The GMRT : System Parameters and Current Status

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Contents

This document gives an overview of the latest status of the GMRT and relevant system parameters useful for planning GMRT observations. Section 1 gives the background and an overall description of the GMRT, covering the legacy system and the upgraded GMRT. Section 2 gives the current status of the GMRT, and is the part most relevant for those planning observations with the facility.

1 General Overview

The GMRT consists of thirty 45 m diameter antennas spread over a 25 km region. Fourteen antennas are in a compact, quasi randomly distributed array, in a region of size about 1 km (called the Central Square). The remaining sixteen antennas are on the 3 arms of a "Y" (NorthWest, NorthEast and South), each of length $\approx$ 14 km, 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=$19.1^{\circ}N$, Longitude = $74.05^{\circ}E$) is located near Khodad village, which is about 80 km north of Pune. The telescope site houses laboratories, a guest house, a library and a canteen. The observatory can be reached using the daily shuttle service that starts from NCRA, Pune at 7 AM in the morning and return from GMRT at 5:30 pm (all days including holidays and weekends), or by a 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 a 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.

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 $+90^{\circ}$. 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 can be operated upto wind speeds of 40 km/h (for safety, the antennas are parked at higher wind speeds). There is a rotating turret at the focus on which the different feeds are mounted. The feeds presently available are the Band-5 (1000-1460 MHz), Band-4 (550-850 MHz), Band-3 (250-500 MHz) and Band-2 (120-240 MHz) feeds. The reflecting surface is formed by a wire mesh and the efficiency of the antennas varies from about 60% to about 40%, from the lowest to the highest frequency. Signals from two orthogonal polarisations are brought to the control room from each antenna, over optical fibre. The native polarisations for all receiver systems are circular, except for the Band-5 system, which delivers linear polarisations.

The GMRT has been open to the international community of users since early 2002, via a proposal submission and approval scheme that presently runs two observing cycles in each year. After over a decade of operations, the GMRT has recently undergone a major upgrade of its capabilities, whose main goals have been to provide (i) near-seamless frequency coverage from $\sim$ 100 MHz to $\sim$ 1500 MHz (ii) improved sensitivity with better quality receivers (iii) a maximum instantaneous usable bandwidth of 400 MHz along with high spectral resolution (iv) a revamped and modern servo system (v) a next generation monitor and control system (vi) improvements in the antenna mechanical structure and (vii) matching improvements in infrastructure and computational facilities. The upgrade has resulted in significant changes to almost all aspects of the GMRT receiver chain and other systems. However, full care was taken in the design of the new systems to ensure that the performance of the existing legacy GMRT system is not affected as the upgrade is implemented. The upgraded GMRT (hereafter, the "uGMRT"), now fully complete, has been made available in an incremental fashion to the user community since GMRT Cycle 30, and Cycle 36 marked the full release of the final uGMRT. Sections 1.1 to 1.4 describe in detail the uGMRT and the observing modes.

1.1 Overview of the uGMRT

The uGMRT replaces the narrow band feed and front-end receiver systems of the legacy system with wide-band receivers. The legacy 325 MHz feed has been replaced with a broadband feed operating from 250 to 500 MHz (Band-3), along with a broadband low noise amplifier with improved noise temperature. A new feed operating from 550 to 850 MHz (Band-4) has replaced the legacy 610/235 MHz co-axial feed, also with a matching LNA with improved noise figure. Due to this, the 235 MHz band of the legacy system is no longer available from Cycle 34 onwards. The legacy 150 MHz feed has also been replaced with a wider bandwidth feed, covering 120 to 240 MHz (Band-2). The L-band feed (Band-5) has been upgraded with a better dynamic range front-end receiver system, covering the frequency range of about 1000 to 1460 MHz, along with four sub-bands, each of 120 MHz bandwidth.

As part of the upgrade, the optical fibre link to each antenna has been modified to provide additional wavelengths to bring back the dual polarisation broadband RF signals from the new front-end receivers directly to the Central Electronics Building (CEB), without disturbing the existing narrow bandwidth path for the legacy system that brings back the two polarisations on IF signals with a maximum bandwidth of 32 MHz. In the CEB, a new signal chain has been developed in parallel to the existing system that handles the narrow-band signals of the legacy GMRT, for catering to the broadband signals of the upgraded GMRT. The broadband RF signals are converted to baseband signals with a maximum bandwidth of 400 MHz, which are then processed with the new digital back-end system, the GMRT Wide-band Backend (GWB), consisting of a correlator, a beam-former and a pulsar receiver, that can handle the full 400 MHz bandwidth. Both these signal paths run independently and in parallel, without affecting each other.

The servo system for all 30 antennas has been upgraded with new brush-less DC motor system along with a new servo computer. A new Tango based GMRT Control and monitor system (TGC) with improved hardware at each antenna connected to the central station via Ethernet, and improved software and user interface, replaces the current control and monitor system. Several improvements to the mechanical structure and reflecting surface of the antennas have been carried out, and continue to be undertaken. Matching enhancements in computing resources and data archiving capabilities are being implemented.

These upgrade activities are now complete and the full uGMRT was released to users from Cycle 36 (April 2019) onwards.

1.2 Front-end Receiver Systems

At the focus of each antenna, the front-end system for each feed has 2 low noise amplifiers (LNAs) (one for each polarisation), with a noise injection facility where the user can select one of 4 levels of injected noise power. For all the bands (except Band-5), the linear polarisation signals from the feeds are converted to circular polarisation signals just before the LNAs.

The two polarisations signals from the front-end receivers of all the bands go to a common box (also located on the feed turret) where the user has to select one of the frequency bands for onward transmission, as only two RF cables go down to the antenna base. The common box also has facilities to select solar attenuators (0, 14, 30 or 44 dB), enable/disable noise and Walsh modulation, and swap the signals between the two polarisation channels.

Legacy GMRT system : In the legacy system, 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 are transmitted on optical fibre to the CEB. 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).

Upgraded GMRT system : In the upgraded system, the RF signals are directly transmitted to CEB using high dynamic range fibre optics system; these form the input to the GMRT Analog Backend (GAB). The GAB converts any of the RF bands to baseband, with a final bandwidth of 100/200/400 MHz. The LO settings for all antennas (both polarisations) can be set independently to any value in the range 10-1500 MHz, with a step size of 1 Hz. Variable attenuation control for power equalisation is available in both polarisations.

1.3 Backend Systems

The backend systems are housed at the CEB, with separate systems for processing the legacy and upgraded GMRT signals. The first stage of these systems is the analog processing chain which provides the final baseband signals (as described in section 1.2 above), which are then digitised and processed by the digital backend systems – the GMRT Software Backend (GSB) for the legacy GMRT (see section 2.2 for details), and the GMRT Wideband Backend (GWB) for the upgraded GMRT.

GMRT Wideband Backend (GWB): The GWB processes a maximum of 400 MHz band for each of two polarisations for all the GMRT antennas. It implements a FX correlator for interferometry mode, supporting both total intensity and full polar mode processing. It also has narrow band spectral zoom modes that are useful for spectral line observations. The maximum number of spectral channels that the GWB provides goes upto 16384 (the default is 2048), though some modes may support a smaller value for the maximum number of spectral channels. The range of integrations for the final recorded visibility data is between 0.6 and 16 secs.

In parallel with the correlator, the GWB also has incoherent array (IA) and phased array (PA) beamformers for the array mode, which are useful for observations of sources such as pulsars. A total of 4 IA or PA beams can be formed simultaneously, with completely independent control over the choice of antennas to be used for each beam. The beam data (total intensity or Stokes parameters) can be recorded individually, with sampling times of 20.48 microsec and larger depending on the specific mode of observations, with some trade-off between the number of spectral channels and the shortest sampling time possible. In addition, the beamformer has an option for providing the voltage beam from the PA output, at Nyquist rate, for upto 2 out of the 4 beams for 100/200 MHz total bandwidth modes, followed by real-time coherent dedispersion (over sub-bands) resulting in multi-channel intensity data at desired time resolution.

The current status of the GWB, including full description of the working and released modes, can be found in Section 2.1. From the Cycle 36, the GWB has been declared as the default backend for the GMRT; however observations with the GSB are still possible, albeit as a secondary backend (see section 2.2 for details of observing with the GSB).

1.4 Control and Monitor System

The Control and Monitor System issues commands to set the parameters of the electronics, to slew and track the antennas and to enable the recording of data. It also provides facilities for monitoring a wide range of parameters. As part of the GMRT upgrade, the control and monitor system is transitioning to a new Tango based GMRT Control (TGC) system in a phased manner, and the GMRT will switch over completely to this new system by Cycle 40.

In practice, the GMRT is controlled by the telescope operator on duty. The responsibility of the user is limited to (1) providing the operator with the observing plan, the settings, and the command file, and (2) ensuring that the data quality is satisfactory. In the new TGC system, the format and syntax of the command files will be different from those in the legacy control system.

Several useful tools for preparing observing files or command files, setup files, calculation of source rise and set times, selection of phase calibrators etc, are available at http://www.gmrt.ncra.tifr.res.in/∼astrosupp/ . Users are encouraged to use these tools to prepare the observing files and mail them to gmrtoperations@ncra.tifr.res.in well in advance.

2 PRESENT STATUS (December 2020)

This section describes the current status of the various systems and modes of the GMRT, as expected to be available for GMRT Cycle 40 (starting from April 2021). Section 2.1 describes the status of the uGMRT system and possible modes of science observations; whereas section 2.2 describes the capabilities of the legacy GMRT system (using the GSB). General issues relevant to both systems are detailed below.

The four main bands of the uGMRT are available on all 30 antennas. Rotation of the feed system to change the frequency of observation is routinely possible; it requires about 1 hour 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. This procedure takes a couple of minutes. If a user would like 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 often be poor at Band-2 and Band-3; the situation is usually better at night, than during day time. It is recommended to use the solar attenuators in the common box for Band-2, to reduce the possibilities of saturation of the downstream electronics chain due to RFI. Observations at Band-3 can be hampered sometimes due to RFI from nearby aviation related activity (especially during day time), as well as from some satellites such as the MUOS which have very strong transmissions in this band. A set of tools are available for predicting the satellite interference in planned observations (which can be used for improved planning of observations by users) and also for checking the same post-facto after observations, at http://gmrt.ncra.tifr.res.in/ astrosupp/ under "Satellite Tools". A real-time version of the tool runs in the control room and produces warnings for satellite interference during the observations, which can be monitored by the operator on duty. Due to increasing interference from mobile phone signals around 950 MHz, some observations in Band-4 and Band-5 can be affected.

Ionospheric scintillation is common near the solar maximum, even at band-5. The probability of scintillation is higher closer to the equinoxes. High winds can halt 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.

From GMRT Observing Cycle 36 onwards, the GWB is the observatory default back-end for the GMRT, though the GSB continues to be available for supporting the legacy system modes.

2.1 Observing with the upgraded GMRT

The GMRT upgrade activity was executed in parallel with science observations with the legacy system, by carrying out the engineering tasks during the day time slots (9 AM to 6 PM) and using the night time slots (and full time on week-ends) for observations. With the tapering down of the upgrade activities gradually from Cycle 33 onwards, more and more day time slots have become available again for science observations. Users should note that the slot from Wednesday 09:00 hours to Thursday 18:00 hours every week is set aside for maintenance and improvement activities, as well as system tests, and no regular science observations are scheduled during this slot. The distribution of the observing slots over the duration of Cycle 40 is shown in the 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 of 04 to 12 hrs, and users are requested to bear this in mind when preparing their observing proposals.

Ongoing maintenance and long-term upgrade activities will have some effect on the observing capabilities with the GMRT. Specifically,

(i) Upgrades of the feed positioning servo system may result in downtime of one antenna up to one week at any given time.

(ii) Antenna structure and surface improvement activities may result in up to two antennas being down during the day time for a week to one month (or more in rare cases) depending on the nature of the repair work.

(iii) With the new TANGO based control and monitor system (TGC) in place from GTAC Cycle 40, the format of the command file and settings may change. Observatory will internally convert the existing command files to the new format as required by TGC.

The GMRT Observatory will try its best to minimise the number of antennas unavailable for science observations, by coordinating the various upgrade, test and maintenance activities. However, due to various issues, some individual antennas may not be available at different points of time. The observatory will strive to guarantee a minimum of 26 working antennas for all science observations. Programs that critically depend on specific antennas (e.g. the longest baseline antennas such as W06, E06 or S06, or the short spacing antennas C05, C06 and C09, etc) should clearly indicate this in the observing proposal.

For GTAC Cycle 40, from April 2021 onwards, the observatory aims to provide the following telescope configuration and specifications to the GMRT users, in "regular release mode". In addition, features available in "shared risk mode" are also mentioned :

1. **Front-End (FE) + Optical Fibre (OF) systems :**

   1.1. All 30 antennas with the Band-5 (1000-1460 MHz) FE receivers, with a choice of full band or one of four 120 MHz wide sub-bands.

   1.2. All 30 antennas with the Band-4 (550-850 MHz) FE receivers, with a choice of full band or one of four 120 MHz wide sub-bands.

   1.3. All 30 antennas with the Band-3 (250-500 MHz) FE receivers, with a choice of full band or one of three 120 MHz wide sub-bands, in regular release mode.

   1.4. All 30 antennas with the Band-2 (120-240 MHz) FE receivers, with an in-band notch filter for television transmitter around 175 MHz, in regular release mode. Note that the Band-2 system is much more prone to strong RFI effects than the other bands of uGMRT, and all the implications of the RFI may not be fully characterised and understood.

   1.5. All the FE receivers have additional features such as noise injection, temperature and total power monitoring facilities, which will continue to be available in shared risk mode.

   1.6. All 30 antennas with high dynamic range wideband OF system, delivering the full wideband signals to the back-end system.

2. **Back-End (BE) systems :**

   2.1. Analog section : GMRT Analog Backend (GAB) for all 30 antennas :
   (a) Converts the selected RF band to baseband, with final BW of 100/200/400 MHz.
   (b) Local Oscillator (LO) settings for all antennas (both polarisations) in 10-1500 MHz range, with 1 Hz step.
   (c) Variable attenuation control for power equalisation.
   Note : minor improvements and additions will continue to be made to this released system, as per the overall plan.

   2.2. Digital section : GMRT Wideband Backend (GWB) for all 30 antennas, with following features :

   2.2.1. Interferometric modes :
   (a) Total intensity mode for 100/200/400 MHz BW choices with upto 8192 channels.
   (b) Full polar mode for 100/200MHz BW with upto 8192 channels and 400 MHz BW upto 4096 channels.
   In both (a) and (b), combination of short integration and higher number of channels may not be possible due to high data rate. For example, while 0.6s integration is okay for 2048 channels, an integration time of 5s is recommended for 8192 channels.
   (c) Narrow bandwidth spectral-line modes (in total intensity) with BW ranging from 100 MHz down to 0.390625 MHz in steps of factors of 2, with upto 16384 channels.

(d) Frequency-switching for narrow-bandwidth spectral-line observations is available, in shared-risk mode in Cycle 40. Users who would like to use this mode should get in touch with Nissim Kanekar (nkanekar@ncra.tifr.res.in) for observing details and possible issues.

2.2.2. Beam modes : These can be operated in parallel with the interferometric modes in Section 2.2.1.

(a) Option for upto 4 total intensity (IA or PA) beams for a choice of bandwidth 100/200/400 MHz.

(b) Option for PA voltage beam on 2 out of the 4 beams for bandwidths of 100/200 MHz with real-time coherent dedispersion (over sub-bands) resulting in multi-channel intensity data at desired time resolution.

(c) Full polar mode for 2 PA beams for a bandwidth of 100/200 MHz. Option for 400 MHz BW in shared risk mode.

(d) Range of choices for integration time - from 0.6 s to 16 s and number of channels - from 2048 to 16384. However a combination of shortest integration time together with largest number of channels may be difficult due to extreme data rates (see below).

2.3. Common back-end features :
(a) Upto 4096 spectral channels for most of the above modes in regular release mode; for other extreme combinations of number of channels and integration times, the system is available in shared risk mode – system may not work reliably for lack of adequate data I/O or recording capabilities at higher channels and shorter integration time.

(b) Phasing of the antennas using standard procedure (regular release mode); additional mode called "wideband phasing" (shared risk mode).

(c) Standard power equalisation scheme for balancing the power levels for all working antennas, using the GAB attenuators (regular release mode); more advanced power equalisation schemes to facilitate Galactic plane / Galactic centre observations (shared risk mode). Users observing near Galactic plane should power equalise at the target location before the start of the observations to avoid saturation and non-linearity. A scheme for automatic adjustment of power levels for observations in the Galactic plane regions is available. More information about this scheme can be found at http://www.ncra.tifr.res.in/ncra/gmrt/gmrt-users/galactic-plane . For additional details, please contact Subhasis Roy (roy@ncra.tifr.res.in)

(d) A scheme for realtime broadband RFI excision at the pre-correlation stage for each polarisation of all antennas is available on shared risk basis, during Cycle 40 as well. While this mode has undergone reasonable amount of testing, the artifacts it can introduce during severe RFI conditions is not fully understood. Users wanting to use this mode should get in touch with Ruta Kale (ruta@ncra.tifr.res.in) well in advance.

NOTE : It is to be understood that not all the modes and combinations specified above under shared risk release have been tested thoroughly, and there may be undiscovered issues in some of these. The aim of the shared risk release is to allow users to exercise the system for a thorough shake-down of such modes.

3. **Offline data analysis and data back-up :** The existing offline programmes such as listscan and gvfits have been upgraded to make them compatible with the wideband

uGMRT data. All interferometry data acquired will be formally archived in the GMRT Observatory Archive (GOA). Note that beamformer data are presently not archived in GOA, and the user is responsible for their own back-up of such data. Users with approved uGMRT proposals are allowed to record and use data from both the GWB and the legacy GSB system.

2.2 Observing with the legacy GMRT

Some of the observation modes in the legacy GMRT system have been affected by the changes implemented as part of the upgrade activities. These include the following :

(i) With all antennas now having the new Band-4 feed and receiver, the dual frequency 235-610 feeds and receivers of the legacy system are no longer available; hence simultaneous dual frequency observations at 235 & 610 in the legacy mode, are no longer possible;

(ii) For some observing frequencies, the choice of 1^{st} LO > RF might not be possible when observing in 250-500 MHz (Band-3) and 550-850 MHz (Band-4). In such cases, observations in legacy mode can still be possible, with the choice of 1^{st} LO < RF;

GSB overview : The main back-end for the legacy system is the GMRT Software backend (GSB) which has been in operation since GMRT Observing the 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 computers 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 per sample (for the "16 MHz" mode) and 2 bits per sample (for the "32 MHz" mode).

Main modes of observations : The GMRT legacy system presently supports the following modes of observations : (i) 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. (ii) 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. (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-sub-array 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. (x) Real-time coherent dedispersion mode attached to the raw voltage mode of the phased array beamformer, working for both "16 MHz" and "32 MHz" bandwidths. This mode takes the raw voltage mode signals for both polarisations from the phased array output, and produces coherently dedispersed intensity time series with a user selectable integration time, for each polarisation.

Users wanting to use the last 2 modes above 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.

Continuum and spectral line observations: 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, 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: gmrtoperations@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.

Users can also find several useful tools in http://www.gmrt.ncra.tifr.res.in/∼astrosupp/ for creating command files, setup files, calculation of source rise and set times, to select phase calibrators from VLA calibrator list, etc. These are especially useful for users who are availing of the absentee observing facility at GMRT. For users interested in polarisation data at bands other than L band, an analysis recipe in NRAO AIPS is now available.

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: gmrtoperations@ncra.tifr.res.in).

Table 1 gives the measured system parameters of the GMRT, and some useful numbers for estimating the required observation time, for the legacy system. Basic system parameters of uGMRT is given in Table 2. Additional information can be found at the GMRT subsection of the NCRA home page (http://www.ncra.tifr.res.in).

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 (each polarisations independently) 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. A real-time coherent dedispersion pipeline is also available since Cycle 31. 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 independent 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.

For further details and clarifications please contact
GMRT Operations (gmrtoperations@ncra.tifr.res.in).

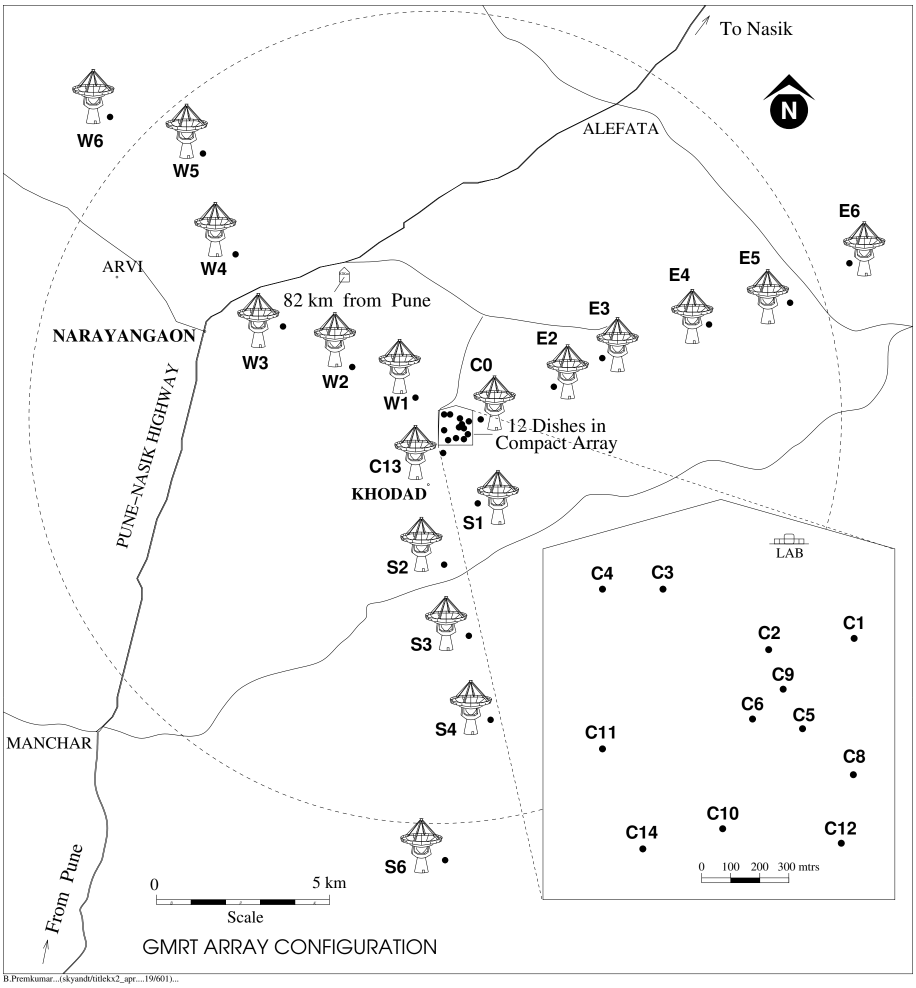

Figure 1: GMRT Array configuration

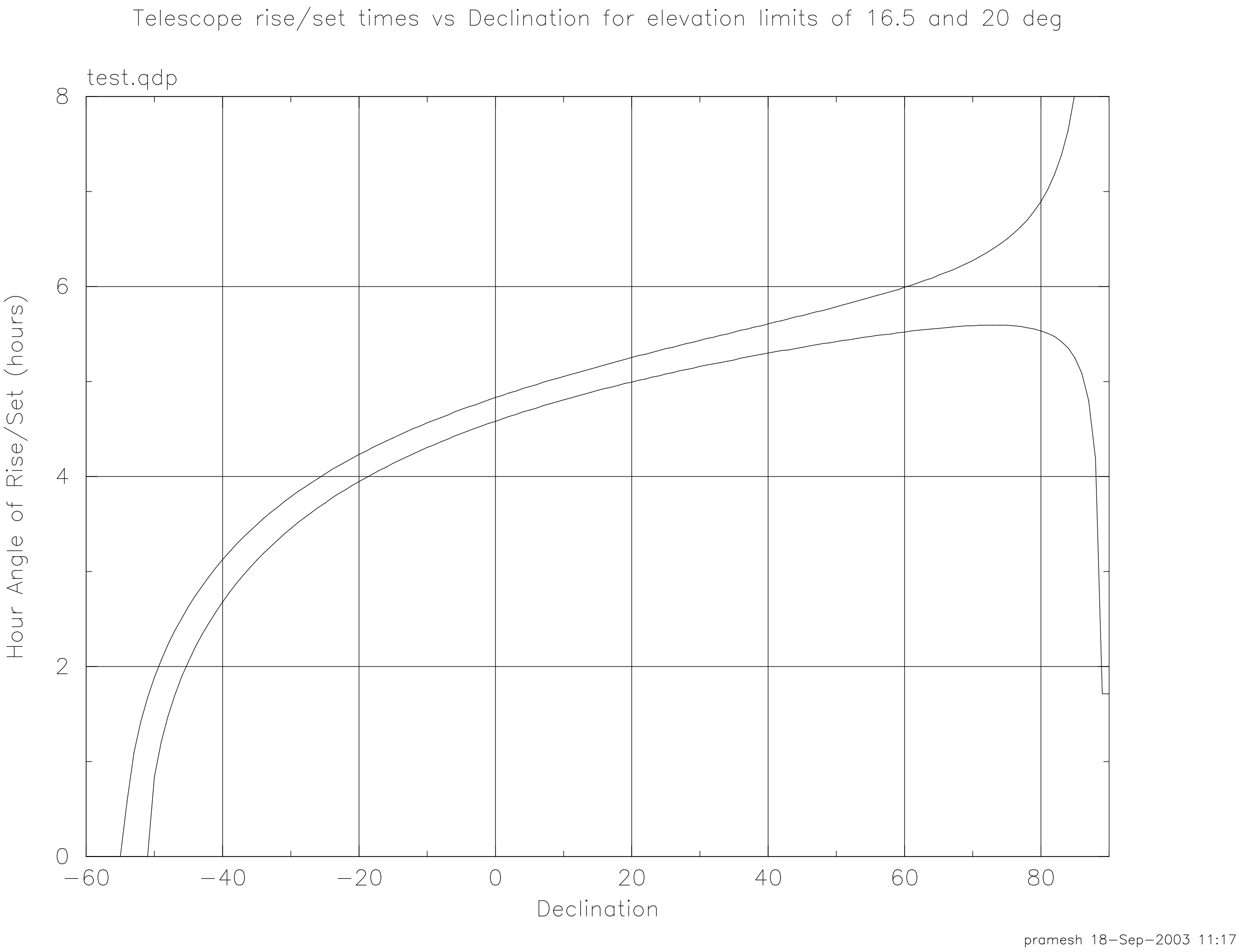

Figure 2: Hour Angle at which sources at different declinations rise and set for GMRT antennas - upper curve if for elevation limit of 16° and the lower for 20°