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An Initial Study of Using the 34-m Antenna for Lunar Mission Support

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As a part of the long-range planning of future Mars and lunar missions, a feasibility study has been made of a 34-m antenna system with differentially pointed multiple beams. The performance loss mechanisms of the differentially pointed multiple-beam systems were identified and quantified. Techniques that can significantly improve the multiple-beam system performance are identified. The goal is to determine the feasibility of using the 34-m antenna to support widely separated elements associated with lunar missions.

I. Introduction

Telecommunication plans for most future planetary missions include the use of 34-m antennas. For lunar missions, smaller antenna aperture sizes are also being considered, since the communications distance is short and the relatively large angle subtended by the Moon at the Earth cannot be covered by the beamwidth of a 34-m antenna at X-band (8.45 GHz) or Ka-band (32 GHz). Nevertheless, there is a good reason to consider using the 34-m antennas for lunar mission support, i.e., the high interest within the DSN in standardizing the 34-m beam-waveguide (BWG) antenna as a platform for cross-mission support. Indeed, the report on *America's Space Exploration Initiative* [1], assumed a lunar/Martian DSN cross-support strategy using 34-m BWG antennas with multiple differential pointing for lunar coverage.

To provide simultaneous coverage of several mission elements on the lunar surface, a number of feeds may be used on the 34-m antenna to realize a multiple-beam system. The Earth–Moon geometry is shown in Fig. 1. It is seen that the Moon subtends a half angle of 0.26 deg at the Earth. As shown in the tabulation that accompanies the figure, this is equal to about 15 beamwidths (BW) at Ka-band and 4 BW at X-band. (Note that the Ka-band frequency of 32 GHz is used expediently in the computations of this study in the interest of obtaining quick approximate results, although this is not the frequency assigned for lunar mission support.)

The large number of beams needed to cover the angle space from the antenna boresight to the lunar limb leads one to expect substantial performance losses, especially at Ka-band, of the 34-m multiple-beam antenna system. One well-known performance loss is scan loss, which refers to the loss of gain of the scanned beams as compared with that of the boresight beam. For a reflector-antenna type multiple-beam system, the severity of the scan loss is generally proportional to the number of beamwidths scanned, although not generally in a simple linear relationship.

The fact that the Ka-band beam which covers the lunar limb would be scanned 15 BW raises the question of the feasibility of using 34-m antennas for lunar mission support. On the positive side, the 34-m antenna starts with a much higher boresight gain as compared with a smaller antenna.

The purpose of the present study is thus to approximately quantify the performance of a 34-m multiple-beam antenna system in order to aid in planning the next phase of studies. It is noted that no serious study has been made of the DSN 34-m antenna scanning characteristics and no current database exists on the 34-m antenna scanning characteristics.

II. The Analytical Model

The analytical model is shown in Fig. 2. The antenna model is the 34-m Cassegrain dual-shaped reflector design of DSS 13. A number of feeds, each generating a beam in the far field, are assumed to be in the focal plane at the Cassegrain focus. It is assumed that the antenna is boresighted at the center of the Moon and the feeds are movable by mechanical means in order to cover moving mission elements on the Moon.

Clearly this is a rudimentary multiple-beam system whose performance can be significantly improved by various means, given more study time. However, this first study has the limited goal of establishing ballpark performance data for a simple 34-m multiple-beam antenna. More complex systems and more elaborate analysis efforts can be undertaken in the next phase of study.

III. Best and Worst Cases in Multiple-Beam Antenna Gain Losses

The best- and worst-case scenarios in using a reflector antenna-based multiple-beam system to support lunar missions are shown in Fig. 3. In the best-case scenario, all mission elements on the lunar surface are widely separated in angle space, see Fig. 3(a). Each mission element can then be supported at the peak gain point of a beam of the antenna. While in the worst-case scenario, three or more mission elements are closely spaced and can only be supported by two beams from two side-by-side horns, as shown in Fig. 3(b). In this case, it is not possible to support the three mission elements by using three beams because there is a minimum amount of spacing between adjacent beams, imposed by the finite physical size of the feedhorns. In the very worst-case scenario, shown in Fig. 3(b), one mission element is located in the direction where the two beams cross over. This scenario would sustain a somewhat higher loss than it would if it could be supported by the peak gain of some beam.

Figure 4 shows the radiation patterns due to four Ka-band side-by-side horns in the 34-m antenna. The first horn is positioned at the Cassegrain focus and gives the boresight beam of the antenna. The best-case antenna gain-loss characteristic for supporting a lunar mission is the curve connecting the peak gain point of the individual beams in Fig. 4. The curve of the peak gain of the beams gives the gain- versus scan-angle curve, defined as the scan loss in reflector antenna literature. The worst-case gain loss is seen to be the locus connecting the crossover point of the main beams generated by side-by-side horns. It is seen that the difference between the best- and worst-case gain loss is at a maximum near the antenna boresight. This is an aspect of multiple-beam antennas that may not be as well recognized as the scan loss, but it is one that certainly needs some attention in future studies and designs.

The crossover level of the first two beams is approximately −15 to −16 dB down from the peak gain of the boresight beam. This is a larger loss than the scan loss from boresight to lunar limb in the X-band case, and thus can lead to potentially bad surprises for lunar missions if not attended to properly.

In Fig. 5, the antenna gain loss versus the scan angle was plotted after a large number of 34-m antenna far-field patterns at Ka- and X-band were computed and data-processed. The Ka-band boresight beam gain is assumed to be 10 dB higher than the X-band boresight beam gain. This difference is based on DSS-13 gain accounting at the Cassegrain focus [2]. It is seen that Ka-band antenna gain is higher than that of X-band for much of the lunar surface. The crossover point of Ka- and X-band gain- versus scan-angle curves is 0.17 to 0.19 deg from the boresight. The X-band gain is, at most, 3 dB higher than that of Ka-band at large scan angles but has a large drop at 0.06 deg, the angle location where the first two X-band beams cross over. This observation may be of some interest as, in the early years of lunar missions, exploration activities may likely be confined to a portion of the lunar surface. It is also of interest to note that the 34-m antenna X-band multiple-beam system may be viewed alternatively as a 10-m antenna Ka-band multiple-beam system. Taking this view, one might conclude that the 34-m antenna gain is higher than that of a 10-m antenna at Ka-band for a partial lunar coverage from 0 to 0.17 deg. It would be interesting and useful to determine the trade-off with other aperture sizes.

A final remark is that the analysis made is applicable at the Cassegrain focus of a BWG antenna. The feasibility of using the intermediate focus and the pedestal room focus of a DSS-13-type BWG antenna to implement a multiple-beam system is not clearly understood at this time.

IV. Summary

The plot of 34-m antenna performance loss versus scan angle characteristics has been established using a simple multiple-beam system model. In addition to quantifying the scan loss curves at X- and Ka-band, the beam-cross levels at small angles are identified as a potential problem that needs some design attention. For a 34-m antenna operating at Ka-band, the worst-case performance loss is determined by the scan loss from the center of the Moon to the lunar limb. For a 10-m antenna operating at Ka-band, the worst-case performance loss is determined by the crossover level of the first two beams rather than the scan loss from Moon center (antenna boresight) to the lunar limb.

It should be stressed that this represents the preliminary results of a study aimed at obtaining order-of-magnitude estimates of 34-m antenna scanning characteristics. In all likelihood, significantly better 34-m antenna scanning performance can be achieved with more design and some technology development efforts. The following elements could contribute to increased performance and implementation feasibility:

(1) Performance loss reduction techniques for 34-m antennas:

  (a) Computer search of the best focal surface (Petzval surface) for offset feed locations.

  (b) Arraying of adjacent feeds for a single beam.

  (c) Under-illuminating the main reflector aperture to reduce scan loss.

(2) Implementation options for 34-m BWG antennas:

  (a) Locations of the feeds on a 34-m BWG antenna.

  (b) Scanned beam losses in the beam-waveguide shroud.

(3) Performance loss versus antenna diameter trade-offs for lunar mission support.

(4) New reflector designs with improved scanning characteristics.

References

[1] T. P. Stafford, *America at the Threshold: Report of the Synthesis Group on America's Space Exploration Initiative*, Superintendent of Documents, no. 033-000-01097-4, Washington, D.C.: U.S. Government Printing Office, June 1991.

[2] D. A. Bathker, W. Veruttipong, T. Otoshi, and P. W. Cramer, "Beam Waveguide Antenna Performance Predictions with Comparisons to Experimental Results," *IEEE Transactions on Microwave Theory and Techniques*, vol. 40, no. 6, pp. 1274–1285, June 1992.

FREQUENCY	Ka-BAND, 32 GHz	X-BAND, 8.45 GHz
BEAMWIDTH OF BORESIGHT BEAM, deg	0.016	0.063
SCAN RANGE TO LUNAR LIMB, BW[a]	15.3	4.1

[a]ASSUMING ANTENNA BORESIGHTED ON CENTER OF MOON.

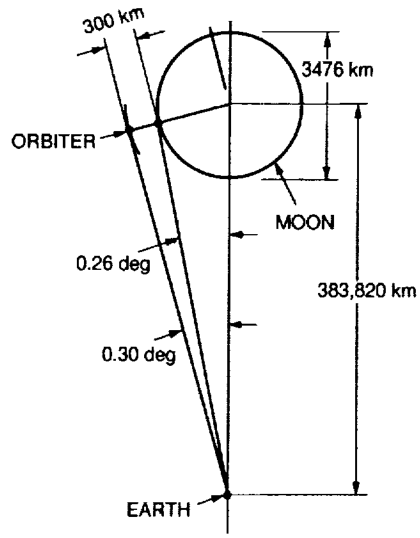

Fig. 1. Earth–Moon geometry.

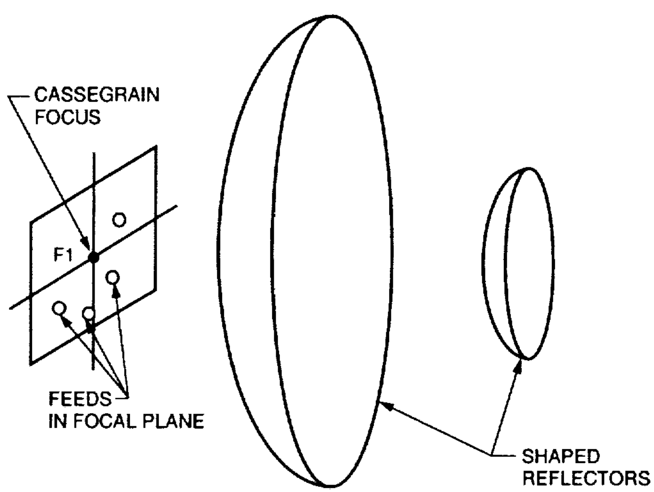

Fig. 2. Analytical model of the DSS-13 34-m dual-shaped reflector antenna, single feed per beam. The calculation matrix includes frequencies of 32 GHz and 8.45 GHz with the feed position offset in the focal plane.

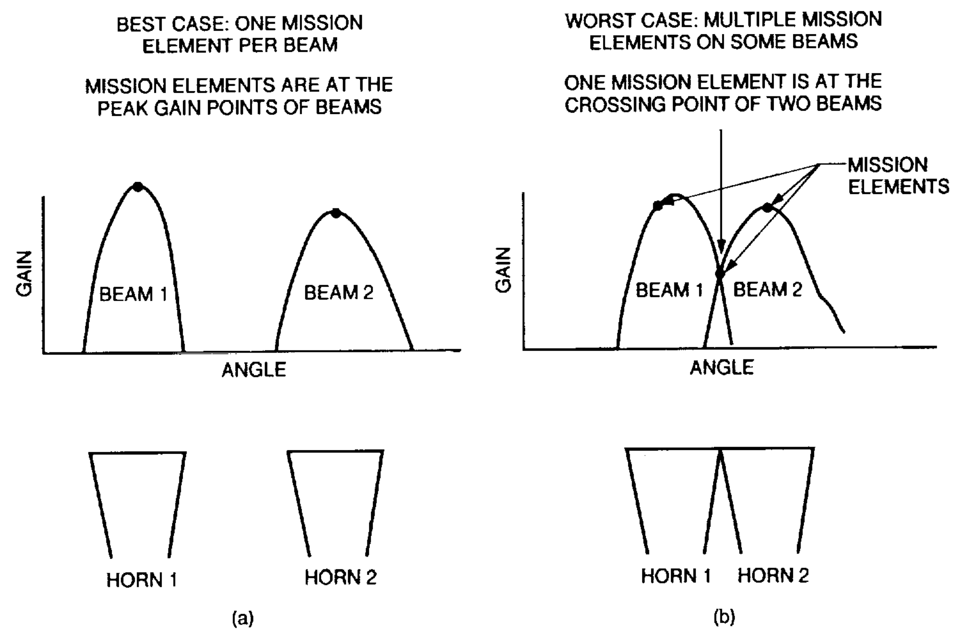

Fig. 3. Best and worst cases of 34-m antenna performance losses for: (a) separated horns and (b) side-by-side horns (minimum spacing).

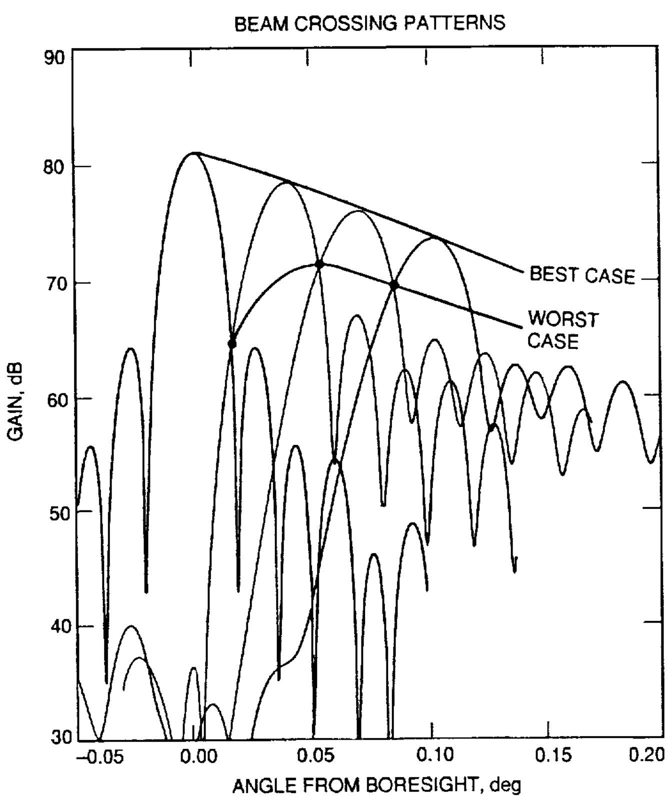

Fig. 4. 34-m antenna scan patterns, Ka-band (32 GHz).

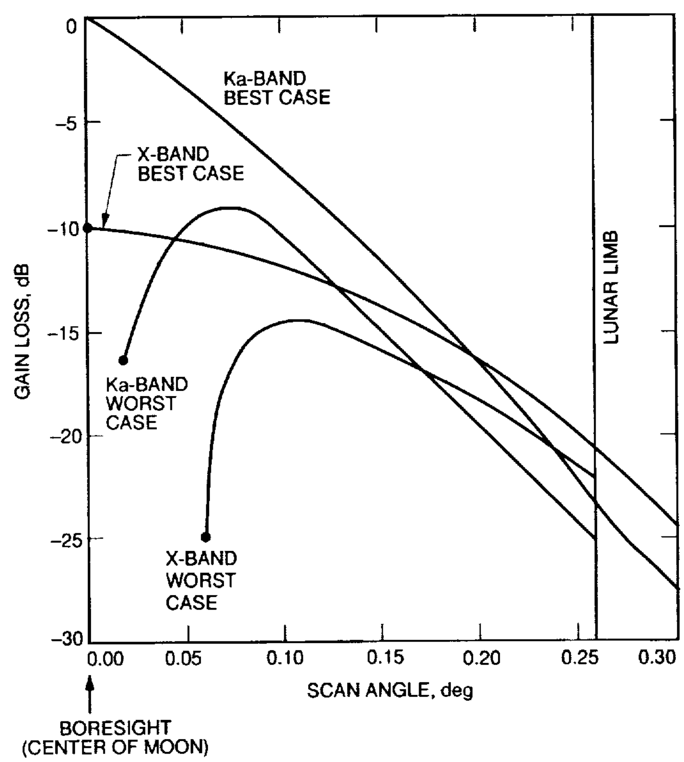

Fig. 5. Performance loss versus scan angle.