The Choice Between Symmetrical and Unblocked-Aperture Designs

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September 1, 1989

In NLSRT Memo No. 50, I offered the opinion that the symmetrical design seemed the most practical choice for the new antenna, based on some preliminary thoughts on the mechanical stability of the focal point support arm, and the amount of work required on the pointing and the active surface. Since that time a good deal more thought has gone into the advantages and problems of the unblocked aperture, and this memorandum presents a brief reconsideration of the factors affecting the choice of design.

The electrical performance of the two designs is discussed in some detail in NLSRT Memo 67, in which the following factors are condsidered: (1) gain and noise temperature, (2) polarization, (3) sidelobes, (4) baseline ripples resulting from reflections, (5) field of view, (6) location of feeds and recievers for ease of access and interchangeability. The field of view can be expressed as the scan angle for which a 1 dB loss of gain occurs. With prime- focus feeds this occurs at 2.7 beamwidths from the field center for the unblocked antenna, compared with 4.3 beamwidths for the symmetrical antenna. At the Cassegrain focus the field is adequately wide in both cases. With the unblocked antenna some special measures have to be taken to avoid polarization problems (with opposite circular polarizations these appear as beam squint). Again, for Cassegrain operation these present no problem, but for prime focus operation specially designed trimode feeds which have bandwidths of only 4% to 5% are required if polarization is important. Thus the unblocked design is at some disadvantage (not necessarily serious) with regard to field of view and polarization, but in the prime focus mode only. In the other four of the six characteristics listed above the unblocked design offers significant advantages.

The mechanical stability of the arm that supports the prime focus elements was discussed in NLSRT Memo 67, based on a single unsupported structure as shown, for example, on the cover of NRAO report "A Radio telescope for the Twenty-First Century". The additional support of two bracing members, as shown in Fig. III-3 of the NRAO proposal document, should greatly improve the stability. However it is desirable that these supports should connect to the hard points of the structure near the elevation axis rather than to the backup structure of the reflector, so as to avoid increasing the gravitational distortion of the reflector. Preliminary opinions by structural engineers indicate that there are no serious problems in supporting the arm with adequate stiffness, although detailed questions such as the mechanical hysteresis remain to be answered. Lee King has pointed out that since the arm does not block the aperture it can be made as large in cross section as desired, which provides the designer with freedom not available in the symmetrical antenna.

If it is generally agreed that the unblocked design is electrically superior, and no serious structural problems are found for it, then the remaining consideration is the cost and its constraints on the size. For a given size the unblocked aperture costs more than the symmetrical design because of the greater amount of steel in the focal support structure, the

greater number of different designs for the individual surface panels, and the greater complexity of the non symmetrical backup structure. Thus for a given cost the unblocked aperture must be smaller in size than the symmetrical design. The resulting difference in performance can be illustrated most simply by considering the sensitivity to a point source. Define a factor

F = (cost of unblocked antenna)/(cost of symmetrical antenna of same size).

Experience has shown that the cost of an antenna is approximately proportional to (diameter)**2.6, so for a fixed cost the relative geometrical area of the unblocked design is equal to F**-1.3. The sensitivity is equal to the geometrical area multiplied by factors to take account of the better G/T ratio for the unblocked aperture. (G/T = gain/system temperature). Estimates of relative gain and system temperature at three frequencies are given in the following table:

	500 MHz	1.4 GHz	22 GHz.
G(unblocked)/G(symmetrical)	1.03	1.06	1.06
T(symmetrical)/T(unblocked)	1.21	1.43	1.09

In estimating the relative gain it has been assumed that in the symmetrical antenna the feed support structure blocks 3% of the incident power. As a result the gain is reduced by 6%. However at the lowest frequency a prime focus feed must be used, and for the unblocked antenna there is a gradient of illumination across the aperture which I estimate reduces its gain by 3%. The values of system temperature shown were estimated by M. Balister and incorporate receiver temperatures corresponding to the best current NRAO designs. The sensitivity of the unblocked antenna relative to the symmetrical one is equal to F**-1.3 multiplied by the two factors in the table, and for the three frequencies is plotted as a function of F in Fig. 1.

At the present time there is no reliable estimate of the cost factor F, but values that have been quoted lie within the range 1.15 to 1.5. A mid-range value of about 1.3 is a good guess at this time. At 1.4 GHz the reduced antenna temperature of the unblocked antenna (which results from elimination of feed-support scattering) produces an overall increase in sensitivity over the whole range of F shown. At this frequency cryogenic front ends provide very low noise temperatures, so the greatest advantage is taken of the low antenna temperature. At the other two frequencies the sensitivity of the unblocked design is generally lower than the symmetrical one. This is because at 500 MHz galactic background radiation limits the antenna temperature, and at 22 GHz there are the effects of higher receiver temperatures and of the noise contribution from the atmosphere. Thus at these two frequencies the lower antenna temperature of the unblocked design provides less advantage than at 1.4 GHz. For a mid-range value of F the loss in sensitivity at 22 GHz is close to 0.5 dB. It would surely be generally agreed that the advantages of the unblocked aperture are worth a loss of 0.5 dB at centimeter wavelengths. At the highest frequencies at which the antenna is useful, the performance is likely to be limited by the pointing, thermal effects, etc. which become less severe as the size is reduced.

In conclusion, the electrical properties of the unblocked aperture design offer definite advantages, and have been demonstrated on many smaller antennas of which the performance which can be extrapolated by scaling. The performance penalty of the higher cost of the asymmetrical structure seems likely to be small. I now feel that if continuing studies of structural performance show no problems, we should take up the full challange of the unblocked aperture as well as active compensation for the surface deformations, to obtain an antenna that is fully state-of-the-art. The precise size, 100 m or a little less as dictated by the cost, should be regarded as a matter of secondary importance.

Fig. 1. The sensitivity to a point source for the unblocked design, relative to that for a symmetrical antenna of the same cost, as a function of the cost factor F.