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Cassegrain *vs.* Prime Focus Operation

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1. General

It seems likely that the new telescope will mostly be fed from the secondary focus, regardless of whether a symmetrical or offset configuration is chosen. Operation from the primary focus should not be excluded from the design, since it may be the only practical feed point for the lowest frequencies, but it should not drive the design nor allow performance at the secondary focus to be compromised.

The statements of the last paragraph are based on the following considerations:

1. In any configuration, the secondary focus can be placed at a much more convenient location for equipment mounting than the primary focus. Access is better, and more space is available so that a large number of receivers can be installed simultaneously.
2. Beam switching will be essential to many observations, and this can be accomplished either by rotation of the subreflector or by a pair of flat mirrors near the feed. This is more difficult to implement at the primary focus.
3. The weight of equipment near the primary focus should be minimized, either to minimize blockage in the symmetrical configuration or for structural reasons in the offset configuration.
4. The additional degree of freedom in the optical design afforded by having two reflectors can be used to advantage. In the offset configuration, the polarization variation across the main beam depends on the effective F/D, and is better at the secondary focus; in addition, the variation can be cancelled almost completely by either of two techniques: placement of the feed and focal point off the main reflector's axis [1], and modifying the shapes of the reflectors [2]. In either configuration, the shapes of the reflectors can be chosen to optimize performance parameters; this is further discussed below.

2. Shaping Of Reflectors

It is well known that shaping for maximum aperture efficiency can approach the ideal of uniform illumination [3], but this results in a more rapid loss of gain for lateral feed displacement (beam switching or multi-beaming) than with the classical paraboloid-hyperboloid. It is not known what shaping gives maximum tolerance to feed displacment, nor whether there is a shaping that gives a good compromise between these requirements. It is also not known how this interacts with minimization of the polarization variation across the beam in the offset configuration. Even if the main reflector is restricted to being a paraboloid, optimization of the subreflector shape only (and appropriate re-focusing) can result in significant improvement in aperture efficiency [4]. Thus, it may be feasible to construct two subreflectors, optimized in different ways, and to swap them according to the observational requirements. Of course, none of these optimizations is possible from the prime focus, where any deviation of the main reflector from a paraboloid is detrimental.

3. Polarization With Offset Reflectors

In the case of the paraboloid-hyperboloid reflector pair, an equivalent paraboloid can be defined whose radiation characteristics are the same as those of the pair; it has the same diameter as the main reflector and a focal length $F' = MF$ where M is the magnification factor. The offset geometry is defined by equivalent angles $\theta_0' = \theta_0/M$ and $\theta_c' = \theta_c/M$, where θ_0 is the offset angle and θ_c is the half-angle subtended by the main reflector at the prime focus (see [7] or [8] for illustrations). At $M = 2$, which places the secondary focus near the main reflector surface, substantial improvement in the polarization purity is obtained, as illustrated in the following table (this table is an extension of that given in [7] and is based on the curves plotted in [8]).

As noted earlier, further improvement in polarization is possible by moving the focal point off axis and by shaping.

F/D	θ_o	θ_c	Peak Cross-Polar Sidelobe for Linear Pol. Feed, 10 dB Taper	
	(θ_o - θ_c = 8°)		M = 1 (Prime Focus)	M = 2 (Cassegrain)
0.4	63°	55°	-13.6 dB	-28 dB
0.5	51.5	43.5	-18.6	-32
0.6	46.5	38.5	-20.5	-33
0.75	37.5	29.5	-24.5	-38
1.0	34	26	-27	-39

4. Subreflector Size and Maximum Cassagrain Wavelength

For the symmetrical configuration, the minimum blockage occurs when the feed and the subreflector are of equal size, and this size is given by [5]

$$D_s = \sqrt{kF\lambda}$$

where F is the main reflector focal length, λ is the maximum wavelength, and $k \approx 2$ is a dimensionless constant dependant on the feed pattern. In order to minimize losses due to subreflector diffraction, we also require

$$D_s/\lambda \geq 20.$$

These two equations can be solved for D_s and λ. Taking $F = 35$ m (for $F/D = 0.35$ and $D = 100$ m), we find $D_s = 3.5$ m and $\lambda = 17.5$ cm. This is a rather small subreflector for a 100 m dish (it's about the same size as the VLBA subreflector), producing only about 0.12% blockage. Blockage by the support legs is expected to be about 3% or more, so we can afford to have about 0.5% subreflector blockage without significant degradation. Therefore, let's take $D_s = 7$ m and $\lambda = 35$ cm. This wavelength would require a rather large feed, about 3.5 m diameter. If some diffraction loss is tolerated, the antenna will be usable in Cassegrain mode at somewhat longer wavelengths, say to 50 cm.

For the offset configuration, a somewhat larger F/D is more practical for mechanical reasons [6], say $F/D = 0.5$. In this case, if we keep the subreflector the same size, $D_s = 7$ m, the feed diameter must be increased to about 5 m at $\lambda = 35$ cm.

From the above it seems that the feed size, rather than the subreflector size, may set the practical longest wavelength for Cassegrain operation. For operation at 91 cm (327 MHz) or 4 m (75 MHz), the prime focus will have to be used; the same may be true at 50 cm.

References

[1] A. W. Rudge and N. A. Adatia, "Offset-parabolic-reflector antennas: A review." Proc. IEEE, 66, 1592–1618, 1978 (see pp. 1613-4).

[2] *Ibid.* (see p. 1615).
[3] V. Galindo, "Design of dual-reflector antennas with arbitrary phase and amplitude distribution." IEEE Trans. AP-12, 403–408, 1964.
[4] G. W. Collins, "Shaping of subreflectors in Cassegrainian antennas for maximum aperture efficiency." IEEE Trans. AP-21, 309–313, 1973.
[5] A. W. Rudge et al., eds., *The Handbook of Antenna Design*, vol. 1. Peter Peregrinus Ltd: London, 1982 (see sect. 3.2.1).
[6] A. R. Thompson, "Possibly feasible approaches to the design of a large offset-feed radio telescope." NRAO, NLSRT Memo No. 43, December 1988.
[7] A. R. Thompson, "Polarization effects and some other considerations in offset-feed antennas." NRAO, NLSRT Memo No. 44, January 1989.
[8] T-S Chu and R. H. Turrin, "Depolarization properties of offset reflector antennas." IEEE Trans. AP-21, 229–345, 1973.