A Prototype DSN X-S Band Feed: DSS 13 First Application Status

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This article discusses a new prototype X-S band horn feed for future use at various DSN sites. This project was undertaken to more nearly optimize the X-band performance of these stations. This feed is a corrugated horn with extremely deep corrugation grooves that are suitable for both the X-band and S-band. The horn is very large, becoming gain limited, so that it performs about equally in both bands. A one-half scale model was fabricated and the measurement results were good reproductions of theoretical predictions. A full scale item has now been completed and will be tested at DSS 13.

I. Introduction

The reflex dichroic S-X band feed has been in successful operation on the 64-meter antennas for a number of years, and was selected for implementation in the 34 meter subnet upgrade project. This feed permits full high performance for telemetry within S-band while at the same time allowing for operation in the new telemetry frequencies within X-band. Although the X-band corrugated horn used with this reflex feed is very good, it is also true that the use of the dichroic plate in the system and the large asymmetric feed structure results in about 0.5 dB G/T compromise of X-band performance. This is because of some small loss in the dichroic plate and some back scatter at X-band resulting in an increase (2-3 Kelvins) in the X-band antenna noise temperature.

In the future, the use of X-band telemetry is to be emphasized, at the expense of S-band if necessary and also fully symmetric antennas are desired. It was decided to develop an alternate feeding technique that would more nearly optimize X-band performance, perhaps with some degradation of S-band performance.

It is evident that if the dichroic plate is to be removed, then the two bands must operate concentrically or coaxially from the same or coaxial apertures. Some obvious approaches to accomplish this are: (1) an X-band horn within (coaxial with) the S-band horn, (2) an X-band end fire element (disc-on-rod or helix) within the S-band horn, and (3) an array of four or more S-band horns surrounding the X-band radiator, much like a monopulse system. These approaches all would result in a considerable S-band performance compromise (say 2 dB), and the use of anything but a good horn for X-band might well have as much loss as the dichroic plate. The only obvious approach available is to actually use the same horn with both bands and develop a technique that will result in acceptable illumination functions in both of these widely separated frequencies.

This has been accomplished by using a very large corrugated horn, operable in both bands, and operating in a "beamwidth saturation" mode at X-band so that the two radiation patterns are very similar. A unique characteristic of this horn is that the phase center has moved back, clear into the throat of the horn, in contrast to previous JPL horns.

II. The Horn Concept

Jeuken (Ref. 1) suggested this technique of operation in different frequency bands. The corrugated horn derives its operating characteristics from the fast wave structure of the horn walls. This structure forces the fields from the walls and reduces wall currents. In this manner, the final aperture illumination is well tapered, the electric fields being zero at the edges. This characteristic is obtained by grooving the walls perpendicular to power flow so that the surface impedance becomes capacitive. For this to occur, the grooves must be between $\lambda/4$ and $\lambda/2$ deep (λ = wavelength) at the operating frequency, or in the range

$$\lambda \left\{ \frac{2N-1}{4} \right\} \quad \text{to} \quad \lambda \left\{ \frac{2N}{4} \right\},$$

where N may assume any integer value. Usually five or more grooves per wavelength are sufficient.

As a horn with fixed flare angle becomes longer, the aperture becomes larger and radiation patterns become narrower. A point is reached however when additional size does not make the pattern narrower nor the horn to develop higher gain, generally because of total phase error in the aperture. For this discussion we may call this "saturated operation." As size is further increased, some change in pattern texture may be detected; however, the pattern remains essentially unchanged.

One now sees the possibilities. A groove depth can be chosen which satisfies the depth requirement above within two (or more) frequency bands for proper corrugated horn operation, and sufficiently large to just be "saturated" in the lowest band so that the higher bands would be operating well above this point for nearly equal pattern characteristics. The beamwidth for these "saturated" conditions is a function only of the horn flare angle, and *not* the aperture size. Narrower flares result in narrower saturated beamwidths, with consequent longer horn lengths.

In this saturated operation, the pattern phase center has moved back into the throat of the horn, approximately at the horn vertex, instead of its usual position near the aperture face. This will give a somewhat unusual appearance to the Cassegrain system because the horn will extend a large distance away from the feedcone-centered hyperboloid focal point, towards the hyperboloid.

III. Calculations

Potter (Ref. 2) has prepared a generalized computer program for the calculation of the performance of corrugated horns. This program was used at length in the calculations of horn patterns for various flare angles from 20 to 40 degrees. Figure 1 represents a compilation of the calculations for a horn of 36 degree flare angle (18° half flare). This figure depicts the 10 dB beamwidth of the horn as it is made larger (longer) through the saturation point. This beamwidth (10 dB) is chosen since it represents in general the taper level in illuminating the hyperboloid subreflector. One notes here that the 10 dB beamwidth reduces to about 27 degrees and holds this level for much larger horns. This "saturation" aperture size is about 7.5 wavelengths, or 0.98 meters for 2.295 GHz. At 8.400 GHz, the aperture is 27.8 wavelengths, and still in the same beamwidth range.

Figures 2 and 3 show the calculated patterns for a horn of 34.2° flare angle and 1.067 meters aperture, using 5.093 cm grooves. This horn has been fabricated for tests and possible use at DSS 13. One notes here that the aperture is 8.16 wavelengths at S-band and 30.0 wavelengths at X-band. The 5.093 cm grooves represent depths of 0.34 λ to 0.403 λ from 2.0 GHz to 2.4 GHz and 1.21 λ to 1.44 λ from 7.1 GHz to 8.5 GHz. Operation slightly below the 1.25 λ limit is due to some unexplained effect.

The 10 dB beamwidths are nearly the same for the two bands. However, there is an obvious difference in the structure of these two patterns. The S-band pattern flares out much more resulting in more spillover energy beyond the normal illumination point of −10 dB taper. Calculated efficiencies of the horn as an equivalent paraboloid prime focus illuminator are as follows, at the polar angle of 13.4°, and 8.150 GHz.

$$\begin{aligned} \eta_s \text{ (spillover)} &= 0.94744 \\ \eta_i \text{ (illumination)} &= 0.88746 \\ \eta_p \text{ (phase)} &= \underline{0.99870} \\ \eta_t \text{ (total)} &= 0.83972 \end{aligned}$$

The X-band phase center is about 1.7 meters behind the aperture. When the S-band pattern is calculated about this same point, the following calculated efficiencies result at the polar angle of 13.4° and 2.295 GHz.

$$\begin{aligned} \eta_s \text{ (spillover)} &= 0.86323 \\ \eta_i \text{ (illumination)} &= 0.88577 \\ \eta_p \text{ (phase)} &= \underline{0.98652} \\ \eta_t \text{ (total)} &= 0.75432 \end{aligned}$$

indicating that X-band is being optimized at some expense to S-band performance. For reference, the same calculations can be made using the present DSN corrugated horns as used in an equivalent paraboloid system. Those results are:

$$\eta_s \text{ (spillover)} = 0.91454$$
$$\eta_i \text{ (illumination)} = 0.89114$$
$$\eta_p \text{ (phase)} = \underline{0.99836}$$
$$\eta_t \text{ (total)} = 0.81365$$

This shows the new feed, as applied in a conventional paraboloid/hyperboloid system gains 2.6% at X-band and losses 5.9% at S-band, as a direct substitute.

Probably one of the most valuable and unexpected results from this type of horn is the complete lack of any sort of sidelobe. Note that the level scale is for a 60 dB range, and at X-band the main lobe reduces to this level and does not reappear. This makes the horn very attractive in the proposed dual reflector antenna shaping applications since it will improve spillover efficiency even more and possibly aid in the further reduction of total antenna noise.

IV. The Half Scale Model

Figure 4 is a photograph of the one half scale model that was constructed and measured during this development. This model had a 34.2° flare angle, a 53.34 cm aperture, and 2.548 cm grooves. Measurements were then made throughout the appropriate frequencies to verify predicted performance. Figures 5 and 6 are these measured patterns at two frequencies, 16.3 GHz and 4.4 GHz. These measurements indicate an excellent agreement with theory. The 10 dB beamwidths are about the same and as expected, sidelobes do not exist.

A full scale version is being constructed for tests and possible other uses at DSS 13, such as VLBI. Figure 7 depicts this installation at DSS 13, indicating the relative horn positions. This figure indicates, as was mentioned above, that the new X-S horn will extend much farther toward the hyperboloid from its feed cone location than the present installation.

References

1. E. J. Jeuken and V. J. Vokurka, "Multi-Frequency Band Corrugated Conical Horn Antenna," 1973 European Microwave Conference Proceedings, Vol. 2, Sept. 4-7, 1973, Brussels University, Brussels, Belgium.
2. P. D. Potter, "Efficient Antenna Systems: A New Computer Program for the Design and Analysis of High Performance Conical Feedhorns," JPL Technical Report 32-1526, Vol. XIII, pp. 92-107, Feb. 15, 1973.

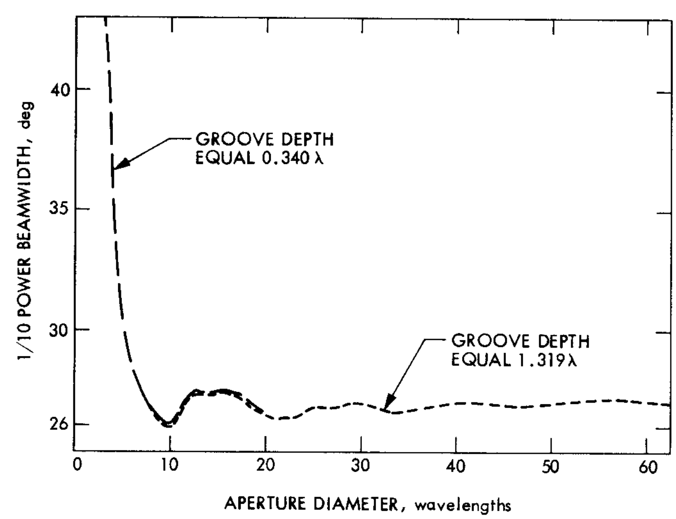

Fig. 1. The "saturated" 36° corrugated horn

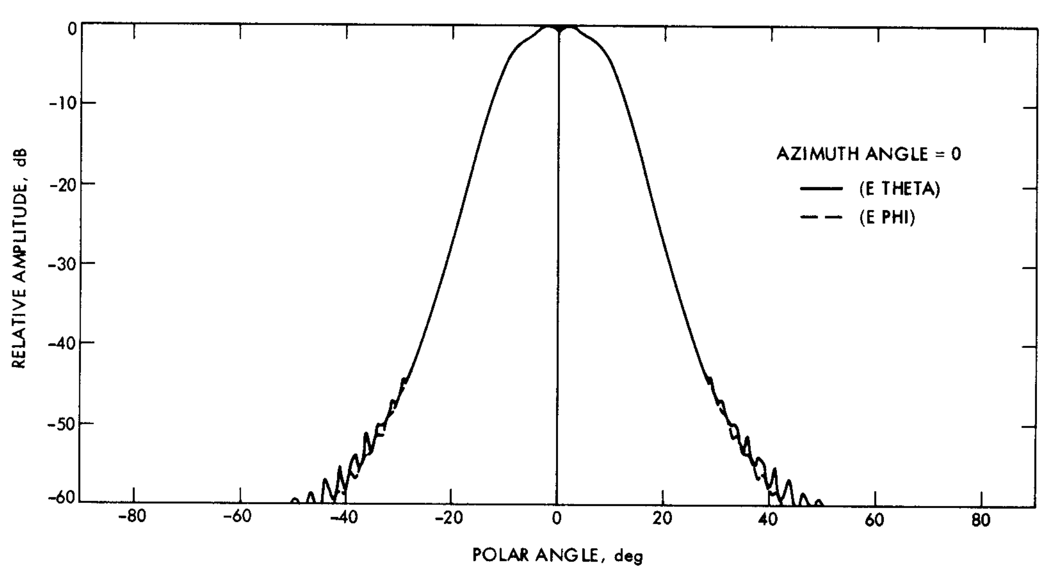

Fig. 2. Amplitude pattern for the 17.1 deg horn, 1.067 meter aperture, 5.093 cm grooves, freq. = 8.150 GHz

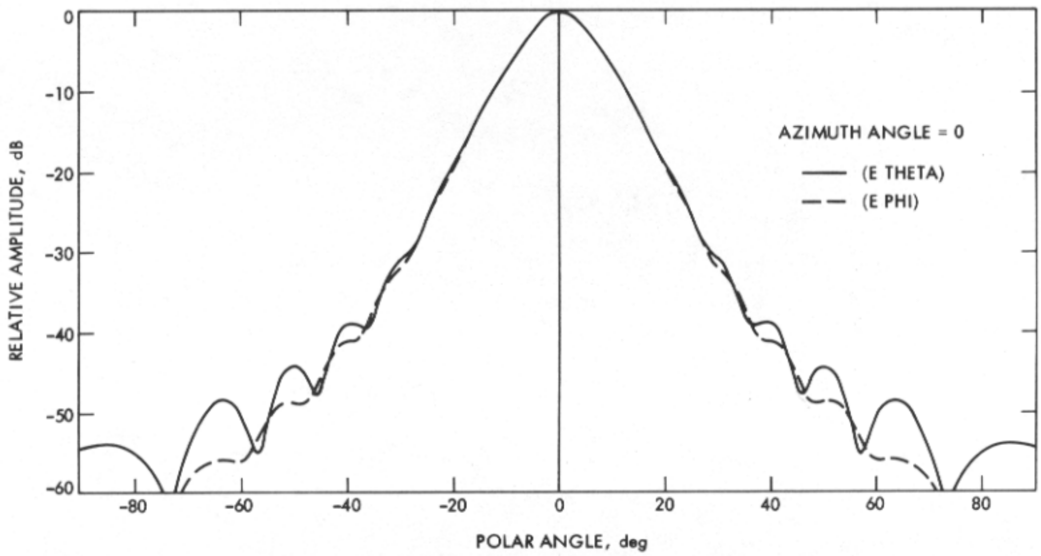

Fig. 3. Amplitude pattern for the 17.1 deg horn, 1.067 meter aperture, 5.093 cm grooves, freq. = 2.200 GHz

Fig. 4. The half scale model

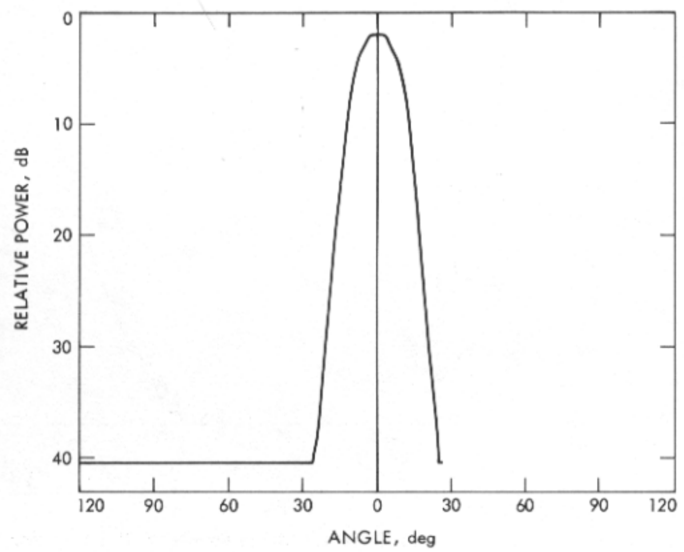

Fig. 5. Measured pattern of a (34.2) 17.1 deg horn, 53.34 cm aperture, 2.548 cm grooves, freq. = 16.3 GHz H-plane

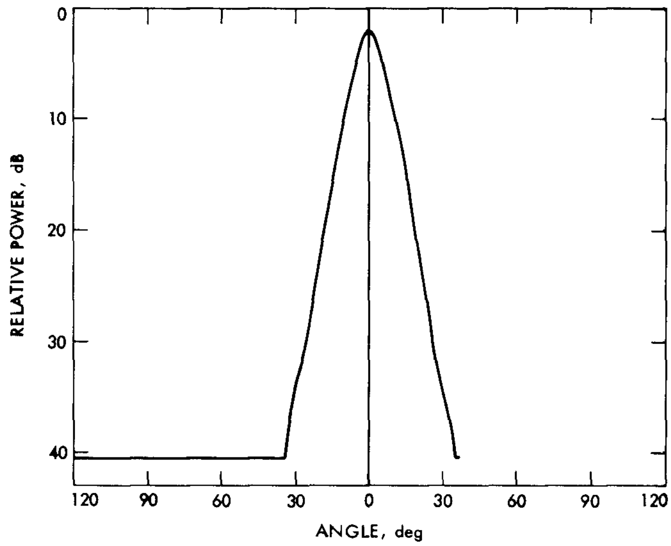

Fig. 6. Measured pattern of a (34.2) 17.1 deg horn, 53.34 cm aperture, 2.548 cm grooves, freq. = 4.400 GHz H-plane

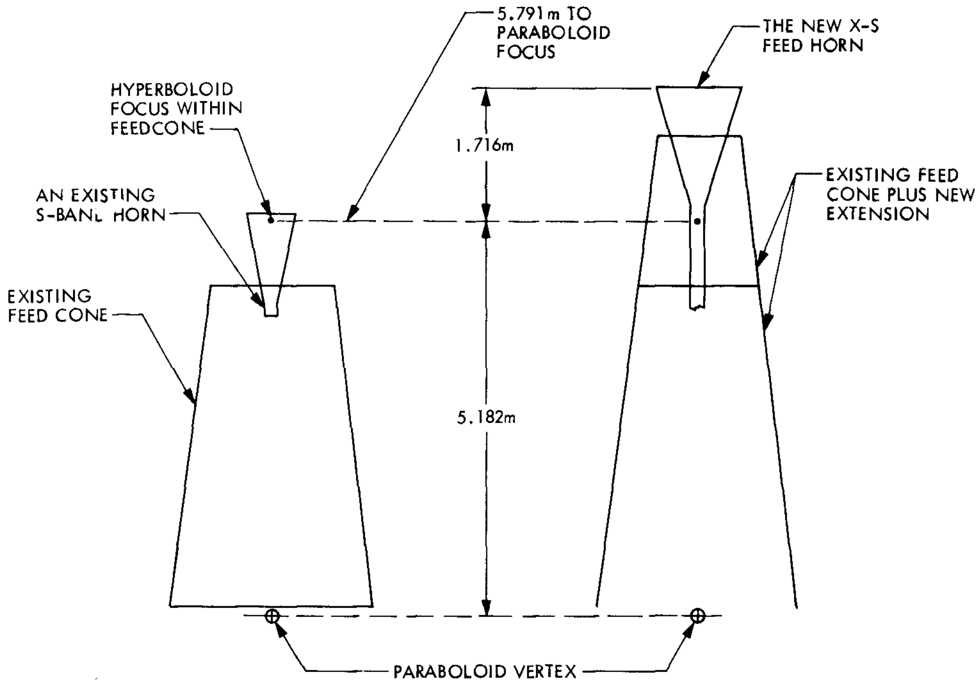

Fig. 7. Comparison of DSS 13 installations