NLSRT Memo No. 29

The Feasibility of Building a Large Radio Telescope of Offset-Feed Parabolic Design.

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This memo is intended to point out, at a very basic level, a few of the problems of constructing a fully steerable reflector antenna of aperture about 100 meters, using an offset-parabolic design to obtain a completely unblocked aperture. The reason for the offset design is to reduce sidelobes to minimum possible levels. Low sidelobes are required to minimize interference, particularly from satellites, as well as for astronomical reasons such as the observation of hydrogen-line emission near the poles of the Galaxy. The low sidelobe levels of offset-feed parabaloids have been well demonstrated by antennas of aperture up to a few meters. Typical results are shown in Fig. 1 which is taken from CCIR Report 677-1 (1986). Report 677-1 also contains results for a small offset paraboloid for which the sidelobes were further reduced by 10-30 dB by the addition of a microwave absorbing coating on the support structure in the vicinity of the focus. There is therefore no doubt that the offset feed design is effective in reducing sidelobes.

Figure 2 shows a part of a parabola that represents a cross section of the main reflector. Suppose that the section AB is illuminated by radiation from the the direction of the focus, either from a feed horn or from a secondary reflector appropriately positioned and illuminated. Since the distance FB is about five times FA, the power per unit solid angle radiated towards B must be a factor of 25 greater than that towards A to obtain uniform illumination in the aperture. There are two ways of reducing the illumination gradient. First, sufficient uniformity for high efficiency can be achieved with a secondary reflector by suitable shaping of the main reflector and the secondary: see for example Mittra et al (1982). Second, one can use only a short length of the parabola near the vertex, such as indicated by "D=f" in Fig.2, which results in making the focal ratio close to unity. The aperture D is shown in Fig.2 for focal ratios of 1/4, 1/3, 1/2, and 1. One should visualise these apertures as scaled to 100 m in each case, and the focal length VF being varied.

There are reasons for wanting to use prime-focus feeds of design similar to those that have been carefully developed for on-axis radio telescopes over the last two decades. One should therefore consider the use of a feed for which the radiated power is essentially uniform with angle over the beam of of the feed, and see how the aperture efficiency factor for the main reflector varies for different focal ratios. In calculating the efficiency, which is shown in Fig. 3, the required integrations have been performed over circular apertures in a plane normal to the plane or the page and parallel to the y-axis. These apertures are indicated by D in Fig.2. The calculations are for uniform illumination with no edge taper.

It would obviously be nice to work in the part of Fig. 3 for which the efficiency factor is high, say for f/D > 0.7. Fig. 4 is intended to help one imagine what an offset feed antenna with f/D equal to 0.7 would be like when stowed with the main reflector in a near horizontal position as would be required in a strong wind. For a 100 m aperture the plane of the main reflector would be at a height of about 65 m, and the tower holding the feed or subreflector would rise to another 70 m, making the total height about 135 m (443 ft). A tower of such height attached directly to the ground would not be a great problem in a wind, but as part of an antenna the forces would be transferred to the ground through the bearings of the antenna. The feed tower could perhaps be hinged at the base and raised and lowered by a hydraulic or other mechanism, but this would be a clumsy solution and could complicate the counterweighting. The tower would have to be sufficiently stiff to avoid vibrations even in calm weather, and rigidly connected to the reflector backup structure. Any support members for the feed tower must not block the antenna aperture. It is difficult to see how one could avoid fairly massive structures for support of the feed or subreflector if the focal length is large.

J. Lockman has suggested that a configuration similar to the famous Hogg-horn antenna used by Penzias and Wilson would offer a solution by keepeng the focus at the same level as the center of the main reflector. In terms of Fig. 2, the main reflector would be represented by something like the section GH. Unfortunately the overall horizontal dimension of this design of antenna is about two-and-a-half times the aperture. With an aperture that is 100 m wide the horizontal dimension of the structure would be 250 m, all of which would have to rotate about the azimuth axis. Also the pointing motion would not allow setting the main reflector to minimize the area presented to wind from any azimuth, although this may not be a consideration of great importance.

One way to reduce the the mechanical problems of an offset feed antenna is clearly to reduce the focal length. The offset feed design may have a chance of being economically competitive with a conventional on-axis antenna if the focal ratio is similar to the usual on-axis value, i.e. about 0.35. Fig.2 indicates that the loss of efficiency for a prime focus feed is then about 8%, which should be tolerable. It seems to me that unless some novel scheme is found, a focal ratio not much more than 0.35 provides perhaps the only economically feasibile approach to a very large offset-feed antenna. What is needed is the opinion of a mechanical engineer on this point.

Figure 5 shows an offset feed antenna with f/D about 0.32 and relatively compact design. With such a design the loss of efficiency of a prime focus feed can be avoided by using a Cassegrain system. The VLBA antennas work down to 1.35 GHz using Cassegrain feeds, so one might hope that an antenna four times as big could be used down to lower frequencies in the Cassegrain mode. A remaining question is that of the polarization response for a short focal ratio. Cross polarization sidelobes can be reduced in dual reflector designs (see, e.g., Rudge and Adatia, 1978). Another thing to be checked is the ability to do multi-beaming with the optimized surfaces that may be required. The possibility of homology is also a question. With a focal ratio of 0.35 the axis of the main beam makes an angle of about 45 deg. with the main reflector. Thus the surface area of the main reflector is about 40% greater than the intercepted wavefront. This may not be much greater than the case for most on-axis antennas. For a review of more details of off-axis paraboloids see Rudge and Adatia (1978).

References.

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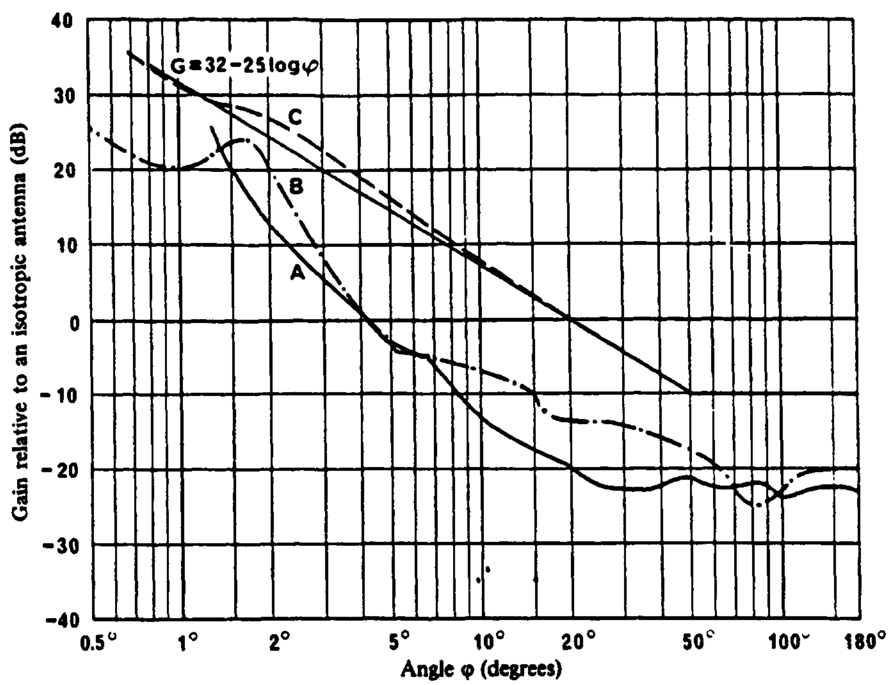
Rudge, A.W. and Adatia, N.A. (1978) Offset Parabolic Reflector Antennas, A Review, Proc. IEEE, 66, 1592-1618.



— *Measured side-lobe patterns (peak value)*

A: offset Gregorian antenna ($D/\lambda = 66$, 25 GHz, $D = 0.8$ m)
B: offset Cassegrain antenna ($D/\lambda = 750$, 19.5 GHz, $D = 11.5$ m)
C: symmetrical Cassegrain antenna ($D/\lambda = 600$)

Figure 1. Examples of sidelobe patterns for on-axis and offset-feed antennas. From CCIR Report 677-1 (1986).

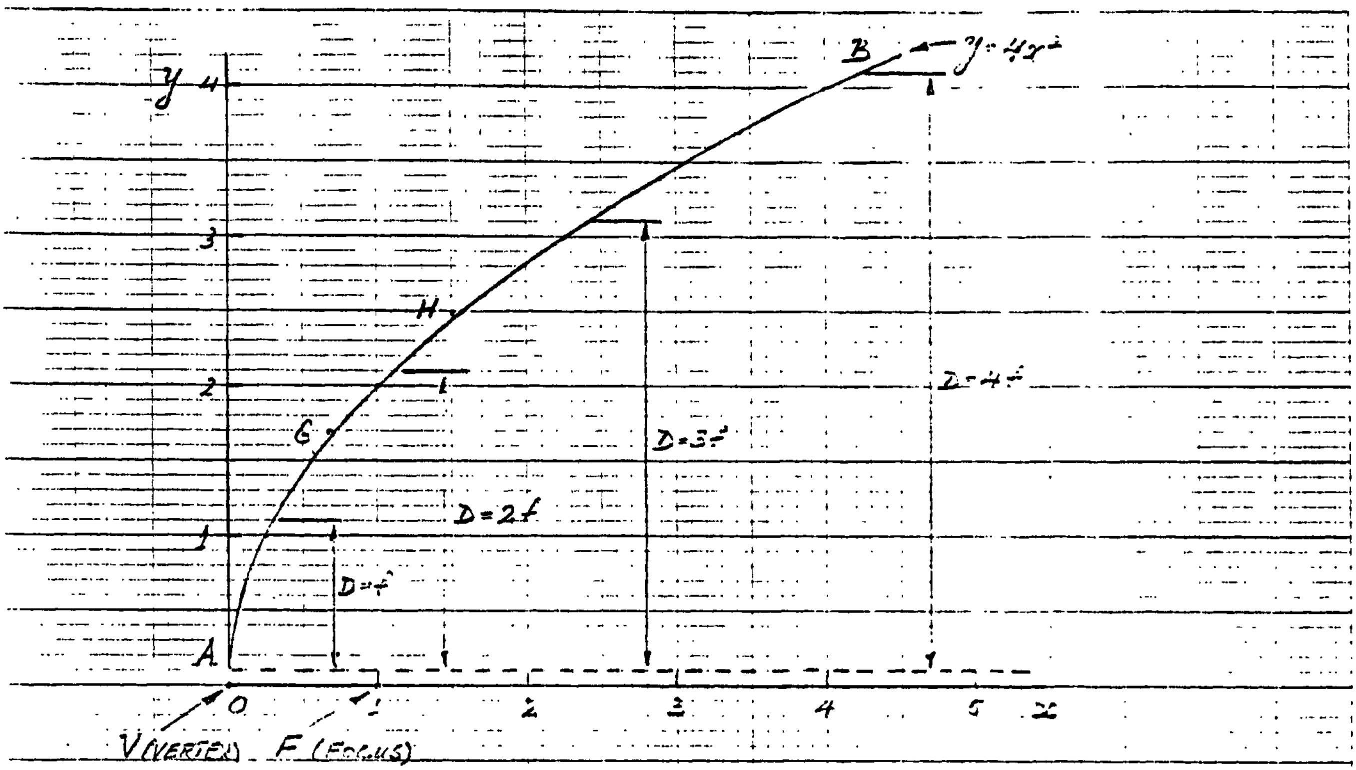


Figure 2. Parabola AB represents section of main reflector, with apertures (D) shown for four focal ratios.

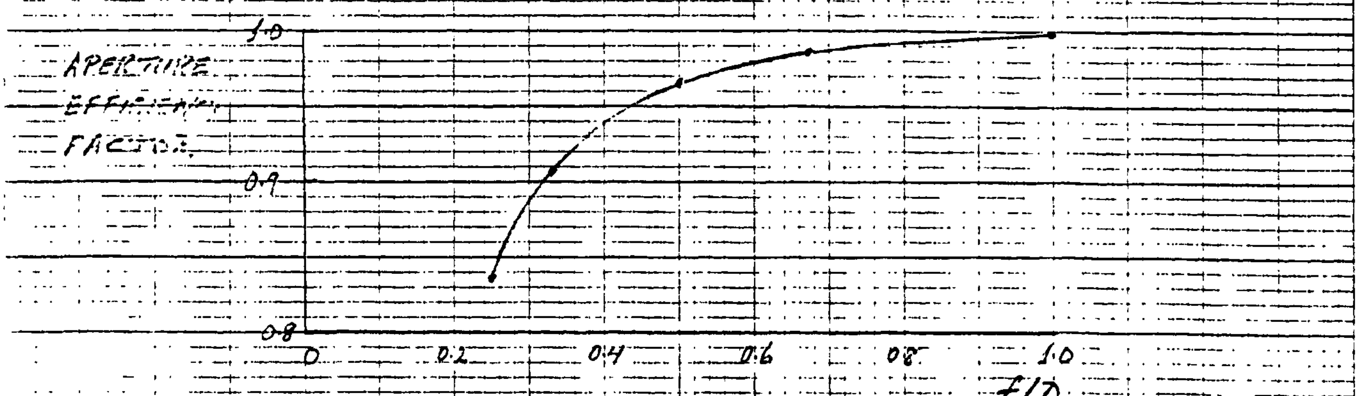


Figure 3. Computed aperture efficiency factor resulting from illumination taper.

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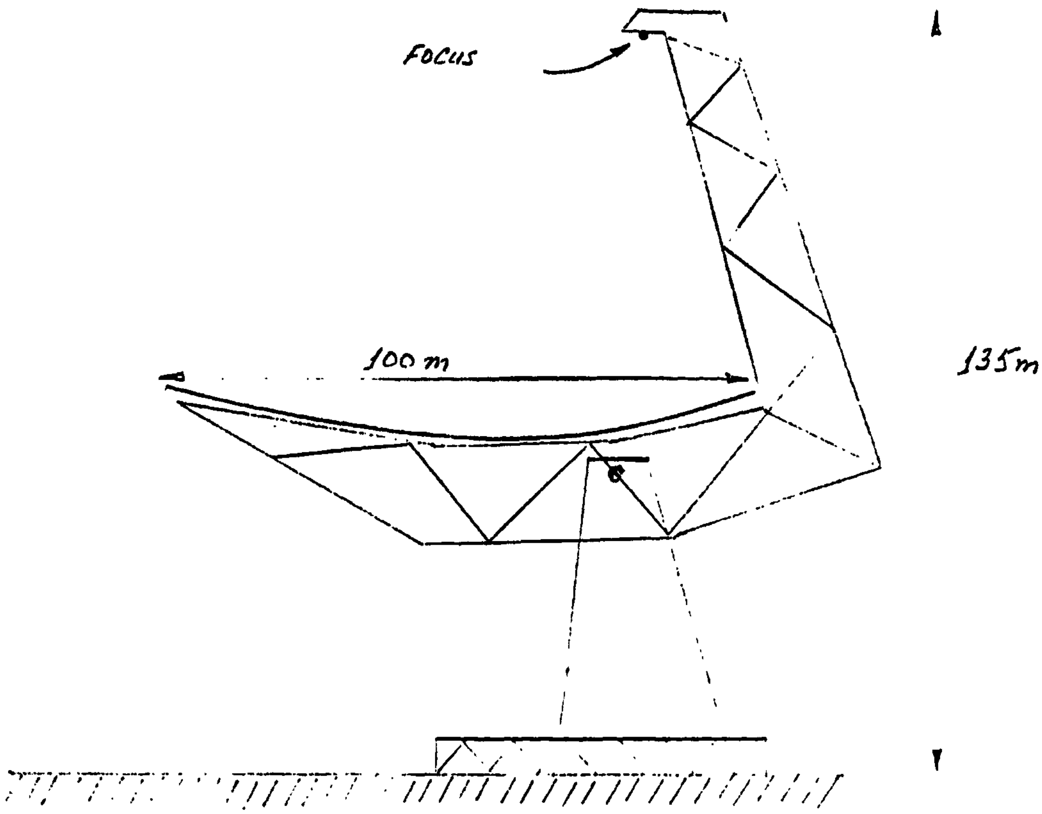

Figure 4. Sketch of possible configuration of main reflector and focus for offset feed antenna with f/D = 0.7, in stow position.

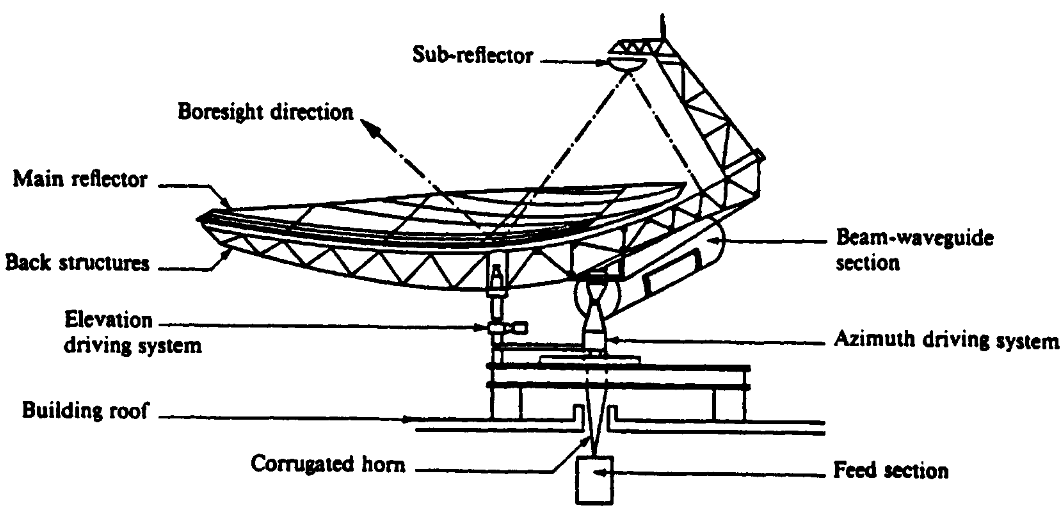

Figure 5. An example of a compact, offset Cassegrain antenna of aperture 11.5 m, built in Japan. From CCIR Report 677-1 (1986).

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