# Design and Development of a 12m Preloaded Parabolic Dish Antenna

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## Abstract

This paper describes the developmental work carried out at the Raman Research Institute (RRI) to evaluate the Preloaded Parabolic dish (PPD) concept. The design studies undertaken to build a 12m PPD, the design of its mount, the challenges faced during the fabrication and installation, and the measurements carried out to establish the surface accuracy of the dish are described.

## 1. Introduction

Conventional designs for parabolic dishes costs an order of magnitude higher than parabolic cylinders of an equivalent collecting area. This in the past has lead to exploration of new designs for parabolic dishes. Swarup and his collaborators [1, 2, 3, 4] evaluated two new and innovative design concepts for construction of parabolic dishes: 1. The pre-loaded parabolic dish concept (PPD), and 2. The Stretched Mesh Attached to Rope Trusses (SMART) concept. After a detailed simulation and experimental studies the SMART concept was adopted for GMRT.

Initial studies had indicated that PPD is a better choice for 12 to 15m class antennas. At the Raman Research Institute (RRI), the PPD concept has now been taken to the stage of a functional 12m radio telescope operating in the cm wave band. It is installed at the Gauribidanur field station, situated 80 Kms away from Bangalore.

## 2. Basic design concept of a PPD Antenna

The preloaded concept is based on the principle that if a structure has an initial stored strain energy, then under certain conditions, it has the capacity to offer a larger stiffness for the same weight to additional external loads. In the present invention, this concept has been applied to the design of the backup structure of a 12m dish antenna in order to reduce its weight while retaining the required stiffness properties [1, 2].

In addition to this, the other attractive feature of this design is that the process of elastically bending a large tube to preload it results in a curve, which is nearly a parabola. This gives the advantage of eliminating the process of separately forming the backup structure of a parabolic dish and thus reduces the overall fabrication cost.

### 2.1 Configuration of 12m PPD

The 12m PPD consists of 24 radial members, which are elastically bent and supported on a central hub with tapered blocks. These radial members are connected to each other at the other end using straight tubular members placed circumferentially at the rim of the dish. These members prevent the spring back of radial members. To obtain additional rigidity against wind and gravitational forces intermediate straight tubular members also connect the radial members. They also provide support for the quadripod that hosts the feed. The elastically bent radial members results in a curve, which is nearly a parabola on which the reflecting panels are mounted using studs to compensate for the deviation from the desired parabola.

### 2.2 Design specifications and constraints

The design specifications and constraints considered for the structural design of the 12m PPD are listed in Table1. The structural design process [4, 5] taking into account the above overall requirement resulted in dimensions for various members as given in Table 2. The most important result of the design process is that one needs material of strength 60 $Kg/mm^2$ for the dish. [4]. Stainless steel (S.S.) was recommended, as the preferred material for its corrosion resistant and impact resistant properties. S.S. pipes do not require painting, which leads to maintenance free operations and hopefully an aesthetic look.

Table 1: Design specifications and constraints of the 12m PPD

| | |
|---|---|
| **Design specifications** | |
| Dish diameter | 12 m |
| Dish focus from parabola apex | 4.8 m (f/D = 0.4) |
| Hub diameter | 4 m |
| Wire mesh-Reflector surface | 6 mm x 6 mm x 0.55 mm |
| Design wind speed | 150 kmph |
| Maximum mass at focus | 100 kgs |
| Wind area at focus | 1 $m^2$ |
| Elevation axis offset | 400mm |
| **Design constraints** | |
| The spoke maximum permissible load | 60% of allowable stress |
| The spoke maximum permissible tension | 60% of allowable stress |
| The spoke maximum permissible compression | 50% buckling stress |
| Dish lowest natural frequency | >2 Hz |

Table 2. Component specifications

| **Component** | **Dimensions** |
|---|---|
| Spoke (Radial members) | S.S Seamless tube of OD= 40mm,ID =24mm and L= 4534mm |
| Circumferential member | S.S Seamless tube of OD= 40mm,ID =24mm and L= 1557mm |
| Inter Bracing member | S.S Seamless tube of OD= 40mm,ID =24mm and L= 962mm |
| Quadripod | S.S Seamless tube of OD= 50mm,ID =34mm and L= 5450mm |

## 3. Material preparation

Market survey revealed that only 54 mm outer diameter (OD), 7.5 mm thick Austenitic Steel tubes with Yield strength of 40 kg/mm$^2$ were available. These specifications are not adequate for our application. A study on the fabrication methods of seamless tubes revealed that the desired mechanical/physical properties could be achieved by cold drawing. In our case, the commercially available 54 mm OD tubes were cold drawn in four stages of 50, 45, 42, 40 mm. It was annealed after 50 mm to bring it back to the ductile state (workable) and to meet the required yield strength of 60 kg/mm$^2$.

It was important and desirable to understand the structural properties of the members used in the fabrication of the 12m PPD antenna. In view of this the following tests were conducted on the sample tubes: tensile test, 3-point bending test and residual stress measurement using Rigaku Strain flex X-ray Analyser. Tensile test indicated that the spoke members had a yield stress of 74 Kg/mm$^2$, much higher than the requirements. The bending stress obtained from 3-point bending is 83.33 kg/mm$^2$. The residual stress measurement indicated that the axial and circumferential stresses are -135 MPa and 121 MPa respectively at a depth of 225 μm, which are acceptable for the components of a dish [4, 6].

### 3.1 Design of Panels

To operate the antenna in cm wave band the mean radial facet error should be of the order of 1 mm. This is possible if 12 planar facets were used along each radial sector. Having 12 planar facets between any two radial members is very unwieldy, so we designed five parabolic shaped panels to fit between any two radial members. Four are mesh panels (see Figure 1a) that gives the effect of 12 Planar facets (The two outer mesh panels have 3 X 4 structure where as the two inner mesh panels have 3 X 3 structure) and one is solid panel (see Figure 1b).

a b c d

Figure 1: Reflector elements and dish assembly. (a) Mesh panel, (b) Aluminium panel, (c) assembled back up structure, and (d) completely assembled PPD telescope.

Mesh Panels are made using tubular frames of S.S. seamless tubes 6 mm OD with 1 mm thick; S.S. wire mesh of 6 mm x 6 mm x 0.55 mm diameter is used as reflecting surface. The solid panel frames are made of aluminium 'T' section (37 mm x 37 mm x 3 mm thick). Aluminium sheet of 1.5 mm thick provides the reflecting surface.

## 3.3 Fabrication methodology

The major steps involved in assembling the PPD are:

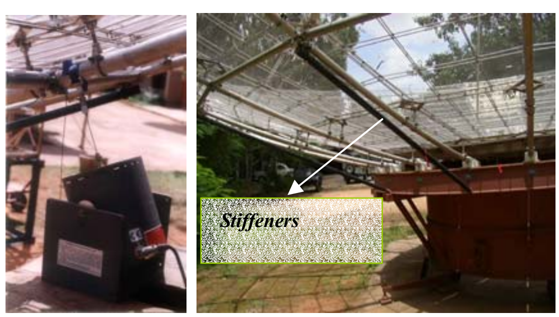
1. Bending the radial spokes to prestress them,
2. getting the circumferential members, inter bracing members and quadripod in place,
3. mounting the panels on the spokes, and
4. adjusting the heights of the studs supporting the panels to get the desired shape. (refer Figure 1c).

The entire assembly of the dish takes approximately 15 man days (8 hr/day).

After several trials the procedure recommended is to use turn buckles for initially getting some lift of the radial spokes and then use vertical poles with shims to get the required level of bending. With these supports one can get the outermost circumferential members in place and then release the vertical loads by removing the vertical poles one at a time. During this phase one has to ensure that the poles remaining at any time are almost uniformly distributed. This is necessary, as the PPD configuration does not have one stable state and can relax in several stable states retaining the same perimeter.

## 4. Modal Analysis

Modal analysis is a procedure to determine the structure's dynamic characteristics such as resonant frequencies, damping ratio and mode shapes [7, 8]. The impact hammer test indicated that the resonant frequency of the dish without panels is about 1.05 Hz whereas with the panels assembled it is about 2 Hz which is lower than expected and hence the stiffness of the dish needs to be increased. Based on the above results it was decided to install 12 stiffeners between the central hub and the alternate spokes (refer Figure 2b)




a b

Figure 2: Modal analysis of the dish. (a) Modal shaker, and (b) stiffeners.

After installing the stiffeners a Single Input Multiple Output (SIMO) testing was carried out on the dish (see Figure 2a). The results indicate that the resonant frequency is about 2.2 Hz and the average damping ratio is 0.978. This indicates that our structure is lightly damped i.e., the system is under-damped [7, 8]. This satisfies our design requirement.

## 5. Surface Accuracy measurement

After carrying out the modal analysis in RRI, Bangalore campus, the dish was disassembled and the sub-assemblies were transported to the Gauribidanur (GBD) field station. The complete dish was reassembled in GBD. The surface accuracy measurements of the wire mesh panels were carried out using a PENTAX, ETH-105A theodolite (5-arc second accuracy). The theodolite was placed at the center of the antenna and measurements of approximately 864 targets (azimuth and elevation) were taken placing the theodolite at two different heights. From these measurements a three dimensional (3-D) best fit paraboloid was determined. The residues had an RMS (root mean square) of ~4.1mm. When the dish surface area was weighted by the radiation pattern of the feed used the effective RMS was found to be 3.3mm.

## 6. Mount Design

Design studies were carried out for the mount of the 12m PPD. An Alt-Azimuth type mount was designed with slew ring bearing for the azimuth axis drive and a sector gear for the elevation axis drive. After successful installation, the azimuth and elevation axes were driven in closed loops using a control system developed in house. This is based on a Linux based PC acting as the position controller.

Considering weight/area as the figure of merit for a given concept of designing parabolic dishes, an interesting observation can be made here. The weight of the GMRT dish is 36 tons whereas the weight of the 12m PPD is 3 Tons. The weight of GMRT mount is 104 tons whereas the weight of 12m PPD mount is 16 tons. This indicates that the figure-of-merit of a 12m PPD antenna is 15% better than a GMRT antenna. Our present studies indicate that the cost/area hits a minimum for a 15m PPD and is $550 per square metre.

## 7. Present status

After the installed mechanical system passed the preliminary tests, the cable wrap, a 4-8 GHz cassegrain feed, and receiver system were installed and test observations were carried out. A photogrammetry measurement exercise was conducted in collaboration with the Indian Space Research Organisation (ISRO), Bangalore. Using this data we have measured the surface accuracy and gravitational deformation of the dish. Preliminary results show a surface RMS (weighted) of ~6 mm. It has also shown that several panels require realignment. After a detailed analysis of the photogrammetry data and carrying out remedial measures if required, estimation of aperture efficiency in the 4-8 GHz frequency range will be carried out using astronomical sources.

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