NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

*Technical Memorandum 33-433*

# *Predicted and Measured Power Density Description of a Large Ground Microwave System*

*D. A. Bathker*



JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
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The work described in this report was performed by the Telecommunications Division of the Jet Propulsion Laboratory.

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# PREDICTED AND MEASURED POWER DENSITY DESCRIPTION OF A LARGE GROUND MICROWAVE SYSTEM

D. A. Bathker

## Abstract

A comparison between predicted and measured microwave field strengths on, near and in the far field of a large ground antenna system is given. The system consists of a high power S-band transmitter and parabolic reflector. Use of the radiation patterns of the feed system is adopted as accounting for the total power output. Estimates of secondary or stray radiation are given and discussed. A first order tubular beam concept is introduced to simplify and provide a clear impression. It is concluded certain safety restrictions are necessary, and these are discussed.

# PREDICTED AND MEASURED POWER DENSITY DESCRIPTION OF A LARGE GROUND MICROWAVE SYSTEM

D. A. Bathker

## Introduction

An obvious possible need for protection from excessive radiofrequency radiation when operating a large (64 m) diameter reflector antenna with 400 KW, CW, of transmitter power at S-band is examined. The thoroughness of this study varies directly with the power density, i.e., densities greater than 10 mw/cm$^2$ are well defined since considered dangerous. Densities from 1 to 10 mw/cm$^2$ are simply examined since this category is considered safe for incidental or occasional exposure. Densities less than 1 mw/cm$^2$ are examined, wherever possible, primarily to acquaint the reader with the system; microwave radiation in this category is considered safe for indefinite exposure[1] (References 1, 2, 3 and 4).

Comparisons between calculations and actual system tests are given. It is concluded certain restrictions are necessary, and will be discussed.

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[1]The Bureau of Radiological Health, U.S. Department of Health, Education and Welfare, standard for commercial and domestic microwave ovens specifies leakage radiation from these devices be less than 1 mw/cm$^2$ when new and less than 5 mw/cm$^2$ during the device life. The Bureau further suggests a suitable level for industrial systems of less than 10 mw/cm$^2$ from conveyor openings, and less than 5 mw/cm$^2$ from other doors, although the industrial level is not yet a formal standard. The Bureau considers the commercial and domestic market as uncontrolled mass consumption while industrial users are presently limited in number and can be subjected to safety surveys with relative ease (Reference 2).

The United States of America Standards Institute recommends a guide of 10 mw/cm$^2$ as averaged over any possible 0.1 hour period, under normal environmental conditions (Reference 3).

The California Institute of Technology Jet Propulsion Laboratory Safety Practice specifies a 1 mw/cm$^2$ maximum for an 8 hour day or 40 hour week. Fields between 1 mw/cm$^2$ and 10 mw/cm$^2$ are restricted to 1 hour maximum in any 24 hour period (Reference 4).

Microwave System Characteristics

The system studied is the NASA 64 m diameter Cassegrain fed parabolic reflector operating at 2.12 GHz with 400 KW, CW transmitter power output. This system is a very carefully optimized transmit/receive arrangement wherein high beam efficiency (percentage of total radiated power delivered to the main beam) and low spillover and scatter (percentage of total wasted as stray radiation) were sought after in design and achieved. This point should not be ignored; a poor selection of a feed system could invalidate the results of this study.

We adopt the point of view of considering the radiation patterns of the feed system as descriptive in accounting for the total power output. Figure 1 gives the far-field E- and H-plane radiation patterns of the hybrid mode corrugated waveguide feedhorn used at 2.12 GHz. This highly symmetric beam is achieved since the feedhorn aperture distributions in both planes are equal, and of low intensity near the waveguide boundaries. Table I (see Appendix) is the output of a machine program giving the beam efficiency as a function of feedhorn polar angle. At 14.7 deg from feedhorn boresight, which is the edge of the Cassegrain subreflector, it is seen that 93.0% of the radiated power has been subtended. The feedhorn axial gain is +21.8 dB above isotropic.

Figure 2 gives the far-field E- and H-plane radiation patterns of the total feed system, i.e., the above feedhorn and the subreflector. The origin of these patterns is the parabolic focal point. Figure 2 shows the feedhorn radiation has been primarily spread over a 60 deg zone, the edge of which represents the rim of the paraboloidal reflector. Figure 2 also shows the reduced radiation in the 60 - 160 deg zone, and the feedhorn spillover past the edge of the subreflector in the 160 - 180 deg zone, as well as the feed system backlobe. Figure 3 is helpful in visualizing the above zones.

Table II (see Appendix) is the output from the same machine program as above, giving the beam efficiency as a function of feed system polar angle

Fig. 1

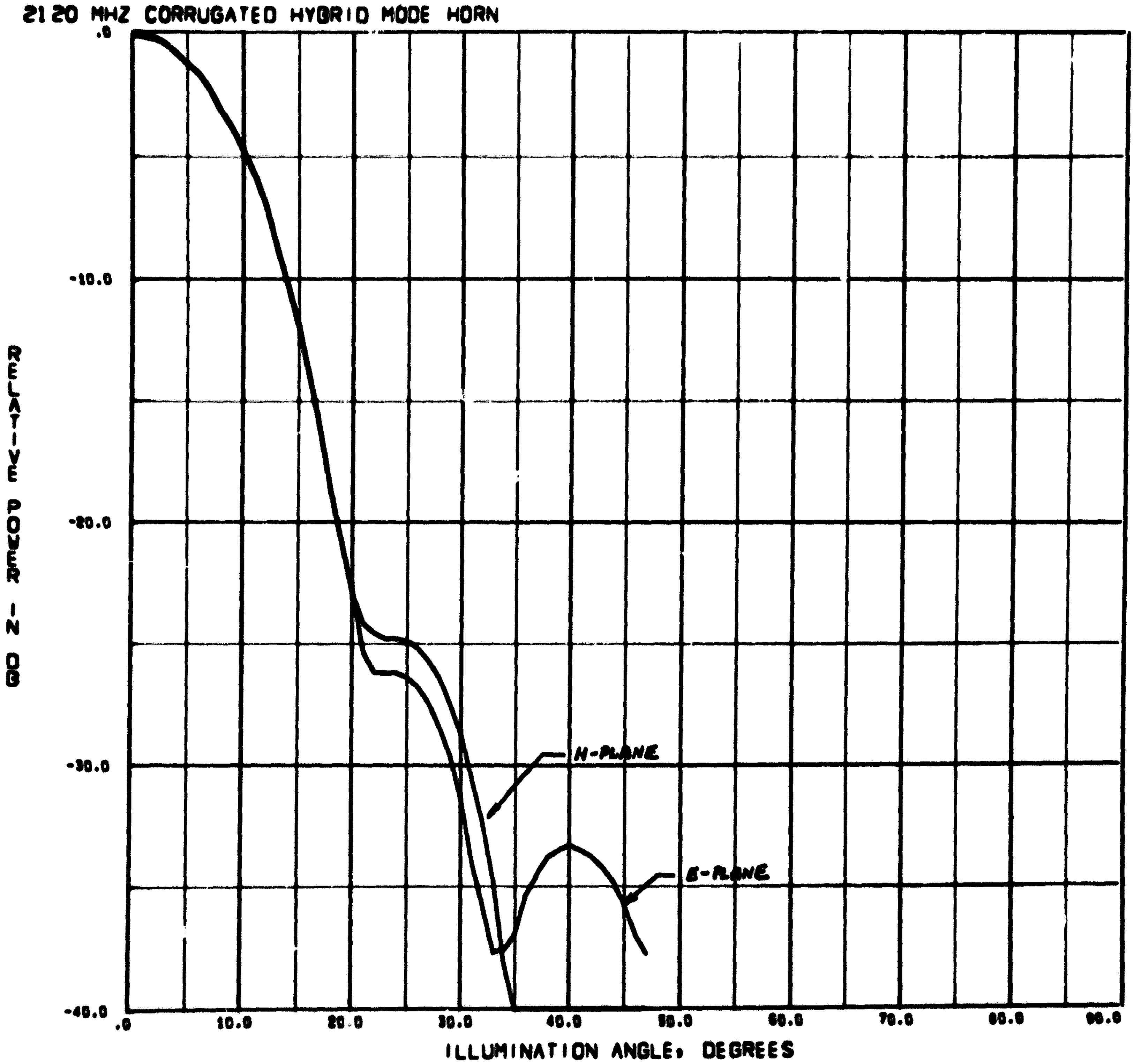
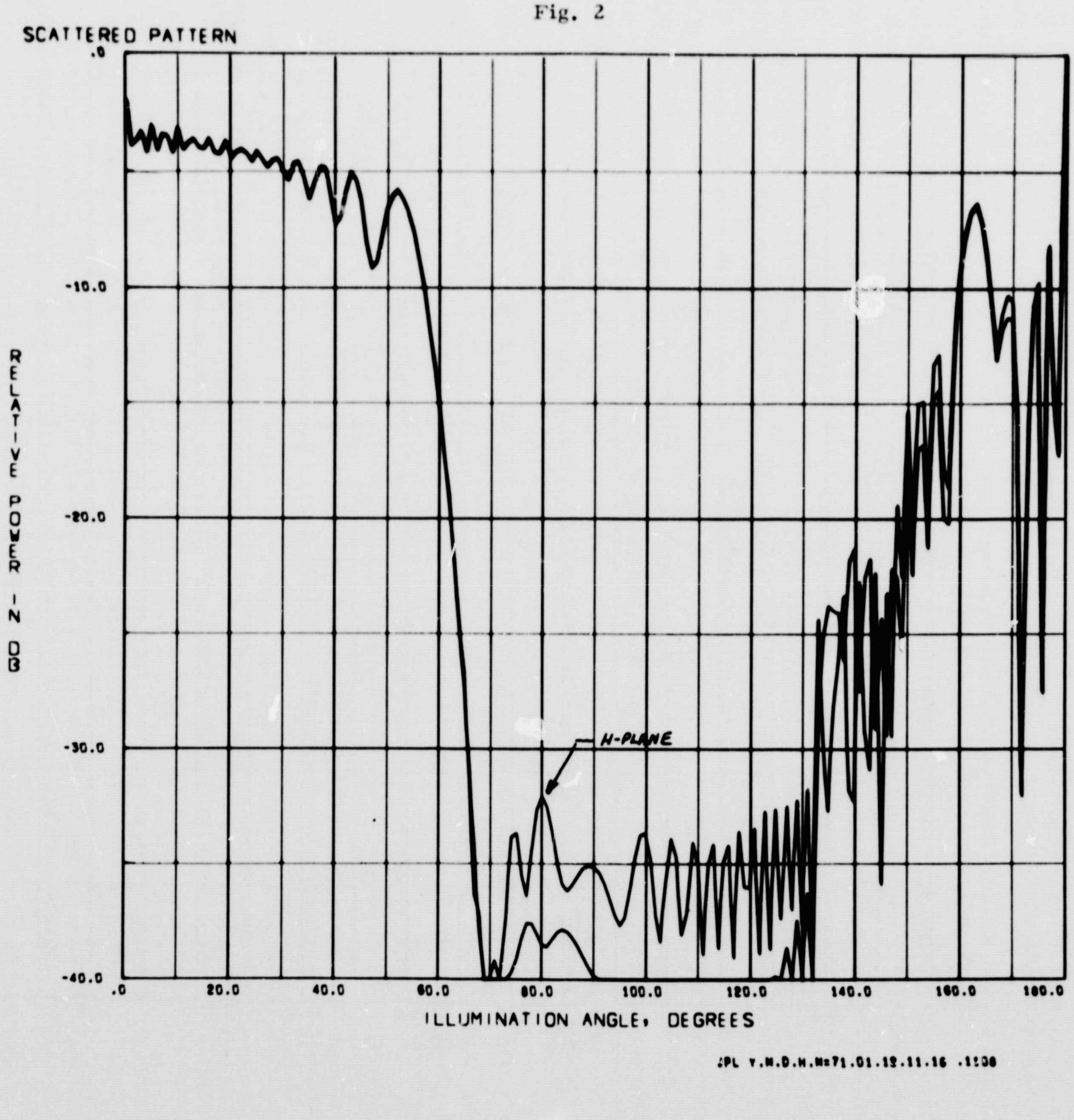
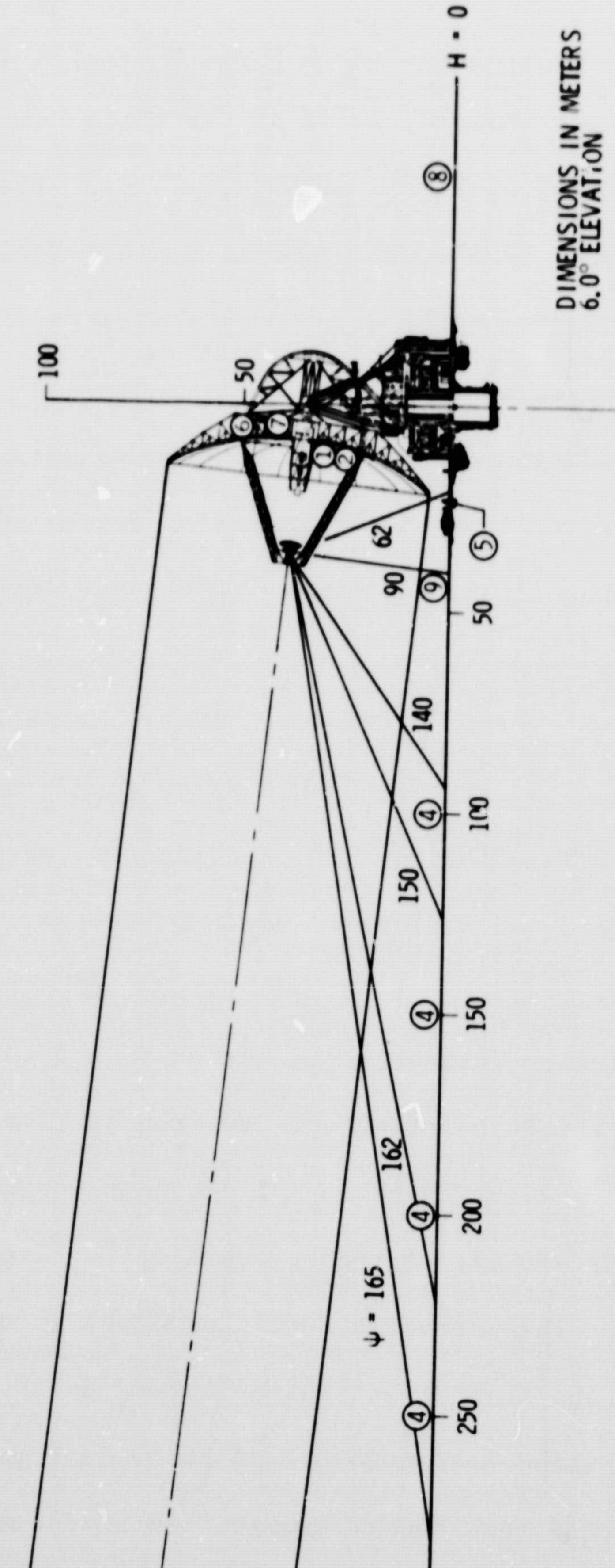

2120 MHZ CORRUGATED HYBRID MODE HORN
.0
-10.0
-20.0
-30.0
-40.0
RELATIVE POWER IN DB
.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
ILLUMINATION ANGLE, DEGREES
H-PLANE
E-PLANE

Fig. 2



SCATTERED PATTERN
.0
-10.0
-20.0
-30.0
-40.0
.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
RELATIVE POWER IN DB
ILLUMINATION ANGLE, DEGREES
H-PLANE
JPL Y.M.D.H.M=71.01.12.11.16 .1200

Fig. 3
**64M ADVANCED ANTENNA SYSTEM**
**POWER DENSITY STUDY**



for the total feed system. At 61.4 deg from feed system boresight, which is the edge of the paraboloid, 92.6% of the power has been subtended. From 61.4 to 90 deg, the rear spillover amounts to 0.4%. Table II further shows the forward spillover, from 90 to 180 deg, which accounts for the balance, 7%. Of the 7%, the bulk (5%) is seen to be contained within the 160 - 170 deg lobe. The total feed system axial gain is given in Table II as +9.7 dB above isotropic.[1]

Three additional factors must be considered in our total power accounting; scattering from the feed system supports (quadripod) and central blockage, leakage through the parabolic reflector, and the parabolic reflector backlobe. The total central power blocked, using the Tricone feedcone system, is 3.0%, from Table II. The area blocked by the quadripod is 6.3%. Accepting the quadripod blocking shadows on the 64 m aperture as pie-slice approximations, we obtain 6.3% power blocking. Recalling that we are blocking 6.3% of 93.0%, we finally obtain 5.9% for the quadripod and 8.9% total power scattered.

Excellent agreement between theory and experiment has been obtained for the RF transmission through metal meshes such as are used for the outer 50% of the radius on the 64 m reflector. For the particular material used, the 2.1 GHz leakage for normal incidence is -42 dB. Non-normal incidence causes the leakage to tend towards -50 dB. An upper bound of 0.01% power leakage due to the mesh is reasonable. The parabolic reflector front to back power ratio has been estimated for the case of an isotropic feed as 58.5 dB (Reference 5). In this case the edge illumination is 6.4 dB below isotropic and the forward gain is about 4 dB better than the isotropic feed produces; the front to back power

[1]An anomaly of scattering computations of importance here is the axial (0 deg) "bright spot", seen in Figure 2. Whether the spot physically exists or not is unknown, but in either event of no consequence since precisely zero power is contained in such a point. It is entirely correct to ignore the bright spot and adopt an axial gain of +8.4 dB above isotropic.

ratio should be 60.9 dB. Approximately $10^{-4}$% power lost due to the backlobe is a reasonable estimate.

Table III can now be assembled, to summarize the feed system and reflector in terms of the total power accountability.

Table III

Total Power Description, 64 m Hybrid Mode Feed System and Reflector

| Radiation Type | Percent of Total |
|---|---|
| Forward Spillover | 7.0 |
| Scattered | 8.9 |
| Rear Spillover | 0.4 |
| Reflector Leakage | $10^{-2}$ |
| Reflector Backlobe | $10^{-4}$ |
| Balance to Main Beam | 83.7 |

Power Density Calculations

The power density PD is obtained from

$$PD = PG/4\pi r^2$$

where P is the power, G is the gain relative to isotropic and $(4\pi r^2)^{-1}$ is the inverse square. Implied in the use of this equation is that we remain in the far zone (divergent rays) of the radiation considered. For example, use of the above equation to predict densities within about $2D^2/\lambda$ from constant phased apertures, where D is the aperture diameter, is incorrect.

But to predict aperture illuminations (either the subreflector by the feedhorn or the paraboloid by the total feed system) or to predict stray fields known to be divergent, the above applies.

The condition selected for calculation is shown in Figure 3. With the system pointing at the lowest operational elevation angle of 6.0 deg, the main beam is in closest proximity to the ground and the forward and rear spillovers as well as the scattered power are in a ground intercept condition.[1] From the H-plane pattern in Figure 2 and the ranges from Figure 3, we can obtain Table IV, a straightforward series of singular field calculations. By singular field it is meant we postpone considerations of possible power additions due to multiple sources, and possible reflections. Further, Table IV postpones estimates for the scattered, leakage and backlobe components.

An examination of Table IV shows power densities greater than 0 $dBm/cm^2$ exist only on the aperture, based on singular fields. We will therefore consider this aperture distribution as first priority and return to multiple sources, reflections and stray radiations later.

[1]The lowest operational elevation angle is site peculiar. 6.0 deg is a selected worst case.

## Table IV

### Calculated Singular Power Densities*

### 64 m Reflector, 6.0 deg Elevation Angle, 400 KW

| PSI deg | G, Gain dB/isotropic | r, Range to Intercept, Meters | Intercept Type | $PG/4\pi r^2$ $dBm/cm^2$ | Notes |
|---|---|---|---|---|---|
| 0 | +8.4 | 27.0 | Paraboloid | +14.8 | 27 m = focal length of paraboloid |
| 10 | 8.4 | 27.2 | | 14.7 | |
| 19 | 7.9 | 27.6 | | 14.1 | |
| 29 | 7.1 | 28.9 | | 12.9 | Mesh Reflector Portion |
| 38 | 6.7 | 30.3 | | 12.1 | |
| 46 | 3.5 | 31.9 | | 8.5 | |
| 54 | 4.9 | 34.0 | | 9.3 | |
| 61 | -5.8 | 36.4 | | -2.0 | |
| 61.4 | -6.4 | 36.5 | | -2.6 | Edge of Reflector |
| 61.4 | -6.4 | 41.5 | Ground | -3.9 | First Ray to Ground |
| 62 | -7.5 | 41.3 | | -4.9 | |
| 64 | -13.1 | 40.8 | | -10.3 | |
| 66 | -19.3 | 40.4 | | -16.4 | |
| 68 | -25.6 | 39.9 | | -22.6 | |
| 75 | -22.1 | 38.9 | | -28.9 | |
| 80 | -20.6 | 38.6 | | -17.4 | Shortest Ray to Ground |
| 90 | -23.6 | 38.8 | | -20.4 | |
| 100 | -22.1 | 40.1 | | -19.2 | |
| 120 | -24.6 | 47.6 | | -19.2 | |
| 140 | -9.7 | 69.0 | | -11.5 | |
| 150 | -3.8 | 94.8 | | -8.3 | |
| 160 | +2.3 | 157 | | -6.6 | |
| 162 | 4.9 | 184 | | -5.4 | Forward Spillover Peak |
| 163 | 5.2 | 201 | | -5.9 | |
| 164 | 4.4 | 218 | | -7.4 | |
| 165 | 3.0 | 241 | | -9.6 | |
| 175 | 1.8 | ∞ | Sky | -- | |
| 180 | 11.6 | ∞ | | -- | |

*Aperture distribution, forward and rear spillovers only

Main Beam Characteristics

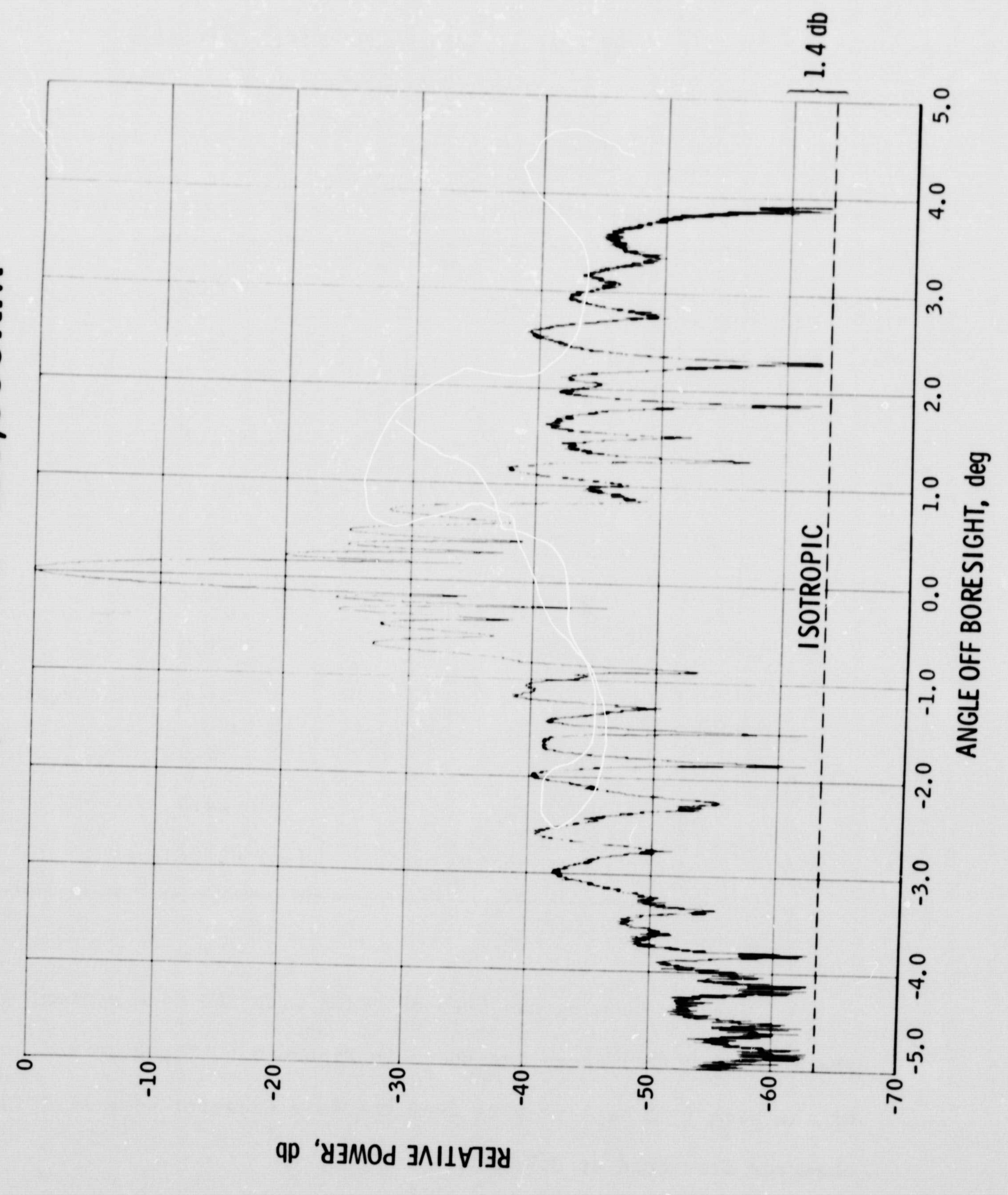
A well known characteristic of constant phase apertures at ranges greater than $2D^2/\lambda$ is the far-field radiation pattern which remains invariant with additional observation distance. Figure 4 is an example of the 64 m system[1] far-field pattern at 2.3 GHz showing the half power beamwidth of 0.14 deg normally considered for such an aperture. At ranges less than $2D^2/\lambda$ but greater than $D^2/2\lambda$, observed patterns are in a transition zone between the far-field pattern and the aperture distribution. At ranges less than $D^2/2\lambda$ a less well known parallel or tubular beam exists which is characterized as exhibiting no divergence and therefore no "space loss". The significance of the tubular beam is that, for practical purposes, one should imagine the aperture distribution being repeated in space beginning at the aperture and extending to about $D^2/2\lambda$. Of course neither range mentioned above represents a sharp demarcation in beam type but we may here assume so for simplicity. Useful and consistent results will be achieved.

For the 64 m reflector at 2.12 GHz the above ranges are 14.5 and 58 km. The peak power densities at these ranges are approximately +15 and 0 dBm/cm$^2$, respectively. It must be emphasized the +15 dBm/cm$^2$ density exists, beginning at the aperture and extending outward to 14.5 km. This tubular beam is 64 m in diameter with approximately -3 dBm/cm$^2$ density at the edges, and an estimated 12 dB/radius decay beyond the beam edge as listed in Table V.

[1]Although Figure 4 represents the 64 m system prior to the Tricone, no significant differences are expected following the modifications.

Fig. 4

**MEASURED AZIMUTH PATTERN OF THE 64 M. ADVANCED ANTENNA SYSTEM AT GOLDSTONE, CALIFORNIA. 2295MHZ, RANGE=400,000KM**



## Table V

**Calculated Tubular Beam Power Densities**

**64 m Reflector, 400 KW**

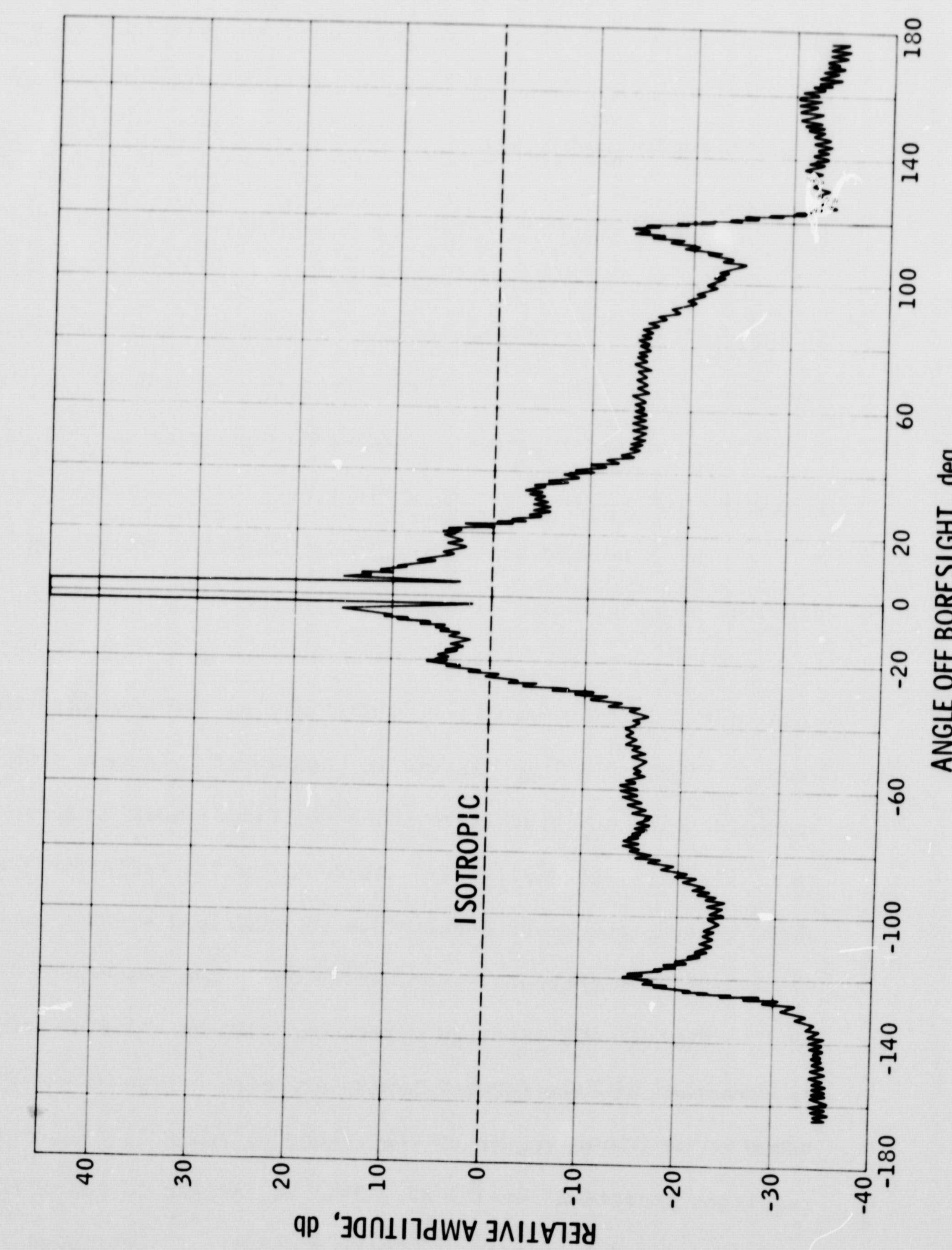
| Radius, meters | Power Density, dBm/cm$^2$ |
|---|---|
| 0 | +14.8 |
| 4.7 | +14.7 |
| 9.1 | +14.1 |
| 14 | +12.9 |
| 19 | +12.1 |
| 23 | +8.5 |
| 28 | +9.3 |
| 31 | -2.0 |
| 32 | -2.6 (beam edge) |
| 48 | -8.6 |
| 64 | -14.6 |
| | (-12 dB/radius) |

Tubular beaming has been observed with the 64 m system, albeit at short (0.05 $D^2/2\lambda$) range, as shown in Figure 5.[1] The observed angular width of the beam ($\approx$ 5 deg) results from the 64 m diameter beam sweeping by the observer stationed at 0.7 km.

[1] As before, Figure 5 represents the 64 m system prior to Tricone installation. Again, possible differences with Tricone are considered insignificant.

Fig. 5

# MEASURED AZIMUTH PATTERN OF THE 64M. ADVANCED ANTENNA SYSTEM AT GOLDSTONE, CALIFORNIA. 2115MHZ, RANGE=700METERS



Energy transport by means of tubular beam transmission has been studied and verified by experiment where high efficiency ($\approx 0.8$) transfer is realized to $D^2/2\lambda$ range. It should be appreciated the 64 m/400 KW system is an efficient power transmission means to 15 km range with calculated power densities in the danger category (Table V).

Stray Radiation, Forward Zone, 6 deg Elevation

The second priority region for study is along the boresight direction of the reflector, at ground level. Table IV gives the singular field power densities along this track arising from the forward and rear spillover components. We will now consider also the scattered components as well as accounting for possible multiple sources and reflections.

The quadripod scattering (5.9%) or -12.3 dB total power is modeled as directed equally in all directions with the exception of the shielding provided by the 64 m reflector, leading to an average gain 1.3 dB above isotropic. The resultant radiation level (-11.0 dBi) may be compared with the -15 dBi plateau seen in Figure 5. This plateau is considered to extend from boresight ±100 deg, approximately, and crudely verifies the simple model. Accepting this radiation as arising from a complex line source along the reflector z axis which is 35 m above ground, the power density due to quadripod scatter is estimated as -7 dBm/cm$^2$ on the ground, immediately below the quadripod.

The central blockage scattering (3%) or -15.2 dB total power is modeled as directed into the forward hemisphere with a gain of +3 dBi. The source is taken to be in the region of the feedhorn, again 35 m above ground. The resultant radiation level (-12.2 dBi) is similar to the quadripod level; the power density due to central blockage scatter is estimated as -8 dBm/cm$^2$ on the ground, immediately below the feedcones.

From Table IV we have $-3.9$ dBm/cm$^2$ from direct spillover on the ground, immediately below the antenna, and from scattering we have $-7$ and $-8$ dBm/cm$^2$. Adding the three nearly equal signals coherently we obtain possible maxima of $+3.5$ dBm/cm$^2$. An intensity maximum of this kind, due to multiple sources, will be found on a spot basis only. Minima will also be found due to destructive interference, again on a spot basis.

Referring to Table IV, a second region of interest in the reflector boresight direction on the ground is the feedhorn forward spillover maximum of $-5.4$ dBm/cm$^2$, roughly 200 m from the other sources. The scattered sources contribute $-18$ and $-19$ dBm/cm$^2$ at 200 m on the ground. A fourth source, the decay of the tubular beam in this region, contributes $-11.6$ dBm/cm$^2$. Again taking the peak or spot maxima for this region on the ground we obtain $+0.3$ dBm/cm$^2$.

Ground (or other) reflections can be relied on for field amplitude doubling or 6 dB spot power maxima, provided the angle of incidence is grazing. For normal incidence, the ground is taken as absorbing. Therefore it appears this region on the ground, in front of the 64 m reflector, and extending perhaps 250 m from the azimuth axis, contains calculated spot maximum power densities on the order of $+4$ to $+6$ dBm/cm$^2$. Uniform power densities in this category are considered safe for incidental or occasional exposure.

<u>Stray Radiation, Rear Zone</u>

We have two indices of back radiation mentioned earlier; mesh leakage and the predicted front to back ratio. With a maximum power density of $+13$ dBm/cm$^2$ on the mesh (Table IV) and a leakage of $-42$ dB, maximum fields immediately behind the reflector will be $-29$ dBm/cm$^2$, due to mesh leakage.

It appears proper to treat the backlobe as another tubular (non-divergent) beam, i.e., within reasonable observing distances it has not yet formed in the far-field sense. The non-divergent beam exhibits no space loss so we may consider the aperture power density maximum (+15 dBm/cm$^2$) down the order of 60 dB; the resultant -45 dBm/cm$^2$ due to the near field or tubular backlobe is indistinguishable in the presence of the mesh leakage above. Calculated power densities in the rear zone are considered safe for indefinite exposure.

Comparisons, Predicted and Measured Power Densities

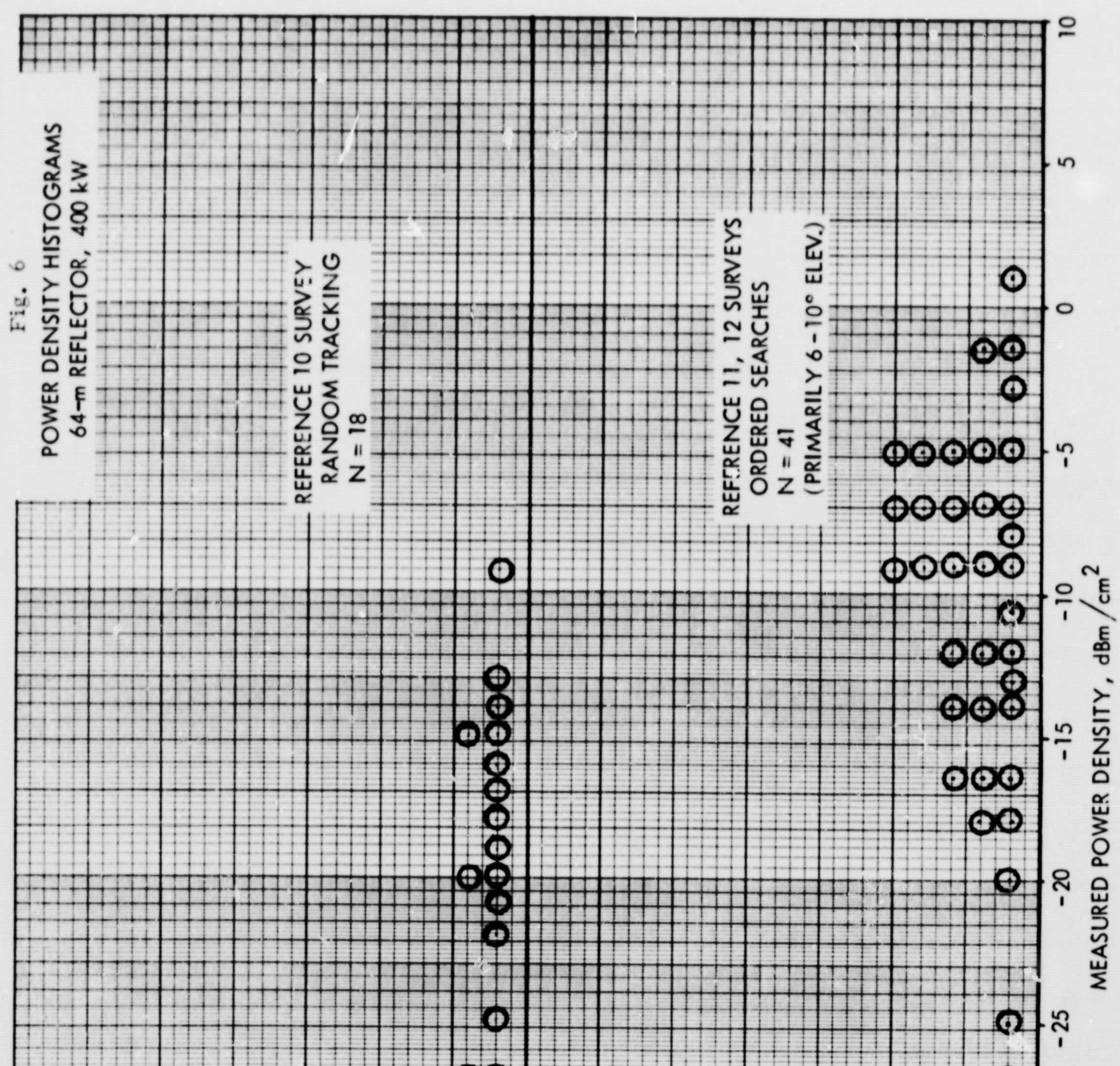
A number of radiation surveys have been made in the station complex area around the 64 m Goldstone reflector (References 6 through 12). Radiation surveys are typically taken with a rather large ($\approx$ 500 cm$^2$) effective area probe and an RF thermal detector with a useable sensitivity in the $10^{-2}$ mw class. Such an arrangement responds to the average power density over a few square wavelengths or several spot maxima and minima, if any exist. The minimum detectable average power density is -50 dBm/cm$^2$, and larger fields are accurately managed by use of attenuators. Experience has shown one characteristic of the stray radiation is strong elliptical polarization, i.e., the polarization tends towards linear for each sample.

A gross view of the results of three of these surveys is given in Figure 6. The conditions for the smaller survey were to select a series of locations without regard to the beam pointing direction, i.e., a brief simulation of randomness existed.[1] The larger survey conditions include ordered searches for power density maxima by means of azimuth and elevation sweeps; most recorded data were obtained at 6 deg elevation angle.

Although both samples in Figure 6 are small, the results are nevertheless interesting. The bulk of the first distribution is below -15 dBm/cm$^2$

[1]Conducted during spacecraft tracking.

Fig. 6


POWER DENSITY HISTOGRAMS
64-m REFLECTOR, 400 kW
REFERENCE 10 SURVEY
RANDOM TRACKING
N = 18
REFERENCE 11, 12 SURVEYS
ORDERED SEARCHES
N = 41
(PRIMARILY 6-10° ELEV.)
MEASURED POWER DENSITY, dBm/cm²
NUMBER OF OCCURRENCES
NUMBER OF OCCURRENCES
-35
-30
-25
-20
-15
-10
-5
0
5
10
0
2
4

while the second bulk is below -5 dBm/cm$^2$. The ordered searches must be considered at least partially successful. A further characteristic worth noting is that in the second survey for maximums, minimum readings are subject to being ignored; the surveyors' tendency to hunt about and peak up before recording an indication is probably significant. This results in a sparsity of low power density points.

Selected results from the various surveys are given in Table VI. Location numbers in Table VI refer to Figure 3. The primary purpose of Table VI is to show the measured high fields on the 64 m aperture, and in the tubular beam. The moderate fields expected on the ground in front of the reflector at 6 deg elevation are found. Location (6) in Table VI is indicative of an area immediately behind a deliberate opening in the reflector (for the quadripod). It is necessary to climb the structure for access to locations (6) and (7). The back radiation is seen to be very low.

We consider the 64 m/400 KW system very adequately described for power densities greater than +10 dBm/cm$^2$. Totally independent studies of apertures with tapered illumination show a ratio of power density at the aperture to the density at $2D^2/\lambda$ of 14.2 dB (Reference 13). The results obtained here yield 14.3 dB. We have the calculated tubular beam maximum agreeing with the measurement at 700 m within 0.3 dB. Limitations in handling the multiple and reflected fields near the ground both analytically and during the field surveys should be appreciated; that is, the spot maxima and minima phenomenon (standing waves) and the averaging provided by the measuring process are important in interpreting the results.

## Table VI

**Selected Power Densities, 64 m/400 KW Goldstone System**

| Location | Measured Power Density dBm/cm² | Calculated Power Density dBm/cm² | Notes |
|---|---|---|---|
| (1) On 64 m reflector | +16.4 | +14.7 | Radius = 5 m |
| (2) On 64 m reflector | +13.4 | +12.8 | Radius = 15 m |
| (3) On tubular beam center | +14.5 | +14.8 | Range = 700 m |
| (4) Below beam, on ground | -17 to +3 | +6 | Range = 100–300 m |
| (5) Reflector edge, on ground | -5 to -1 | +4 | Height = 1.7 m |
| (6) Directly behind reflector | -9.5 | — | Leak near opening |
| (7) Directly behind reflector | < -17 | -29 | Continuous panel |
| (8) Behind reflector, on ground | -27 | ≈ -45 | ≈15° elevation |
| (9) Backlobe search, on ground | < -30 | ≈ -45 | Plunge tests |
| (10) Under hyperboloid, on ground | -9.5 | — | Height = 1.7 m |

Items 4, 5 and 9 at 6° elevation

## Discussion

The first order tubular beam approach taken above is considered totally valid in the context of this study. Adequately accurate results are quickly obtained and the interested reader is presented a clear impression not likely to be forgotten. It is worthwhile noting a second order tubular beam theory predicts a power density increase of 2 dB at a range of half the 14.5 km value mentioned above. The most intense power density for the system considered here would thus be +16.8 dBm/cm$^2$ at a range of 7 km. A survey party using the hand held equipment mentioned in the measurement paragraphs above would collect about 25 watts at 7 km; a 2 m diameter dish would collect nearly a kilowatt.[1] Higher densities are possible in a mis-focussed condition. An approximate density increase of 6 dB is available at 14.5 km; the reflector should always remain focussed at infinity when transmitting.

Returning to the intermediate (0 to +10 dBm/cm$^2$) zone, which is likely to necessarily be more loosely controlled, mention of unlikely but possible effects should be made. Resonant or focussing devices, perhaps keyrings, metal eyeglass frames or wrenches are capable of exhibiting a reasonable absorption area at S-band. For example, a halfwave dipole (7.0 cm) in a 0 dBm/cm$^2$ field will deliver 25 mw to a matched load.

Effects of this kind have been reported (Reference 14), but are considered little more than an unlikely irritation. It should be recalled

---

[1] A 2 m dish 1.5 km from a 26 m/400 KW system operated at 2.39 GHz has been inadvertently swept, during normal tracking, by the tubular beam. The power density and range of the tubular beam in this case is +22.7 dBm/cm$^2$ and 2.7 km, respectively. Further, the 2 dB increase at half range was active here; the dish collected approximately 5 KW with resultant loss of feed and cabling due to thermal damage. It is worthwhile noting at this point, that for a given power output, smaller systems produce higher power densities in the tubular beam.

that normal tracking motion of the antenna will time limit the intermediate zone to some extent. In this intermediate zone we have seen calculated spot power densities, but measured average densities (the average over the aperture of the test horn). From Table VI, the average appears lower as might be expected. It is considered the average value is important in terms of personnel exposure, while the spots are important in the event of resonant phenomena, if any. In either case, this zone, on the ground, is considered safe for incidental or occasional exposure, even at 6.0 deg elevation angle.

The greatest hazard is thus the tubular beam itself. Because acceptable siting of large microwave ground antennas generally places such installations in depressions, for noise masking to improve reception, the primary restriction is to avoid intercept of the tubular beam with the surrounding terrain. Surrounding terrain includes man-made objects such as towers, other antennas, power lines and possibly building roofs near in to the antenna. Generally, the NASA 64 m station sites are such that the transmitter will be inoperative at 6 deg elevation angles due to the above primary restriction. This helps in further alleviating the power density in the intermediate zone, by inspection of Figure 3.

Figures 7 and 8 show the proposed transmitter elevation limits for the Canberra and Madrid complexes (Reference 15). Adoption of these limits will insure the tubular beam remains well above the obvious land masks. Figures 9 and 10 show plot plans for the two sites, which are (with the obvious exception of the 26 m reflectors) similar to the Goldstone installation in the siting of operations and other buildings relative to the reflector. It is finally clear that each Station Director will necessarily be required to impose additional restrictions which are site peculiar, as the occasion arises. It is hoped this study will provide an unambiguous guide for this purpose.

Fig. 7

CANBERRA COMPLEX LAND MASKING PROFILE

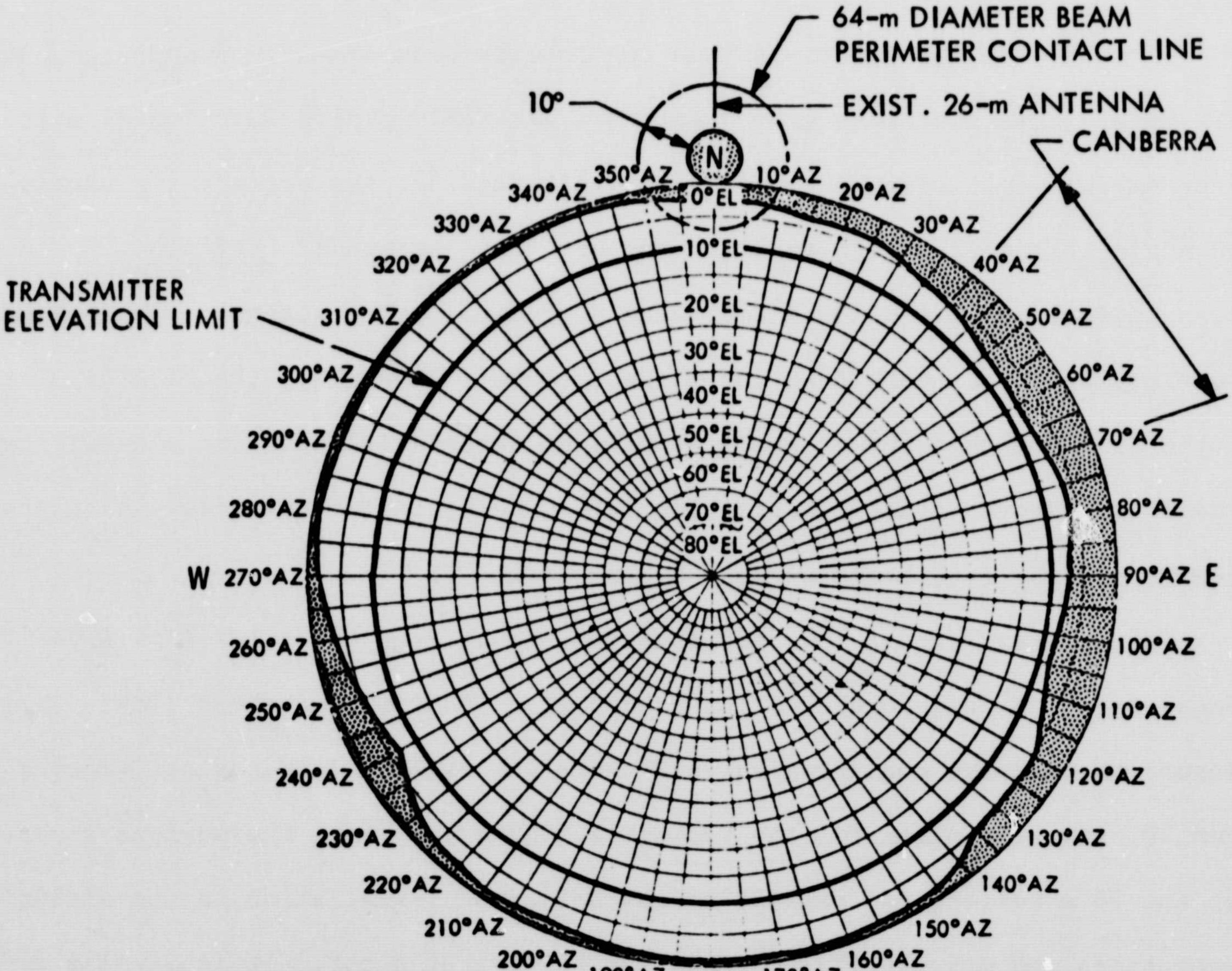
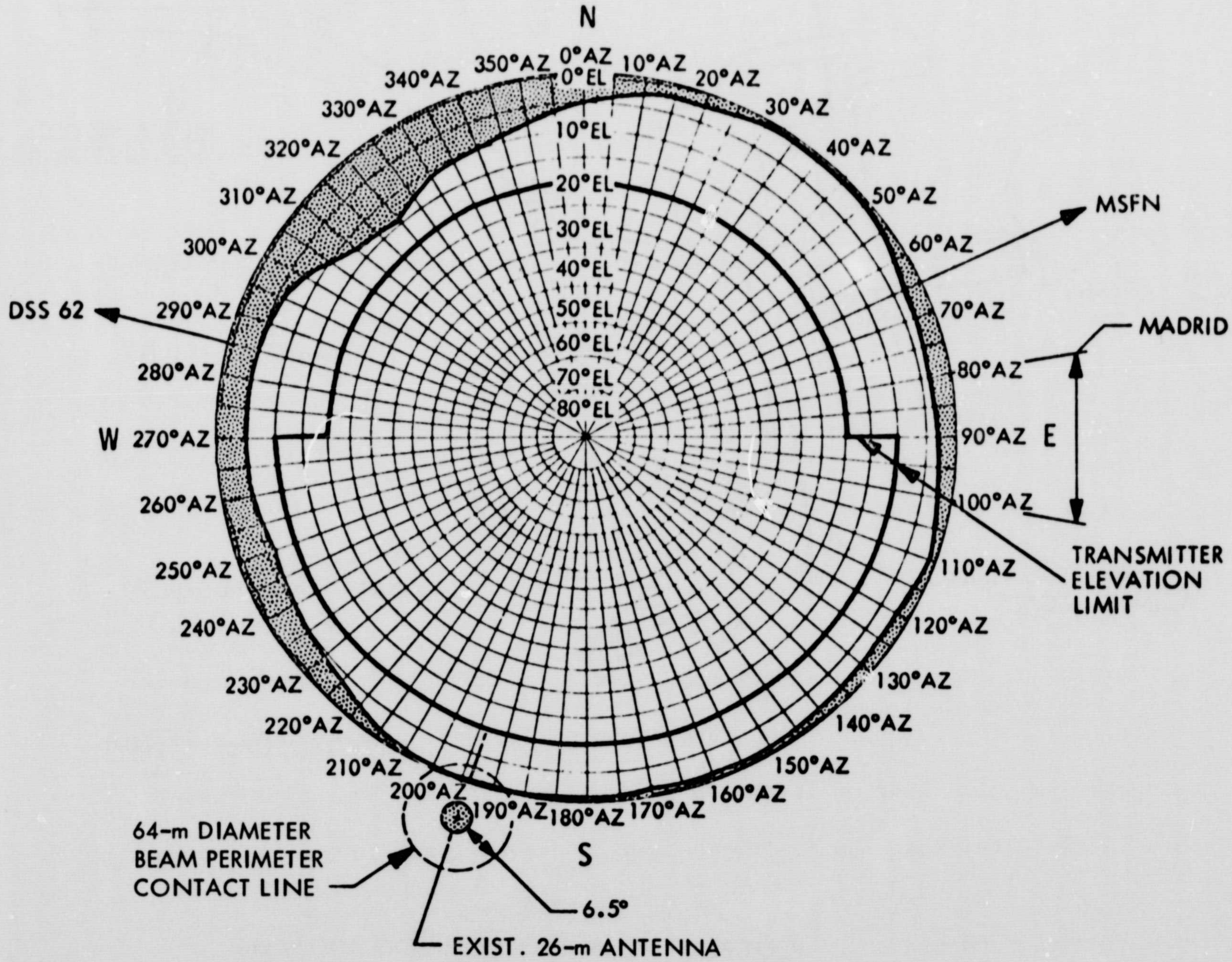


Fig. 8

MADRID COMPLEX LAND MASKING PROFILE



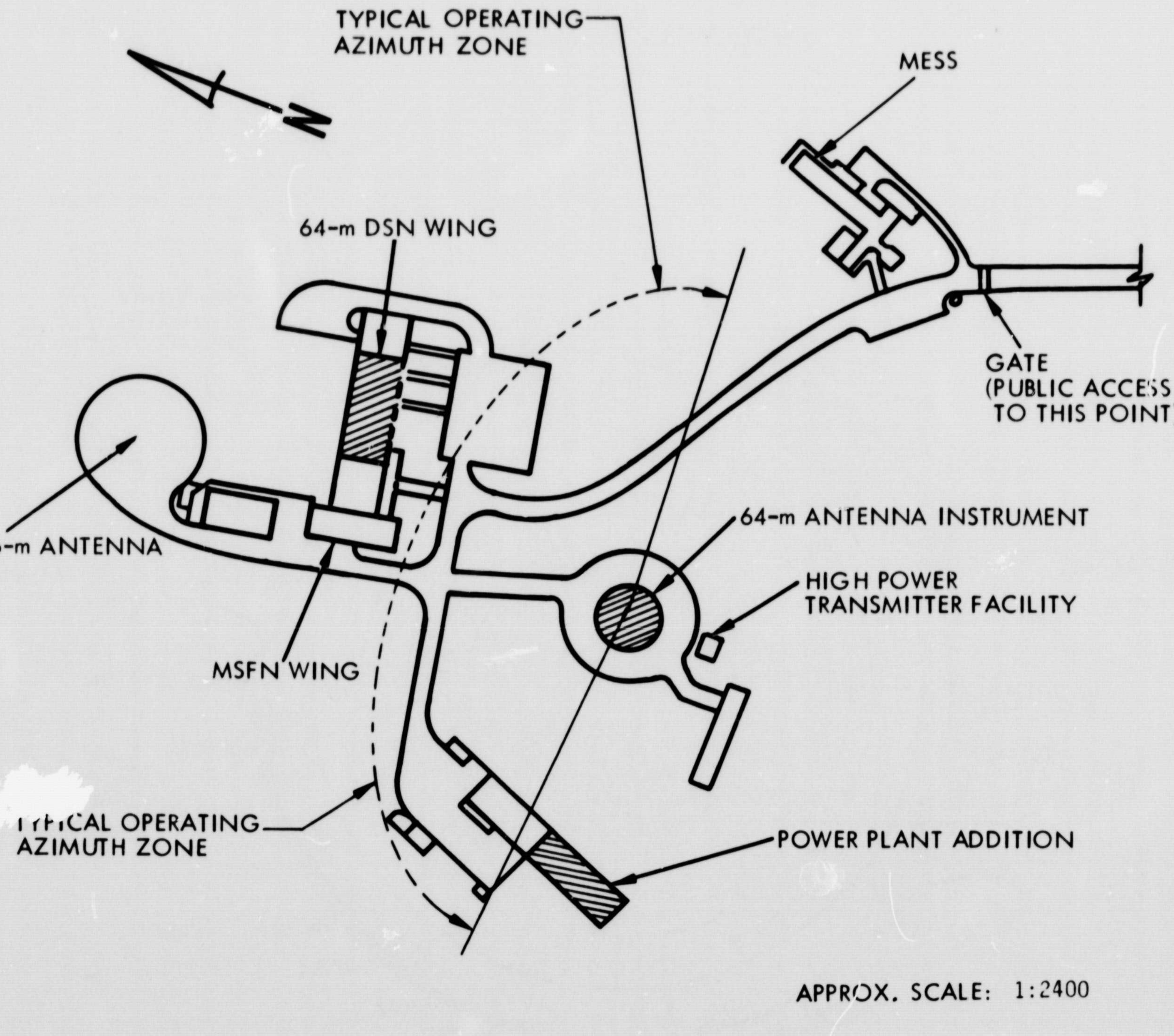



Fig. 9

PLOT PLAN - CANBERRA COMPLEX, AUSTRALIA

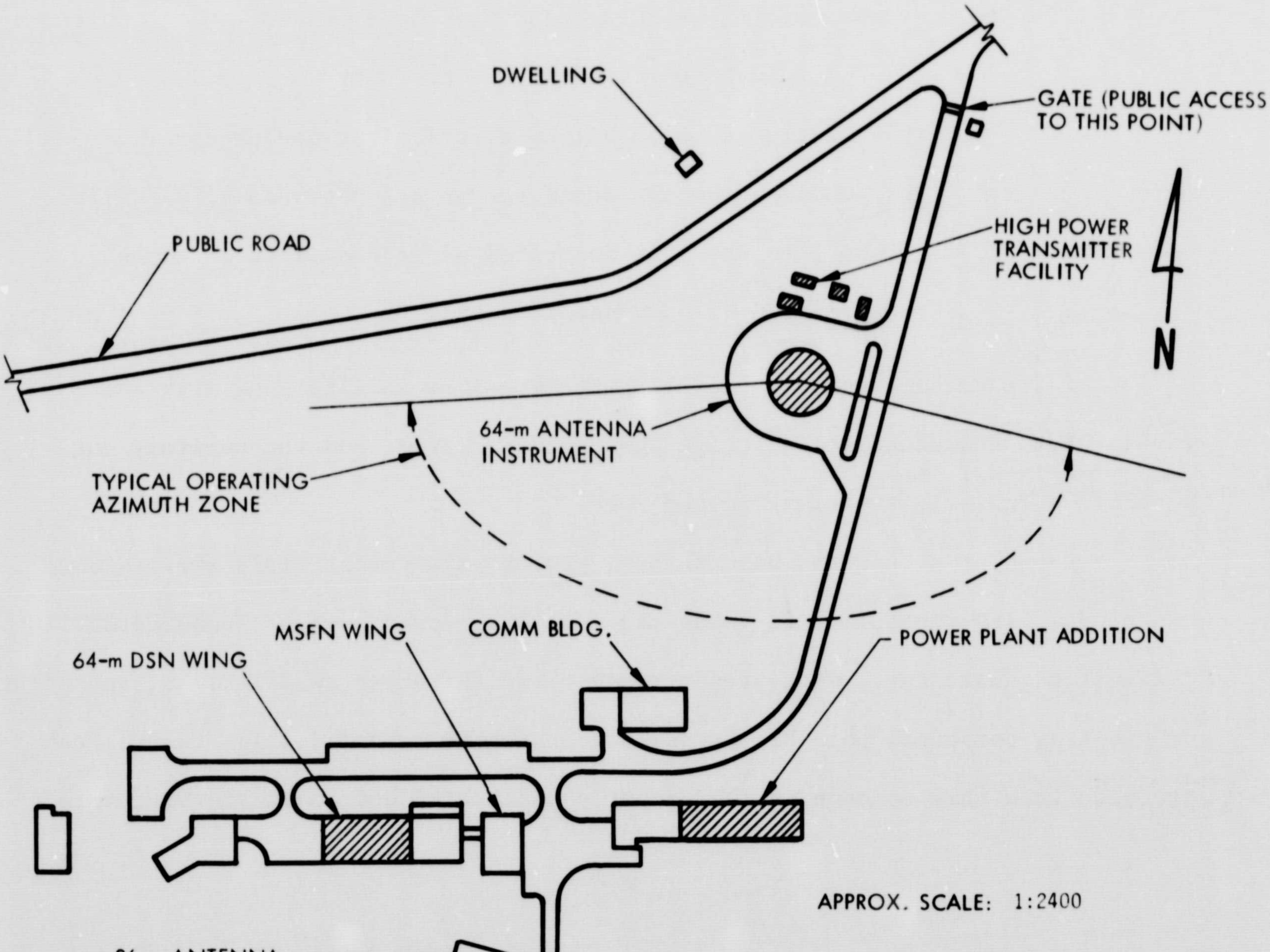



Fig. 10
PLOT PLAN - MADRID COMPLEX, SPAIN

## Conclusions

The following personnel restrictions when operating the described system are required, as a result of the adopted standards:

(1) Access to the reflecting surfaces must be avoided.

(2) Access into the tubular beam must be avoided.

(a) Land mask restrictions are necessary.

(b) Station complex height restrictions are necessary.

(c) Collimation and other towers are potentially dangerous.

(3) Access into the zone described as intermediate is to be time-limited (1 hour per 24 hours).

It is recommended all operating personnel be familiarized with the tubular beam characteristics (range and power density), and the unlikely but possible effects in the time-limited zone.

Based on straightforward theory, present standards, field surveys and experience with the Goldstone Venus and Mars high power systems, considered judgment suggests that, with proper respect for the above restrictions, operating or visiting personnel possibly experience a greater hazard driving to and from the site than they do once on the properly understood and administered complex.

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# APPENDIX

## Table I

### Antenna Feed Efficiency, Feedhorn Radiation Pattern

ORIGINAL INPUT PATERN

| PSI FEEDHORN | ETA (OVERALL) | ETA S (SPILL) | ETA I (ILLUM) | ETA X (X-POL) | ETA P (PHASE) | ETA B (BLOCK) |
|---|---|---|---|---|---|---|
| 1.00 | .01130 | .01129 | 1.00058 | 1.00000 | 1.00000 | 1.00000 |
| 2.00 | .04448 | .04447 | 1.00016 | 1.00000 | 1.00000 | 1.00000 |
| 3.00 | .09787 | .09787 | .99995 | 1.00000 | 1.00000 | 1.00000 |
| 4.00 | .16752 | .16762 | .99942 | 1.00000 | 1.00000 | 1.00000 |
| 5.00 | .24901 | .24941 | .99840 | 1.00000 | 1.00000 | 1.00000 |
| 6.00 | .33954 | .34056 | .99701 | 1.00000 | 1.00000 | 1.00000 |
| 7.00 | .43428 | .43656 | .99478 | 1.00000 | 1.00000 | 1.00000 |
| 8.00 | .52471 | .52983 | .99034 | 1.00000 | 1.00000 | 1.00000 |
| 9.00 | .60767 | .61762 | .98388 | 1.00000 | 1.00000 | 1.00000 |
| 10.00 | .68110 | .69837 | .97526 | 1.00000 | 1.00000 | 1.00000 |
| 11.00 | .74124 | .76921 | .96364 | 1.00000 | 1.00000 | 1.00000 |
| 12.00 | .78690 | .82947 | .94868 | 1.00000 | 1.00000 | 1.00000 |
| 13.00 | .81357 | .87660 | .92809 | 1.00000 | 1.00000 | 1.00000 |
| 14.00 | .82211 | .91168 | .90175 | 1.00000 | 1.00000 | 1.00000 |
| 15.00 | .81690 | .93778 | .87109 | 1.00000 | 1.00000 | 1.00000 |
| 16.00 | .79858 | .95589 | .83544 | 1.00000 | 1.00000 | 1.00000 |
| 17.00 | .76934 | .96764 | .79508 | 1.00000 | 1.00000 | 1.00000 |
| 18.00 | .73241 | .97492 | .75125 | 1.00000 | 1.00000 | 1.00000 |
| 19.00 | .69116 | .97933 | .70575 | 1.00000 | 1.00000 | 1.00000 |
| 20.00 | .64910 | .98214 | .66091 | 1.00000 | 1.00000 | 1.00000 |
| 21.00 | .60825 | .98404 | .61812 | 1.00000 | 1.00000 | 1.00000 |
| 22.00 | .57048 | .98555 | .57885 | .99999 | 1.00000 | 1.00000 |
| 23.00 | .53705 | .98701 | .54414 | .99998 | 1.00000 | 1.00000 |
| 24.00 | .50782 | .98850 | .51374 | .99997 | 1.00000 | 1.00000 |
| 25.00 | .48207 | .99003 | .48695 | .99996 | 1.00000 | 1.00000 |
| 26.00 | .45901 | .99154 | .46295 | .99994 | 1.00000 | 1.00000 |
| 27.00 | .43792 | .99294 | .44107 | .99993 | 1.00000 | 1.00000 |
| 28.00 | .41814 | .99418 | .42062 | .99992 | 1.00000 | 1.00000 |
| 29.00 | .39915 | .99519 | .40111 | .99990 | 1.00000 | 1.00000 |
| 30.00 | .38069 | .99596 | .38227 | .99989 | 1.00000 | 1.00000 |
| 31.00 | .36246 | .99651 | .36378 | .99988 | 1.00000 | 1.00000 |
| 32.00 | .34456 | .99687 | .34569 | .99986 | 1.00000 | 1.00000 |
| 33.00 | .32559 | .99710 | .32817 | .99986 | .99518 | 1.00000 |
| 34.00 | .30588 | .99725 | .31134 | .99985 | .98533 | 1.00000 |
| 35.00 | .28745 | .99737 | .29567 | .99985 | .97491 | 1.00000 |
| 36.00 | .27032 | .99752 | .28149 | .99985 | .96285 | 1.00000 |
| 37.00 | .25431 | .99771 | .26870 | .99984 | .94879 | 1.00000 |
| 38.00 | .23938 | .99792 | .25708 | .99983 | .93325 | 1.00000 |
| 39.00 | .22548 | .99816 | .24647 | .99982 | .91670 | 1.00000 |
| 40.00 | .21255 | .99842 | .23670 | .99980 | .89958 | 1.00000 |
| 41.00 | .20057 | .99868 | .22765 | .99978 | .88242 | 1.00000 |
| 42.00 | .18950 | .99893 | .21918 | .99977 | .86572 | 1.00000 |
| 43.00 | .17927 | .99917 | .21121 | .99976 | .84966 | 1.00000 |
| 44.00 | .16983 | .99940 | .20369 | .99975 | .83450 | 1.00000 |
| 45.00 | .16116 | .99961 | .19652 | .99974 | .82059 | 1.00000 |
| 46.00 | .15321 | .99979 | .18963 | .99974 | .80834 | 1.00000 |
| 47.00 | .14592 | .99995 | .18302 | .99974 | .79753 | 1.00000 |

TOTAL RADIATED POWER .732127-04 WATTS
RESULTANT PHASE ANGLE .000 DEGREES
GAIN 21.777 DB

## Table II

### Antenna Feed Efficiency, Subreflector Scattered Pattern

SAFETY PROJECT 2120 MHZ CORRUGATED HORN

| PSI FEED SYSTEM | ETA (OVERALL) | ETA S (SPILL) | ETA I (ILLUM) | ETA X (X-POL) | ETA P (PHASE) | ETA B (BLOCK) |
|---|---|---|---|---|---|---|
| 1.00 | .00000 | .00053 | .99765 | .99997 | .99167 | .00000 |
| 2.00 | .00000 | .00191 | .99842 | .99998 | .99685 | .00000 |
| 3.00 | .00000 | .00435 | .99917 | .99999 | .99800 | .00000 |
| 4.00 | .00000 | .00758 | .99904 | .99999 | .99807 | .00000 |
| 5.00 | .00000 | .01190 | .99890 | .99999 | .99823 | .00000 |
| 6.00 | .00000 | .01716 | .99885 | .99999 | .99863 | .00000 |
| 7.00 | .00000 | .02313 | .99894 | .99999 | .99897 | .00000 |
| 8.00 | .00000 | .03051 | .99913 | 1.00000 | .99916 | .00000 |
| 9.00 | .00162 | .03820 | .99906 | 1.00000 | .99930 | .00000 |
| 10.00 | .00598 | .04710 | .99903 | 1.00000 | .99938 | .04238 |
| 11.00 | .01250 | .05701 | .99904 | 1.00000 | .99923 | .12724 |
| 12.00 | .02036 | .06711 | .99898 | 1.00000 | .99910 | .21967 |
| 13.00 | .02996 | .07865 | .99912 | 1.00000 | .99916 | .30400 |
| 14.00 | .04071 | .09085 | .99917 | 1.00000 | .99909 | .38161 |
| 15.00 | .05216 | .10330 | .99906 | 1.00000 | .99882 | .44886 |
| 16.00 | .06508 | .11716 | .99911 | 1.00000 | .99871 | .50600 |
| 17.00 | .07885 | .13165 | .99909 | 1.00000 | .99881 | .55665 |
| 18.00 | .09270 | .14589 | .99879 | 1.00000 | .99890 | .60023 |
| 19.00 | .10818 | .16183 | .99879 | 1.00000 | .99898 | .63690 |
| 20.00 | .12429 | .17828 | .99871 | 1.00000 | .99904 | .66999 |
| 21.00 | .14043 | .19460 | .99844 | 1.00000 | .99904 | .69874 |
| 22.00 | .15796 | .21234 | .99841 | 1.00000 | .99907 | .72344 |
| 23.00 | .17624 | .23079 | .99837 | 1.00000 | .99911 | .74578 |
| 24.00 | .19437 | .24899 | .99809 | 1.00000 | .99913 | .76560 |
| 25.00 | .21343 | .26811 | .99790 | 1.00000 | .99917 | .78283 |
| 26.00 | .23339 | .28812 | .99778 | 1.00000 | .99921 | .79840 |
| 27.00 | .25254 | .30729 | .99728 | 1.00000 | .99924 | .81247 |
| 28.00 | .27224 | .32701 | .99682 | 1.00000 | .99924 | .82471 |
| 29.00 | .29345 | .34824 | .99666 | 1.00000 | .99921 | .83582 |
| 30.00 | .31415 | .36899 | .99620 | 1.00000 | .99918 | .84616 |
| 31.00 | .33327 | .38823 | .99510 | 1.00000 | .99918 | .85534 |
| 32.00 | .35384 | .40891 | .99445 | 1.00000 | .99913 | .86336 |
| 33.00 | .37694 | .43206 | .99437 | 1.00000 | .99907 | .87092 |
| 34.00 | .39902 | .45429 | .99392 | 1.00000 | .99893 | .87819 |
| 35.00 | .41760 | .47337 | .99217 | 1.00000 | .99883 | .88467 |
| 36.00 | .43599 | .49238 | .99040 | 1.00000 | .99865 | .89019 |
| 37.00 | .45848 | .51514 | .99001 | 1.00000 | .99842 | .89528 |
| 38.00 | .48349 | .54028 | .99009 | 1.00000 | .99830 | .90042 |
| 39.00 | .50545 | .56277 | .98929 | 1.00000 | .99797 | .90539 |
| 40.00 | .52142 | .58022 | .98622 | 1.00000 | .99774 | .90972 |
| 41.00 | .53532 | .59614 | .98236 | 1.00000 | .99742 | .91328 |
| 42.00 | .55292 | .61520 | .98040 | 1.00000 | .99670 | .91648 |
| 43.00 | .57649 | .63933 | .98029 | .99999 | .99633 | .91977 |
| 44.00 | .60219 | .66532 | .98052 | .99999 | .99626 | .92323 |
| 45.00 | .62415 | .68834 | .97982 | .99999 | .99560 | .92657 |
| 46.00 | .63878 | .70570 | .97652 | .99999 | .99468 | .92951 |
| 47.00 | .64709 | .71836 | .97004 | .99999 | .99438 | .93190 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 48.00 | .65375 | .72993 | .96293 | .99999 | .99409 | .93565 |
| 49.00 | .66331 | .74371 | .95803 | .99999 | .99299 | .93753 |
| 50.00 | .67882 | .76200 | .95614 | .99999 | .99161 | .93959 |
| 51.00 | .69985 | .78445 | .95600 | .99999 | .99094 | .94176 |
| 52.00 | .72418 | .80936 | .95648 | .99999 | .99106 | .94391 |
| 53.00 | .74851 | .83436 | .95685 | .99999 | .99116 | .94594 |
| 54.00 | .76962 | .85722 | .95645 | .99999 | .99044 | .94777 |
| 55.00 | .78574 | .87682 | .95471 | .99999 | .98669 | .94939 |
| 56.00 | .79544 | .89237 | .95083 | .99999 | .98602 | .95077 |
| 57.00 | .79899 | .90427 | .94440 | .99999 | .98285 | .95193 |
| 58.00 | .79686 | .91288 | .93494 | .99999 | .97982 | .95289 |
| 59.00 | .78979 | .91888 | .92235 | .99999 | .97716 | .95367 |
| 60.00 | .77902 | .92298 | .90686 | .99999 | .97529 | .95431 |
| 61.00 | .76490 | .92558 | .88840 | .99999 | .97426 | .95481 |
| 62.00 | .74831 | .92722 | .86764 | .99999 | .97380 | .95520 |
| 63.00 | .72973 | .92820 | .84494 | .99999 | .97379 | .95551 |
| 64.00 | .70928 | .92872 | .82051 | .99999 | .97390 | .95574 |
| 65.00 | .68779 | .92902 | .79529 | .99999 | .97386 | .95591 |
| 66.00 | .66542 | .92917 | .76951 | .99999 | .97346 | .95603 |
| 67.00 | .64248 | .92923 | .74335 | .99999 | .97286 | .95610 |
| 68.00 | .61971 | .92925 | .71751 | .99999 | .97208 | .95616 |
| 69.00 | .59714 | .92927 | .69211 | .99999 | .97100 | .95619 |
| 70.00 | .57520 | .92927 | .66740 | .99999 | .96994 | .95621 |
| 71.00 | .55453 | .92928 | .64387 | .99999 | .96923 | .95623 |
| 72.00 | .53501 | .92928 | .62142 | .99998 | .96886 | .95626 |
| 73.00 | .51659 | .92929 | .60008 | .99998 | .96872 | .95630 |
| 74.00 | .49922 | .92932 | .57999 | .99998 | .96851 | .95635 |
| 75.00 | .48220 | .92935 | .56092 | .99998 | .96720 | .95641 |
| 76.00 | .46506 | .92938 | .54255 | .99998 | .96430 | .95647 |
| 77.00 | .44796 | .92940 | .52481 | .99998 | .96016 | .95653 |
| 78.00 | .43110 | .92943 | .50782 | .99998 | .95484 | .95659 |
| 79.00 | .41493 | .92947 | .49165 | .99997 | .94916 | .95666 |
| 80.00 | .40024 | .92951 | .47617 | .99997 | .94520 | .95674 |
| 81.00 | .38719 | .92956 | .46125 | .99997 | .94385 | .95681 |
| 82.00 | .37495 | .92960 | .44679 | .99996 | .94348 | .95689 |
| 83.00 | .36254 | .92963 | .43273 | .99996 | .94178 | .95696 |
| 84.00 | .34965 | .92966 | .41908 | .99996 | .93779 | .95702 |
| 85.00 | .33672 | .92968 | .40586 | .99996 | .93244 | .95709 |
| 86.00 | .32460 | .92971 | .39308 | .99996 | .92800 | .95715 |
| 87.00 | .31381 | .92973 | .38075 | .99996 | .92614 | .95722 |
| 88.00 | .30389 | .92976 | .36884 | .99996 | .92573 | .95729 |
| 89.00 | .29375 | .92979 | .35732 | .99996 | .92360 | .95735 |
| 90.00 | .28309 | .92981 | .34617 | .99995 | .91868 | .95742 |
| 91.00 | .27283 | .92984 | .33535 | .99995 | .91385 | .95749 |
| 92.00 | .26377 | .92986 | .32485 | .99995 | .91195 | .95756 |
| 93.00 | .25532 | .92988 | .31465 | .99995 | .91128 | .95762 |
| 94.00 | .24648 | .92990 | .30473 | .99995 | .90831 | .95768 |
| 95.00 | .23750 | .92992 | .29508 | .99995 | .90376 | .95774 |
| 96.00 | .22937 | .92993 | .28572 | .99995 | .90133 | .95780 |
| 97.00 | .22192 | .92995 | .27667 | .99995 | .90052 | .95786 |
| 98.00 | .21417 | .92997 | .26793 | .99994 | .89736 | .95793 |
| 99.00 | .20632 | .92999 | .25946 | .99994 | .89258 | .95799 |
| 100.00 | .19929 | .93002 | .25123 | .99993 | .89035 | .95806 |
| 101.00 | .19273 | .93004 | .24322 | .99992 | .88933 | .95812 |
| 102.00 | .18582 | .93006 | .23541 | .99991 | .88580 | .95819 |
| 103.00 | .17910 | .93007 | .22777 | .99991 | .88232 | .95824 |
| 104.00 | .17307 | .93009 | .22038 | .99991 | .88116 | .95830 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 105.00 | .16697 | .93011 | .21325 | .99990 | .87848 | .95837 |
| 106.00 | .16075 | .93013 | .20632 | .99989 | .87411 | .95844 |
| 107.00 | .15514 | .93015 | .19953 | .99989 | .87220 | .95850 |
| 108.00 | .14967 | .93016 | .19290 | .99989 | .87033 | .95855 |
| 109.00 | .14404 | .93018 | .18653 | .99988 | .86609 | .95862 |
| 110.00 | .13888 | .93020 | .18036 | .99987 | .86358 | .95869 |
| 111.00 | .13392 | .93021 | .17427 | .99987 | .86176 | .95875 |
| 112.00 | .12882 | .93022 | .16838 | .99987 | .85790 | .95881 |
| 113.00 | .12414 | .93025 | .16274 | .99986 | .85531 | .95889 |
| 114.00 | .11959 | .93026 | .15717 | .99985 | .85311 | .95896 |
| 115.00 | .11497 | .93027 | .15174 | .99985 | .84938 | .95902 |
| 116.00 | .11074 | .93029 | .14658 | .99984 | .84688 | .95910 |
| 117.00 | .10652 | .93031 | .14145 | .99984 | .84411 | .95917 |
| 118.00 | .10235 | .93032 | .13649 | .99983 | .84044 | .95925 |
| 119.00 | .09850 | .93034 | .13174 | .99983 | .83792 | .95933 |
| 120.00 | .09458 | .93036 | .12704 | .99983 | .83421 | .95941 |
| 121.00 | .09085 | .93038 | .12256 | .99982 | .83049 | .95950 |
| 122.00 | .08727 | .93039 | .11813 | .99982 | .82767 | .95959 |
| 123.00 | .08367 | .93041 | .11386 | .99981 | .82314 | .95968 |
| 124.00 | .08032 | .93043 | .10969 | .99981 | .82014 | .95977 |
| 125.00 | .07695 | .93045 | .10564 | .99980 | .81581 | .95986 |
| 126.00 | .07372 | .93047 | .10173 | .99980 | .81145 | .95997 |
| 127.00 | .07062 | .93049 | .09794 | .99980 | .80732 | .96008 |
| 128.00 | .06753 | .93051 | .09427 | .99979 | .80192 | .96019 |
| 129.00 | .06463 | .93053 | .09071 | .99979 | .79747 | .96031 |
| 130.00 | .06173 | .93055 | .08722 | .99979 | .79211 | .96043 |
| 131.00 | .05897 | .93057 | .08385 | .99978 | .78698 | .96056 |
| 132.00 | .05629 | .93059 | .08057 | .99978 | .78172 | .96069 |
| 133.00 | .05364 | .93068 | .07787 | .99977 | .77039 | .96094 |
| 134.00 | .05174 | .93087 | .07588 | .99977 | .76214 | .96138 |
| 135.00 | .04963 | .93107 | .07384 | .99974 | .75075 | .96179 |
| 136.00 | .04642 | .93129 | .07195 | .99972 | .72008 | .96225 |
| 137.00 | .04369 | .93154 | .07028 | .99971 | .69339 | .96276 |
| 138.00 | .04239 | .93182 | .06873 | .99971 | .68728 | .96330 |
| 139.00 | .04118 | .93210 | .06712 | .99969 | .68314 | .96383 |
| 140.00 | .03894 | .93241 | .06545 | .99961 | .66193 | .96434 |
| 141.00 | .03588 | .93268 | .06384 | .99959 | .62480 | .96487 |
| 142.00 | .03280 | .93293 | .06221 | .99958 | .58564 | .96540 |
| 143.00 | .03025 | .93320 | .06053 | .99954 | .55469 | .96591 |
| 144.00 | .02826 | .93344 | .05886 | .99952 | .53253 | .96643 |
| 145.00 | .02671 | .93361 | .05691 | .99951 | .52011 | .96687 |
| 146.00 | .02534 | .93376 | .05490 | .99950 | .51120 | .96729 |
| 147.00 | .02406 | .93397 | .05317 | .99949 | .50084 | .96780 |
| 148.00 | .02267 | .93434 | .05203 | .99948 | .48186 | .96849 |
| 149.00 | .02116 | .93475 | .05095 | .99947 | .45874 | .96920 |
| 150.00 | .01960 | .93554 | .05074 | .99945 | .42582 | .97019 |
| 151.00 | .01805 | .93645 | .05075 | .99944 | .39129 | .97123 |
| 152.00 | .01661 | .93739 | .05077 | .99943 | .35922 | .97228 |
| 153.00 | .01544 | .93890 | .05178 | .99941 | .32630 | .97358 |
| 154.00 | .01447 | .93988 | .05171 | .99940 | .30578 | .97458 |
| 155.00 | .01344 | .94112 | .05205 | .99938 | .28134 | .97568 |
| 156.00 | .01225 | .94329 | .05386 | .99937 | .24688 | .97710 |
| 157.00 | .01119 | .94464 | .05415 | .99936 | .22387 | .97815 |
| 158.00 | .01034 | .94524 | .05272 | .99935 | .21217 | .97884 |
| 159.00 | .00937 | .94658 | .05287 | .99934 | .19123 | .97987 |
| 160.00 | .00843 | .95014 | .05623 | .99934 | .16090 | .98145 |
| 161.00 | .00761 | .95599 | .06200 | .99934 | .13071 | .98328 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 162.00 | .00683 | .96345 | .06925 | .99935 | .10396 | .98508 |
| 163.00 | .00608 | .97174 | .07719 | .99935 | .08216 | .98672 |
| 164.00 | .00540 | .97925 | .08410 | .99935 | .06646 | .98807 |
| 165.00 | .00473 | .98472 | .08815 | .99936 | .05515 | .98912 |
| 166.00 | .00412 | .98816 | .08855 | .99936 | .04757 | .98989 |
| 167.00 | .00357 | .99012 | .08546 | .99936 | .04258 | .99046 |
| 168.00 | .00301 | .99176 | .08132 | .99936 | .03766 | .99098 |
| 169.00 | .00255 | .99368 | .07762 | .99936 | .03337 | .99155 |
| 170.00 | .00210 | .99555 | .07341 | .99935 | .02900 | .99211 |
| 171.00 | .00168 | .99662 | .06636 | .99935 | .02568 | .99254 |
| 172.00 | .00135 | .99683 | .05511 | .99935 | .02468 | .99273 |
| 173.00 | .00104 | .99693 | .04407 | .99935 | .02377 | .99289 |
| 174.00 | .00075 | .99751 | .03692 | .99935 | .02063 | .99334 |
| 175.00 | .00052 | .99856 | .03164 | .99935 | .01652 | .99401 |
| 176.00 | .00033 | .99896 | .02330 | .99935 | .01430 | .99442 |
| 177.00 | .00019 | .99936 | .01621 | .99935 | .01157 | .99498 |
| 178.00 | .00009 | .99985 | .00996 | .99935 | .00861 | .99573 |
| 179.00 | .00002 | .99494 | .00328 | .99935 | .00599 | .99628 |
| 180.00 | .00000 | 1.00018 | .00000 | .99935 | .00000 | .99996 |

TOTAL RADIATED POWER .730696-04 WATTS
RESULTANT PHASE ANGLE -2.706 DEGREES
GAIN 9.654 DB


NASA — JPL — Coml., L.A., Calif.