PRELOADED PARABOLIC DISH ANTENNAS FOR THE SQUARE KILOMETER ARRAY

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SUMMARY

A novel and economical concept has been developed for a parabolic dish antenna, which can provide a very large collecting area, over a wide frequency range, for SKA at an affordable cost. The backup structure of the parabolic dish is considerably simplified by preloading its structural members. A set of high tensile tubular members are clamped rigidly to a central hub, bent elastically to lie close to a parabolic curve and then bolted at the far end to the same number of straight tubular members placed circumferentially along the rim of the dish. A similar number of straight structural members are also clamped circumferentially at one or more intermediate locations. This results in a rigid framework of the backup structure of a preloaded parabolic dish (PPD) antenna. It is important to note that all the structural members are suitably prestressed in order to store in them sufficient initial elastic energy for enabling them to resist gravitational and wind forces under operational and survival wind

conditions. The preloaded design minimizes inertia and wind loads on the dish. It also allows rapid fabrication of the antenna. Static and dynamic finite element analysis has been made to develop a detailed design of a 12 m dish. Preliminary studies have also been made for a 25 m dish.

A 12 m diameter preloaded parabolic dish antenna has been fabricated at the Raman Research Institute (RRI), Bangalore. Its reflecting surface consists of panels made of welded stainless steel wire mesh of size 6 mm x 6 mm x 0.55 mm with rms error of about 2 mm. Therefore, the 12 m dish is expected to operate upto about 10 GHz although with a reduced efficiency at the highest frequency. Economical designs are now being developed by RRI for the mechanical and servo drive system of the 12 m dish which will be fully fabricated and tested by mid 2003. Present cost estimate for 8000 nos. of fully steerable preloaded parabolic dish antennas of 12 m or 5000 nos. of 15 m diameter for operation upto about 10 GHz is about US $ 500 million. Possibility of extending its operation from 30 MHz to 22 GHz is also discussed briefly in this report.

The new concept of the “Preloaded Parabolic Dish antenna and the Method of Making It” is described in detail for a 12 m diameter dish, as an example, in the Patent application No. 721/MUM/2000 dated 1st August 2000 filed in India by Swarup and Tapde, and Patent application No. PCT/IN 01/00137 dated 30th July 2001 filed by the above authors under the International Patent Corporation Treaty (PCT) of the World Patent Intellectual Organization (WIPO) & published as reference No.WO 02/13314 A2 dated 14.02.2002/Serial 1806 (www.WIPO.org)

1. Introduction

It is indeed a very challenging task to design an economical antenna system for the Square Kilometer Array [1] for covering a wide frequency range, good polarization characteristics, low system temperature and steerability over a large area of the sky.

Parabolic dishes have been used quite widely for the antenna system of radio telescopes as they have point focus, which makes it possible to obtain low system temperature and good polarization characteristics over a wide frequency range. Also, it is possible to cover a large area of the sky. However, conventional designs of parabolic dishes are quite expensive, e.g. the cost of each of the ten 25 m parabolic dish antennas of the Very Long Base Line Array (VLBA) using accurate Al panels for the reflecting surface, was about US $ 2.3 million in 1987 (about $ 5000/m^2). The VLBA dishes can operate upto about 44 GHz. The present cost of a VLBA type antenna is likely to be about US $ 4 million. The cost of a parabolic dish antenna of diameter d is expected to scale as $d^{-2.5-2.7}$, as has been suggested empirically by many workers. The cost also depends upon the shortest wavelength of operation, perhaps scales as $\lambda^{-0.25}$ for a similar basic design, but using stiffer back up structure, and Al panels and mechanical/electrical drive system of higher tolerance. It may be noted that the back-up structure of conventional parabolic dishes, as well as GMRT, are quite labour intensive as they require considerable effort in assembly and welding of the structural members.

Being located outdoors, parabolic dishes are subjected to large forces due to wind and must be designed for survival wind velocities. Force, F, due to wind is given by $F = p.A.\ C_d$, where p is pressure of wind, A is area and C_d is drag factor. For a parabolic dish antenna with the reflecting surface panels made of solid Al sheet, $C_d \simeq 2$. Actually wind forces and torques depend on the orientation of the dish [2]. For reflecting surface made of wire mesh, the value of C_d for the dish can be decreased to = 0.25 - 0.3, depending upon the wire mesh size.

For the 30 Nos. of 45 m diameter parabolic dishes of the Giant Metrewave Radio Telescope (GMRT) [3] , we used a so called `SMART' design, i.e. Stretched Wire Mesh Attached to Rope Trusses. The mesh size is 10 mm x 10 mm, 15 mm x 15 mm and 20 mm x 20 mm for the inner, middle and outer one-third area of the GMRT parabolic dishes. The mesh is made of stainless steel wire of 0.55 mm diameter and is made in automatic machines using resistive arc welding. The cost of each of the 45 m diameter dish was about US $ 300,000 at 1993 prices. Although labour cost is much lower in India, material cost is higher in India than prevalent internationally. The possibility of using GMRT type design for SKA is discussed by Swarup [4].

In order to further simplify the backup structure of a parabolic dish antenna, a novel concept of preloading its structural members has been developed, and it is called as Preloaded Parabolic Dish Antenna (PPD). The members of the PPD are mostly bolted and thus minimize the labour involved in its assembly. It is important to note that all the structural members are provided suitable prestress in order to store in them sufficient internal strain energy so that their stresses remain within the specified bounds as per the national codes for structures under conditions of the specified operational and survival wind velocity.

The basic principle of the Preloaded Parabolic Dish antenna is described in Section-2. In Section-3 are given details of a 12 m parabolic dish which has been fabricated and assembled at the Raman Research Institute (RRI), Bangalore. The detailed design of the 12 m PPD antenna is based on computer calculations made by Professor Ashok Joshi of the Indian Institute of Technology, Mumbai. Prof. Joshi has also made a preliminary design of a 25 m PPD antenna and results are also summarized in Section-3. Procedures used for fabrication of the 12 m dish are described in Section-4.

The mount for the 12 m dish and its mechanical and electrical (Servo) system is being developed by the Raman Research Institute and different concepts being examined by a Consulting Engineering firm are briefly discussed in Section-5. Preliminary estimates have been made for the cost of the mount and drive system which seems to form a major part of the PPD antenna.

A Strawman's design for the SKA using Preloaded Parabolic Dish Antenna is described in Section-6 including preliminary cost estimates. Discussions are given in Section-7 and Conclusions in Section-8.

2. Basic design aspects of the Preloaded Parabolic Dish (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 large stiffness to additional external loads. In the present invention this concept has been applied to the design of the backup support structure of a dish antenna in order to reduce its weight while retaining the required stiffness properties.

In the preloaded parabolic dish (PPD) antenna several straight radial members are supported on a central hub and are bent by a normal force at their tips, which generates bending strain energy in each of the members. A large number of such members are bent and then connected to each other at their tips through straight tubular members placed circumferentially at the rim of the dish which prevent the springback of the bent members. Thus, a skeleton of the bent radial members that are prestressed by the bending load applied by the rim members at their tips, is obtained which resembles the configuration of a parabolic dish. By selecting a suitable geometry, the curvature of each of the elastically bent radial members is made nearly the same as the curvature of the required parabolic dish antenna at its location. The amount of bending (or the preload stress) is greater than or equal to the maximum stress that is expected to be carried by the radial members under the survival wind conditions. Such a structural configuration shows enhanced insensitivity to the external gravitational and wind loads due to storage of internal strain energy. For obtaining additional rigidity against wind and gravitational forces and also vibrational instabilities, the radial members are also connected to one or more sets of bracing structural members at intermediate locations.

In order to minimize wind loads on the structural members, it is preferred to use tubes or pipes for the structural members which have low wind drag factor, C_d.

The reflector panels that are light in weight and also have low wind loading are fabricated by means of making stainless steel frames using thin tubes or channels and then fixing welded wire mesh of appropriate mesh size and made of stainless steel wires of suitable diameter depending upon the highest frequency of operation of the preloaded parabolic dish.

Alternatively, the conventional reflector panels made of solid or perforated metal or metallized-plastic sheets are used. One may use panels made of metal sheets or pressed parabolic dish for the central part of the preloaded parabolic dish, and wire mesh or perforated sheets for the outer part in order to reduce wind loads yet allow operation upto about 22 GHz.

3. Detailed Description of the 12 m Preloaded Parabolic Dish Antenna.

3.1 ***Design Procedure***

Fig. 1 (a) shows a single structural member that is bent by a preload P_s . After the bending, the tip of the structural member is anchored to a stationary point `S', with the help of another elastic member. At this point the preload is removed, which results in the relaxed shape of the structural member but results in the tensile straining of the Anchor member. However, as the Anchor member is fairly rigid in the axial direction, there is no significant reduction in the preload and the combined system attains an internal elastic equilibrium (Fig. 1(b). In the preloaded parabolic dish, the above anchoring is provided by the circumferential rim members which are considered fairly rigid in the axial direction of the tube and this is the actual configuration of the backup structure of the parabolic dish antenna under the zero wind condition.

It may be noted that when the wind forces act from the front (concave) side of the dish, its shape will be maintained because the rim and bracing members which are fairly rigid, will take all the wind load and the radial members will act as simply supported beams with marginal distortion of their shape. In the event of wind coming from the back (convex) side, the dish will retain its original shape as long as the kinetic energy of the wind forces is less than the stored internal strain energy. In fact this is used to decide the amount of preload strain energy in order to ensure that this condition is always satisfied. However, in case wind forces do exceed the preload, the difference is supported by the rim and bracing members which can take significant amount of compressive load and prevents any significant distortion of the shape of the dish. Finally, it may be noted that while the primary intention of preload is to provide an initial strain energy, the process of bending the radial members results in a curve which is nearly a parabola. This gives the additional advantage of eliminating the process of separately forming the parabola and, thus, reduces the overall fabrication cost of the antenna.

In Fig. 2 is shown details of a preloaded parabolic dish antenna of a 12 m circular diameter. The preloaded antenna consist of a hub, curved radial members, straight rim members of the outer circumferential ring**,** straight bracing members of the intermediate circumferential ring, a quadripod, inner ring and reflector panels. The radial members , rim members and bracing members are joined together rigidly using clamps, joints and other gadgets. Inside the hub the antenna has inner curved radial members connected to a ring at the centre.

The back-up structure of a parabolic dish incorporates a hub for the purpose of its connection to a drive system mounted on a yoke and a tower for supporting the dish. In practice, the diameter of the hub varies from about 1/4 to 1/2 of the diameter of the dish. In the present example, the hub has a diameter of 4m i.e. 1/3rd of the dish diameter. The design of the inner parabolic dish between its apex and hub is relatively straight forward and is based on conventional practice.

It may be noted that the rim members connected at the periphery of the dish and also the bracing members at intermediate positions of the radial members form a polygon, as all these members are straight structural members. Since there are 24 radial members, the polygon is nearly circular for all practical purposes.

For the said 12 m diameter parabolic dish described in this embodiment, a welded wire mesh was selected for the reflecting surface for minimizing the wind loads, which results in considerable economy. The wire mesh has a size of 6 mm x 6 mm and consists of stainless steel wire of 0.55 mm diameter which allows operation of the dish upto about 10 GHz. Finer wire mesh or perforated metal sheets or metallic plates may be used for operation at higher frequencies. One may use panels made of metal sheets or a pressed parabolic dish for the central part of the dish and wire mesh or perforated sheets for the outer part in order to reduce wind loads yet allow operation upto about 22 GHz.

It may be mentioned that the initial setting angle, θ_h , of the radial members at the hub is an important parameter that affects (1) the magnitude of the preload and (2) the deviation between the shape of the bent radial members and the exact parabola. Further, it is to be mentioned here that if preloading of the radial members is to be reduced, pre-curved radial members can be used which reduce the extent of the elastic deformation and the preload or prestress. However, then the advantage of the stored internal strain energy is lost to some extent and it is necessary to understand the trade-off between these two for deciding to use the straight or the pre-curved radial members. Finally, the design of the radial member is subject to the condition that the deformed shape must always lie below the exact parabola because the deviations then can be exactly covered using adjustable bolts, leading to a fairly close match of the reflector surface with the exact paraboloidal surface. A detailed finite element stress analysis of the entire back-up structure including the hub, radial members, rim members, bracing members, quadripod, and reflector panels under the maximum load conditions, corresponding to the dish facing horizon and the maximum wind (150 kmph) coming from the front and the back, has been carried out for the 12 m dish and it was decided to use high tensile (yield strength 60 kg/mm^2) radial tubular members of 40 mm diameter and 8 mm wall thickness. In the analysis carried out, both the wind load and the dead load are added in a scalar sense and it is seen that the effective stress due to wind loads is of the order of 73% of the allowable stress at the survival wind speeds. The allowable stress is taken as 85% of the yield strength. It may be recalled here that the prestress is of the order of 95% of the allowable stress which indicates that the maximum wind kinetic energy at 150 kmph is only about 75% of the stored internal strain energy of the radial members in the form of prestress. Thus, there is about 20% margin for the stress before rim members go slack and go in compression. There is no significant increase in the stress of the radial members because they are effectively anchored in the rim members and bracing members.

The circumferentially located straight rim members have the important function of connecting the adjacent tips of all the 24 parabolic radial members. These rim members also prevent the springback of the pre-stressed radial members, besides providing the hoop mode strength to the dish structure. However, as the radial member is a large member, it can bend significantly between its two end points (i.e. one end at the tip and the other end at the hub), in addition to the requirement of quadripod being supported on the radial member which can cause additional deformations. All these have the potential to increase the dish distortion to unacceptable levels under the operational conditions and in order to reduce this distortion, the intermediate bracing members are provided for the 12 m dish.

The intermediate bracing members together with the hub and the rim members, divide the total outer dish into radially two equal parts. It is seen that when the radial members try to bend inwards (dish overall closing mode), the rim members and bracing members go into compression and when the radial members try to bend outward (dish overall opening mode), these members go into tension so that the overall dish distortion is minimized. It may be mentioned here that these rim members and bracing members do not play any role in the dish overall pure twisting mode as they undergo in-plane rigid body rotation in this mode of elastic deformation and in this case only the radial members provide the total twisting stiffness to the dish. For the 12 m dish although the rim members and the bracing members are subjected to smaller loads than that of the radial members**,** but the tube diameter of 40 mm and wall thickness of 8 mm is chosen for these members also. This is also considered adequate for the purpose of resisting compressive loads in the dish closing mode.

A finite element analysis was also carried out for determining the natural frequencies and mode shapes of the 12 m dish as described herein. The boundary conditions were taken as four point clamped supports at the hub**.** The lowest natural frequency of the vibration of the disk was 1.49 Hz for inplane bending mode (ovalling) and is considered satisfactory.

The difference in the shape of the elastically bent radial member and the exact parabolic curve can be compensated suitably by using adjustable bolts and is, therefore, not a cause for concern in the design of the preloaded parabolic dish and is also not treated as an error, but only as a deviation which is to be adjusted. The parabolic reflector surface is required to be assembled from the wire mesh panels which are made of stainless steel wire mesh tack welded by resistive arc welding to a metallic frame attached to mounting plates**.**

3.2 *Details of the 12 m PPD antenna*

The said 12 m diameter preloaded parabolic dish antenna consists of 24 radial tubular members and has a focal length of 4.8 m (Fig. 2). The said 12 m dish has been designed for a survival wind velocity of 150 kmph. The radial members are connected to a hub of 4 m diameter made out of welded mild steel plates of 8 mm thickness and its cross-section has a width w_1 = 200 mm and height of H = 200 mm. (Fig. 2). The radius of the inner ring, hub, intermediate circumferential bracing ring and outer circumferential ring (rim) are 600 mm, 2000 mm, 4000 mm and 6000 mm respectively. In Fig. 3 the dotted line shows schematically location and inclination of the radial members before their elastic bending; the broken line shows the elastically bent radial tube and the full line the required parabola. It is found that the deviation of the curved radial members from the parabola lies within ± 40 mm, which can be compensated by using adjustable bolts. The radial, rim and bracing members consist of high tensile seamless tubes of 40 mm diameter and 8 mm wall thickness, with a yield strength of 60 kg/mm^2. Alternatively tubes of 50 mm dia and 6 mm thickness may also be used. Quadripod consists of seamless tubes of 50 mm dia and 8 mm wall thickness. The reflecting panels are made of stainless steel welded wire mesh with a size of 6 mm x 6 mm (distance between adjacent wires of 6 mm) and wire diameter of 0.55 mm.

The total weight of the 12 m diameter preloaded parabolic dish including weight of the hub, various structural members, clamps and joints and the reflecting panels is about 2.5 tonnes. For wind velocity of 150 kmph, the dish is subject to a wind force of 2.7 tonnes when facing to horizon and the wind torque about the elevation axis is 3 tonne m . The dead load torque about the elevation axis is 4.7 tonne-m, before balancing of the dish by a counter weight. The frequency of the lowest vibrational mode is 1.5 Hz.

Calculations have also been made for a preloaded parabolic dish antenna of 25 m diameter for a survival wind velocity of 140 kmph. The 25 m dish has a total weight of 14 tonnes, wind force (horizon) 13 tonnes, wind torque about elevation axis of 19 tonne-m and dead load torque (before balancing) of 42 tonne-m. These weights and torques are much lower than those for conventional dishes. Calculated values for the 12 m and 25 m dishes are summarized in Table-1.

Thus it has been shown that application of preload to the structural members as well as the selection of an optimum configuration results in considerable reduction in the weight and wind torques on the drive system of a parabolic dish and minimizes the labour required for assembly including welding and bolting of various structural members compared to that of a conventional back up structure, thus leading to considerable economy.

4. Procedure for Fabrication of the 12 m Preloaded Parabolic Dish Antenna

Firstly, the hub of 4 m diameter with a cross section of 200 mm x 200 mm is made of 8 mm plates and its top surface is machined. The hub is mounted on four temporary pillers by clamping on four legs of the hub. Next, 24 nos. of hub mounting-pads are bolted at equal circumferential distances on the hub (in case of mass production, can be welded during fabrication of the hub). All the 24 nos. of radial members are then connected rigidly by clamping on the mounting-pads. Using a theodolite placed at the centre of the parabolic dish, it is ensured that the tips of all the 24 nos. of radial members lie at equal angular distances and are in one horizontal plane. The radial members are then bent elastically by applying a force with an effective normal component at their tips using steel ropes and turnbuckles attached to a ring-plate supported on a vertical tower connected on the hub which is erected temporarily to lie along the central axis of the 12 m parabolic dish. The ring can also be made to rise gradually upto the plane of the rim using ropes and turn buckles. Alternatively, for mass production, jacks supported on the ground or pullers supported on the roof of a construction shed can be used. Each of the radial members is bent elastically to a specified height from the `x' axis of the parabola in the `y' direction, (Fig. 3) using a theodolite placed at the centre of the dish and thus the radial members get pre-stressed or preloaded to a calculated value.

Radial members are then interconnected to straight bracing members of the intermediate circumferential ring using bracing joints. Adjustment bolts of the bracing members (say, on 4 out of 24 bracing members) are adjusted, if required to ensure that the intermediate ring is rigidly connected to the radial members. Next, the tips of the radial members are rigidly connected to the rim members using the rim joints at the periphery of the dish. Next, the steel ropes and turn buckles are loosened and adjustments made using adjustment-bolts of the rim members to ensure that the circumferentially placed rim members get rigidly connected to the radial members. Next the central tensioning tower is removed and the quadripod is mounted on the radial members at the location of the bracing members of the intermediate ring using the quadripod flange. Next panel-mounting gadgets for mounting the reflector panels, are attached to the radial members. The length of adjustable bolts of these gadgets is adjusted using a centrally placed theodolite to ensure that the heights of the mounting plates for bolting the reflector panels lie along the desired parabolic curve within a tolerance of ± 0.5 mm. The reflector panels are then mounted on mounting plates and surface accuracy is then measured using the theodolite. Suitable adjustments are made in order to ensure that the reflecting surface lies within specified tolerances.

5. Antenna mount & drive system for the 12 m Preloaded Parabolic Dish Antenna:

On behalf of the Raman Research Institute, a firm in Bangalore, has made preliminary design calculations for mount and drive system of the 12 m antenna. For the elevation drive of an Alt-Azimuth system, two different concepts have been considered : (i) Ball screw drive (ii) Sector Gear drive. For the azimuth drive either (a) four point contact Slew Ring or (b) Wheel & Track arrangement have been examined. For the RRI mount, it is proposed to freeze the design by July 2002 using Sector Gear for elevation and either Slew Ring or Wheel and Track for azimuth. The mount and the drive are expected to be fabricated by early 2003 and will then be integrated with the 12 m preloaded parabolic dish. Servo motors have been purchased and electronic drive units are already being assembled at RRI. A Cassegrain system is being developed by RRI for a survey of Methanol masers near 6.7 GHz, which would also allow testing of the performance of the 12 m PPD antenna by the middle of 2003.

Preliminary cost estimate of the backup structure and reflecting surface of the 12 m dish, its mount and drive system, including gear boxes and encoders, are given in Table-2. It may be noted that these are rough estimates considering mass production and for location in a Western country. More accurate estimates will be made by the middle of 2003. The present estimates for the cost of mount and drive system seems to be about two times higher than that of the 12 m PPD dish including reflector panels. However, mechanical design has not been optimized.

6. Strawman's Design for the Antenna System of SKA using 8343 Nos.of

12 m PPDs

For meeting the major specifications of SKA, it is proposed to use a total of 8343 PPD antennas of 12 m diameter placed in a suitable array of about 500 km in extent or larger as may be recommended by the scientific, antenna array and correlator groups. Each station will consist of a closely placed 2-dimensional array of 12 m dishes, e.g. if 103 stations are decided, each station will consist of an array of 9 x 9 dishes of 12 m diameter so that the total number of dishes being 8343. Alternatively, one may choose 102 stations of 7 x 7 dishes of 15 m diameter with the total number of dishes being 4998. About 30% of these antennas may be placed in a closely spaced central array of a suitable design, as may be considered optimum for meeting some of the scientific objectives of SKA.

In order to cover the frequency range from 0.15 to 10 GHz and also to get nearly the same E & H beamwidth for achieving good polarization characteristics, one may place four log periodic antennas in a quad arrangement at the primary focus of the 12 m dishes. A Cassegrain design may be possible if one restricts the frequency range suitably, as is being adopted for the 6.1 m offset parabolic dishes of the Allen Telescope Array (ATA) of the SETI institute. For the proposed 12 m dishes of SKA, it should be possible to adopt the basic design of the feed and receiver system of ATA.

In Fig. 4 is illustrated a possibility of extending operation of the 12 m or 15 m PPD antennas from about 30 MHz to 22 GHz as may be required for SKA. As stated earlier, one may use accurate panels of metal sheets for the central 6 m diameter and a Cassegrain feed for covering 5 GHz to 22 GHz, a primary feed of a quad of four log – periodic array for 150 MHz to 5 GHz and active antennas on the periphery/ rim of the PPDs for covering 30 MHz. to 150 MHz.

As described in Section-5, a 12 m dish has been fabricated at the Raman Research Institute with panels of 6mm x 6mm x 0.55 mm having deviation of 2 mm rms from the required parabola. In Table-2 are presented expected performance of the 12 m PPD antennas. In Table-3 are given a rough cost analysis of the 12 m dish. Cost estimates given in Tables-2 & 3 are tentative and will be improved by mid 2003.

The lowest computed frequency of vibrations or elastic modes of the PPD according to the finite element analysis made by Professor Joshi of IIT, Bombay is around 1.5 Hz. However, the measured frequency is about 1.2 Hz. During the windy days at Bangalore, it is planned to measure the effect of wind on the PPD. If a higher value of frequency is required, we may connect some additional tubular members from the lower side of the hub to a suitable location (say 6 m diameter circle) of the 12 m PPD.

In Table-4 we have made a comparison of the "SKA design goals" with the achievable specifications of the Strawman's design using 12 m dishes. It may be seen that if parabolic dishes are selected for the antenna elements of SKA, they will meet all the design goals for the SKA (as have been summarized in the Science Document for SKA), except No. of instantaneous beams. However, it should be possible to make sub-arrays of the 12 m dishes, pointing in different directions. Further, within the primary beams of each 12 m dish, the correlator system will provide the full coverage. Advantages of using parabolic dishes for SKA is discussed in Section-7.

7. Discussions

7.1 *Advantages of Preloaded Parabolic Dishes*

As is widely known that parabolic dishes have several advantages for use in a radio telescope. Some of these are listed below:-

- Steerability over all the sky.
- Wide frequency coverage (< 100 MHz to ~ 22 GHz.).
- Wide bandwidths are possible which will allow dynamic channel assignments for minimizing RFI.
- Sidelobes of each 12 m antenna are likely to be about - 20 dB and further a null can be produced in specified directions by suitable phasing of the array of 9 x 9 antennas at each station or of few thousand antennas in the central array.

- Good Polarization Characteristics.
- Less Complex electronics than phased arrays which may allow:
  - Lower system temperature,
  - Better phase and gain stability resulting in better calibration capabilities, which is extremely important for achieving the required 10^6 dynamic range at 1.4 GHz.

7.2 *Antenna element for SKA*

A brief comparison of different concepts being developed by the SKA partners was presented by the Antenna Working Group at the SKA workshop held at Berkely in July 2001. In order to make a relative comparison of these concepts, it is suggested that we may consider a "Figure of merit", F, for each concept:

$$F_1 = [\text{ sky coverage } (\delta) \text{ x Freq. coverage}] / [(\text{cost}/m^2) \,.\; T_{sys}]$$

An additional parameter, F_2, will be the no. of instantaneous beams, which will increase the cost of SKA. Therefore, the total cost of the antenna and receiver system will have to be considered, along with F_1 & F_2, and some other factors such as achievable dynamic range, RFI susceptibility, maintenance aspects, etc.

8. Conclusions

Over the last few years, considerable work has been done by NCRA-TIFR for developing the novel concept of the preloaded parabolic dish antenna. A detailed design of the 12 m PPD antenna has been made. RRI has fabricated the 12 m dish and has also developed lightweight panels for the reflecting surface. A firm in Bangalore is developing a design for the mechanical drive system. The full 12 m dish including the servo system and electronics is expected to be operational by the middle of 2003. An approximate cost estimate has been made for the 12 m PPD antennas including mechanical and servo system. The cost of the antenna system of SKA for achieving T_{sys} = $2 \times 10^4\ m^2\ K^{-1}$ at 1.4 GHz will be about US \$ 500×10^6 using 8333 dishes of 12 m or

5000 dishes of 15 m diameter. Better estimates will be made by mid 2003. As is known, the antenna system may form about 50 or 60% of the cost of SKA.

Parabolic dishes offer an attractive option for SKA. The cost of the antenna system is likely to be optimised if the PPD antennas described in this report are employed for SKA.

9. Acknowledgements

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Hck/Swarup/SKA

Table 1 : Parameters of the Preloaded Parabolic Dishes of 12 m and 25 m diameter.

Sr. No.	Item	Units	Diameter ----------------- 12 m	Diameter ----------------- 25 m *
1.	Area (Physical)	m^2	113	491
2.	No. of Radial Spokes	-	24	36
3.	Hub Diameter	m	4.0	7.0
4.	Wire Mesh Size	mm	6 x 6 x 0.55	10 x 10 x 0.55
5.	Solidity	%	22	28
6.	Maximum mass at focus (feed & electronics)	kg	50	200
7.	Maximum mass of full dish excluding gear drive system and antenna mount	Tonnes	2.7	14.0
8.	Survival wind velocity	kmph	150	140
9.	Wind Force (horizon)	Tonnes	2.7	13
10.	Wind Torque About Elevation Axis	t-m	2.0	19
11.	Dead Load Torque about elevation (before balancing)	t-m	4.7	42

- Values for 25 m dish are tentative

Table -2 : Approximate performance parameters for a set of 8333 dishes of 12 m diameter using 4 log-periodic feeds & pulsed cooled receiver, similar to that of the Allen Telescope Array(ATA).

f	λ (mm)	η** (effi-ciency	Ae' (m^2)	Aeff = 8333xAe' (10^5 m^2)	Tsys** (K)	Aeff/Tsys (M^2/K)	Beam-Width (deg.)
0.15	2000	0.50	56	4.67	350	1333	11.65
0.30	1000	0.60	68	5.67	90	6296	5.83
0.60	500	0.65	73	6.08	40	15208	2.91
1.42	210	0.64	72	6.00	30	20000	1.22
5.00	60	0.50	56	4.67	45	10370	0.35
10.00	30	0.25	28	2.33	60	3888	0.17

* Assuming (a) Antenna aperture efficiency due to illumination of 0.5 at 150MHz and 0.65 at higher frequencies.

(b) rms error of the reflecting surface = 2mm.

(c) Reflectivity leakage of the wire mesh of size 6mm x 6mm x 0.55mm size as a function of frequency, based on calculations.

** Assuming galactic background temperature of 50 x $(f(MHz)/300)^{-2.6K}$, ATA type receiver but with a primary feed of 4 log-periodic antennas and ground leakage for the wire mesh of size 6mm x 6mm x 0.55mm.

Table 3 : Comparison of the "SKA Design Goals" with the achievable specifications
of the Strawman design using Preloaded Parabolic Dishes of 12 m diameter.

Item	Specifications	12 m dish	Notes
Frequency Range	0.15-20 GHz	0.15-10 GHz	1
Image field view	1 square deg. at 1.4 GHz	1.22 deg.	2
Number of Instantaneous beams	At least 100	Sub-arrays	3
Angular resolution	0.1 arcsec at 1.4 GHz	Yes	4
Number of spatial pixels	10^8	Yes	5
Surface brightness sensitivity	1K at 0.1 arcsec (continuum)	Yes	5
Instantaneous bandwidth	(0.5+0.2 x frequency) GHz	Yes	5
Number of spectral channels	10^4	Yes	5
Sensitivity	Aeff/Tsys = $2x10^{-4}$ m^2 K^1	Yes	-
Image dynamic range	10^6 at 1.4 GHz	Yes	6
Polarization purity	-40 dB	Yes	7

NOTES :

1. 20 GHz possible if the central 6 m part of the 12 m dish is made of Aluminum sheets (solid or perforated).
2. 1 degree field of view for a 15 m dish.
3. 100 instantaneous beams not possible if dishes used (however, see Section-6)
4. Resolution will depend on overall extent of SKA ; an array of more than 500 km in extent will be required.
5. These parameters will depend upon design of the receiver and correlator system.
6. Requires careful study by correlator and image analysis group.
7. Each dish with primary feed will give polarization purity of only about -25dB but it may be possible to get -40dB by suitable electronics for an array of 9 x 9 12 m dishes.

Table 4 : Preliminary cost estimate for 12 m Preloaded Parabolic Dish Antenna including the Mount and Drive System.

Item	Cost (US $)
1. Fabrication and erection of preloaded backup structure of 12 m PPD antenna :	
(a) Cost of hub including fabrication (660 kg:M.S. Plate)	1200
(b) Cost of Joints (clamps & bolts) : 500 kg	1000
(c) Cost of tubular structural members of PPD: 1220 kg	2000
(d) Cost of S.S. Mesh & fabrication of Panels : 320 kg	3200
(e) Labour Cost for Assembly of hub, tubular structural members of PPD, Joints and wire mesh panels.	6400
(f) Central dish	1200
(g) Miscellaneous	1000

	16000
	=====
2. Mount & Mechanical Drive System	
(a) Elevation drive including gear boxes	8000
(b) Azimuth drive including gear boxes	14000
(c) Mount & foundation	8000
(d) Miscellaneous	4000

	34000
	---------
3. Servo System including encoders	10000
	=====
Total US $	60000

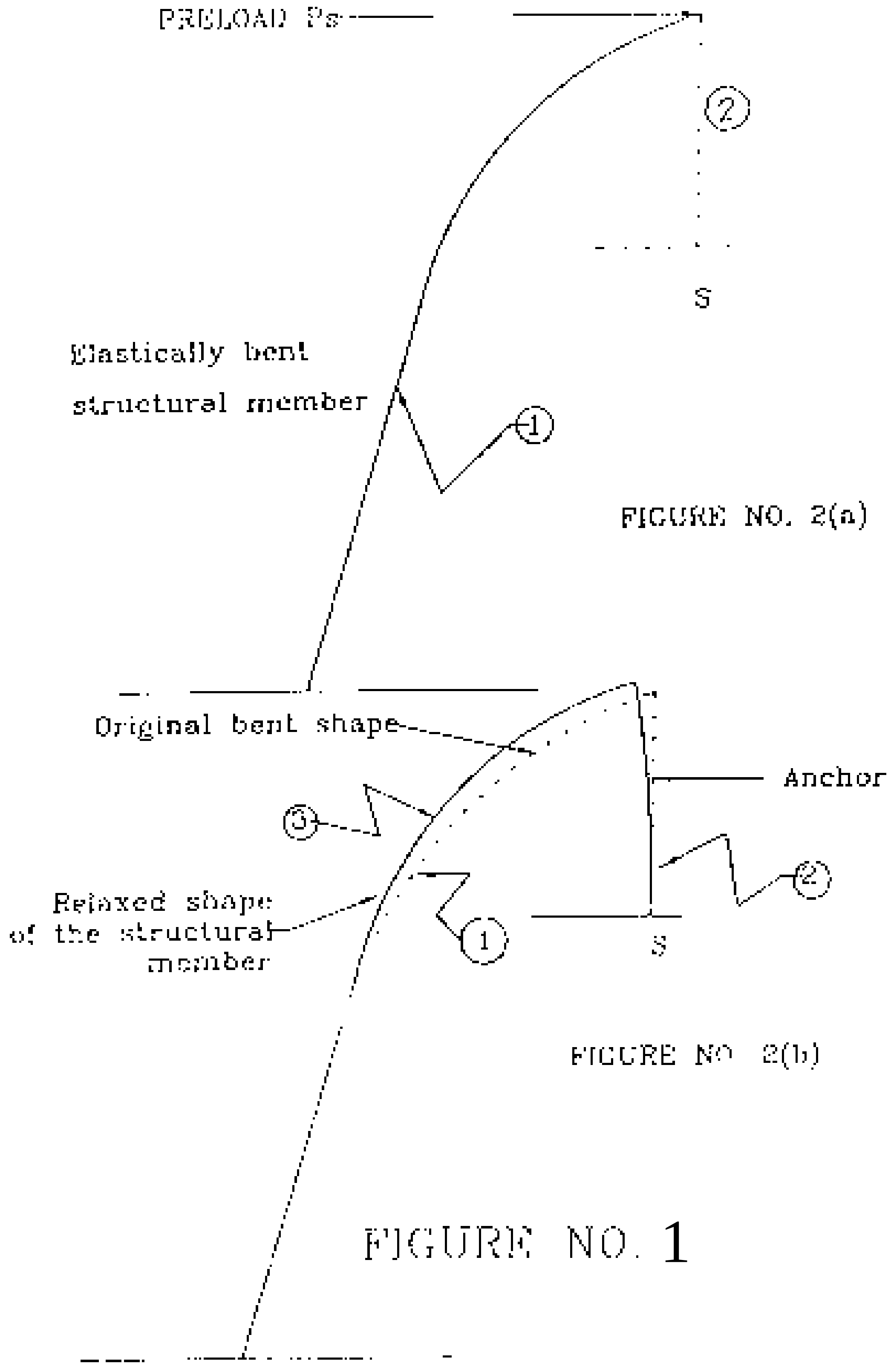

Fig 1: Basic principle of a preloaded structural member supported by an anchor member.

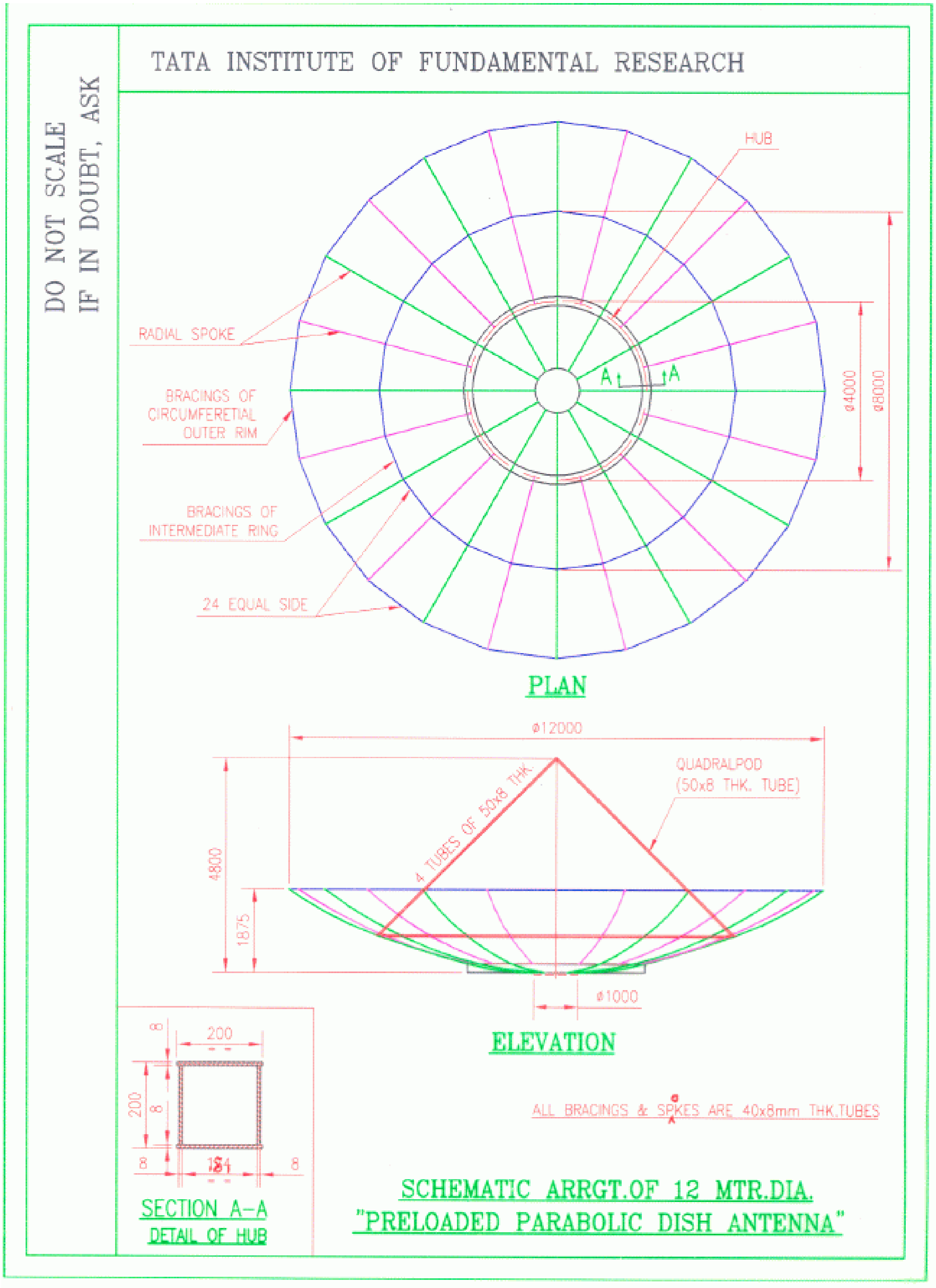

Fig 2: Details of the 12 m preloaded parabolic dish (PPD) antenna.

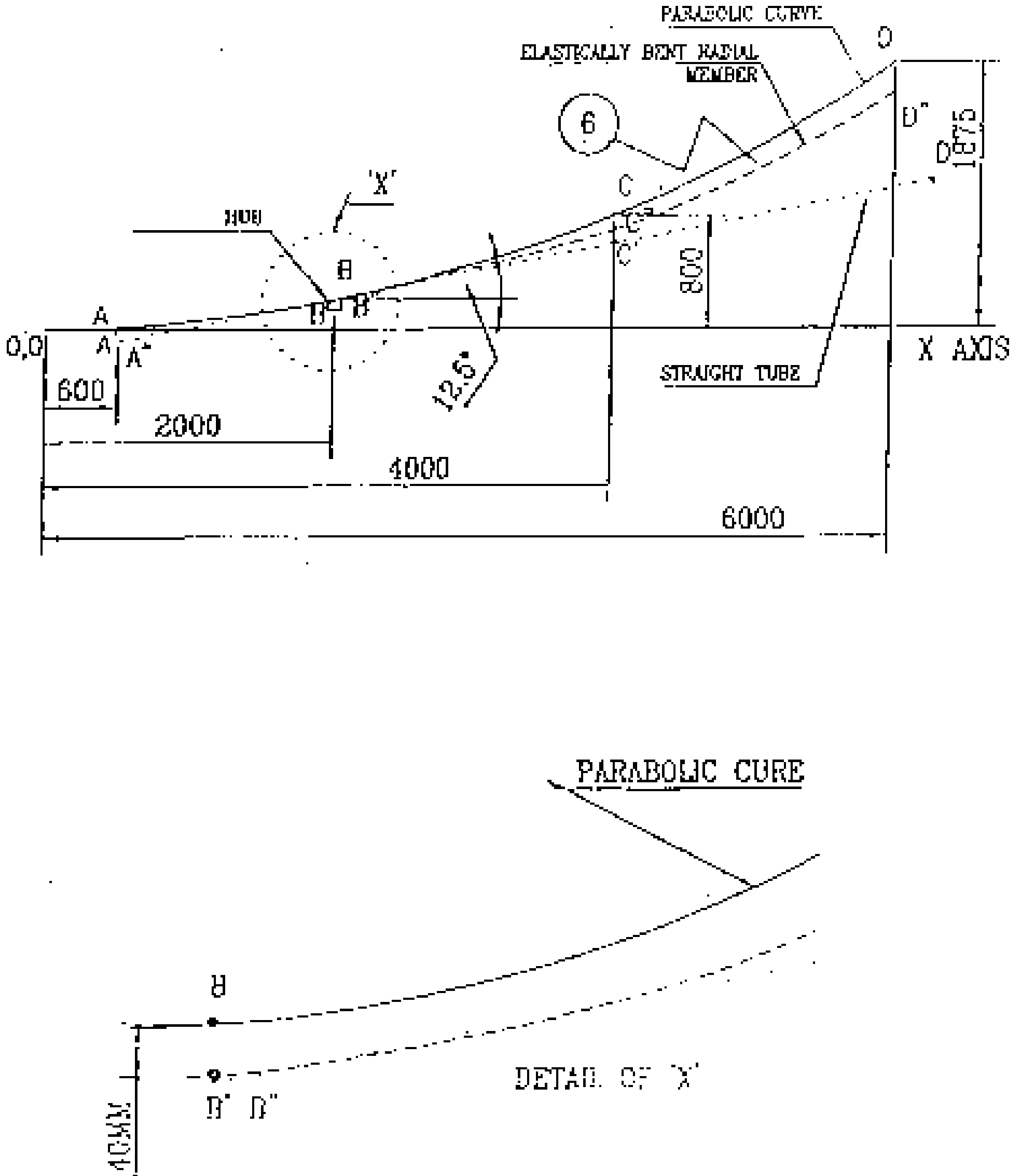

Fig 3: A sketch illustrating the geometry of one of the straight radial structural members of the 12m dish clamped on the hub at an angle of 12.5° to the plane of the hub and then bent elastically so as to lie closely to the required parabolic curve.

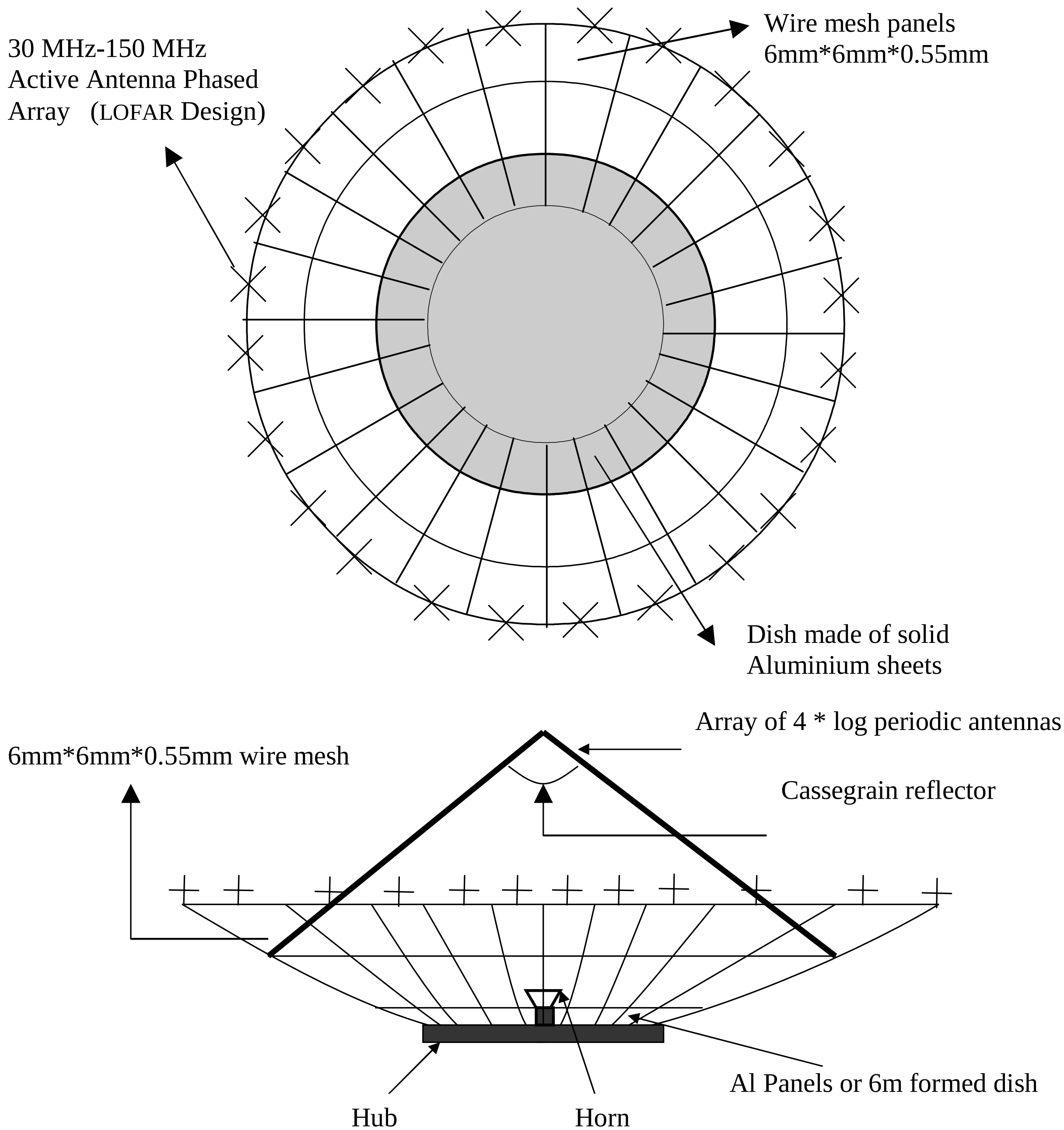

Fig. 4: Proposed sketch of a 12m preloaded parabolic dish with *(a)* solid reflector of 6m diameter with Cassegrain system for covering 5–22 GHz; *(b)* wire mesh 6m to 12m; with primary feed to cover 0.15 GHz to 5 GHz and *(c)* active antennas on the rim of the dish for 30MHz to 150MHz.