

Chapter 2¹

Deep Space Station 11: Pioneer— The First Large Deep Space Network Cassegrain Antenna

2.1 Introduction to the Cassegrain Concept

The two-reflector system invented by Nicholas Cassegrain has been used extensively in optical telescopes, primarily to achieve a long effective focal length with a convenient physical configuration. During the late 1950s, widespread interest developed in the use of this type of system for microwave frequencies. An excellent tutorial paper by Hannan [1] from 1961 discusses the Cassegrain antenna from a geometric optics standpoint and mentions its possible advantages over a focal-point feed system: superior physical configuration, greater flexibility in feed-system design, and possible longer equivalent focal length for simultaneous lobing applications. The specific advantages of the two-reflector system applications, that is, minimum rear hemisphere radiation and high front-to-back ratio, were pointed out by Foldes and Komlos in 1960 [2]. They discuss detailed experimental measurements relating to the deviation of the feed-system performance from that which would be expected based on geometric optics; their design was, in fact, experimentally optimized, taking into account the empirically determined diffraction effects of the optical subreflector. Under Jet Propulsion Laboratory (JPL) sponsorship, this work was extended by Foldes to large low-noise antenna applications [3]. At the same

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time, experimental work was being done at JPL with a low-noise, 26-m Cassegrain system, described by Potter [4]. Potter showed that the major factors in choosing the feed-system configuration were the forward sidelobe distribution, which must be controlled to reduce the effect of solar noise interference, and the backlobe level, which must be controlled to reject black-body radiation from the antenna environment. The 26-m antenna operating at 960 MHz has an aperture efficiency of approximately 50 percent and a measured zenith noise temperature of 9.5 K.

2.2 Factors Influencing Cassegrain Geometry

The basic geometry of the Cassegrain system is shown in Fig. 2-1. A hyperboloidal subreflector is interposed between the focal point of the reflector and the reflector surface and provides a constant path length for the rays from the feed to the aperture plane. Based upon geometrical optics, it can be seen that the Cassegrain system has no spillover. However, due to the finite size of the feed, there *is* forward spillover past the subreflector. Since the subreflector is only moderately sized in terms of wavelengths, there is also diffraction spillover past the main reflector. For tracking missions involving the planets Mercury or Venus, the geometry is such that the antenna may be pointed to within a few degrees of the Sun. Since the Sun is an extremely strong noise source, it is important that the antenna sidelobe level be well controlled in the solar region.

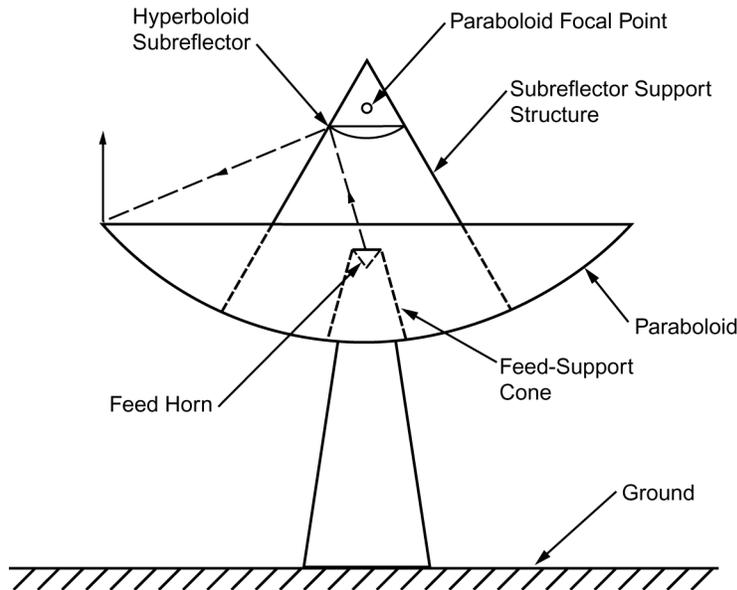


Fig. 2-1. Basic Cassegrain geometry.

In addition to the normal aperture-distribution diffraction pattern, the Cassegrain system introduces spurious sidelobe energy from two separate mechanisms: subreflector aperture blockage and forward spillover around the subreflector. The aperture distribution with blockage is thought of as being composed of the linear superimposition of the aperture distribution without blockage, minus the blockage aperture distribution. Potter [4] demonstrates that, at higher frequencies, it is reasonable to use the first sidelobe level of the blocking pattern as the criterion for maximum subreflector size, since the angular distribution of the blocking energy is very narrow.

Generally speaking, in order to illuminate the paraboloid efficiently, the hyperboloid must be illuminated more or less uniformly. On the other hand, in order to avoid undue forward spillover energy loss, the feed horn must be of sufficiently high gain to contain 70 to 90 percent of its energy within the area subtended by the subreflector. A typical compromise between these two considerations results in subreflector edge illumination about 10 dB below the central illumination. The spillover energy-peak gain relative to isotropic gain will thus be approximately given by the feed-horn gain reduced by the subreflector edge-taper ratio. It is clear that the feed-horn gain must be minimized to reduce the forward spillover. This may be accomplished by (a) using the largest subreflector possible and (b) using a geometry that places the feed-horn aperture as close to the subreflector as is structurally practical. The final configuration choice, therefore, involves the following steps:

- 1) Choose the largest subreflector possible, based on analysis of the blocking sidelobe level
- 2) Use the smallest horn aperture-to-hyperboloid spacing that is structurally practical and does not further increase the blockage by feed-horn shadow on the main reflector caused by the central rays from the subreflector.

Observe that in Cassegrain geometry, the subreflector subtended angle is small (almost always less than 20 deg), resulting in the need for a modest gain horn (~20 dB) that leads to a fairly high forward spillover. Potter [5] suggested an improvement in the subreflector design, involving the use of a flange that would both reduce forward (less noise from the Sun) and rear (less noise from the ground) spillover while simultaneously increasing aperture efficiency. The geometry of the beam-shaping flange is shown in Fig. 2-2. The forward spillover is reduced because of the larger extended angle, and the rear spillover is reduced because the energy radiated from the flange near the edge of the dish subtracts from the energy radiated from the hyperboloid, effectively steepening the slope at the edge of the dish and consequently reducing the rear spillover. Both effects are actually due to the increased size of the subreflector. Based upon scale model tests, an 18.4-deg flange angle was chosen by Potter as a suitable compromise between aperture efficiency and low-noise performance.

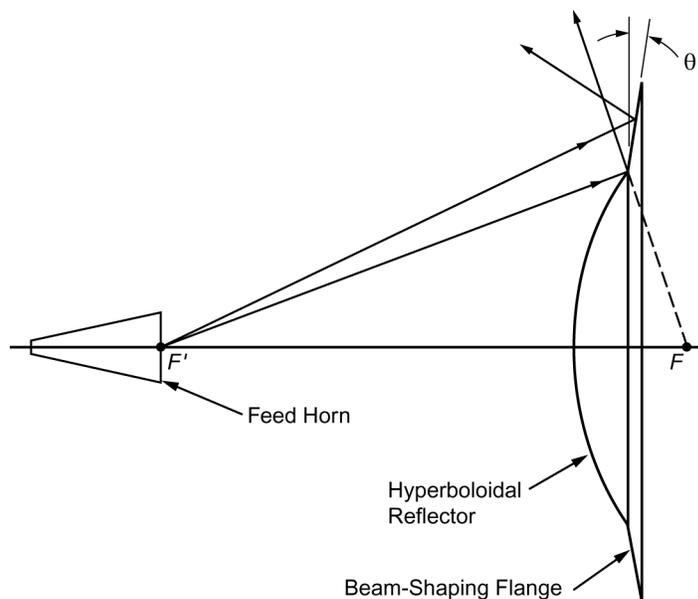


Fig. 2-2. Geometry of a beam-shaping flange.

2.3 The DSS-11, 26-Meter Cassegrain System

In order to obtain firsthand knowledge of the performance and operational convenience of a well-designed, low-noise Cassegrain system, JPL installed and tested one on the Goldstone 26-m polar mount antenna known as Deep Space Station 11 (DSS-11). The basic design and mechanical properties of this antenna have been previously described [6]. As was typical of many of the early Deep Space Network (DSN) antennas, it was named after the first mission it supported, the Pioneer 3 and 4 lunar missions.

Although the surface tolerance of the antenna is sufficiently accurate to allow efficient operation in the S-band (2.2–2.3 GHz) region, the feed system operational frequency was chosen to be L-band (960 MHz) to allow its use for tracking the Ranger and Pioneer spacecraft. Figure 2-3 shows the feed system configuration. Figure 2-4 is a photograph of the installation. The feed system is composed of five basic components: subreflector, subreflector mount and alignment system, feed-horn, support cone, and transmission line system.

The subreflector, in this case, consists of an 8-ft (2.438-m)-diameter hyperboloid together with a beam-shaping extension flange [5] and a vertex plate in the central region [2]. Because of the small size of the hyperboloid in this system (approximately 8 wavelengths), it was necessary to use the beam-shaping

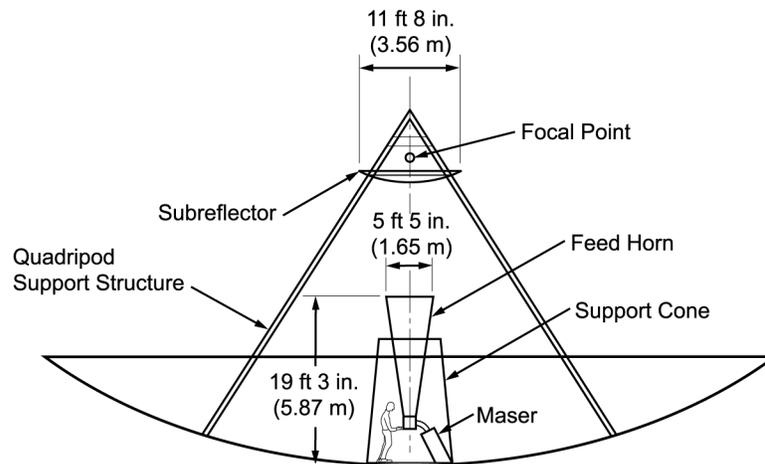


Fig. 2-3. Feed-system configuration of the DSS-11 twenty-six-meter Cassegrain antenna.

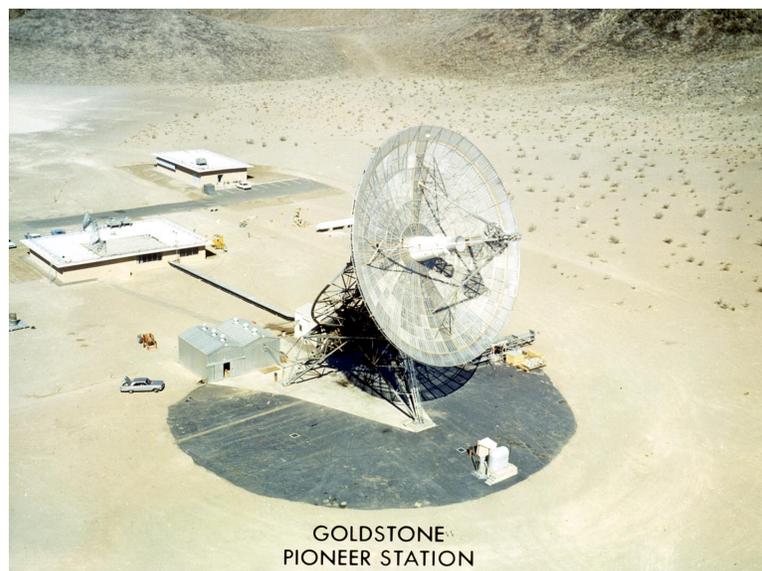


Fig. 2-4. The Cassegrain installation at DSS-11.

flange to effect a low spillover. The vertex matching device was found necessary to prevent reflection of energy by the subreflector back into the feed horn.

The subreflector mount consists of a square trusswork with a three-point jackscrew support. The three jackscrews are chained together and motorized with remote control. The system is thus designed for rapid focus adjustment on

far-field radio star sources. Boresight adjustments are made by removing the chain and independently adjusting the three jackscrews.

The feed horn is a pyramidal horn of circular cross-section, with a 5.3-wavelength aperture and a 9.5-deg half-flare angle. Symmetry about the antenna axis is used not only in the feed horn but also in the subreflector, allowing complete polarization flexibility. A maximum horn aperture and minimum flare angle, constrained in this case by structural limitations, was utilized in order to minimize the energy spilled past the subreflector. The latter must be minimized not only to prevent undue aperture-efficiency degradation due to loss of energy, but also to prevent an unduly high forward sidelobe level, which would make the system susceptible to solar noise jamming.

In order to minimize loss, the transmission-line system uses WR975 (9.75-in. [248-mm]) rectangular waveguides wherever practical and rigid 3-1/8-in. (79-mm) coaxial line elsewhere. A turnstile junction [7] is used as a polarizer. This junction, together with two rotary joints, provides for dual polarization with either right- and left-hand circular or two orthogonal rotatable linear modes.

The measured and predicted noise-temperature contributions for the 960-MHz Cassegrain system are given in Table 2-1. The aperture efficiency corresponding to a given feed system illumination function may be established by simple graphical integration techniques [9]. For the 960-MHz Cassegrain system, this method predicted a 58 percent efficiency as compared with a measured value of 50 percent \pm 8 percent.

Table 2-1. Cassegrain noise contributions, 960 MHz (antenna at zenith).

Source of Noise	Fractional Loss	Physical Temperature (K)	Predicted Noise Contribution (K)	Measured Value (K)
Extra-atmospheric	N/A ^a	N/A	1.5 (estimate)	3.5
Atmosphere	N/A	N/A	2 K [8]	Not available
Direct spillover	0.013	240 ^b	3	Not available
Scattering from subreflector support	0.010	240	2.5	Not available
Total			9	9.5 \pm 2

^aNot applicable.

^bIncludes ground reflection coefficient.

DSS-11 was decommissioned in 1981. In 1985, the National Park Service declared the site a national historic landmark.

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