A Conceptual 34-Meter Antenna Feed Configuration for Joint DSN/SETI Use From 1 to 10 GHz

S. D. Slobin
Radio Frequency and Microwave Subsystem Section

This article is a continuation and expansion of previous work and demonstrates the very satisfactory performance of a conceptual 34-m DSS-12 type HA-Dec antenna feed system over the frequency range of 1 to 10 GHz A seven-feedhorn baseline design is developed which will allow Search for Extra-Terrestrial Intelligence (SETI) investigations using each horn over a 1.4:1 frequency range. A gain/system noise temperature (G/T) *figure of merit is calculated for the frequency range of each horn; it is found that system performance down to 20° elevation is possible with a* G/T *degradation of less than 3 dB at every frequency. The design presented here will allow shared but independent antenna use by the Deep Space Network (DSN) and SETI with a minimum of operational impacts to DSN functions and no intrusions into the DSN microwave equipment configuration.*

I. Introduction

Previous work (Ref. 1) has shown that the existing DSN 34-m HA-Dec (hour angle-declination) antenna feed system is capable of operating over the frequency ranges of 1.9 to 2.6 GHz and 7.0 to 9.4 GHz (34% of the 1–10 GHz SETI range) with no deleterious effects due to gain degradation or system noise temperature increase. Figure 1 shows the DSS-12 34-m antenna with the S/X reflex feed system. To achieve the stated bandwidth, X-band wideband operation with this antenna would require removal of the narrow band dichroic plate. In general, gain reduction comes about because of decreased aperture efficiency (a function of feedhorn illumination) and decreased surface efficiency (due to reflector roughness and deviation of shape). Increased system noise temperature results from illumination spillover, causing interference from the ground and atmosphere. Quadripod scatter noise temperature is not a significant function of frequency (in these systems) and thus is independent of the number of horns or frequency ranges considered.

Work has begun to study DSN antenna performance over the entire 1- to 10-GHz frequency range. Initially, it was felt that the existing S/X reflex feed system could remain in place and other horns could be added externally to the existing feedcone to fill in the 1.0–1.9, 2.6–7.0, and 9.4–10.0 GHz frequency ranges. This possible design would share use of the existing DSN S- and X-band feedhorns for SETI investigations; consequently, intrusion into controlled DSN tracking configurations was a recognized concern. Further thought resulted in a decision to design a SETI feed system completely independent of the DSN S/X feed system. This will allow a minimum of impact with DSN operations, and will allow both DSN and SETI operations, maintenance, and modification tasks to proceed without interference. In particular, periodic modification (for SETI use) of controlled DSN equipment configurations would be eliminated. It is anticipated that the switchover from DSN to SETI use, or back again, would take only a matter of minutes.

To cover the 1- to 10-GHz frequency range with DSN-type corrugated feedhorns, each operating over a 1.4:1 frequency range, would require seven feedhorns ($1.4^7 = 10.54$). A preliminary design requires all feedhorns to be scaled (by frequency) from the existing DSN S- and X-band feedhorns. As these horns have a narrow 6.25° flare (half-angle), the low frequency horns (long wavelength) scale to enormous size. The 1.0–1.4 GHz horn would have a length of 187 inches. Since the existing DSS-12 feedcone has a height of 131 in., it was decided to limit the horn design to a flare section length not to exceed 100 in. The overall horn length will be slightly longer than this with the addition of an orthomode polarizer. This length limitation causes the flare angle to increase because the horn diameter is held equal to its scaled size.

Table 1 shows the results of a series of horn performance calculations for the low-frequency horn operating at its nominal design frequency of 1.18 GHz (the geometric mean of 1.0 and 1.4 GHz). Horn 1 is the DSN-type scaled horn with a 6.25° flare angle and an aperture of 50.67 in. Shorter horn lengths (using the same aperture) result in increased hyperboloid edge illumination and hence more forward spillover (as evidenced by the decreased beam efficiency). Note also that the far-field phase center position changes as a function of horn length. Compared to the 187-in. horn, the 100-in. horn shows acceptable performance. Although the edge illumination increases by 2.38 dB, the beam efficiency (fraction of horn power intercepted by the subreflector) decreases from 0.965 to 0.925, a gain loss of only 0.18 dB

Table 2 describes the seven horns selected to cover the 1- to 10-GHz range. Note that neither the S-band horn (horn 3) nor the X-band horn (horn 7) is identical to its DSN counterpart (Ref. 1). There is no reason for any correspondence, as the SETI system is being purposefully designed to be physically and operationally independent of the configuration-controlled DSN system.

II. Feedcone, Feedhorn, and Subreflector Design

The existing DSS-12 feed system operates in the reflex mode, where the S- and X-band beams appear to emanate from the same location (the X-band horn). This is accomplished by placing an ellipsoidal reflector over the S-band horn and a dichroic plate over the X-band horn. This system is described in Refs. 1, 2, and 3.

The feedcone used on DSS-12 type antennas (Fig. 1) is an asymmetrically tapered cylinder, with a base 120 in. in diameter, and an oval top 86 by 120 in. The S- and X-band horns are installed in the top of the feedcone, with their apertures elevated approximately 2 ft above the surface.

Because of the reflex design, the hyperboloidal subreflectors on DSS-12 type antennas remain fixed and do not tilt or rotate to access different horns as do those on 64-m antennas, which rotate to access the different feedcones. The X-band horn position in the S/X reflex system is the location of the subreflector "focus"; thus the addition of seven feedhorns for SETI use would result in a grossly asymmetric system if no provision for subreflector movement were made.

A first simple approach to the seven-horn design (nine, if the existing S- and X-band horns are included) might be to add on the horns in a circle or semicircle surrounding the existing cone (as in the 64-m L-band feed). This simple arrangement is shown in Fig. 2. Note that the phase centers of these horns are all displaced from the X-band horn position, so that large asymmetries due to offset feeds would result. This is a particular problem for the high-frequency (short wavelength) horns, where displacements are large in units of wavelength. Antenna efficiency is greatly reduced by even small amounts of misfocus. Also, the dichroic plate over the X-band horn might have to be tipped off, or folded away, depending on interference with the horn patterns.

To minimize the asymmetry problem, the subreflector would have to rotate *and* tip in order to access each individual horn. The tipping portion of this motion will result in varying and detrimental main reflector illumination, as the subreflector shape and angular tilt (in both the 34-m and 64-m designs) are optimized for maximum illumination, with special concern for minimum rear spillover. This "add-on" concept might save the cost of a new feedcone, but requires a rotatable and tilting subreflector assembly. Because of the numerous inherent RF performance problems in this design, including especially the detailed question of main reflector spillover and blockage, this concept has been rejected. Other versions of the add-on technique can be imagined, but one or another of the above problems will still remain.

III. Improved Conceptual Design

The improved conceptual design involves both feedcone and subreflector redesign. It is proposed that the feedcone be enlarged to a 120-in. diameter for its entire height, rather than tapered, as in the present design. In this manner, all feedhorns can be properly contained within the cone, and excessive waveguide runs can be eliminated. As any additional horn will not be located at the X-band horn position, it becomes necessary to rotate and index the subreflector as in the proven 64-m system. The phase center of any added horn must be on a circle centered on the paraboloid center line and passing through the X-band horn. In this way, there will be no beam position shift as different horns are accessed. Figure 3 shows this concept with all seven horns in place in addition to the existing S- and X-band DSN horns. Clearly, in this design, both the dichroic plate over the X-band horn and the ellipsoidal reflector over the S-band horn must be tipped or folded away from the top of the cone area during SETI use. Precedent for this exists (the initial 64-m reflex system was foldable for precise gain and noise differencing tests) but it is an unwieldly solution at best.

IV. Suggested Conceptual Design

A suggested simpler design recognizes that SETI does not require all horns in place at a given time, and has one or two horns located in large adapter plates (or plug-in modules) as shown in Fig. 4. SETI plans to use only one frequency band (horn frequency range) at a time; thus it would not be necessary to have all seven horns in place simultaneously. Perhaps several weeks or months of observation would be carried out in each band, and then the horn and waveguide assembly would be changed (not to exceed a 1-day job) to continue operation in another band. Plug-in modules designed to accommodate all horns would facilitate this exchange. The use of two modules enables the operation of one SETI system, with a second system in an installation, maintenance, or checkout mode.

V. Performance Evaluation

Calculations have been carried out to determine G/T (gain/system noise temperature) figures of merit similar to those determined in Ref. 1. This analysis is valid for any feed system in which the various feedhorns can be precisely focused and in which the resulting antenna beam does not "squint" or move away from its normal position along the main reflector axis of symmetry (cf. Figs. 3 and 4). G/T is defined as

$$G/T \sim \frac{\eta_{aperture} \times \eta_{surface}}{T_{ground} + T_{atmosphere} + T_{quadripod} + T_{base}}$$

The aperture efficiency, $\eta_{aperture}$, represents the fraction of incident power (in the sense of illumination) actually captured by the feedhorn. The surface efficiency, $\eta_{surface}$, is a function of both surface roughness and main reflector deformation due to gravity loading, T_{ground} is the noise temperature contribution from the ground due to both forward and rear spillover; $T_{atmosphere}$ is the atmospheric noise contribution due to the same two causes; $T_{quadripod}$ is the quadripod noise temperature contribution due primarily to scattering of ground radiation. T_{base} is the non-changing baseline noise temperature due to low-noise amplifier, cosmic background, and waveguide contributions. Since no DSN operational systems exist over the needed range of frequencies, it is necessary to estimate a plausible T_{base} value for each of the seven different horn systems. In fact, for the purposes of this study, the baseline noise temperature component is defined to be a constant 20 K at all frequencies.

Note that the *total* system noise temperature includes T_{base} *plus* ground, atmosphere, and quadripod contributions, the last three varying with frequency and/or elevation angle. The zenith atmospheric noise temperature is accepted to vary linearly from 2 to 4 K over the 1- to 10-GHz range. Spillover effects will result in atmospheric contributions (at zenith) somewhat higher than these values. Quadripod noise temperature varies as a function of elevation angles only, from 2.5 K at zenith to 6 K at 0 deg. Surface efficiency varies with frequency and elevation from 0.999 at 1.0 GHz and 30-deg elevation to 0.762 at 10.54 GHz and 90-deg elevation. These values result from estimates of the DSS-12 type antenna mechanical surface tolerance due to both antenna gravity distortions and surface roughness.

The highest calculated figure-of-merit value occurs at 3.24 GHz (the middle of the middle horn) and 90-deg elevation. For comparison purposes, all other figures-of-merit were referred to this value. The components of this reference figure-of-merit are

$$\eta_{aperture} = 0.783$$

$$\eta_{surface} = 0.975$$

$$T_{ground} = 1.11 \text{ K}$$

$$T_{atmosphere} = 2.74 \text{ K}$$

$$T_{quadripod} = 2.50 \text{ K}$$

$$T_{base} = 20.00 \text{ K}$$

(Note: Quadripod blockage is not considered in this figure-of-merit comparison, as it is common to all frequencies and elevation angles.) Table 3 shows the G/T figures-of-merit (dB) relative to the peak value at 3.24 GHz and 90-deg elevation. Figure 5 shows the G/T figure-of-merit values with each horn G/T separately drawn.

Table 3 shows that G/T degradation less than 3 dB is available for all elevation angles greater than 20 deg. If an observing scheme has sufficient freedom to view only portions of the sky at elevations greater than 30 deg (e.g., Goldstone and sources with declinations greater than −25 deg), a less than 2-dB degradation will be experienced. In either event, even a single-band reflector antenna would suffer a similar G/T degradation, primarily due to atmospheric and quadripod noise contributions.

VI. Conclusions

A conceptual seven-horn feed system is considered for SETI use on a 34-m HA-Dec type antenna over the frequency range of 1 to 10 GHz. Only one or two of the seven proposed feed systems would be mounted at a given time, and independence of DSN systems from the SETI systems is preserved, an aspect considered very important to the DSN. This system shows quite acceptable performance over the entire frequency range. Again, it should be noted that this design considers only antenna and feedhorn performance. The design of wideband low-noise preamplifiers, polarizers, and orthomode components over this frequency range has not yet been accomplished and may require a substantial development effort. Further studies will address this consideration and the use of beam waveguide in a shaped dual-reflector system for wideband SETI requirements.

References

1. Slobin, S. D., "DSN 34-Meter Antenna Optics Analysis for Wideband SETI Investigations," *TDA Progress Report 42-80*, Jet Propulsion Laboratory, Pasadena, Calif., pp. 202–219, Feb. 15, 1985.

2. Slobin, S. D., "Antennas" in *The Deep Space Network – A Radio Communications Instrument for Deep Space Exploration*, JPL Publication 82-104, Jet Propulsion Laboratory, Pasadena, Calif., pp. 3-1 through 3-23, July 15, 1983.

3. Nixon, D. L., and Bathker, D. A., "S-/X-Band Microwave Optics Design and Analysis for DSN 34-Meter-Diameter Antenna," *DSN Progress Report 42-41*, Jet Propulsion Laboratory, Pasadena, Calif., pp. 146–165, Sept. 15, 1977.

Table 1. Low-frequency corrugated horn comparison, frequency = 1.18 GHz, aperture diameter = 50.67 in.

Horn	Flare Length, in.	Flare Half-Angle, deg	Hyperboloid Edge Illumination, dB	Beam Efficiency	Phase Center Position, in.[a]
1	186 572	6.250	−16 25	0 965	17.648
2	160.	7.277	−15 82	0.959	20.870
3	140.	8 304	−15 37	0.953	22.530
4	120.	9 663	−14 75	0 942	25.428
5	100.	11.548	−13.87	0 925	29 014
6	80.	14 328	−12.57	0 896	33.407
7	60.	18 806	−10.56	0 838	38.482

[a]Inside horn, relative to aperture Phase center calculated from ±15.79° spread of far-field points (the edges of the DSS-12 subreflector)

Table 2. Corrugated horns to cover the 1- to 10-GHz frequency range

Horn	Frequency Range, GHz	Nominal Design Frequency GHz	Phasing Section Length, in.	Diameter of Phasing Section and Small End of Flare, in.	Flare Length, in.	Aperture Diameter, in.	Groove Depth, in.	Phase Center Position Inside Horn Aperture at Nominal Frequency, in.[a]
1	1.00-1.40	1 18	0.0	9.803	100.000	50.67	3.080	27 418
2	1.40-1.96	1.66	0.0	6.969	100.000	36.02	2 189	14.787
3	1.96-2.74	2.32	0.0	4.986	94.917	25.78	1.566	8.244
4	2.74-3.84	3.24	0.0	3.570	67.965	18.46	1 122	5 908
5	3.84-5.38	4.55	0.0	2 542	48 397	13.14	0.799	4 197
6	5.38-7.53	6.36	0.0	1.819	34.624	9.40	0.571	2 999
7	7.53-10.54	8.91	0.0	1.298	24.715	6.71	0.408	2.143

[a]Inside horn, relative to aperture Phase center calculated from ±16° spread of far-field points.

Table 3. G/T figure-of-merit, dB

Horn	Frequency GHz	Elevation Angle, deg.									
		0	10	20	30	40	50	60	70	80	90
	1.00	-5.237	-3.194	-2 143	-1.494	-1.237	-1 104	-1.036	-1.061	-1.299	-1.358
1	1.18	-5.040	-2.856	-1.677	-1.072	-0.811	-0 667	-0 568	-0.545	-0.580	-0.675
	1.40	-5.266	-2 907	-1.696	-1.161	-0.894	-0.731	-0.614	-0.557	-0.602	-0.592
	1.40	-4 821	-2.723	-1 662	-1.097	-0.845	-0 704	-0 632	-0 639	-0 851	-0.873
2	1.66	-4.644	-2 364	-1 286	-0.761	-0.500	-0 346	-0.242	-0 206	-0.302	-0.285
	1.96	-5.042	-2.605	-1.481	-0 980	-0 707	-0 536	-0.406	-0.337	-0.346	-0.321
	1.96	-4.704	-2.502	-1 401	-0.863	-0.599	-0.446	-0.363	-0 355	-0.520	-0.480
3	2.32	-4.539	-2 156	-1 119	-0.611	-0 341	-0 182	-0 066	-0.025	-0.088	-0.056
	2.74	-5.052	-2.526	-1 455	-0.953	-0.677	-0 499	-0.366	-0.291	-0 278	-0.259
	2.74	-4.871	-2.578	-1.394	-0 828	-0.556	-0 391	-0.293	-0 266	-0.370	-0.321
4	3.24	-4.736	-2.244	-1.169	-0.630	-0.352	-0.179	-0.054	-0.001	-0.030	-0.000
	3.84	-5 330	-2.709	-1.604	-1 079	-0.791	-0.607	-0 476	-0 404	-0.403	-0.404
	3.84	-5.222	-2.796	-1.492	-0 880	-0.577	-0 393	-0 280	-0.227	-0.273	-0.249
5	4.55	-5 185	-2 553	-1.404	-0.830	-0.529	-0.348	-0.226	-0.165	-0.197	-0.215
	5.38	-5 784	-3.007	-1 844	-1.291	-0 991	-0 809	-0.683	-0.627	-0.652	-0.681
	5.38	-5.758	-3.166	-1 793	-1.158	-0.837	-0.644	-0.526	-0.478	-0.529	-0.571
6	6.36	-5.773	-2 966	-1 744	-1 140	-0.828	-0.647	-0 540	-0.501	-0.580	-0.634
	7.53	-6.465	-3.485	-2.222	-1 626	-1.307	-1.127	-1.026	-0.994	-1.074	-1.159
	7.53	-6 520	-3.777	-2.318	-1.643	-1.311	-1.135	-1 051	-1.046	-1.200	-1.295
7	8.91	-6.552	-3.500	-2.173	-1.520	-1.194	-1.016	-0 945	-0.953	-1 104	-1.222
	10.54	-7.362	-4 984	-2.673	-2.012	-1.678	-1.500	-1.441	-1.461	-1.627	-1.807

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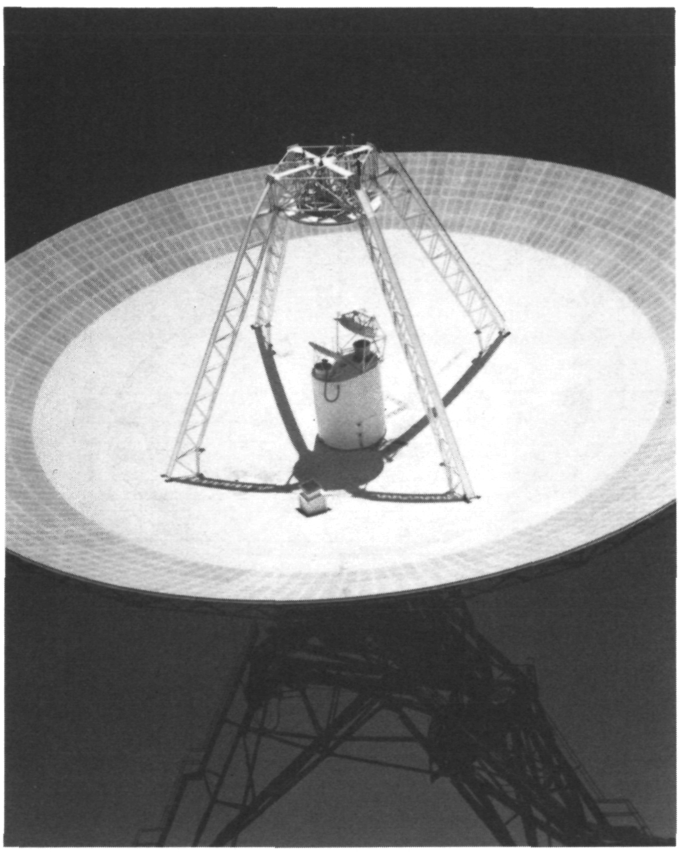

Fig. 1. DSS 12 34-m HA-Dec antenna with S/X reflex feed system

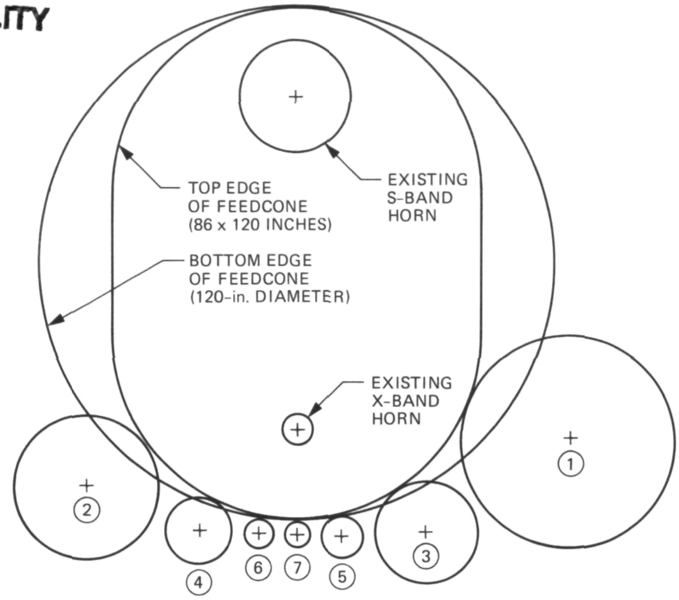

Fig. 2. Existing 34-m antenna feedcone with add-on horns

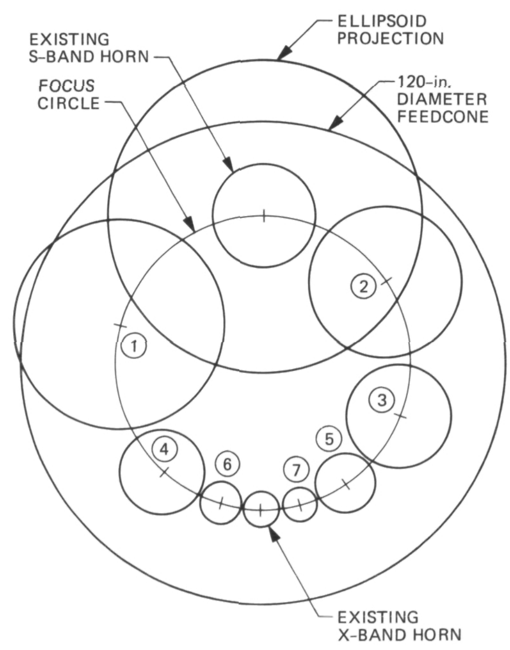

Fig. 3. New design 120-in. diameter feedcone with seven SETI horns in place

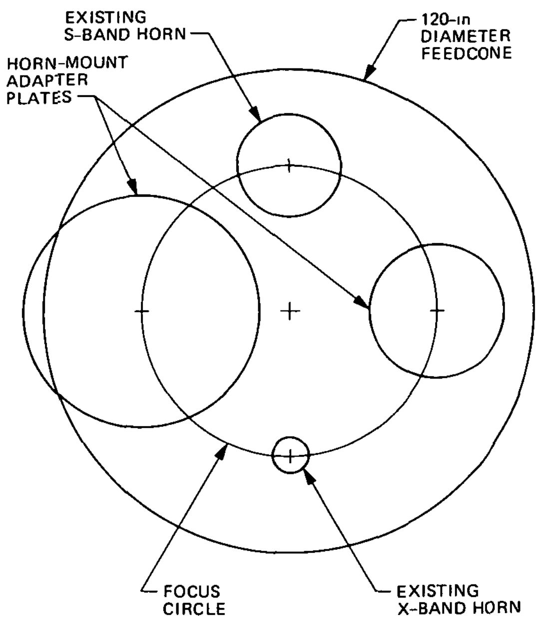

Fig. 4. New design feedcone with adapter plates for mounting SETI feedhorns

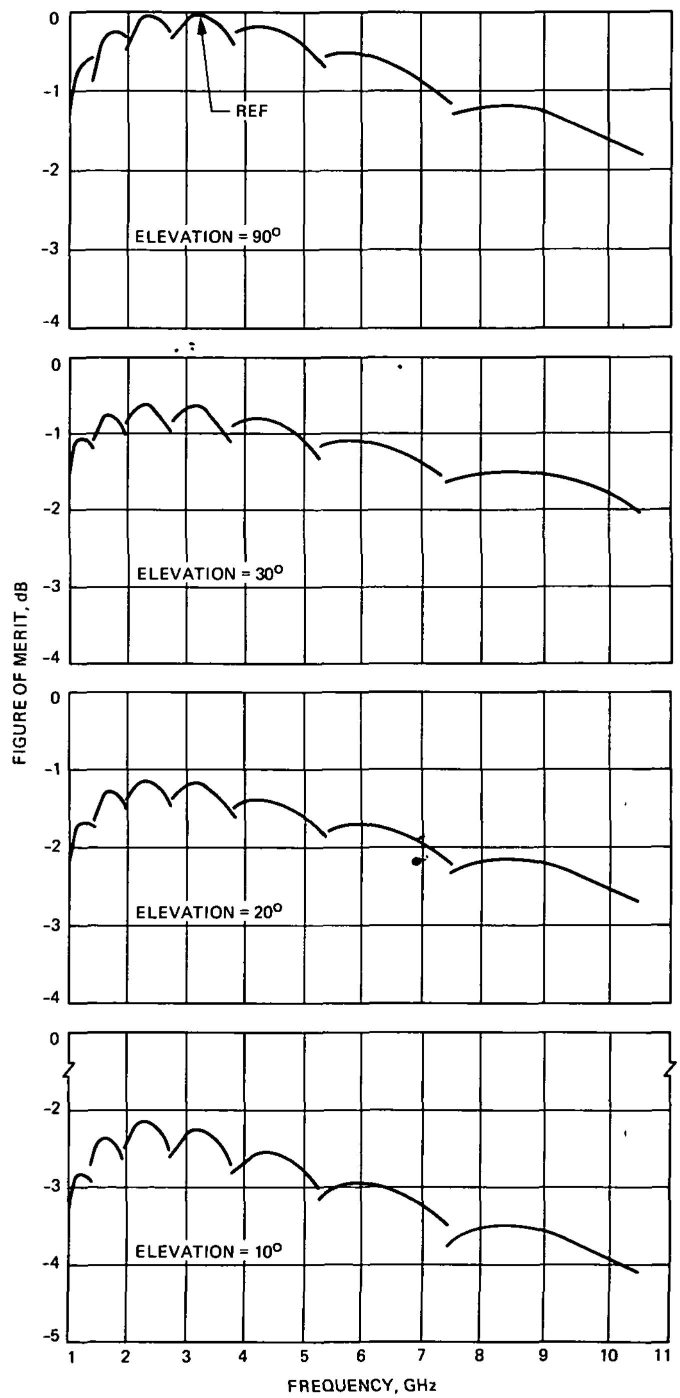

Fig. 5. Gain/system noise temperature figure-of-merit