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A Low Frequency Feed for Big Reflector Antenna

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Abstract. A novel low frequency dual polarized feed with symmetric pattern is presented for use in big reflector antennas. In this paper we describes the design, construction and characterization of a low frequency feed for GMRT antennas covering the frequency range 30-90 MHz as an example for the proposed feed. Two main goals of our design are, 1) to get a feed system in which the sky noise dominates the system temperature in the frequency range of interest, with reasonable aperture efficiency and symmetrical E & H plane patterns with the constraint that 2) its physical dimension is suitable for mounting it along with one of the existing feeds on the GMRT antenna turret, with minimum interference to its operation. In the first phase of this project, receiver systems consisting of V-dipole feeds and front-ends have been installed on four of the thirty GMRT antennas. Test observations were carried out on a number of bright 3C sources. The initial results are encouraging.

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1. Introduction

The main objective of the present work is to equip the big reflector antennas such as GMRT with a low frequency feed and receiver system in the frequency below 100 MHz and to use the system to image some selected regions of the sky visible to astronomers for carrying out astrophysical studies. There is a paucity of large aperture, high sensitivity, and synthesis instruments operating below 100 MHz.

The Giant Metre-wave Radio Telescope (GMRT) is a national facility available for observations at meter wavelengths. It is an interferometer array consisting of thirty, 45-m diameter antennas spread over 25 km, operating in the frequency bands 151, 325, 610/235, and 1000-1420 MHz; Receivers and feeds for operation at frequencies below about 100 MHz are currently not available. A 50MHz system for GMRT is being built in the Raman Research Institute, Bangalore, India as a first prototype of proposed feed.

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2. Characterization of feed

The frequency of operation (30 to 90 MHz) is chosen to facilitate imaging in a band around 38 MHz, protected for radio astronomy, to have an overlap with the 74 MHz system at the VLA, and to minimize the RFI due to the FM Radio band starting beyond 90 MHz. Another important design goal is to achieve symmetric antenna patterns, low side-lobes, and well-defined main lobe without the extended low-level off-axis response. Polarization performance in this frequency range is secondary. The design is constrained by the available space for the new feed in the present GMRT cubical turret. The available GMRT feeds occupy all the four faces of the turret.

The unique feature of the boxing ring configuration is that it has more symmetric radiation characteristics (E and H plane patterns) than a single dipole like feed. Here one pair of dipoles, combined as an adding type interferometer provides sensitivity to one linear polarization and another pair orthogonally oriented with respect to the first pair give sensitivity to the other polarization state.

The design parameters that one can tune to get a good performance of the feed are:

a) The distance between the two parallel dipoles in the boxing ring
b) The shape of the dipoles to achieve the required bandwidth.
c) The height of the dipoles above the reflector
d) The impedance mismatch at frequencies away from the resonance

A two-element interferometer with a spacing of $\lambda/2$ gives an H plane pattern, which is very similar to the E plane pattern. So it is appropriate to design the boxing ring with this dimension at the resonant frequency. Further it is known that a V-antenna in a boxing ring configuration has better symmetry in E & H plane patterns than a conventional half wave dipole. In addition more length can be accommodated in a given space and the inclination between two arms of the V-antenna can be used to control the beam patterns. A dipole with a ground plane has an increased gain but also has a different radiation pattern and impedance characteristics. As long as the height above the ground plane is less than λ/4, the gain increases and the shape of the radiation above the ground plane remains almost the same. In addition the impedance mismatch increases at lower frequencies but is compensated by an increased sky temperature and one can still have a system temperature dominated by the sky temperature.

The radiation pattern of a thin resonant dipole is sensitive to frequency variations. Several configurations, which provide broadband characteristics, have been discussed in the literature. Simple cylindrical dipoles are some of the most commonly used configurations to achieve broadband operation. Since the feed we are trying to design is at a low frequency we found that even to make a reasonably fat dipole was difficult in the space available.

The folded shape dipoles are chosen for each arm instead of thick dipoles since they have the same broadband characteristics of a fat dipole, easier to mount and have less metal structure relative to a fat dipole. On the other hand by folding the dipole the input impedance increases to a value of ~300Ω, and needs an impedance matching network when used with a 50Ω system. However, the need for broadband performance of the balun is not stringent since some mismatch at lower frequencies can be accepted.

3. Description of the feed

The low frequency feed consists of four V-Dipoles measuring 2.4m in length placed on four sides of the extended reflector plane of the 327MHz feed (Figs. 1 & 2). This is the longest dipole that can be accommodated in the present turret. By its length its resonant frequency is 62 MHz and is very close to the desired resonance at 60 MHz. The feed point of the dipole is positioned 1-meter above the reflector. For a resonant frequency of 60 MHz, this should have been ideally 1.25m (h=λ/4). The present value of h=1m (λ/5) does not affect the pattern much[1]. The reflector plane used is a 3m X 3m square with a 50mm mesh on the extended dimension. The existing 327 MHz feed with the mesh gets inscribed into this with the aid of four clamps.

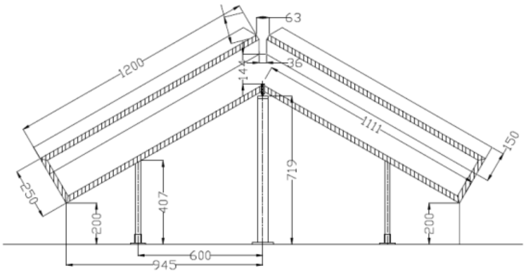

Fig. 1: Low Frequency inverted V-Dipole (dimensions are in millimeters)

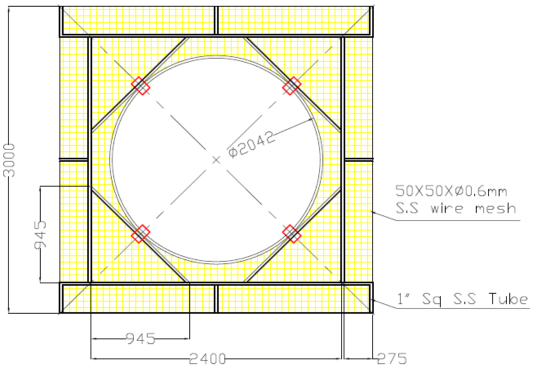

Fig. 2: The extended reflector plane of GMRT low frequency feed

4. Construction and Measurement

Models of the dipoles were constructed using thin aluminum tubes (Fig. 3) and simulated using NEC based method-of-moments (MoM) code, taking into account the properties of ground plane.

After fabrication the return loss measurements were carried out using a network analyzer. The best response is around 60 MHz, with a return loss of around –25dB. At 38 MHz we have a return loss of around –6 dB and at 80 MHz around –10dB. A VSWR < 2 is achieved over the frequency range 55 to 80 MHz.

We also carried out return loss measurements of the 327 MHz feed with & without the LF Feed on the same ground plane[2]. Plots of return loss measurements indicate that in the presence of LF Feed the return loss of 327 MHz feed changes from –15.3dB to –14.8dB at the band center. The changes through out the operating frequency range are of this order. These are within tolerable limits for mutual coupling between the two feeds as measured by the VSWR.

In the first phase of installation feeds were installed on two central square GMRT antennas (C04 and C11 antennas). Following this, observations were carried out in self and cross pointing modes. Subsequently, LFD's were also installed on two more antennas on west arm (W02) and east arm (E02). Self and cross pointing observations were repeated on all the four antennas. The maximum east-west baseline is around 6 km, while the north-south baseline is around 0.5 km.

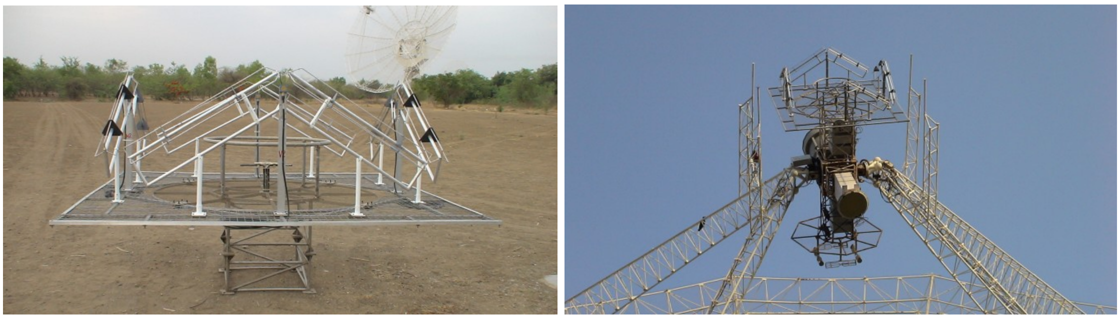
(a) (b)

Fig. 3(a) Four folded V-dipoles, each ~ 2.4 m length. The feed point is positioned 1 m above a 3 m × 3 m square reflector with a 50 mm mesh. (b) The feed co-located with the existing 327 MHz GMRT feed.

5. Test observation with the new feed system

In September 2007, several 3C sources (including Cyg-A and Cas-A) were observed using the existing GMRT receiver system. Observations of Cyg-A, centred at 55 MHz, for an hour showed:

- Aperture efficiency of 65%. This is based on the expected background temperature given by Milogradov-Turin and Smith (1973) and the flux density of Cyg-A given by Baars et al. (1977).
- The rms noise observed in a single channel, with a bandwidth of 31.25 kHz, is 6% of the flux density of Cyg-A.

- The RMS of closure phase is 1.5°, which is as expected for a measured SNR of 17 on the amplitude measurement of Cyg-A in each baseline.

Test observations carried out at GMRT showed that improvement in signal-to-noise ratio as a function of bandwidth and integration time was not forthcoming when observed using the existing GMRT receiver chain [3]. This is a well known issue with GMRT continuum observations at other frequencies also. The SNR saturated at a value of 17 for all the observed baselines. While the reasons for this were not clear, RFI was suspected to be one of the causes. To study if this limitation could be overcome by digitizing the outputs of the low frequency front-end receivers right at antenna bases, direct voltage recording systems were developed.

6. Conclusion

A novel low frequency dual linear polarized feed for GMRT, operating in the frequency range 30 – 90 MHz, has been designed and manufactured. It has a VSWR less than 2 in the frequency range 50 – 90 MHz. In spite of mismatch at lower frequencies, its performance will be in a regime where the sky noise dominates system temperature. The feed provides low side-lobe level better than –12 dB. It is also shown very symmetric pattern with constant beam width and aperture efficiency of around 50% at lower band and 70% at higher band. The VSWR measurements and the simulations of beam patterns along with space constraint indicate that best place for Low Frequency Feed in GMRT antenna turret is to co-locate this feed along with the existing 327 MHz feed. In this paper we have also described the results obtained from the test observations carried out using the Low Frequency Feed, recently installed on 4 GMRT antennas.

Acknowledgment

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References

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