LAAS Studies: 26-, 34-, and 40-Meter Elements

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The Large Advanced Antenna Station (LAAS) studies have now included arraying modified 34-meter antennas and new 40-meter antennas. This article discusses the microwave performance expected from these antenna elements when arrayed and fed with the new dual-band coaxial X/S feed. Performance of the 26-meter elements is also discussed for comparison to the new modified antennas.

I. Introduction

The Large Advanced Antenna Station (LAAS) program is an ongoing study to determine a most cost-effective way to obtain a substantial increase in RF performance for a new DSN station, over that presently available with the 64-meter antenna network. Early in this study it was determined that this increase could be provided by a high-grade, 100-meter reflector utilizing specially shaped surfaces and improved feed horns, as well as updated electronic equipment. Later, arrays of smaller antennas were investigated for performing equally to the basic 100-meter unit. Various sizes were considered. These are discussed in Ref. 1. This has led finally to a study of some specific arrays utilizing modified versions of the existing 26-meter antennas of the DSN and STDN, as well as some new antennas.

Subjects to be discussed in this report are the microwave performance of improved 26-meter units, the 34-meter units, which are built by modifying the 26-meter antennas, and 40-meter antennas, which are new.

Improved 26-meter antennas are obtained by relocating the antennas at a common array site and installing new subreflectors more suitable to X-band.

The 34-meter antennas are obtained by expanding these 26-meter antennas to the larger diameter. New surfaces are provided according to special shaping that yields a near-optimum combination illumination and spillover efficiency. The newly developed coaxial X/S horn is used in determining this shaping, and the location of this feed relative to the reflector vertex is held near to that of the present 26-meter antennas so that the present feed cone and feed cone designs can be used. This shaped design is a "best fit" to the 26-meter paraboloids, which minimizes structural changes and suggests that some 26-meter panels might be reused.

The new 40-meter shaped antennas are similarly determined, and the existing feed cone design can be used. An alternate 40-meter design is presented that uses a larger coaxial X/S feed, but again the same feed cone. This design permits a larger equivalent focal length to diameter (F/D) ratio that would, perhaps, be more easily constructed.

II. The Antenna Types

A. Relocated 26-Meter Antennas

An example of this antenna is the 26-meter antenna located at DSS 11. These antennas can be used at X-band with the provision of new subreflectors that are better suited to X-band performance. This subreflector (requiring new tooling) would, relative to the present subreflector, remain at 3-meters diameter, but the outer flange region would be reduced in width and the vertex cone would be smaller.

The radiation pattern of the X-band frequency, X/S horn, was theoretically scattered from this new subreflector design to determine microwave performance. The result is depicted in Fig. 1. The central hole region, ±8 deg from 0 deg, is very noticeable showing the success of the central vertex plate. The calculated efficiencies of this pattern are indicated below:

Forward spillover	0.988
Back spillover	0.998
Illumination	0.832
Cross polarization	0.997
Phase	0.968
Central blockage	0.990
Total RF efficiency	0.784

A dual-hybrid mode corrugated horn has been developed for enhancement of performance at DSS 14. This horn has a pattern shape that results in a higher illumination efficiency when using the standard paraboloid-hyperboloid cassegrain system. The radiation pattern of this horn was also theoretically scattered from the new subreflector with the result shown in Fig. 2. The more uniform illumination function can be noted here when compared to Fig. 1. Below are tabulated the efficiency numbers:

Forward spillover	0.961
Back spillover	0.997
Illumination	0.889
Cross-polarization	0.998
Phase	0.961
Central blockage	0.990
Total RF efficiency	0.809

This represents an improvement of over 2 percent. Although the illumination efficiency improves by over 5 percent, much of this is lost in additional spillover from the sidelobes of the dual-hybrid mode horn. It should be pointed out that in trials using the special shape type of surface, all illumination efficiencies became very good and the dual-hybrid mode offers no particular advantage. To complete this picture, the standard 22-dB gain horn pattern (X-band) was also scattered from the new subreflector. The results below:

Forward spillover	0.960
Back spillover	0.997
Illumination	0.836
Cross polarization	0.997
Phase	0.954
Central blockage	0.990
Total RF efficiency	0.753

This again shows the improvement to be obtained using the dual-hybrid mode horn.

B. 34-Meter and 40-Meter Performance, Special Shapes

The X-band pattern of the new X/S feed horn is used to determine the special shapes for both the modified 34-meter antenna and the new proposed 40-meter antennas. Resulting shapes are similar and the final scattering is similar. Figure 3 depicts the solution for the 40-meter dish. Note that in holding the feed focus at 5.18-meters from dish vertex and using the 17-deg X/S feed, the equivalent F/D has become 0.3, i.e., a very deep dish.

When the X-band pattern is theoretically scattered from the 34-meter and 40-meter shaped subreflectors, the following results:

	34-meter	40-meter
Forward spillover	0.992	0.992
Back spillover	0.996	0.997
Illumination	0.983	0.987
Cross polarization	0.999	0.999
Phase	0.994	0.998
Central blockage	0.985	0.986
Total RF efficiency	0.950	0.960

It should be noted that a slight advantage accrues to the larger antenna. Figure 4 depicts the scattering from the 40-meter antenna subreflector.

When the dual-hybrid mode horn is used for shaping determination, the final reflector is more closely a paraboloid. However, illumination efficiency is no better than the above cases, and forward spillover is worse, with a final result that is 1.5 percent below the 34-meter unit.

C. Using a Larger X/S Horn

It is, of course, possible to use the X/S horn gain-limited technique with different horn flare angles and consequently different illumination angles for the subreflector. For instance, if a narrower flare angle is used with this gain-limited technique, then the beams will be narrower also.

A 14-deg half flare angle horn (instead of a 17.1-deg horn) was chosen to use in a sample shaped antenna design of 40-meter diameter. The constraint was that the feed horn focus have the same location from dish vertex as the other designs, about 5.18-meters, allowing the same feed cone use. The result of this design was an increase in the equivalent F/D from 0.3 to 0.35, which is perhaps mechanically desirable. Further increases in horn size would permit F/D to approach 0.4. Of course, if greater feed location displacements from dish vertex are allowed, then larger F/D values are possible without the larger horns.

The RF efficiency of this configuration was essentially the same as the other 40-meter design, about 96 percent.

III. Other Factors

Surface tolerance efficiency follows the formula of Ruze Ref. 2:

$$\text{surface efficiency} = e^{-\left(\frac{4\pi\epsilon}{\lambda}\right)^2}$$

with ϵ equal to the rms variations of the surface from its prescribed values. The rms variations for the 26-meter antennas are about 1.5 mm, and this results in a surface efficiency of 0.757 for these antennas. The 34-meter modifications would, as discussed above, include mostly new specially shaped reflector sections mounted on the old existing structure. The mechanical design estimates for the rms of this modification are about 1.25 mm. This results in a surface tolerance efficiency for the 34-meter antennas of 0.824. Potential suppliers of new 40-meter antennas have indicated an rms estimate of 0.9 mm, or surface efficiency of 0.903.

The spars or subreflector support legs block or interfere with the aperture distribution. This "spar blockage" efficiency is directly proportional to the percentage area being blocked. It is not quite so simple though, because the spars may be small enough to discount a geometric optics view altogether. Also, because of the real aperture distribution being somewhat greater in the central region, spar shadowing in this central region becomes more important. These factors and past experience leads us to a modification of the spar blockage efficiency rule, as follows:

$$\text{spar blockage efficiency} = \left(1 - 1.2\frac{A_b}{A_a}\right)^2$$

with A_b the subreflector blocked area and A_a the main reflector aperture area.

Spar area blockage on the 26-meter antennas is about 6 percent, resulting in blockage efficiency of 0.861. For the modified 34-meter antennas, a value of 4.5 percent is expected, for a blockage efficiency of 0.895. An estimate for the larger 40-meter antenna is 5 percent for a blockage efficiency of 0.884.

These antennas are to be arrayed in various ways to achieve a final gain in excess of 77 dB. It is anticipated that in performing this arraying, each antenna will suffer a further loss of 0.17 dB, meaning an additional efficiency term of 0.96, here called the "array efficiency." Also, each horn system will suffer some loss from dissipation and VSWR. This loss, or efficiency term, is estimated at 0.98 for the X/S corrugated horns.

The DSN 26-meter antennas have perforated sheet metal panels for lightening the main reflector. An investigation (Ref. 3) of these holes in a "worse case" indicated that they might add an additional 0.4 Kelvin to noise temperature, which will be ignored.

IV. Final Performance of the Array

Below is tabulated the efficiency performance of each of these antennas as elements of an antenna array.

Antenna	Spar blockage	Surface rms	Array combining	VSWR loss	RF	Percentage total
26-meter	0.861	0.757	0.96	0.98	0.784	48
34-meter	0.895	0.824	0.96	0.98	0.95	66
40-meter	0.884	0.903	0.96	0.98	0.96	72

These larger antennas are compared with the present 26-meter antenna with its standard feed in Table 1.

We note that, everything else being equal, i.e., if all antennas were the same diameter, the improvement from shaping, a more accurate surface, and a more efficient horn feed, is nearly 2 dB.

References

1. *Large Advanced Antenna Station Status Report*, Report 890-74, Jet Propulsion Laboratory, Pasadena, Calif., August 1978 (internal document).

2. John Ruze, Antenna Tolerance Theory – A Review, *Proc. IEEE* Vol. 54, pp. 633-640, Apr. 1966.

3. T. Y. Otoshi, *A Study of Microwave Transmission through Perforated Flat Plates* Technical Report 32-1526, Vol II, Jet Propulsion Laboratory, Pasadena, Calif.

Table 1. Comparison of antennas by size and type

Parameter	26-meter paraboloid			34-meter shaped	40-meter shaped
Feed used	22-dB standard	Dual – hybrid mode	X of X/S	X of X/S	X of X/S
Efficiency, %	46	50	48	66	72
ΔdB (everything else being equal)	−1.95	−1.58	−1.76	−0.38	0

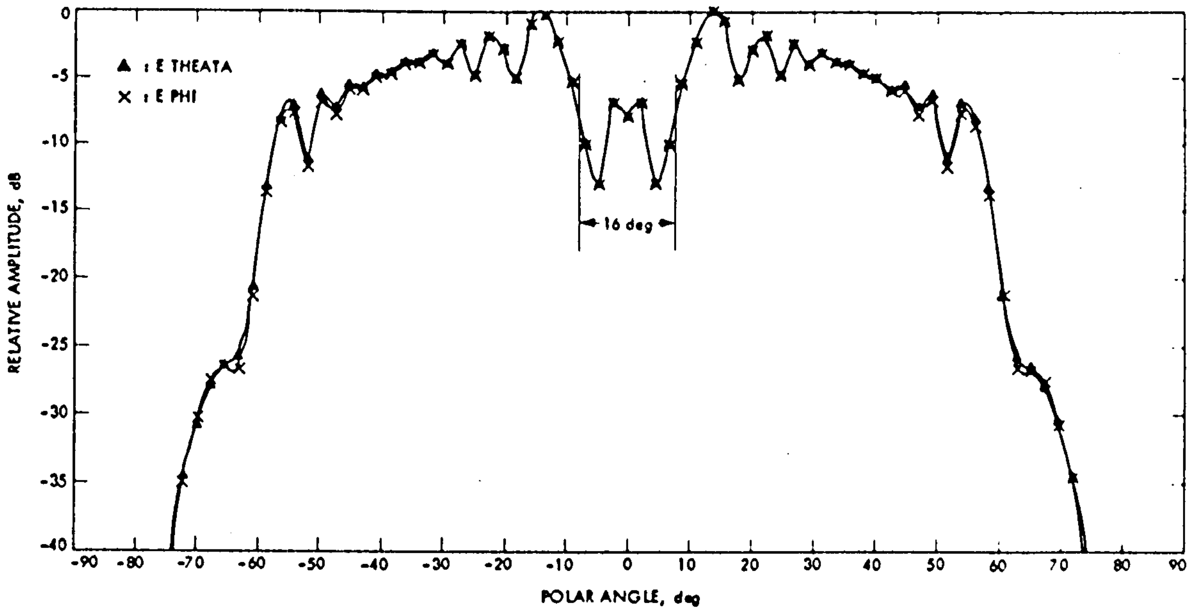

Fig. 1. 55 modes of the theoretical 17.1-deg horn pattern at 8.415-GHz scattering from the subreflector of the 26-meter antenna

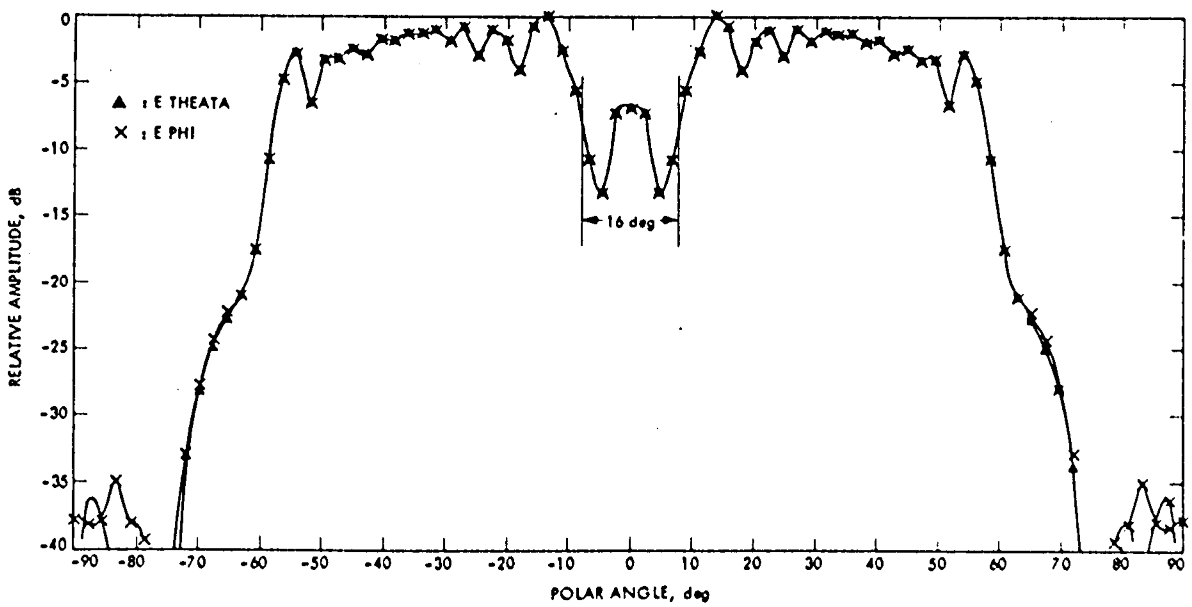

Fig. 2. 55 modes of the dual-mode horn pattern at 8.415-GHz scattering from a 26-meter antenna (54-in. hyperboloid)

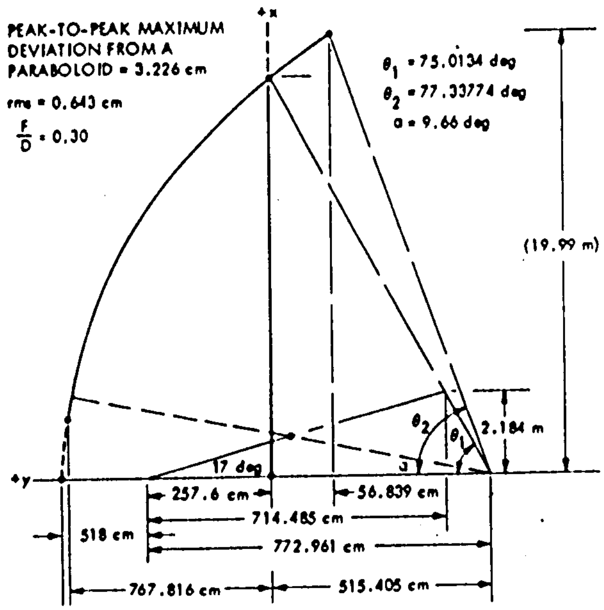

Fig. 3. The "best fit" solution of a 40-m antenna using 8.45 GHz of the X/S horn

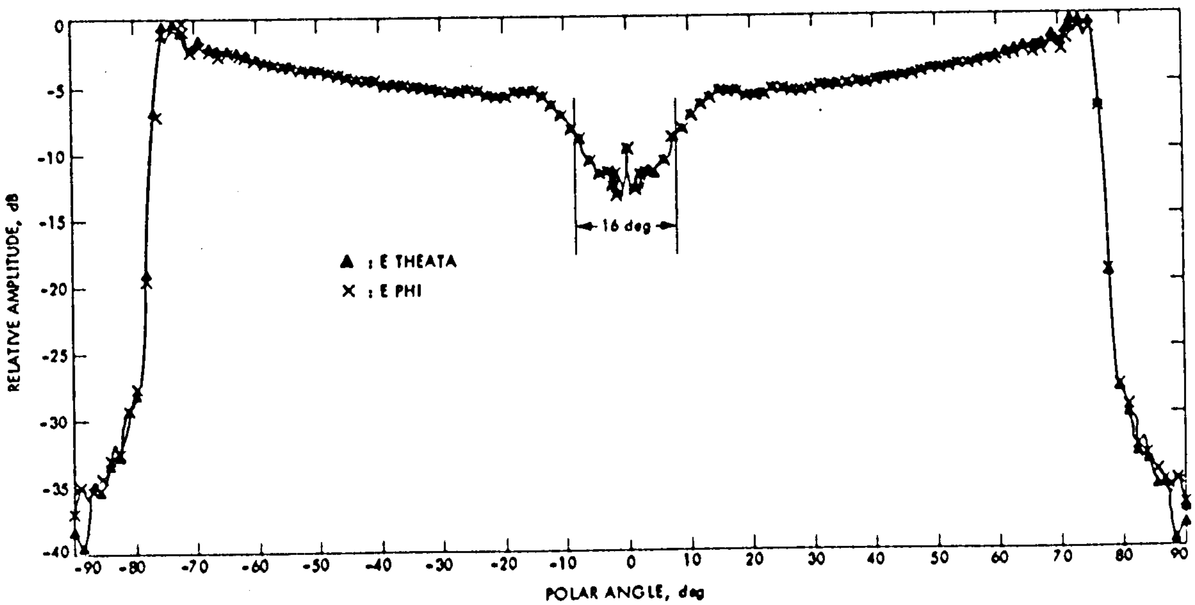

Fig. 4. Scattering of X-band of the X/S horn from the shaped subreflector of the shaped 40-meter antenna