NLSRT Memo No. 44

Polarization Effects and Some Other Considerations in Offset-Feed Antennas.

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1 Polarization Effects.

When a paraboloidal reflector is fed by a linearly polarized feed centered at the prime focus, some oppositely polarized components of the electric field are generated in the aperture plane as a result of rotation of the electric vector in the reflection process. These oppositely polarized components are generally only a few percent of the copolarized field. In both on-axis and offset feed antennas the symmetry of the distribution of these components results in a cancellation of their contribution on the axis of the beam. However they produce cross polarized sidelobes that peak near the half power level of the main beam in offset feed antennas, and near the first nulls of the main beam in on-axis antennas. In the absence of any compensation scheme, the cross polarization responses are generally more serious in offset feed antennas, and on the beam axis the rate of change of this radiation with angle is very large (the cross polarized pattern has a cusp on the axis), whereas in on-axis antennas the rate of change is zero on the main beam axis. In offset feed antennas with circularly polarized feeds the crosspolarized sidelobes are absorbed within the main beam in a way that causes an angular offset in the main beam, sometimes referred to as beam squint. The offset is in opposite directions for the two opposite hands of circular polarization. For a detailed description of these effects see, for example, Chu and Turrin (1973).

Chu and Turrin have calculated the magnitude of the cross polarization sidelobes and beam squint for offset axis antennas and give graphs of these quantities. The data that they give are for an illumination taper of -10 dB at the edge of the reflector: values for -20 dB are almost the same. The configuration of the feed and reflector is specified in terms of the offset angle theta-subscript-zero and the half angle theta-subscript-c subtended by the reflector at the focus. These angles are shown in Fig. 1. Table 1 gives values for the cross polarization sidelobes and the beam offset for the two types of antenna discussed in NLSRT Memo No. 43, the modified Bell-System horn reflector antenna and the conventional design (see footnote) for several values of f/D. Note that for the latter I use theta-sub-zero - theta-sub-c = 8 deg to allow the feed structure to be clear of the aperture, and that my aperture "D", as used in table 1 and NLSRT Memos 29 and 43, is different from the usage in Chu and Turrin, and is the same as their "d".

In examining the results in Table 1, one should bear in mind that for an on-axis antenna with no feed offset the level of the cross polarization sidelobes depends upon the feed characteristics and is typically -20 to -30 dB. Also there is no beam offset for circular polarization. For the VLA

Footnote on terminology. The Bell System antenna sometimes referred to as a "Hogg-horn" or "sugar-scoop" is properly referred to as a "horn reflector antenna". I shall refer to the system derived from it (J. Lockman, NLSRT Memo 27) as a "modified horn reflector antenna". I shall refer to the other design of NLSRT Memo 43 (small-theta case) as a "conventional offset feed antenna", since it is similar in design to most existing offset feed antennas.

antennas, the offset arrangement of the feeds results in a beam offset of approximately 1/30 of a half-power beamwidth, i.e. a beam separation of 1/15 of a beamwidth. The VLA characteristics are satisfactory for measurement of linear polarization, but very poor for circular polarization: see VLA Scientific Memo. No. 125. Table 1 shows that the polarization effects get worse as either theta-sub-zero or theta-sub-c increases. For a maximum acceptable value of the cross polarization sidelobes we can take -20 dB as a tentative value, since anything larger would mean that the performance would be a step backwards from existing instruments. To determine a maximum acceptable beam offset with circular polarization consider the response to a source on the position that would be the beam axis in the absence of the offset. Then each of the two oppositely polarized beams will be off the source by an angle equal to the offset. We can represent the beam near the central part quite accurately by the Gaussian exp[-2.77(x**2)] where x is the angle from the beam axis measured in half-power beamwidths. The response to the source is decreased by 5% for x = 0.136. This would be a resonable criterion for, say, VLBI observations with the antenna, but may not be stringent enough for some other cases. In Table 1 the conventional offset feed design meets the criteria given above for f/D = 0.6 or greater. The modified horn reflector has a similar performance for theta-sub-c = 14 deg, which is the value for the horn flare half-angle in the Bell System design. Note that the polarization performance is not the same as that of the original horn reflector in which the feed was a single-mode horn.

The polarization and beam offset for all of the cases in Table 1 can be greatly reduced by the use of a subreflector with a feed offset that compensates for the effects of the main reflector. For further information on this point see the section on double offset reflector antennas in Rudge and Adatia (1978). These authors state that the limit to this method of suppression of cross polarized sidelobes is set by diffraction and the finite size of the subreflector, and that to reach a level of -40 dB requires a subreflector of diameter 25 wavelengths. For a 100 m antenna, the diameter of the subrefledtor would most likely be about 10 m, which is 25 wavelengths at 750 MHz. Thus if satisfactory Cassegrain feeds can be made, tnere should be good performance down to below one GHz in the Cassegrain mode. However, one of the important requirements for the new antenna is that it should operate satisfactorily with prime focus feeds, so the performance values in Table 1 are critical.

The minimum f/D of 0.6 for the conventional offset feed design from Table 1 is not greatly different from what was surmised to be the optimum value from structural considerations in NLSRT Memo 43. The modified horn reflector does not offer much advantage in terms of polarization performance over the conventional offset feed design. When the cost of the tower and rail track and the difficulty of mounting the large reflector are considered, it seems to me that if an offset feed antenna is to be seriously considereu, the conventional design with f/D of about 0.6 is clearly the direction to follow.

2 Aperture Efficiency.

The gradient in the illumination over the aperture resulting from the variation in the distance from the focus to the reflector surface results in a loss of aperture efficiency of only 2% for f/D = 0.6, according to the curve in Fig.3 of NLSRT Memo 29 which is based on an approximate calculation. This small loss is acceptable. In a system with a secondary reflector it could be reduced by shaping of the two reflectors (see Von Hoerner, 1978), but shaping would limit the possibilities for use of array feeds, and it seems generally agreed that it should not be included in the design for the Green Bank telescope. Note that compensation of cross polarization effects in dual reflector systems does not require shaping of the reflectors.

In NLSRT Memo 43 it was stated that the aperture efficiency of an offset feed antenna is about 5% higher than that for an on-axis antenna of the same diameter. Good values of aperture efficiency would be about 0.75 and 0.65 for the two cases respectively, so 15% would be a better figure for the offset feed advantage. For frequencies below about 500 MHz the sky noise sets the limit on the system temperature, and aperture efficiency is an appropriate measure of sensitivity. At higher frequencies the G/T (antenna gain/antenna temperature) ratio is a more appropriate index of sensitivity, and here the offset feed advantage may be nearer 20%. A 20% increase in area is roughly equivalent to an increase of 28% in cost, so in going to an offset feed design one could get back perhaps 28% of the cost increase by reducing the diameter by 10% for the same sensitivity.

3 Some Mechanical Considerations.

In Fig. 6 of VLSRT Memo 43 two possible orientations for the elevation axis of an offset feed antenna were shown. The axis AB in the figure, which lies in the plane of symmetry of the reflector, is structurally difficult to implement. This can be seen from Fig. 2, which shows that either one bearing would have to be supported by the feed tower, which would greatly increase the strength and weight required in that part of the structure, or else the axis would have to be behind the whole reflector surface, in which case the structure would be very much out of balance. An axis at 90 deg. to the plane of the paper in Fig. 2 seems to be the better choice.

A mechanical drawing of an offset reflector antenna with f/D (my definition) of about 0.55 can be found in the report for JPL by Ford Aerospace (1981). In this design the arm supporting the subreflector is on the top side of the main reflector when the beam is pointing near horizontally. The elevation axis is on a level with the center of the circular aperture of the main reflector. For two reasons it would appear to be desirable to have the elevation axis offset from the center of the aperture in a direction towards the side where the feed support arm is attached. First, this would help to counterbalance the weight of the feed arm. Second, it would reduce the offset between the elevation axis and the effective electrical axis of the antenna. By the effective electrical axis I mean a line through the phase center of the antenna in the direction of the main beam axis. The phase center can be defined as a point about which the antenna can be rotated through small angles without changing the phase of the signal being transmitted or received. Note that for an on-axis antenna the electrical axis coincides with the main reflector axis so long as the feed has a symmetrical radiation pattern and is accurately pointed. However, for an offset feed antenna the position of the phase center depends on the feed pattern and the gradient of the illumination over the aperture. If an antenna is used in interferometry it is desirable that the electrical axis should intersect the azimuth and elevation axes, so that the phase center does not have a component of motion along the main beam as a result of pointing motion. If there is a significant offset between these axes it becomes necessary to introduce pointing-dependent terms in the phase reduction algorithms. Small offsets (a few cm) are unavoidable but large ones could be a limitation. The pointing accuracy of the new antenna is likely to be of order 15 arcsec, and with, say, a 10 m offset the corresponding uncertainty in the wave path length is 0.7 mm. This is small compared with atmospheric effects, but could concievably be a nuisance if methods of atmospheric caibration are greatly improved or if the antenna were to be used in a short-baseline connected-element mode.

If the elevation axis is moved towards the feed arm, the the height of the elevation axis could be reduced by mounting the antenna so that the feed arm is at the bottom when the antenna is pointing to the horizon. Figure 3 is a sketch of what I imagine such an antenna might look like. Because of the angle between the beam and the aperture, the main reflector has to be turned so that the top edge leans forward to get the beam down to the horizon. This requirement would put a lower limit on the height of the elevation axis, and so the scheme shown in Fig. 3 may not be the best mechanical design after all. With a prime focus feed the spillover past the main reflector in Fig. 3 is directed mainly towards the cold sky, whereas witn the feed arm at the top side it would be directed mainly towards the ground.

It seems that the backup structure would need to be be stronger in some area towards the edge of the reflector where the feed arm is connected, in order to provide a stiff enough base for the arm. This is the case in the masked-ring-and-rib design of JPL/Ford, where the main trusses converge towards the vertex of the paraboloidal surface. Thus the reflector surface should be stiffest and most accurate near the base of the feed arm, rather than near the center of the reflector as in on-axis antennas. A high accuracy area for high frequency operation might not be in the center of the reflector. This would mean that the phase center for the highest frequencies would be at a different position from that at lower frequencies.

4 Do We Really Want an Offset Feed Design?

It is useful to review the advantages and disadvantages of the offset feed design. The advantages are as follows.

(1) Low sidelobes for interference protection. Figure 1 of NLSRT Memo 29 shows that the sidelobe levels for an offset reflector antenna can fall to the isotropic level as close as 5 deg to the main beam, whereas for an on-axis antenna the sidelobes typically remain above the isotropic level for angular distances of about 20 deg from the main beam. If an interfering signal from a satellite is just at the harmful threshold level when received in sidelobes of gain 0 dBi, then one would be able to observe to within 5 deg of the satellite with an offset feed antenna, but only to within 20 deg with an on-axis antenna. On the other hand if the signal is 30 dB above the harmful threshold when received in 0 dBi sidelobes, it would be received at a harmful level over most of the entire sky with either type of antenna. The low interference

levels for which the greatest benifit is obtained from the low sidelobes might be encountered, for example, as out-of-band emissions at frequencies within radio astronomy bands. Outside of the radio astronomy bands much stronger signals may be encountered. Thus the protection afforded by the offset feed design is limited to particular conditions. The low sidelobe levels require high surface accuracy, and J. R. Fisher has pointed out that sidelobes resulting from surface inaccuracy tend to be close to the main beam. These are the ones that set the limit on the amount of sky lost to interfering satellites.

(2) Protection from interference from celestial sources. Essentially the same considerations apply as in the case of man-made interference, except that the levels from the sun (except for very strong bursts), the galactic center, Cassiopeia A, etc. do not reach the high levels of man-made signals. The low sidelobes are therefore likely to be of benefit in most cases. Observation of hydrogen line emission at high galactic latitudes without confusion from the galactic center in the sidelobes is an important example. However the full angular resolution of the 100 m aperture is probably not needed for the data required, and the measurement may be feasible using the small unblocked aperture provided by a smaller antenna or one quadrant of a large on-axis antenna.

(3) Reduction of standing waves on the antenna. Reflections from the main reflector or subreflector that return radio waves into the feed are a well known cause of variation in the total power baseline in radio telescopes that incorporate on-axis antennas. The problem has received considerable attention on the past but has not been solved in any completely satisfactory way. A detailed discussion is given by J. R. Fisher (1978). It is possible to reduce the main reflection from the vertex area of the dish by about 20 Db by a spoiler, but at that level reflections from many other parts of the antenna may become important. In an offset feed antenna the reflection from the vertex, and probably numerous other points, are eliminated or reduced. However there may still be a reflection from the edges of the surface panels, if these are mounted in the usual way, following the contours of the paraboloidal surface. Use of an offset feed antenna is an attractive way to pursue the reflection problem, but it is not clear that further progress cannot be made with on-axis antennas.

The principal scientific and technical disadvantages of the offset feed design are the following.

(1) The cross polarization and beam offset problems discussed in section 1.

(2) Somewhat greater difficulty in defining the phase center. This is only of importance in interferometry, and then may be more of a nuisance than a serious problem.

The mechanical problems and the cost of building a large offset feed antenna need to be assessed by a mechanical engineer. The problems that seem most apparent to me are the following.

(1) The offset feed design requires more steel and is therefore more expensive.

(2) There is no experience with designs that incorporate homology. Lee King thinks that it would take a year or more to complete the required computer

studies.

(3) It is probably true that no offset feed antenna has yet been built that is big enough that gravitational effects set the limit on performance. Thus in building a very large offset feed antenna we would be breaking new ground, and a very careful and detailed analysis would be required to obtain sufficient confidence in the design.

At this point I do not think that one can go much further without mechanical and structural studies. From scientific considerations my personal view is that the advantages of the offset feed design outweigh the disadvantages provided that there is no sacrifice in the high-frequency operating range of the antenna. Thus we need a mechanical study of the deformation of the surface with changing elevation to see if there are penalties in the frequency coverage in going to an offset feed design.

5 Erratum.

NLSRT Memo 43, page 1, paragraph 3, line 2, "off-axis" should be "on-axis".

6 References.

Chu, T.S. and Turrin, R.H., Depolarization Properties of Offset Reflector Antennas, IEEE Trans. Ant. and Prop., AP-21, 339-345, 1973.

Fisher, J.R., Reflection Measurements on the 140-foot and 300-foot Telescopes, NRAO Electronics Division Internal Report No. 184, Green Bank, 1978.

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

Von Hoerner, S., Minimun-Noise Maximum-Gain Telescopes and Relaxation Method for Shaped Asymmetric Surfaces, IEEE Trans. AP-26, 464-471, 1978.

WDL Technical Report 9147, Offset Antenna Study, Ford Aerospaceand Communications Corp., Western Development Labs. Div., Palo Alto, Cal.

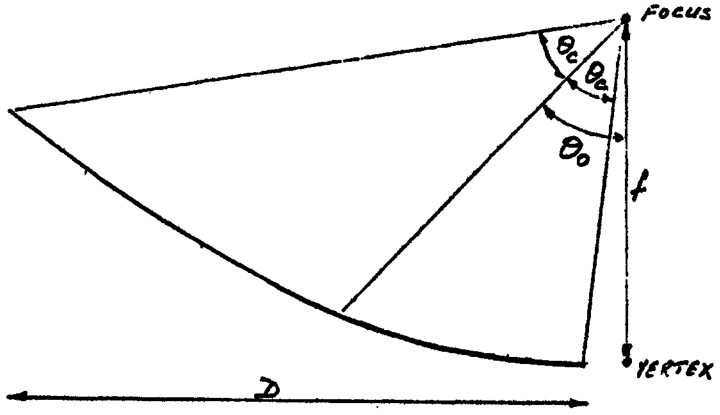

Fig. 1. The angles θ_o and θ_c.

	θ_o	θ_c	Cross-Polarization Sidelobes	Beam Offset, Unit = HPBW.
Modified Horn Reflector	90°	14°	-22dB	0·085
Conventional Offset Feed Ant. ($\theta_o - \theta_c = 8°$)				
f/D = 0·4	63°	55°	- 1[illegible] dB	0·22
0·5	51·5°	43·5°	-18·6 "	0·13
0·6	46·5°	38·5°	-20·5 "	0·11
0·75	37·5°	29·5°	-24·5 "	0·062
1.0	34°	26°	- 27 "	0·048

Table 1. Polarization Effects in Offset Feed Antennas.

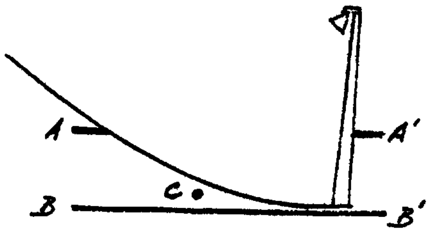

Fig. 2. Two possible locations (AA' and BB') for the elevation axis in the plane of symmetry of the antenna. An axis normal to the plane of the page at C appears to be more practical.

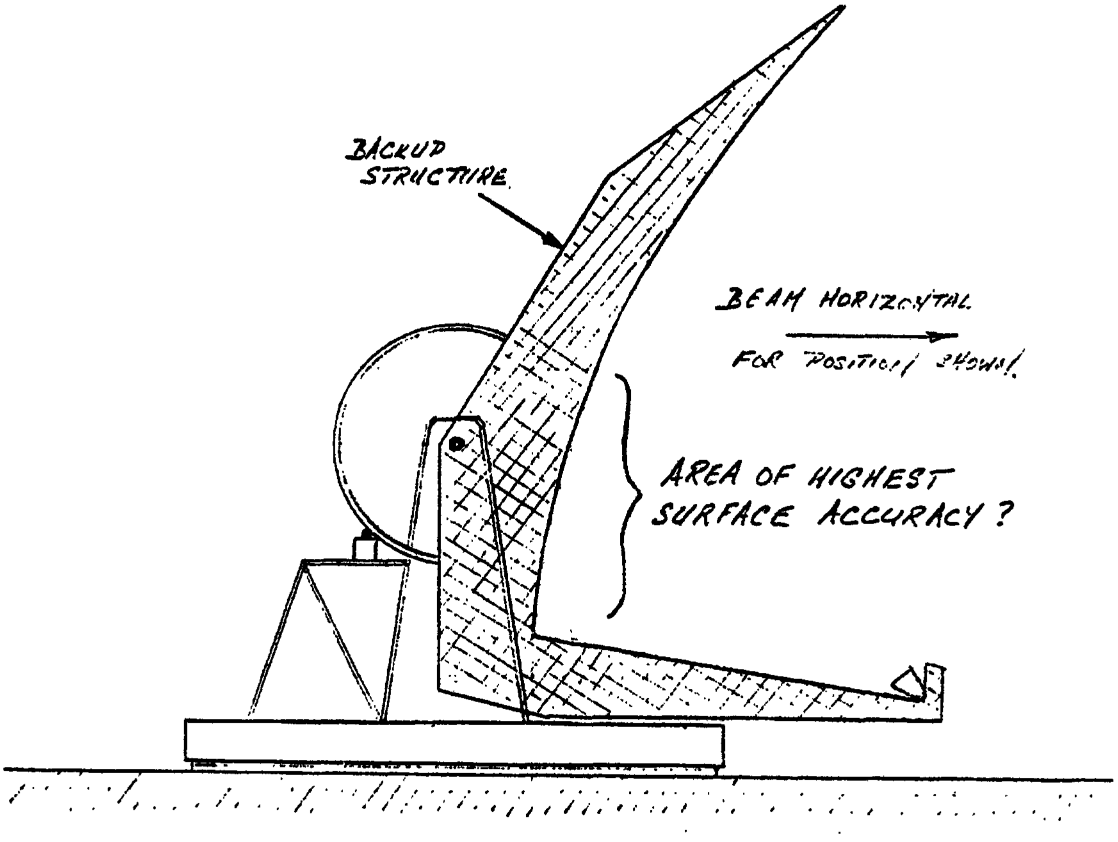

Fig. 3. Antenna with feed arm at the lower edge when pointing horizontally, for f/D = 0.6.