MMA Memo 182: A 12-m Antenna Design for a Joint US-European Array

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Abstract:

This memo describes a new 12-m antenna design for the proposed US-European Joint Array project. This design includes a light weight dish structure, independent feed leg support, optimum counterweight arrangement and a parallel deformed yoke. This antenna uses carbon fiber reinforced plastics (CFRP) material for the dish and the yoke. The antenna will have accurate pointing, low surface errors, and good phase stability.

1. Introduction.

On June 26, 1997 the European Southern Observatory and the National Radio Astronomy Observatory decided to explore the possibility of a joint US-European array project. The proposed antenna design is for this Joint Array project.

2. Dish Design.

For achieving a homogeneous dish design, most antennas support their dishes at a ring which is close to or just on the axis of the paraboloid. However, there are a few exceptions when lightweight panels and trusses are involved; for example, the SMT telescope on top of Mt. Graham, Arizona, US and the recently proposed LSA dish by D Plathner. JCMT supports the dish through a cone structure at a larger diameter too. This proposed 12-m design applies the same design idea and the supporting ring of the dish is about 6 to 7m in diameter (see Figure 1).

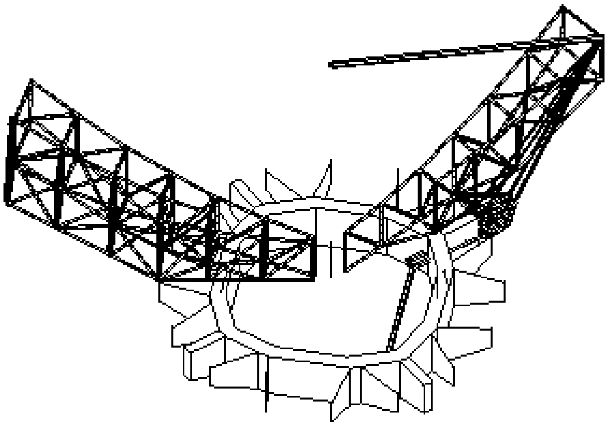

Figure 1: Support ring and part of the backup structure.

In the proposed design, carbon fiber reinforce plastics (CFRP)) material is used for the dish to meet the stringent thermal requirements of a millimeter wavelength antenna. The dish is a space double-layer truss structure. The bottom surface of the dish is about 1 m away from the vertex of the paraboloid for a very conservative design. If the back surface is about 0.5 m away from the vertex, the design may still meet the surface rms requirements.

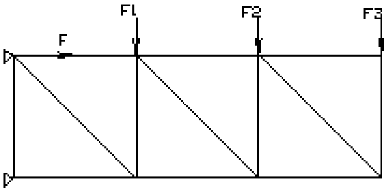

Figure 2: Force condition of the cantilever truss structure.

For a cantilever double-layer space structure as shown in Figure 2, if the separation is equal to its height, the maximum force on the structure members is equal to the sum of the applied load. That is: F = 1F1 + 2F2 + 3F3 or F = 0F1 + 1F2 + 2F3 as shown in the figure. If the height of the truss is halved, the maximum force will be doubled. From this force of the first beam member, and the member cross-sectional areas of the truss, the displacement of the first grid could be determined. The vertical displacement is the same as the horizon displacement. The maximum displacement of the truss is at the far end. The amount of this displacement is equal to the sum of 3d1 +2d2 +d3, where d1 is the displacement of first grid caused by the force of the first member beam, d2 is that of the 2nd grid caused by the force of the 2nd beam and d3 is that of the 3rd grid caused by force on the 3rd beam. In the real dish structure, the contributions of the circumferencial members should be included in the analysis.

To meet the stress requirement under a survival wind of 65 m/sec (1300N/m^2 wind head pressure), a rough calculation could determine the cross-sectional area of the member beams. The calculation shows the total weight of carbon fiber tubes used being 600 Kg for a 1.2x10^8 N/m^2 tube axial strength. To meet the deformation requirement of 15 um rms, a rough calculation shows that the dish requires a total weight of 2200 kg for tubes with modulus of 1.2x10^11 N/m^2 if the panel is 13 kg/m^2 in density. The inner part of the dish has a smaller surface area per rib, the dish thickness of that part could be thinner. However, if the panel weight doubles, the CFRP truss weight will double as well.

There are two difficulties in applying the above dish structure idea to the 12 m design. One is the support of the large diameter ring and retaining the ring shape under different gravitation force conditions; the other is the subreflector support problem. These difficulties can be solved by adding a steel sub-structure and a lower CFRP feed leg truss structure. The sub-structure provides the rigidity (tortional and bending direction) of the ring, on which the CFRP dish sits. The main part of the sub-structure is a multi-sided ring supported at four points. The sub-structure ring is about 1-m in height. On the ring, 8 equal softness points are formed around these four support points. From the 8 equal-softness points, 16 fins will provide 16 support points at a CFRP ring dish support. The feed leg support has to be fulfilled by a lower CFRP truss directly from the four hard support points. The feed leg support points on the steel ring are located at the same ring of the dish support. Figure 3 shows a not very stiff feed leg structure. If deformation of the secondary mirror is too much (this may be the case.), 4 groups of double-layer trusses are required to extend the feed leg bottom support points away from the dish support ring.

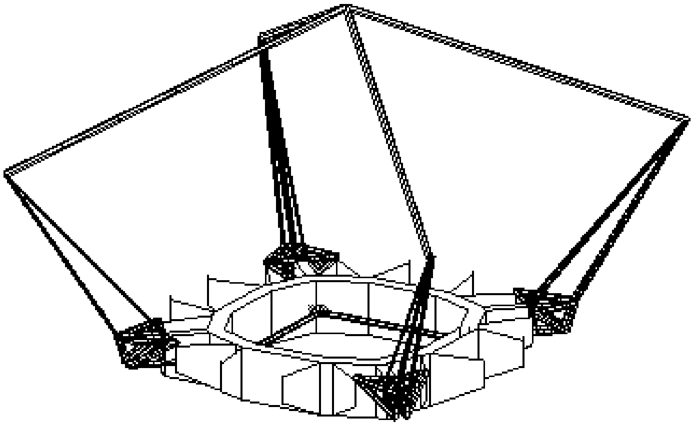

Figure 3: Feed leg support structure arrangement.

Supporting a CFRP dish on a steel sub-structure has already been proven. The SMT telescope shows this structure arrangement is very stable in pointing accuracy and surface rms accuracy. When temperature changes, the flexible joints produce no thermal stress to the dish structure. At the same time, radial and front-back thermal gradients have no effect on the surface and pointing of the dish. The only effect on pointing is by the thermal gradient from one side to the other. The effect is about 0.4 arcsec/deg-C. Since the sub-structure is flat in shape, the phase error due to temperature change is also small.

By estimation, the weight of the dish is about 9000kg which includes 1500kg of panels, 2200kg of CFRP tubes, 1500kg of joints, 200kg of adjusters, 650kg of secondary mirror structure, and 3000kg of steel sub-structure.

3. Elevation Structure.

The elevation structure of the antenna includes two elevation beams, groups of counterweights, and elevation drive systems. The elevation structure is all made of steel. The purpose of the elevation structure is to provide four equal softness supports to the dish sub-structure. The connection between the dish sub-structure and the elevation structure should be via spherical washers so moments will not be transferred into the dish (including dish sub-structure and CFRP dish feed leg structures). The distance between the elevation axis and the dish sub-structure is about 0.4m for an asymmetric yoke design and is about 0.8m for a symmetric design. The elevation structure could be stiffened by adding material on top of it inside the dish sub-structure ring as shown in Figure 4. Between two elevation beams, Material could be added between two elevation beams for tortional stiffness as well.

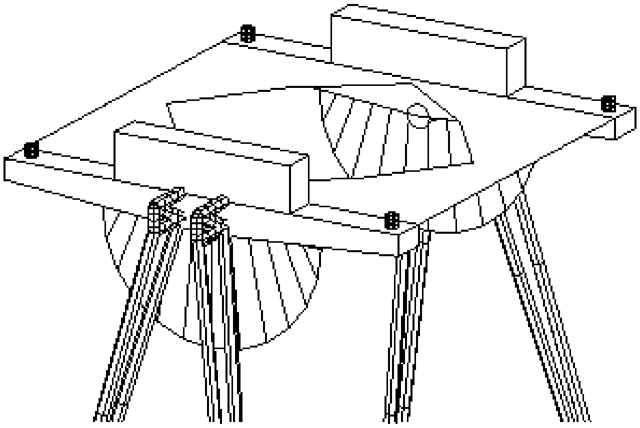

Figure 4: Elevation structure of the design.

The counterweight of the antenna has been a subject of study for a long time. In most cases, the counterweight wastes material, and lowers the rigidity of the structure. Therefore a number of new designs have removed the counterweight altogether. However, this produces either an unbalanced design (LSA) or an unusual mounting structure (slant axis design). In this design, the counterweights are located away (about four meters) from the elevation axis. In this way, the material required for the counterweight is much reduced (about 2500Kg). This produces a lighter but balanced antenna design. Long beams of the counterweight will have a lower mode of vibration. These lower frequency modes of the counterweight structure can be damped out by adding polymer materials to the surface of the beams. These modes should be removed from the control system as well. To put the counterweight too far away may produces larger moment in drive system which is also undesirable. So optimization is required in this aspect.

The proposed antenna design uses two sets of drive systems in the elevation axis. This practice has been used in the SMT telescope and the IRAM 30-m antennas. This arrangement is different from a single bull gear or screw type drive system. It could provide an open, accessible receiver space. Care has to be provided in avoiding the torque which bends the dish structure. The elevation structure could also be used as a platform for instruments or receivers.

The weight estimation of this part is 4000kg.

4. Receiver Space and Arrangement.

There are two platforms for receiver mounting. One is at the back of dish sub-structure, and the other is at the elevation structure. On the back of the dish substructure, the load should be small and should provide no moment to the dish structure. The platform on the elevation structure could take asymmetric loads without affecting the homology of the dish. On this platform, a light weight protection cabin could be adapted as well. The present design space of the receiver area is about 3m x 3m x 2m.

5. Yoke Structure.

In the past, study has shown that in response to wind, a strong yoke produces a very small displacement but a large change in angle(in arcsec level) at the top of the yoke. Thermal problems of a steel yoke are also a big problem for observers. The problem of the thermal pointing error of an asymmetric yoke will be even greater. Therefore a CFRP tube structure is preferred in the proposed yoke design. This arrangement ensures the stability of the structure against thermal variations. The yoke structure details are not finalized at this moment. However, we will use the principle of the tube ’A’ truss design from optical telescopes to ensure no angle change under wind loading. We estimate that the phase change under 6m/sec wind will be less than 10 um for a CFRP yoke structure of 500kg.

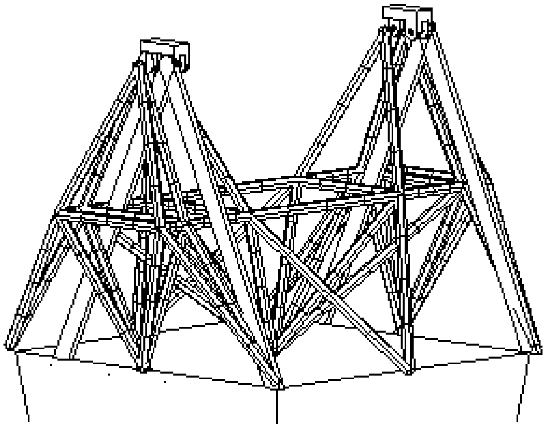

Figure 5: Yoke structure in the 12 m design.

The CFRP tubes have little rigidity in shear, so an independent protecting steel cover may be needed to avoid any damage during receiver changing. At the same time, calibration beams could be arranged from the base to the elevation bearings for measuring the displacement of the bearing in three directions. These measurements could be used for pointing and phase error correction.

At the moment, there are two yoke designs, one for a symmetric yoke, the other for an asymmetric yoke. The asymmetric yoke is preferred since it provides a more compact design for the antenna. The symmetric yoke design requires about 0.8 m between the elevation axis and the bottom of the dish, while the asymmetric design requires only 0.4 m in distance. There is also a way to design a zero-pointing error truss structure on a flat base. In Figures 7 and 8, an asymmetric yoke is set on a tilted base structure.

The weight of the yoke is about 4000kg, including CFRP tube 500kg, elevation drive system 1000kg, protection and other structure 2500kg.

6. Base Structure.

The base structure is a solid cylinder, which holds the azimuth bearing and the cable wrap. On the top of the base structure, tilt meters could be used to help correct the pointing. The base structure has a mechanism for antenna relocation and lifting. The weight of the base structure is about 18000kg. The total weight of the antenna is about 38000kg.