# Part 9

# Instrumentation and Techniques

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# GMRT — Current Status

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**Abstract.** The Giant Metrewave Radio Telescope (GMRT) is a major new facility available for observations at metre wavelengths. This paper describes the the GMRT with emphasis on the features that are of relevance to a potential user. The current state of the GMRT is also described.

## 1. Introduction

The GMRT consists of 30 $45m$ diameter antennas spread over $25km$. Half the antennas are in a compact, randomly distributed array with a diameter of about 1km. The remaining antennas are on 3 arms of length 14km (NorthWest, North-East and South) with 5-6 antennas on each arm. The longest baseline is $26km$ and the shortest is $100m$ which comes down to about $60m$ with projection effects. The array configuration is shown in Fig. 1 and the $u - v$ coverage for some declinations is shown in Fig. 2. The telescope (Latitude=19.1°, Longitude −74.05°) is located near Khodad village, which is about $80km$ north of Pune. Narayangaon, the closest town, is about $8km$ from the Observatory and is connected to Pune and Mumbai by the public bus transport system. The facility is run by the National Centre for Radio Astrophysics, which is a part of the Tata Institute of Fundamental Research, Mumbai.

## 2. Antennas and Feeds

The GMRT antennas are $45m$ alt-azimuth mounted dishes one of which is shown in Fig.3. 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. The total weigth of the moving structure, excluding the counterweight of 34 tonnes, is only 82 tonnes, making it one of the lightest antennas, in proportion to its size. While the dishes can go down to an elevation of 16°, at present, the elevation limit has been set at 20°, giving a declination coverage from −50° to +90°. The slew speed of the antennas is $30°/min$ in azimuth and $20°/min$ in elevation and they are not operated when winds are higher than $50km/h$. There is a rotating turret at the focus on which the different feeds are mounted (Fig.4). The feeds presently available are the 151, 325, 610/235 and the 1000-1420 MHz feeds. While the feed turret can be rotated from the control room and in principle under the control of the user, at the present time, feed turret rotation is done only by the system engineers. Both the orthogonal polarizations are brought

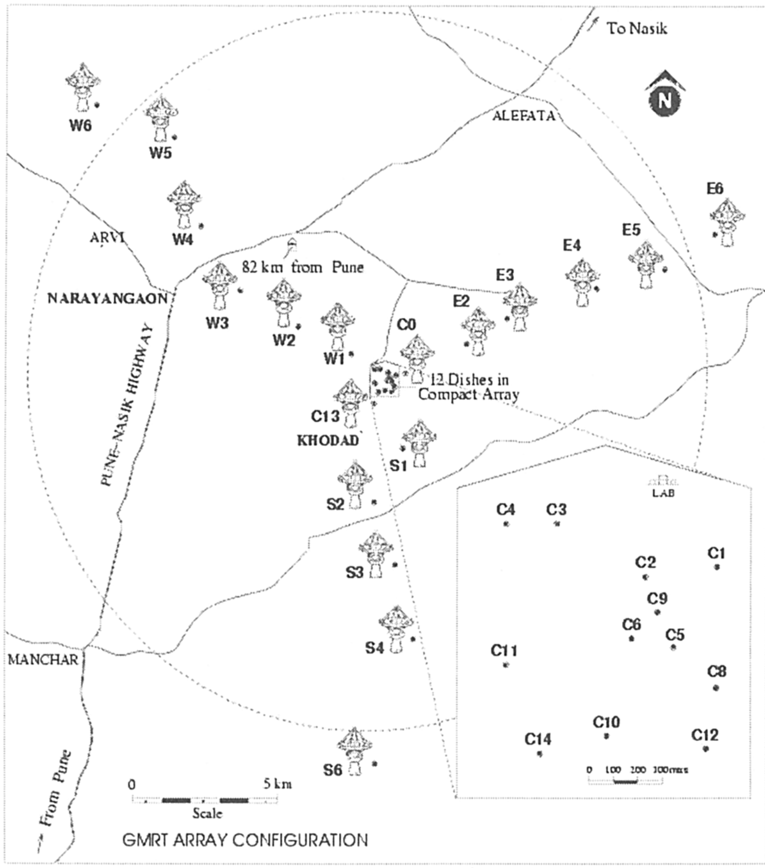


Figure 1. Layout of the antennas of GMRT. The antennas in the central are shown in the inset

from each antenna. The orthogonal polarizations are circular for all feeds except the 1420 MHz feeds which are linear. The L-Band feed is a corrugated horn that was designed and fabricated by the Raman Research Institute, Bangalore, India. The 610/235 MHz feed is a dual concentric coaxial cavity, and with both feeds at the focus at the same time, the system allows simultaneous observations at 610 and 235 MHz with one polarisation at each frequency. The 325 MHz feed is a Kildal feed ( half wave dipole over a ground plane with a beam forming ring in front) and the 151 MHz feed consists of two orthogonal pairs of dipoles in front of a plane reflector. A 50-70 MHz feed for the system is under development.

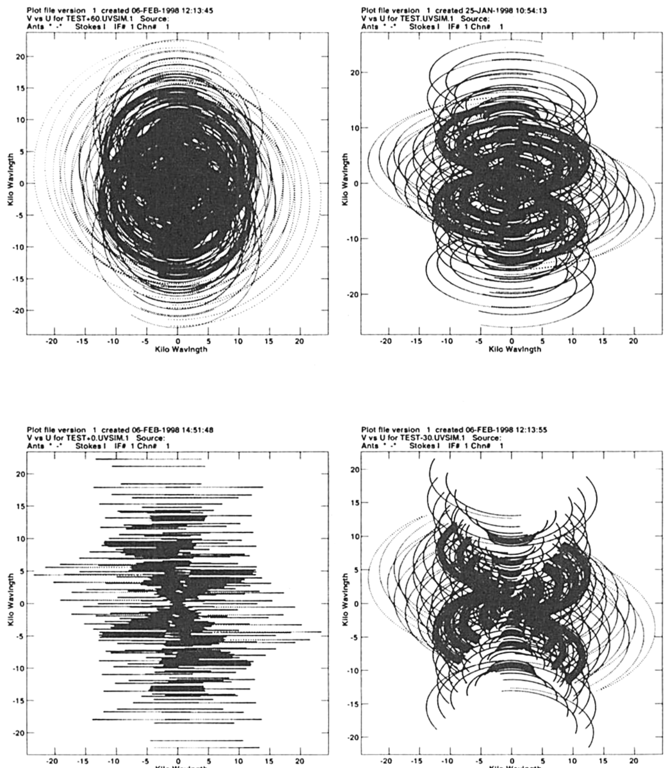


Figure 2. $u - v$ coverage for the GMRT at 4 declinations for $1m$ wavelength

## 3. Electronics

A block diagram of the Electronics system is shown in Fig. 5. At the focus of each antenna, each feed has 2 low noise amplifiers, (one for each polarization), followed by a noise injection facility where the user can select 4 noise values. The two signals go to a common box (also on the feed turret) where the user can select which frequency signals appear at the output of the common box since only 2 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 noise and Walsh modulation and swap the polarisation inputs.

At the antenna base, the RF signals are mixed with a coherent local oscillator (Ist LO) to give 70 MHz IF signals. The user can select the local oscillator frequency ( 1 MHz steps from 100 to 354 MHz and 5 MHz steps from 350 to 1795 MHz), IF attenuators ( 0 to 32 *db* in 2 *db* steps) and the IF bandwidth

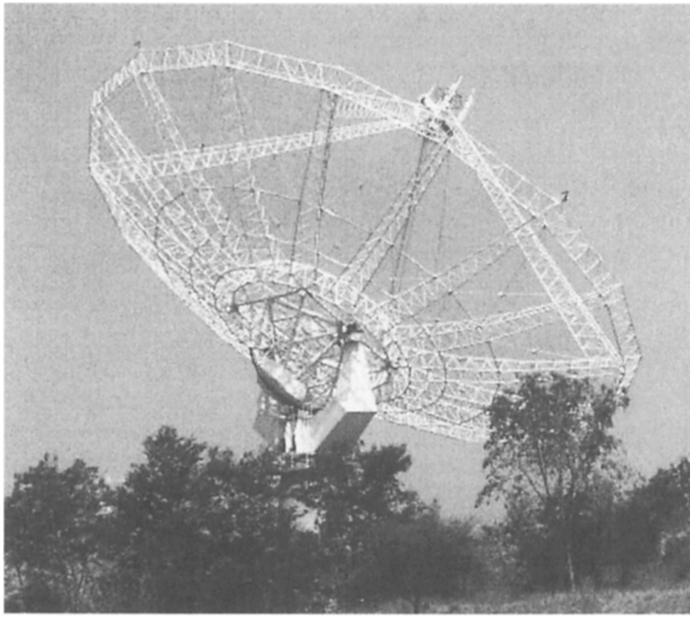

Figure 3. One of the 45m GMRT antennas

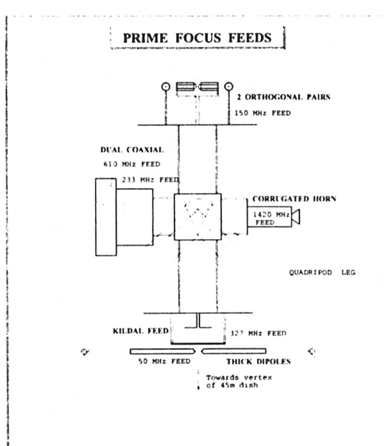


Figure 4. Layout of the feeds on the rotating turret at the focus of the GMRT antennas

(8,16 or 32 MHz). The IF signals from each antenna go to the Central Electronic Building (CEB) through an optical fibre and there is a facility to turn on or off an Automatic Level Controller (ALC) before the optical modulator. Since the IFs of both the polarisations are carried on the same optical fibre, a second local oscillator system shifts one of the IFs to 130 MHz and the other to 175 MHz and the signals are combined and sent to the optical modulator. At the CEB the optical signal is converted back to electrical and the third local oscillator system converts the 130 and 175 MHz channels back to separate IF signals at 70 MHz. The IF signals are converted to baseband using the 4th LO which the user can set from 50 to 90MHz in steps of 100 Hz. Since the digital back end can handle a maximum bandwidth of 16 MHz, each of the 2 IFs which can have a maximum bandwidth of 32 MHz, is split into 2 bands - the Upper and the Lower sidebands, which are separately amplified, attenuated and filtered ( filter widths= 64, 128, 250, 500, 1000, 2000, 4000, 8000 and 16000 KHz ).

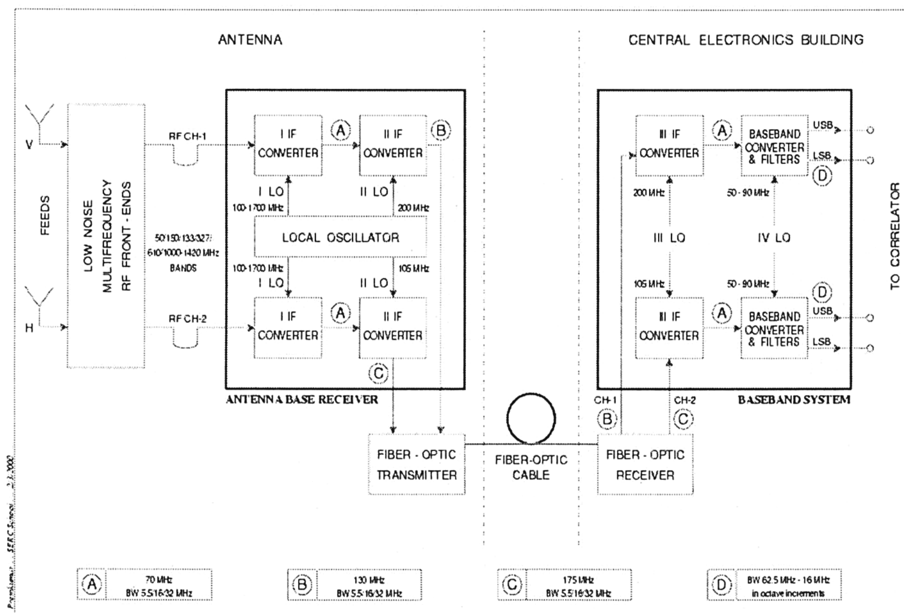


Figure 5. Overview of the GMRT electronics chain

## 4. Digital Back End

The Upper and Lower sideband signals are handled by 2 nearly independent correlator systems. The GMRT correlator which is an FX type correlator, runs at 32 MHz but can be programmed to use only every $2^n$ th sample so that the effective sampling interval is larger and the bandwidth narrower. iThe basic components of the system are the samplers, delay system, the FFT pipeline and the multiplier and accumulator (MAC). The baseband signal is sampled (4 bits) and compensated for propagation delays. The data stream is Fourier transformed to give 256 channels across the band but while multiplying and averaging, adjacent frequency channels are averaged giving effectively 128 channels across the band. The channel width depends on the base band filter and the effective sampling interval and can range from a maximum of 128 KHz to 0.5 KHz with the total bandwidth ranging from 16 MHz to 64 KHz in each sideband for each polarisation. The voltage spectrum from each antenna is multiplied with that from every other antenna and the resultant $30 * 31 * 128/2$ signals for each polarisation (including the self correlation) are averaged for $128ms$ in the hardware, before being read out and further integrated. The hardware provides a variety of facilities like fringe stopping, delay compensation, walsh and noise switching demodulation, window functions before Fourier transforming and the possibility of blanking the signal for interference rejection. The 2 sideband correlator system gives 4 outputs, 2 RR and 2 LL, effectively doubling the bandwidth of the system. However, it can also be reconfigured to give the 4 stokes parameters for one of the 2 IF systems. The full spectral line data is recorded with user selectable integration time that can be a multiple of $8 * 128ms = 1.024s$. The default integration time is $16s$ which generates 53Mbytes of data every hour. There are options to record only a subsection of the baseline and frequency channels if one needs much shorter integration times.

The output of the FFT pipeline can also be isent to the GMRT Array Combiner (GAC) where signals from different antennas can be combined to give a single time series of spectra with a sampling interval of $\sim 16\mu$s. The data from the antennas can be combined either coherently (voltage) or incoherently (power) depending on the users requirements. The output of the GAC can recorded for VLBI, pulsar search etc or sent to the pulsar back end where one has facilities for dedispersion ( both coherent and incoherent), polarimetry, etc.

## 5. Control System

The control of the whole array is done by a distributed system of microprocessors that communicate with and are controlled from a workstation in the control room. At the base of each antenna is the Antenna Base Computer (ABC) which controls all functions at the antenna. The ABC generates tracking commands for the Servo Computer and issues instructions to the various Monitor and Control Modules (MCMs) that control the state of the RF, IF Local Oscillator and feed positioning systems. The servo system, designed by the Reactor Control Division of the Bhabha Atomic Research Centre, ensures that a source is tracked with an rms error of $\sim 1'$. The ABC collects monitoring signals from the various subsystems and periodically sends them back to the control room. The control instructions and return telemetry information are sent on the same optical fibres and there are various displays for the user to ensure that the system is healthy. There is also provision for the main computer to take instructions from a user generated control file.

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

| | Frequency (MHz) | | | | |
|---|---|---|---|---|---|
| | 151 | 235 | 325 | 610 | 1420 |
| Primary Beam (Degrees) | 3.8 | 1.8 | 1.5 | 0.7 | $0.4 * (1400/f)$ |
| System Temperature (K) | 450 | 180 | 100 | 90 | 70 |
| Antenna Temp (K/Jy/Antenna) | 0.35 | 0.3 | 0.35 | 0.3 | 0.25 |
| 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 |
| Sensitivity for 1min, 1MHz(rms image noise mJy) | | | | | |
| Whole Array | 5.2 | 3.9 | 1.2 | 1.2 | 1.2 |
| Central Square | 10.4 | 7.8 | 2.4 | 2.4 | 2.4 |
| Usable Frequency Range (MHz) | | | | | |
| Reliable | ??? | 232 to 238 | 315 to 335 | 590 to 630 | 1000 to 1450 |
| With some Luck | 150 to 158 | 230 to 240 | 305 to 360 | 580 to 640 | 850 to 1450 |
| Fudge Factor(actual to estimated time) | | | | | |
| Short Observations | ? | 10 | 10 | 5 | 5 |
| Long Observations* | ? | 5 | 4 | 3 | 3 |
| Best rms Sensitivities while Imaging (mJy) | ??? | 1 | .5 | 0.2 | 0.05 |
| Typical Dynamic Ranges | ??? | 300 | 900 | 1000 | 2000 |

* For spectral observations fudge factor is close to 1

## 6. Present Status (as of May 2001)

All the antennas are functional and all the feeds are available except the 50MHz feed, though, at a given time 2 or 3 antennas may not be available for various maintenance works. One sideband of the 30 antenna correlator system is in operation and has been used for regular observation by local astronomers. The GMRT Array combiner is also operational and various aspects of the pulsar backend are being exercised. The system is being used for a variety of observations ranging from spectral line studies of red shifted hydrogen in the GMRT bands, continuum and spectral studies of galactic objects like HII regions, SNRs and the galactic centre, low frequency studies of clusters of galaxies, radio galaxies, nearby galaxies etc. The data from the GMRT is converted to FITS files and analysed in standard packages like AIPS. All observations, including continuum, are in the spectral mode and the data is being used for debugging the system and exploring the usable bandwidth at the various bands. A number of pulsar observations are also being carried out to test the diffent modes of the pulsar receiver.

While the GMRT is in operation and being used for observations, there are a number of modes that have not been implemented and problems that need to be solved. User rotation of the feed system is not allowed and the array cycles through the 4 feed system spending typically 2 months at each frequency. The interference environment is bad at 150 MHz and is also sometimes a problem at 235 MHz. Night time scintillation is not uncommon, even at 1400MHz and the probability of scintillation is higher closer to the equinoxes. Presently only a single sideband correlator is installed giving a maximum bandwidth of 16MHz. Polarisation observations are not possible till the second sideband correlator is installed. Walsh and Noise Cal modulation for real time Tsys measurements will also be available only after the second sideband correlator is installed and till then, absolute flux calibration in regions where the system temperature varies ( like the galactic plane ) is not automatic. Currently the elevation limit of the antennas is set at 20°.

In Table 1 we give the measured system parameters of the GMRT antennas and some idea of the useable bandwidth at the different frequencies. The table also gives the achievable sensitivity for different integration times including a fudge factor that takes into account ground realities which in time should reduce to 1.

**Acknowledgments.** The GMRT is the effort of many people, too many to be individually mentioned. The contributions made by sister organisations like the Raman Research Institute and the Reactor Control Division of the Bhabha Atomic Research Centre are gratefully acknowledged. I personally would like to acknowledge the contibutions of all my colleagues on whose behalf I have given this talk.

## References

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