A Low Frequency Feed for GMRT

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Abstract

A novel low frequency dual polarization feed with symmetrical E&H plane patterns is presented for use in reflector antennas. In this paper we describe the design, construction and characterization of a low frequency feed for GMRT antennas covering the frequency range 30 to 90 MHz. Main goals of our design are, 1) the 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, 2) the feed has symmetrical E & H plane patterns with reasonable aperture efficiency ($0.5 < \eta_{ap} < 0.7$), and 3) the sky power transmitted from feed to receiver dominates the system temperature ($T_{sky} > 5\ T_{Rec}$) in the frequency range of interest. Currently four GMRT antennas are equipped with these low frequency feeds. Preliminary testing indicates that we have met most of our design goals.

1. Introduction

Receivers and feeds for operation at frequencies below about 100 MHz are currently not available at GMRT. The main objective of the present work is to equip GMRT with a receiver system in the frequency band 30 to 90 MHz and to use the system to image some selected regions of the sky visible to GMRT for carrying out astrophysical studies.

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 ~ 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.

2. Considerations for feed location

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. Simple geometrical and optical considerations ruled out the possibility of using the 21 cm horn and dual frequency feed (610/233 MHz) faces. To study the effect of co-locating Low Frequency feed (LF feed) with the existing 150 or 327 MHz feeds, we used field trials for VSWR measurements and simulations for the beam pattern. The VSWR measurements were carried out with an experimental dipole. Our measurements showed that the mutual coupling effects are negligible if the LF feed is co-located with the 327 MHz feed. Simulation of beam patterns of the 327 MHz feed surrounded by four dipoles in a boxing ring configuration clearly indicate that the illumination pattern almost remains unaffected by the presence of the LF feed. With these observations we decided to make the full prototype of the LF feed with four dipoles in boxing ring configuration which can be co-located with the 327 MHz feed.

3. The Feed Design

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 and
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. Our research studies indicate 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. As long as the height above the ground plane is less than λ/4, the effective gain increases and the shape of the radiation pattern above the ground plane remains almost the same. As the distance increases to 3λ/8, the pattern starts to split and at a height of λ/2, the pattern splits into two symmetrical lobes. Thus to ensure a well-behaved radiation pattern it is necessary to have the resonant frequency of operation close to 2/3^{rds} of the highest frequency of operation. Thus we chose a resonant frequency of 60 MHz, since we are interested in an operating frequency close to 90 MHz at the higher end. This resonant frequency is an octave away from the lowest frequency of operation. This does not affect the system performance, as the dipole tends to be a Hertzian dipole as the frequency decreases and its effective beam pattern does not change much. However the impedance mismatch increases at lower frequencies. Fortunately this loss is compensated by an increased sky temperature at low frequencies 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. Biconical antenna, its geometrical approximation to a triangular sheet antenna (or a bowtie antenna) or 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.

We have chosen folded dipoles for each arm instead of thick dipoles since they have the same broadband characteristics of a fat dipole, but are much 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.

4. Construction 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 illumination pattern much. 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. The photographs of dipoles are shown in figure 3.

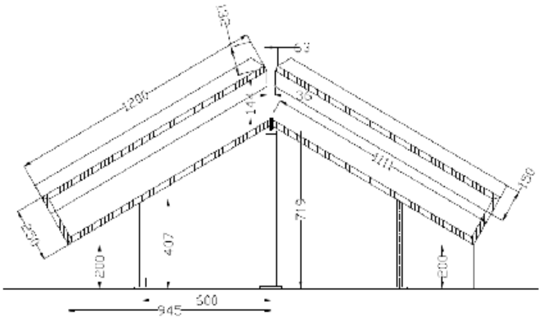

Fig. 1: Low Frequency inverted V-Dipole

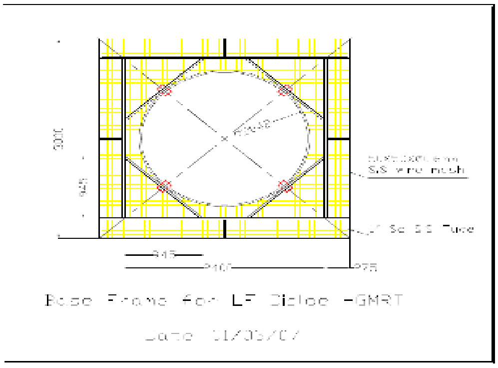

Fig. 2: The extended reflector plane for Low Frequency feed

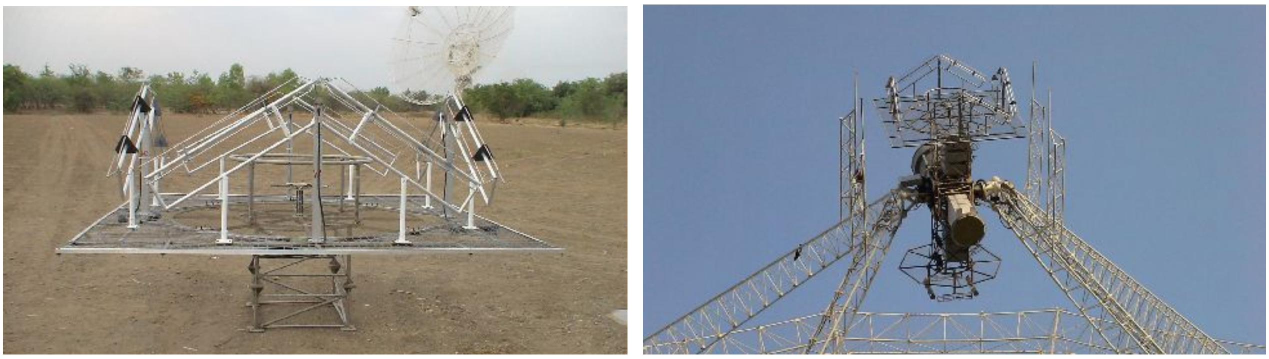

Fig. 3. Low Frequency Feed in boxing ring configuration co-located with the existing 327 MHz GMRT feed with extended reflector. The picture to the right shows its mounting on the turret of a GMRT antenna.

5. Testing

After fabrication the return loss measurements were carried out using a network analyzer. Figure 4 shows the return loss response of LF Feed. A VSWR < 2 is achieved over the frequency range 80 to 55 MHz. As one comes down in frequency the mismatch increases. A survey of the radio background at 34.5 MHz by Dwarakanath and Udaya [1] shows that the coolest region of the sky that we may encounter with a GMRT dish has a temperature of ~5000K. T_{sky} can be approximately modeled as $T_{sky} \sim 5000\,(34.5/f)^{2.5}$,where f is observing frequency in MHz. Figure 5 shows the sky temperature as a function of frequency given by the above equation. The figure also shows the amount of sky temperature coupled to the feed taking into account the mismatch. One can see from the figure that if one uses a LNA with a noise temperature ~200K, the contribution from the receiver will be utmost 20% of the system temperature for all frequencies below 80 MHz. This is a satisfactory solution. However the first prototype has been built using an amplifier with a 300 K noise temperature. This will degrade the system performance to a certain extent [2]. It will be improved in the subsequent versions.

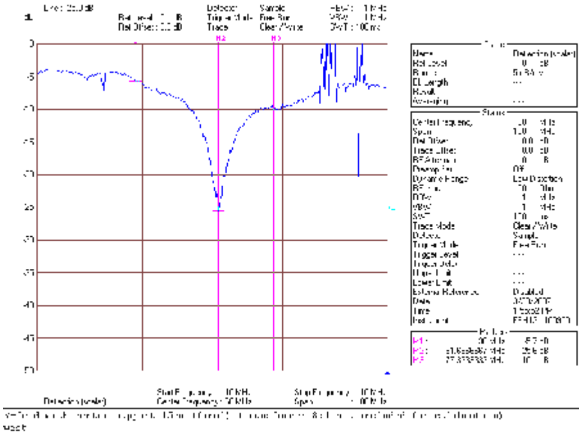

Fig. 4 : Return Loss measurement of the L F Feed in the presence of 327 MHz feed.

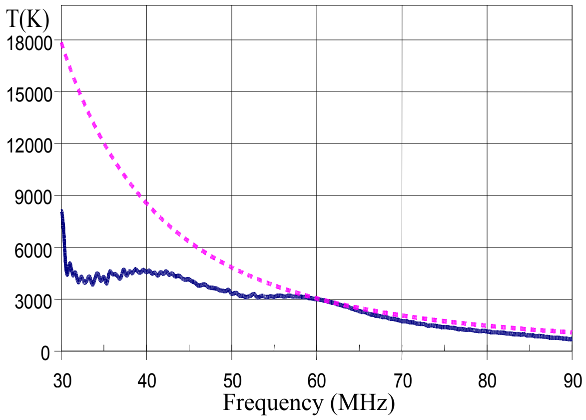

Fig. 5: A plot of the temperature of the Galactic radio background . The solid line is obtained by scaling the sky temperature by the expected coupling efficiency of the LF Feed. The coupling efficiency is obtained from the return loss measurements shown in figure 4.

LF feed has been installed on four GMRT antennas. The antennas which are equipped with LF feed are C04, C11, E02 and W02, giving a maximum NS baseline of ~ 0.5 km and a maximum EW baseline of ~ 5.7 km. The full widths at half maxima of primary beams of the four antennas were measured using cross-pointing scans on Cygnus A. Figures 6A and 6B show amplitude and phase response of an elevation scan on Cyg-A. It is important to note that the constancy of the phase in the primary beam is within reasonable limits.

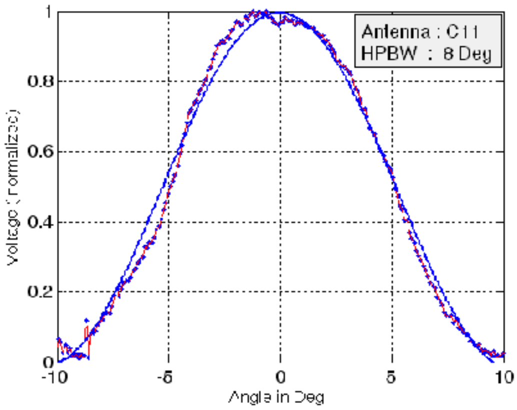

Fig. 6A: Elevation scan of C11 antenna observed using Cyg A. Frequency=53 MHz , Reference antenna= C04, Resolution Band Width=62.5 KHz.

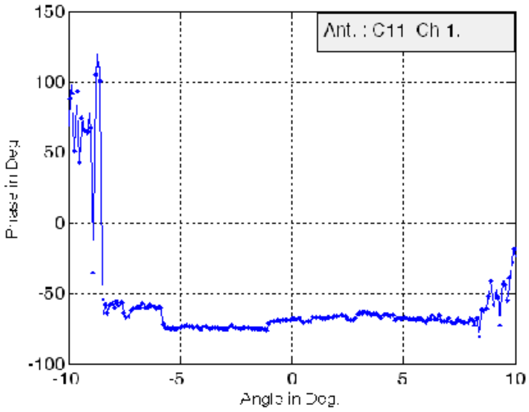

Fig. 6B: Phase response of C11 antenna during the elevation scan.

The table 1 shows the HPBW, Side Lobe Level (S.L.L.) and the edge taper as per the theoretical calculation for a dipole (first row), by simulation using NEC code (second row) and assuming a parabolic taper on a Pedestal (third row). The measured HPBW and S.L.L. for different antennas are also shown in the table (fourth row). While some of the observations show that the HPBW is very close to which is expected (~10°); there are a few observations where the HPBW observed is 20% lower than expected. More observations are required to obtain better statistics.

An estimate of aperture efficiency was carried out in the resent test observations [4] on Cygnus A. The measured average values of aperture efficiencies are 0.25 and 0.6 at 40 and 60 MHz respectively.

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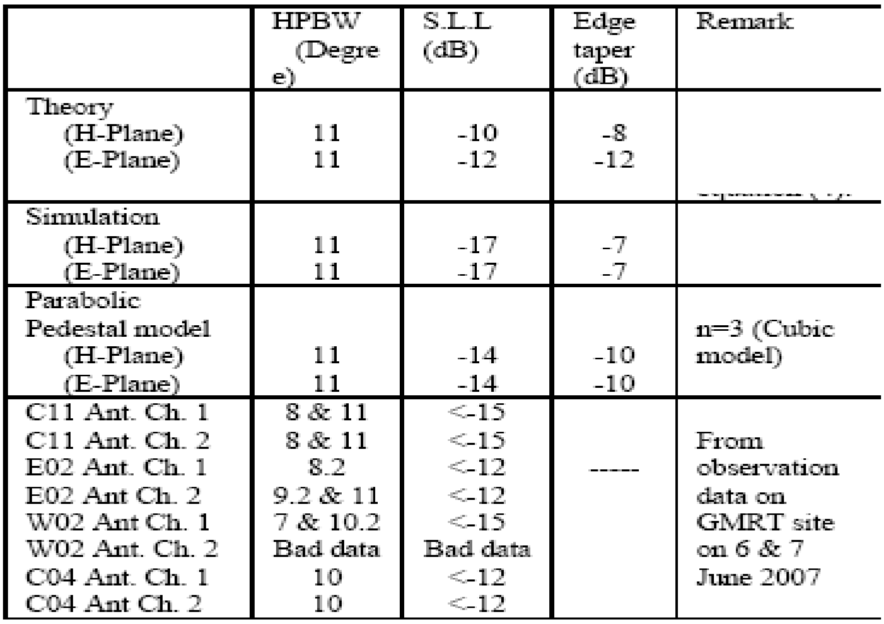
Table 1: The summary of results from patterns measurements on GMRT site.



	HPBW (Degree)	S.L.L (dB)	Edge taper (dB)	Remark
Theory				
(H-Plane)	11	-10	-8	
(E-Plane)	11	-12	-12	
Simulation				
(H-Plane)	11	-17	-7	
(E-Plane)	11	-17	-7	
Parabolic Pedestal model				n=3 (Cubic model)
(H-Plane)	11	-14	-10	
(E-Plane)	11	-14	-10	
C11 Ant. Ch. 1	8 & 11	<-15	-----	From observation data on GMRT site on 6 & 7 June 2007
C11 Ant. Ch. 2	8 & 11	<-15		
E02 Ant. Ch. 1	8.2	<-12		
E02 Ant Ch. 2	9.2 & 11	<-12		
W02 Ant Ch. 1	7 & 10.2	<-15		
W02 Ant. Ch. 2	Bad data	Bad data		
C04 Ant. Ch. 1	10	<-12		
C04 Ant Ch. 2	10	<-12		

6. Conclusion

A novel low frequency dual polarization feed, operating in the frequency range 30 – 90 MHz, has been designed, fabricated and tested on four GMRT antennas. It is co-located along with the existing 327 MHz feed. 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 the system temperature. The feed provides side-lobe level better than –12 dB. It also shows symmetric pattern with constant beam width and an aperture efficiency of around 25% at lower band edge and 60% at the band center. More observations are planed to gain a better understanding of the system.

5. Acknowledgments

We thank our colleagues at NCRA/GMRT for their help and cooperation during the installation and testing phases on site.

6. References

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