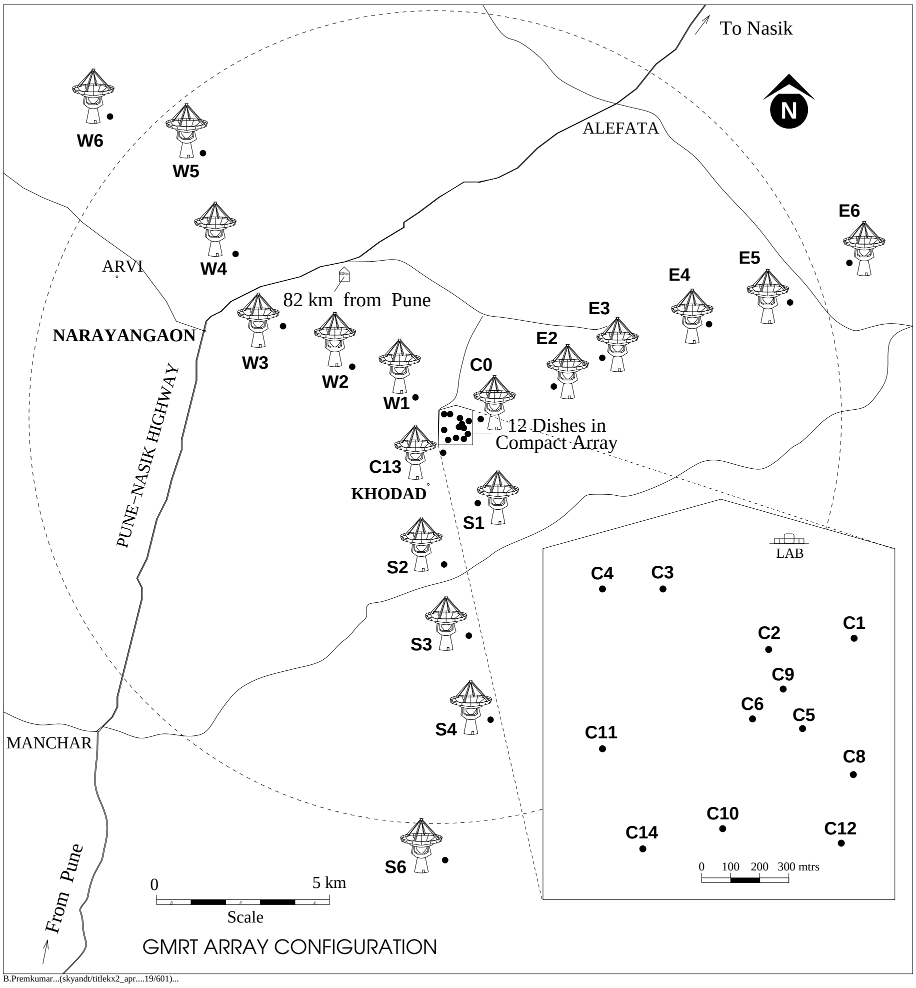

Figure 1: GMRT Array configuration

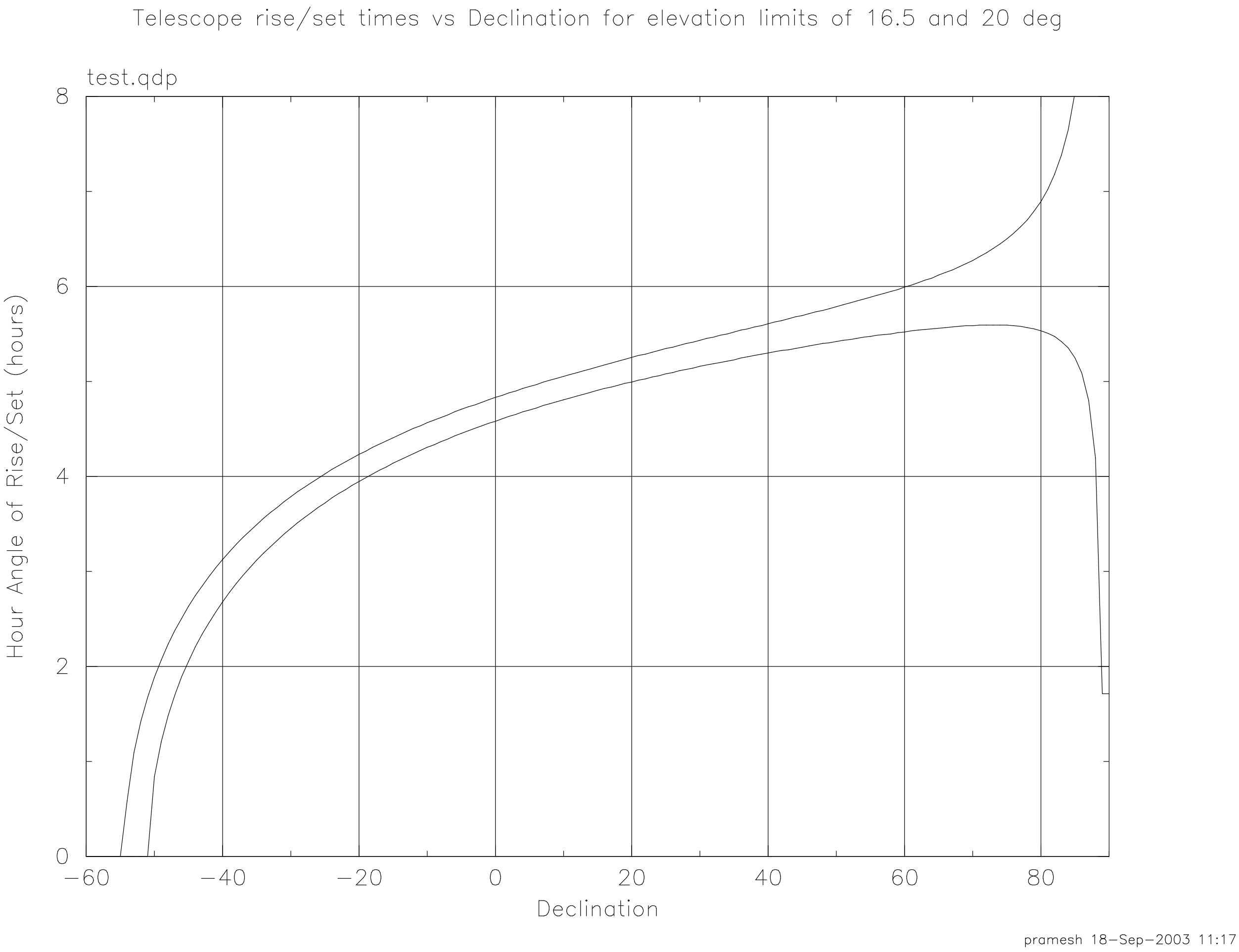

Figure 2: Hour Angle at which sources at different declinations rise and set for GMRT antennas - upper curve if for elevation limit of 16° and the lower for 20°