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AN EVALUATION OF SELECTED SATELLITE COMMUNICATION SYSTEMS AS SOURCES OF ENVIRONMENTAL MICROWAVE RADIATION

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

An Evaluation of Selected Satellite Communication Systems as Sources of Environmental Microwave Radiation

By

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W. D. Rowe, Ph.D.
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ABSTRACT

Selected satellite communication (SATCOM) systems are evaluated analytically and, for some of these systems, through measurement of the microwave radiation power densities generated by them. The evaluation is directed toward assessing the radiation exposure hazards which exist for specific systems and generally for SATCOM systems as a class of high power nonionizing radiation source. The paper includes determinations of anticipated maximum power density levels as functions of distance from the source, a description of the analytical method used, and the results of measurements of the power densities produced by certain SATCOM systems. Included also is a discussion of potential hazard analysis and its uses in identifying systems which may constitute environmental hazards.

AN EVALUATION OF SELECTED SATELLITE COMMUNICATION SYSTEMS AS SOURCES OF ENVIRONMENTAL MICROWAVE RADIATION

Section 1 - Introduction

Background

The U.S. Environmental Protection Agency supports a field operations group to obtain data on the levels of existing environmental radiation, to determine any change in the radiological quality of the environment, to identify sources of radiation and their contributions to environmental levels, to provide data for estimating population exposure to ionizing and nonionizing radiation, and to determine if environmental radiation levels are within established guidelines and standards. This report evaluates some selected satellite communication systems, a category of microwave emitting source with the potential for significant environmental exposure. This evaluation and others concerning specific source types and the general ambient environment will be used together with the results of biological effects studies to determine the need to establish guidelines for environmental exposure to nonionizing radiation.

Measurement Objectives

Satellite communication systems, evaluated on the basis of effective isotropic radiated power, are the most powerful continuous wave (CW) sources of environmental microwave radiation. The determination, by measurement, of the environmental radiation levels generated by certain of these sources has several different objectives, the primary ones being:

(1) to determine actual environmental radiation levels (power density) as a function of distance from the system antenna,

(2) to determine the applicability of a model, using known system characteristics in predicting power density as a function of distance from the source, by comparing measured and predicted levels, and

(3) to evaluate the potential of a source to produce hazardous environmental radiation levels.

Other important objectives may be realized through use of the results of the measurements performed, i.e., (1) identification of other factors which may be involved in affecting the sources contributions to environmental levels, e.g., the procedures used in system operation, system power losses which occur before power is introduced into the antenna system, and the effect of reflections from structures on power density levels in the environment; (2) determination of the most significant criteria which can be used to identify sources having the potential for creating significant radiation levels, and to rank these sources relative to each other; and (3) evaluation of the contents of the source inventory used to identify sources which may be involved in an environmental situation under investigation, or have the potential for significant contribution to environmental radiation levels.

Section 2 - Satellite Communication System Earth Terminals

General Description

Satellite communication system earth terminals, as a source type, have the greatest potential for creating hazardous environmental situations in that significant power densities may exist at greater distances from the antenna than would be possible for other types of radiating systems. They have the potential for irradiating a particular region of the environment for long periods of time while tracking satellites in various earth orbits out to geostationary (synchronous) orbits at a height of 22,300 miles above earth.

The antenna diameter and maximum transmitter power are characteristics of particular interest from an environmental aspect. The need to transmit power over large distances determines the transmitter power to be used with an antenna whose diameter has been determined usually on the basis of reception requirements. Generally, as systems are required to provide high data transmission rates at increasing distances, the earth terminal transmitter power and antenna diameter increase. It is the combination of high transmitter power and antenna diameter that is responsible for producing a region of significant power density which may extend over very large distances.

Source Identification

Characterization of the environment, either analytically or through measurement, requires identification of the radiating sources which contribute to that environment. These sources must be identified in order to determine how many there are, where they are, and how they may affect the environment. In addition it is desirable to rank the sources to determine their potential relative environmental importance. Sources were identified for EPA through the use of a computerized inventory of sources operated by the Electromagnetic Compatibility Analysis Center (ECAC) located in Annapolis, Maryland.

The ECAC data base contains an inventory of transmitting sources and their characteristics, and includes all U.S. equipment, both military and civilian, common carrier microwave equipment, and all FCC licensed equipment except for amateur and citizens bands. The sorting criterion, used in the search of the inventory, was effective isotropic radiated power (EIRP).* This system characteristic is the product of the antenna gain and the transmitter power. The sources of interest include both non-pulsed (CW) systems and pulsed (radar) systems. Computer listings of unclassified sources were derived for both source categories (1). The CW sources were ranked in the order of decreasing EIRP. The listing includes all CW sources whose EIRP is greater than or equal to 1 megawatt (10^6 watts). Other source characteristics resident in the ECAC data files were included in the computer printout in order to provide additional information on the characteristics of these systems. Twenty of the most powerful CW systems identified are listed in table 1 (2). They are all satellite communication earth terminals. On the basis of these results, selected systems in the category of satellite communication earth terminals were studied, analytically and through measurement.

Since the date of the inventory sort yielding the results of table 1 (July 1972) other powerful sources have been constructed and are now in operation. A search of the current ECAC source inventory would result in a rearrangement of the source ranking presented in table 1, and include several sources which did not previously exist. One of the new sources which would

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*Effective isotropic radiated power is defined as the hypothetical total power which a non-isotropic source of EM radiation would be required to radiate isotropically (assuming it to be a point source of radiation) so that the power radiated per unit solid angle would be the same as that actually radiated. EIRP is obtained by multiplying the power radiated by a source by its antenna gain characteristic, gain being a measure of the antenna's directivity, or concentration of radiation, and ideally equivalent to the ratio of 4π to the solid angle subtended at the source by its collimated beam.

Table 1

Ranking of Sources by EIRP

Rank	Location	Frequency (MHz)	Use	Average EIRP (GW)
1	Westford, MA	7748	Satellite Communication	31.6
2	Lakehurst, NJ	8004	"	20.0
3	Roberts, CA	7985	"	20.0
4	Rosman, NC	5925	"	11.3
5	Paumalu, HI	5925	"	7.9
6	Jamesburg, CA	5925	"	7.9
7	Etam, WV	5925	"	7.9
8	Brewster, WA	5925	"	7.9
9	Andover, ME	5925	"	7.9
10	Bartlett, AK	5925	"	7.9
11	Archer City, TX	217	"	6.4
12	Mojave Desert, CA	5985	"	6.4
13	Pt. Loma, CA	7997	"	5.0
14	Helemano, HI	7990	"	5.0
15	Ft. Monmouth, NJ	7990	"	5.0
16	Brandywine, MD	7986	"	5.0
17	Camp Parks, CA	7990	"	5.0
18	Wildwood, AK	7986	"	5.0
19	Floyd Test Annex, NY	7986	"	5.0
20	Elgin, IL	8004	"	5.0

144 CW unclassified sources have average EIRP's of 1 MW or greater.

Of 79 nonpulsed, classified emitters, none had an EIRP greater than 5.0 GW.

be included was the subject of a measurement and evaluation discussed in this paper. In addition, several other sources have become operable, and the transmission characteristics for the Mars and Venus communication systems at Goldstone, California are presented in another section of this paper.

The initial selection of effective isotropic radiated power as the criterion used in identifying and ranking sources resulted because EIRP is a characteristic commonly used in describing the power radiating capability of an antenna and transmitter system. The system characteristics used in calculating EIRP; i.e., antenna gain and transmitter power, are entered directly into the ECAC data inventory.

These systems, identified on the basis of selection by EIRP, have a functional requirement to communicate with earth orbiting satellites and possess a capability to produce significant radiation levels at great distances. This illustrates, at least qualitatively, a degree of applicability of EIRP in identifying categories of sources potentially capable of producing the most hazardous exposure situations; i.e., existence of relatively high power density at considerable distances from the source.

Therefore, if it is desired to perform measurements relating directly to high power CW sources with the greatest potential for creating hazardous environmental situations, satellite communication systems provided the logical first choice for evaluation.

Antenna Characteristics

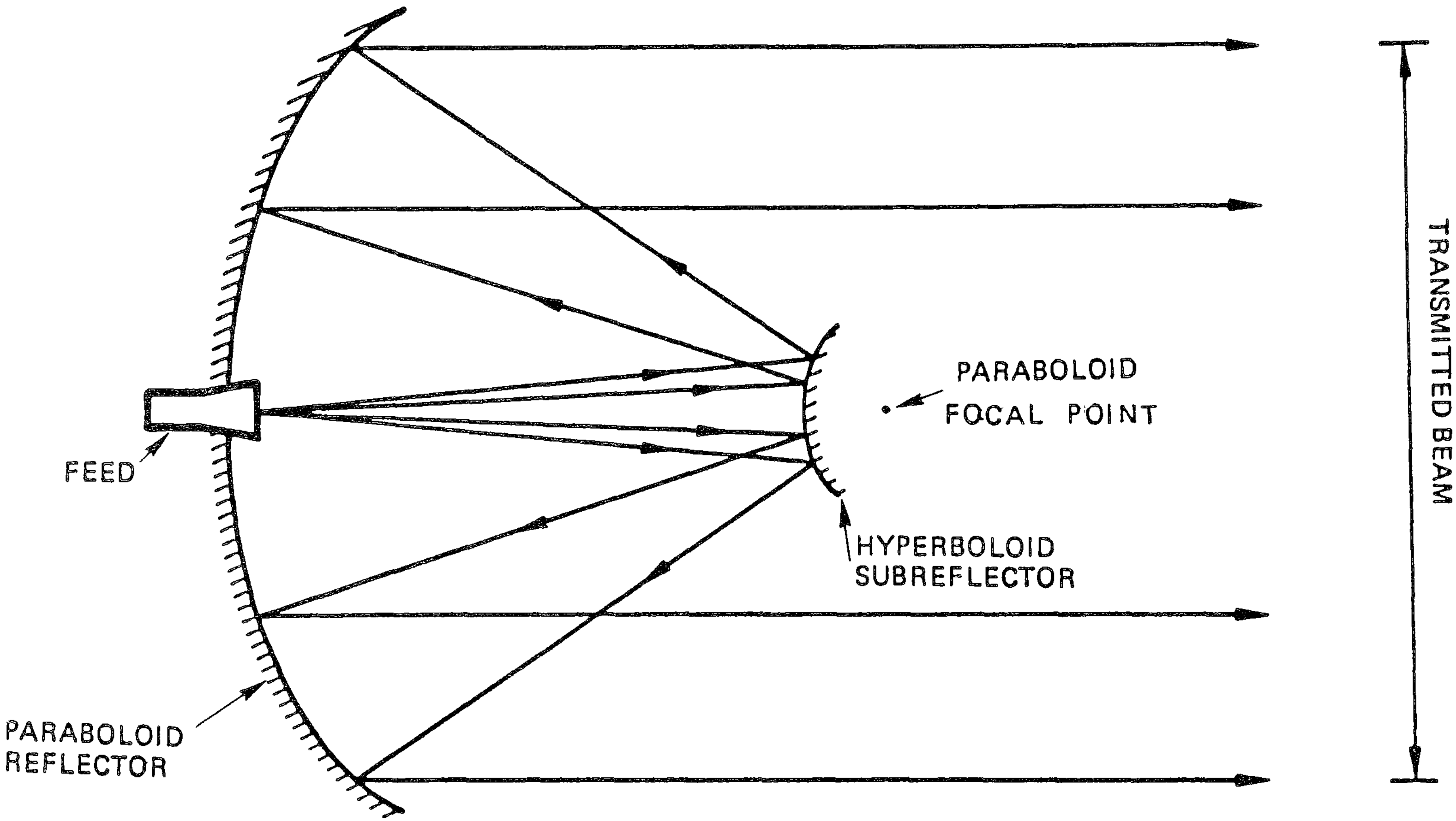
The satellite communication systems which are studied analytically and by measurement, and most of the systems listed in table 1, have paraboloidal antennas with a Cassegrain design. In the Cassegrain geometry, power is introduced to the antenna from the primary radiating source (power feed) located at the vertex of the paraboloidal reflector. The radiation is incident on a small hyperboloidal subreflector located between the vertex and the focus of the antenna (figure 1). Radiation from the power feed is reflected from the subreflector, illuminates the main reflector as if it had originated at the focus, and is then collimated.

The Cassegrain antenna has advantages relative to a system which has the power input at the focus; i.e., the very low-noise microwave receiving preamplifier and the transmitter power amplifier are located immediately behind the antenna resulting in lower transmission line loss and noise which may interfere with the reception of transmissions from satellites which operate at much lower transmitter powers than the earth situated systems. In addition, spillover radiation from the power source is directed toward space resulting in a lower antenna noise temperature.

The systems which have been studied all transmit and receive circularly polarized microwave radiation. The polarization generally is right-hand for transmission and left-hand for reception.

Use of a Model in the Calculation of Satellite Communication Earth Terminal Characteristics

An empirical model was selected which allows the characteristics of satellite communication (SATCOM) earth terminals to be calculated for use in evaluations of hazards (3). This model applies to antennas (reflectors) that are circular cross section paraboloids, a characteristic of almost all large SATCOM systems, and calculates the on-axis power density at any distance from the antenna as a function of antenna diameter, radiation wavelength, and transmitter power.



Geometric Relationship Between Antenna Feed, Subreflector, and Main Reflector in a Conventional Cassegrain Design

Figure 1 Cassegrain Antenna

The on-axis radiation field characteristics for circular cross-section paraboloidal antennas can be described using figure 2.* The maximum value of power density at any given distance from the antenna exists on the antenna axis. In the near field of an antenna the magnitude of the power density oscillates with distance, however, the maximum value of the on-axis power density, W_{nf}, is constant over the extent of the near field, and the beam is collimated so that most of the power is contained in a region having approximately the diameter of the reflector.

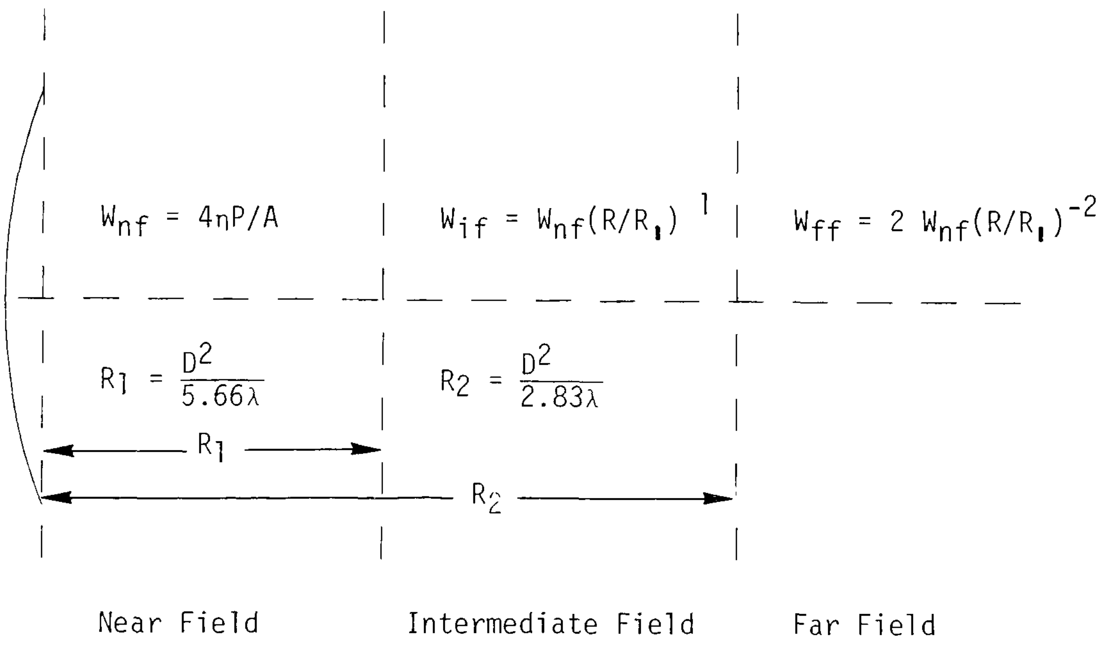


Figure 2 Radiation Zones for Paraboloidal Reflectors

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*The model used in defining the extent of the various regions and the magnitudes of the on-axis power density which exist in these regions were developed by the U.S. Army Environmental Hygiene Agency (3).

The value of the maximum on-axis near field power density, W_{nf}, is given by eq.(1):

$$W_{nf} = \frac{4\eta P}{A} \qquad (1)$$

where

P = total power radiated by the power feed

A = cross sectional area of antenna

η = antenna efficiency

The efficiency of the antenna (4) is the ratio of the power radiated into the main beam to the total power fed into the antenna system, and is the product of two factors:

1) the fraction of the total feed power incident on the reflector
2) the efficiency of the reflector in concentrating the available energy into the peak of the main beam.

The efficiencies of circular paraboloidal antennas in concentrating the available energy into the peak of the main beam typically range from 0.50 to 0.75 depending upon the method used in irradiating the hyperboloidal subreflector.

The maximum on-axis near field power density for a circular paraboloidal antenna expressed in terms of antenna diameter, D, using eq.(1) and $A = \frac{\pi D^2}{4}$, is

$$W_{nf} = \frac{16\eta P}{\pi D^2} \qquad (2)$$

An important characteristic of high power sources, in addition to the maximum power density which can be generated, is the extent of the near field; i.e., the distance from the antenna over which the power density can be a maximum before it begins to decrease with distance. This parameter and the maximum power density in the near field determine the value of the on-axis power density at any distance from the antenna. The extent of the near field, R_1, is given as eq. (3).

$$R_1 = \frac{D^2}{5.66\lambda} \tag{3}$$

where λ is the wavelength of the transmitted radiation and is expressed in the same units as the antenna diameter.

The far field of the antenna is the region in which the beam diverges and the power density in the far field decreases inversely as the square of the distance from the antenna. The far field on-axis power density, W_{ff}, can be expressed relative to W_{nf} by

$$\frac{W_{ff}}{W_{nf}} = 2\left(\frac{R}{R_1}\right)^{-2} \quad ; \; R \geq 2R_1 \tag{4}$$

where the distance from the antenna, R, must be at least as great as $2R_1$.

The intermediate field region is a transition region between the near and far fields in which the power density decreases inversely with distance. The transition from one region to another is continuous, and this is taken into account in the model; the on-axis power density, in each region, being equal at the "transition boundary." The on-axis power density in the intermediate field, W_{if}, can be expressed as

$$\frac{W_{if}}{W_{nf}} = \left(\frac{R}{R_1}\right)^{-1}; \; R_1 \leq R \leq 2R_1 \tag{5}$$

where R, the distance from the antenna, lies in the interval between the end of the near field region and the beginning of the far field region.

The on-axis radiation field characteristics which have been described were determined empirically (3) and yield the maximum power density, as a function of distance, of which the system may be capable. This constitutes an assessment of the potential of the source for creation of a hazardous exposure situation.

A frequent occurrence in evaluating the potential hazard situation created by a specific source, is the lack of information regarding antenna diameter and efficiency. However, if another characteristic, antenna gain, is available, and the antenna is known to be a circular paraboloid, the antenna diameter may be approximated assuming η to be 0.50. The antenna gain is a measure of the directivity (collimation) of a reflector as compared to an isotropic radiator and may be expressed (4) as

$$G = \frac{4\pi A_e}{\lambda^2} \qquad (6)$$

where A_e is the effective area of the antenna.

For the specific case of a circular paraboloidal reflector the expression for aperture gain becomes

$$G = \eta\left(\frac{\pi D}{\lambda}\right)^2 \qquad (7)$$

The gain is generally expressed in dB, and is then defined

$$G = 10 \log \left[\eta\left(\frac{\pi D}{\lambda}\right)^2\right] \qquad (8)$$

The effective isotropic radiated power (EIRP), previously described as the basis for the identification of sources in the order of decreasing potential hazard from the ECAC inventory, is commonly used also in describing satellite communication earth terminals. The value is related to the antenna gain and radiated power capability of the system by

$$EIRP = G \cdot P \qquad (9)$$

where P = maximum power capability of the system, including losses of power which occur before power is fed into the antenna, and the value used for G is the absolute gain.

A simple computer program has been written which calculates the various pertinent characteristics for circular paraboloidal antennas and plots these characteristics on a cathode ray tube (CRT). The display may represent characteristics for one or several antenna diameters. A printout of the numerical values of the characteristics may also be obtained on a CRT display or in a teletype printout.

The calculations performed include: (1) gain (dB) as a function of wavelength for various antenna diameters and for any specified antenna efficiency (using eq. 7), (2) the extent of the near field region as a function of wavelength for various antenna diameters (eq. 3), (3) the maximum (on-axis) near field power density as a function of antenna diameter for 1 kW of transmitter power for any specified antenna efficiency (from eq. 2), (4) a dimensionless presentation of the ratio of the far field on-axis power density to the near field on-axis power density as a function of the ratio of the distance from the antenna to the extent of the near field (eq. 4), and (5) a dimensionless plot of the on-axis intermediate field power density to the on-axis near field power density as a function of the ratio of the distance from the antenna to the extent of the near field (eq. 5). The latter two curves allow rapid predictions of on-axis power density during measurements at locations in the far and intermediate fields.

Displays of these characteristics, generated by a Varian ADAPTS minicomputer system, are presented in figures 3 to 8. An example of a listing of characteristics displayed on the CRT is shown in table 2. Characteristics can be displayed for paraboloidal systems over a range of diameters of 1 to 200 feet and a wavelength range of 1 to 60 cm.

These mathematical expressions and the resulting graphical displays characterize the pertinent characteristics and generally describe the on-axis power density as a function of distance in terms of the near field on-axis maximum power density and the near field extent for antennas used in satellite communication system earth terminals.

Section 3 - Satellite Communication System Measurements

System Description

Measurements were made of environmental power densities produced by three high power, large diameter, satellite communication earth terminals located at Fort Monmouth, New Jersey and Fort Detrick, Maryland. An invitation extended by the U.S. Army Environmental Hygiene Agency to join them in hazards evaluation studies at these locations provided the opportunity to study the radiation characteristics of the satellite communication systems located there. These systems were operated in accordance with directions furnished by the personnel performing the measurements in order to evaluate them with respect to their potential hazards; the systems were not operated under normal operational procedures.

The systems studied were the AN/TSC-54 and the Lincoln Experimental Terminal, both located at Fort Monmouth, and the AN/MSC-60 located at Fort Detrick. The characteristics for these systems are summarized in table 3.

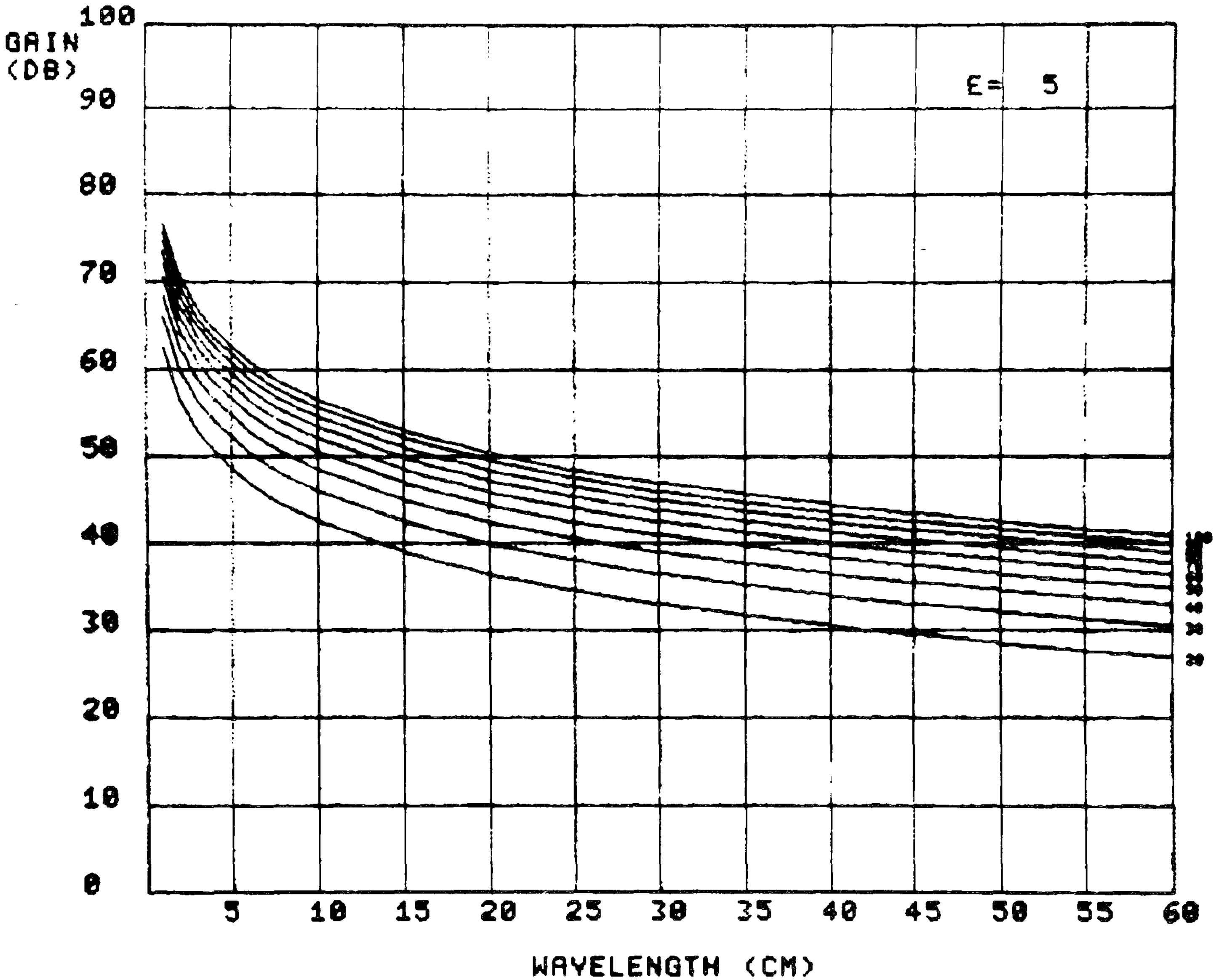


Figure 3 Antenna Gain vs. Wavelength

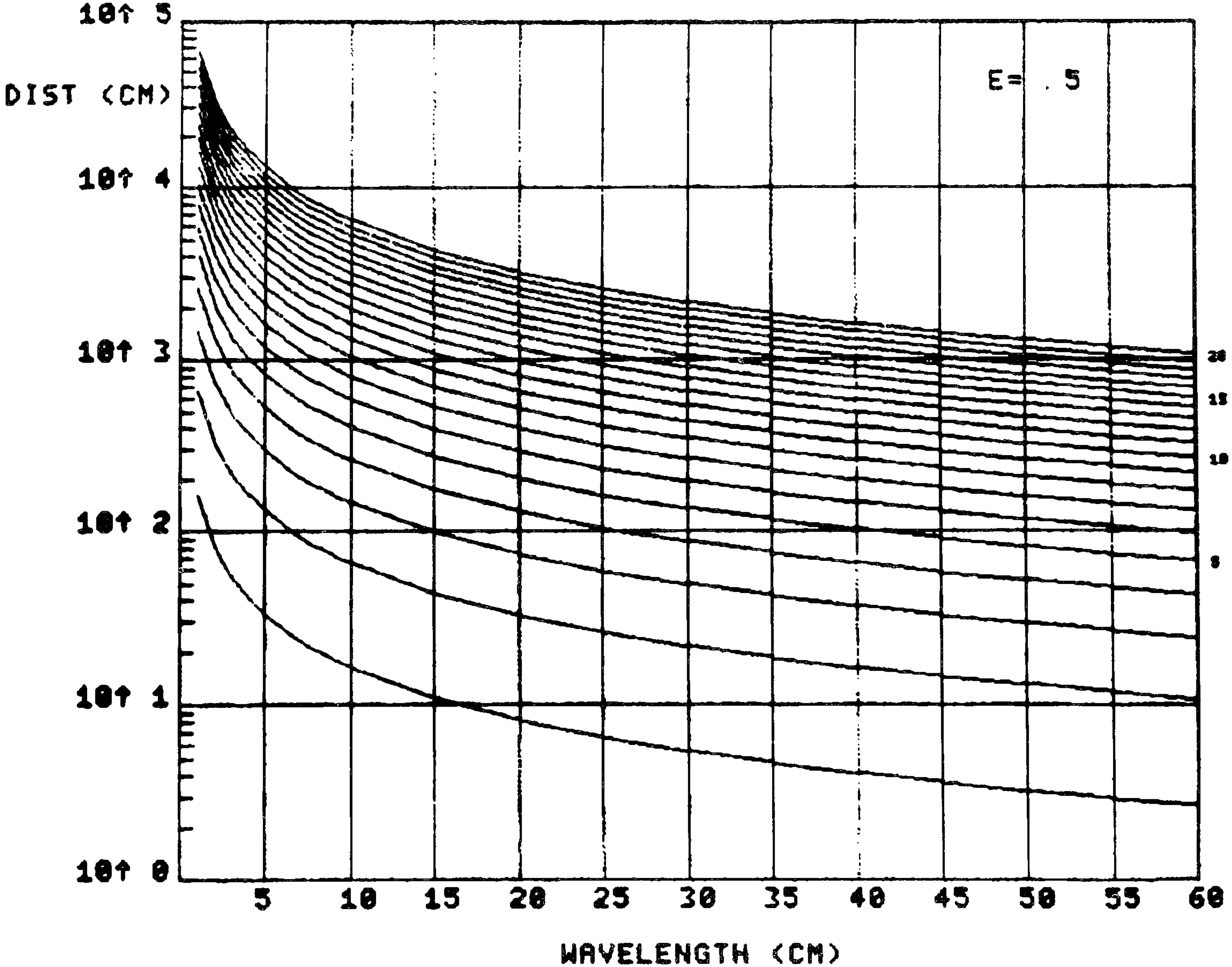


Figure 4 Near Field Extent vs. Wavelength

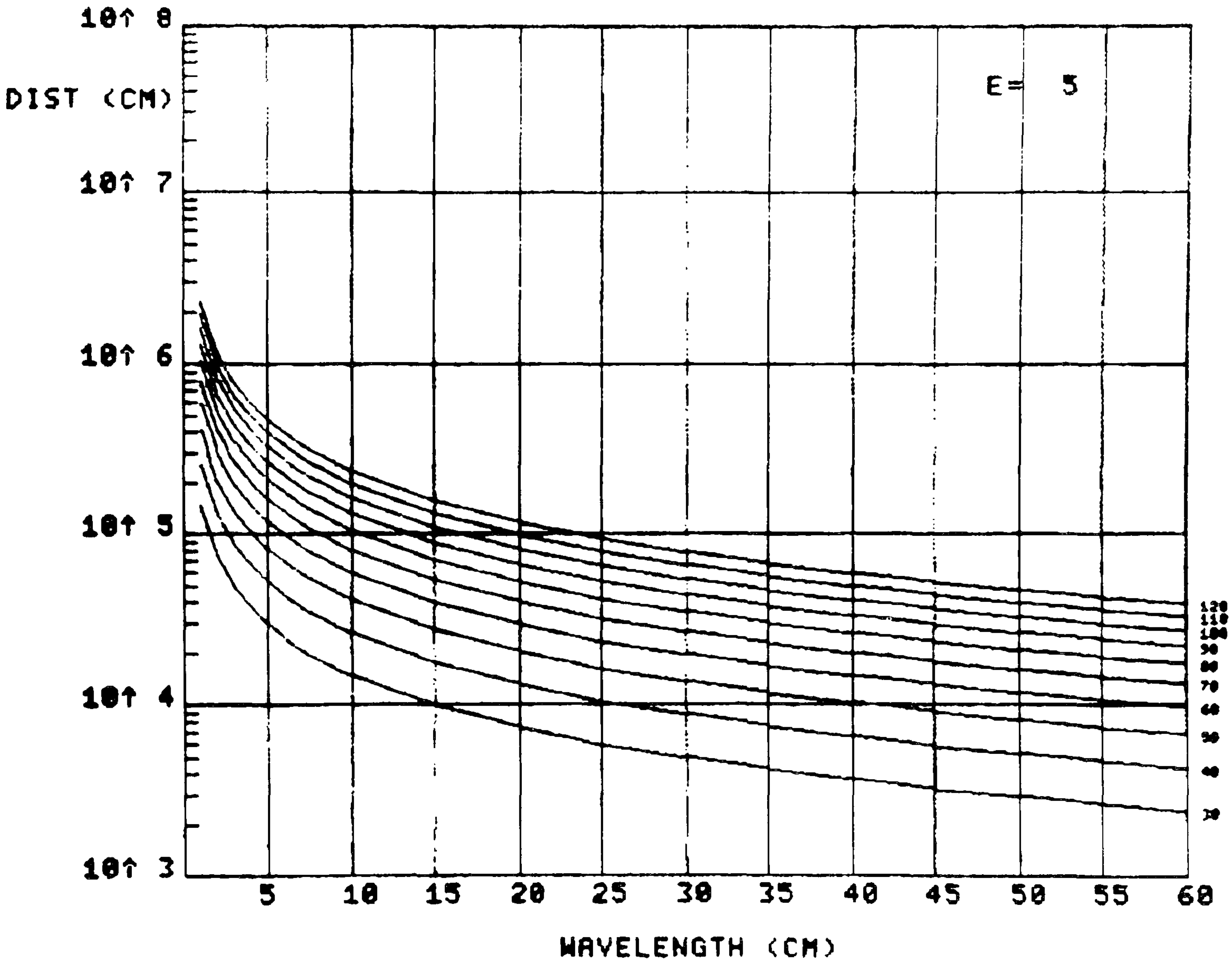


Figure 5 Near Field Extent vs. Wavelength

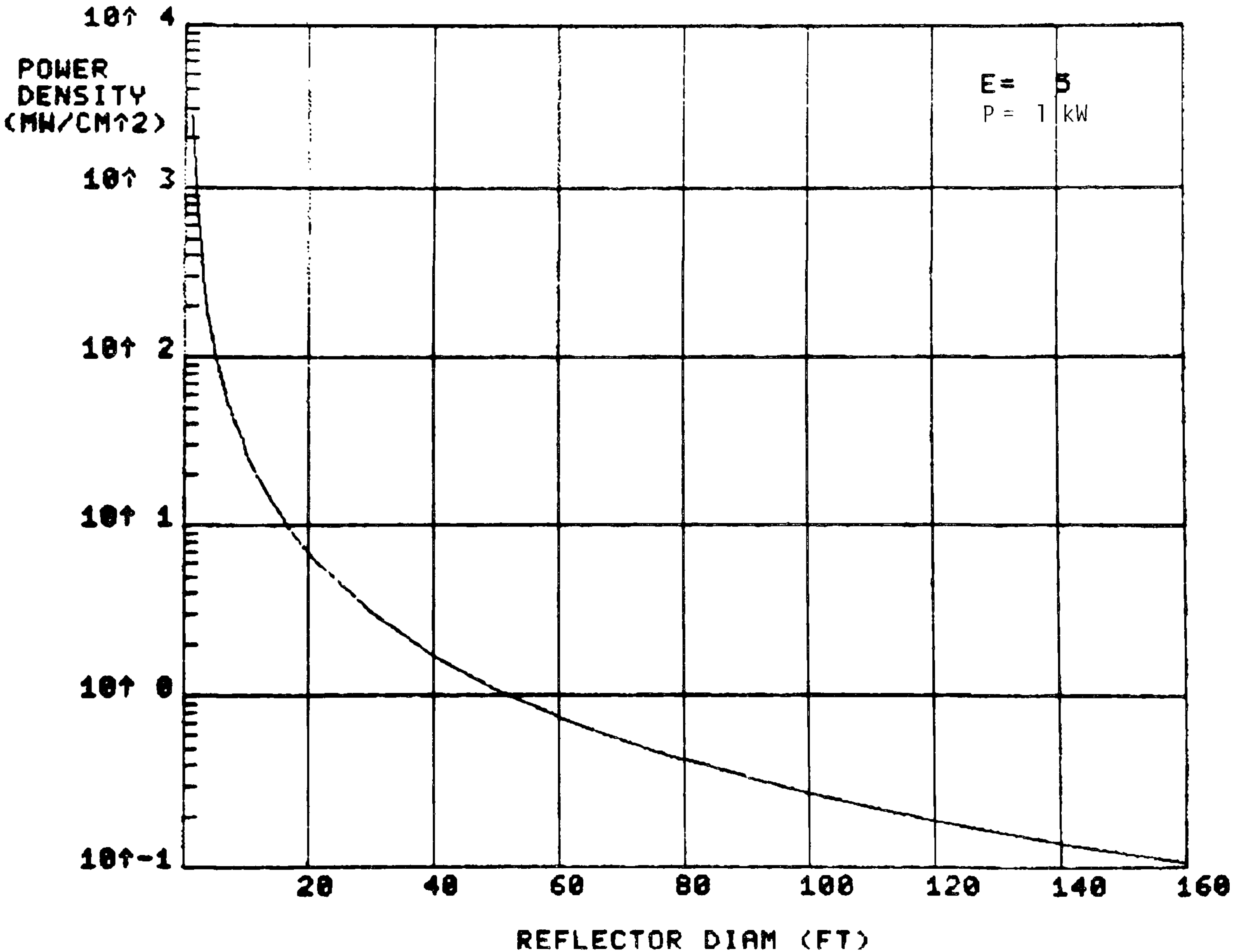


Figure 6 On-Axis Near Field Power Density vs. Antenna Diameter

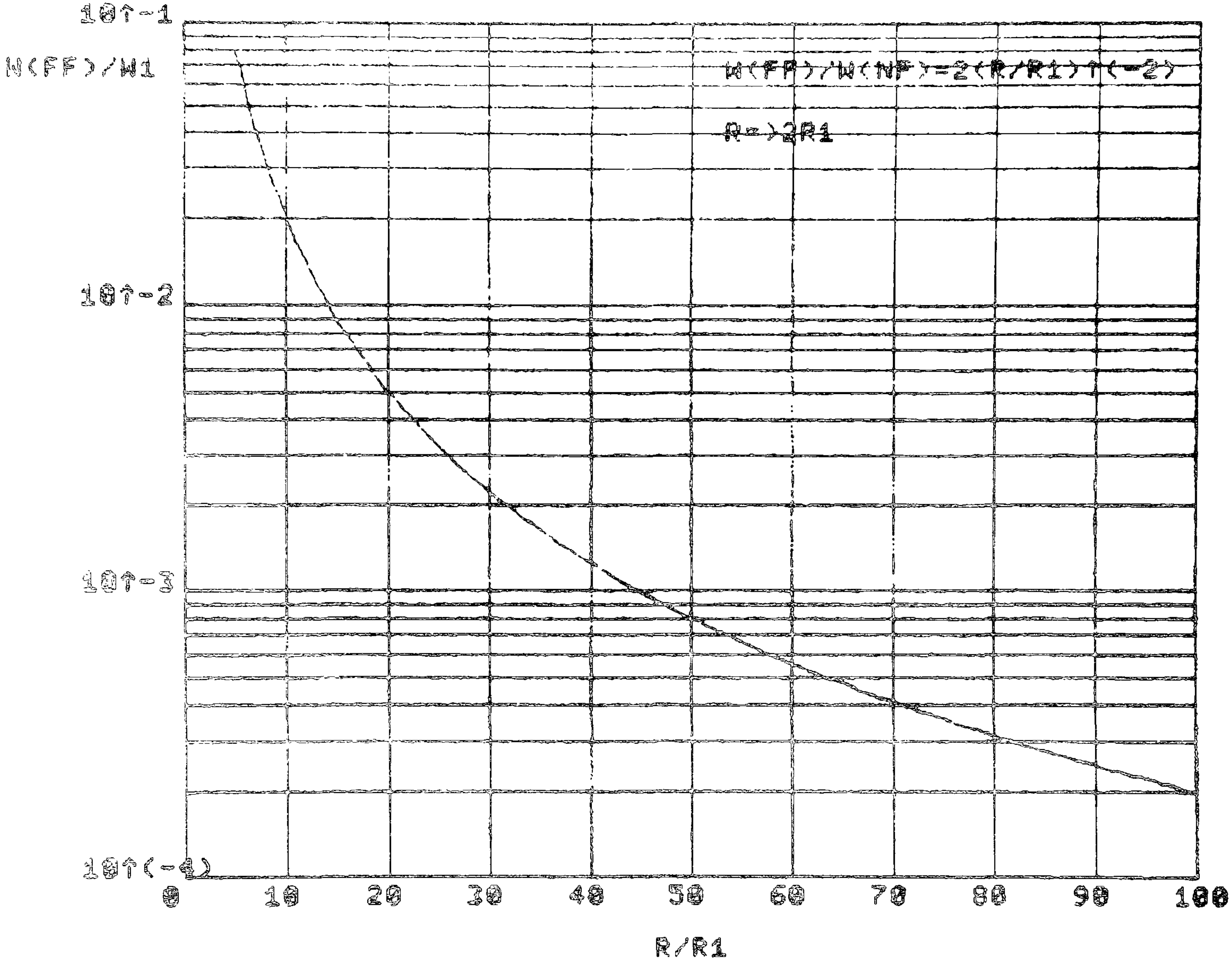


Figure 7 Far Field Power Density/On-Axis Near Field Power Density vs. Distance from Antenna/Near Field Extent

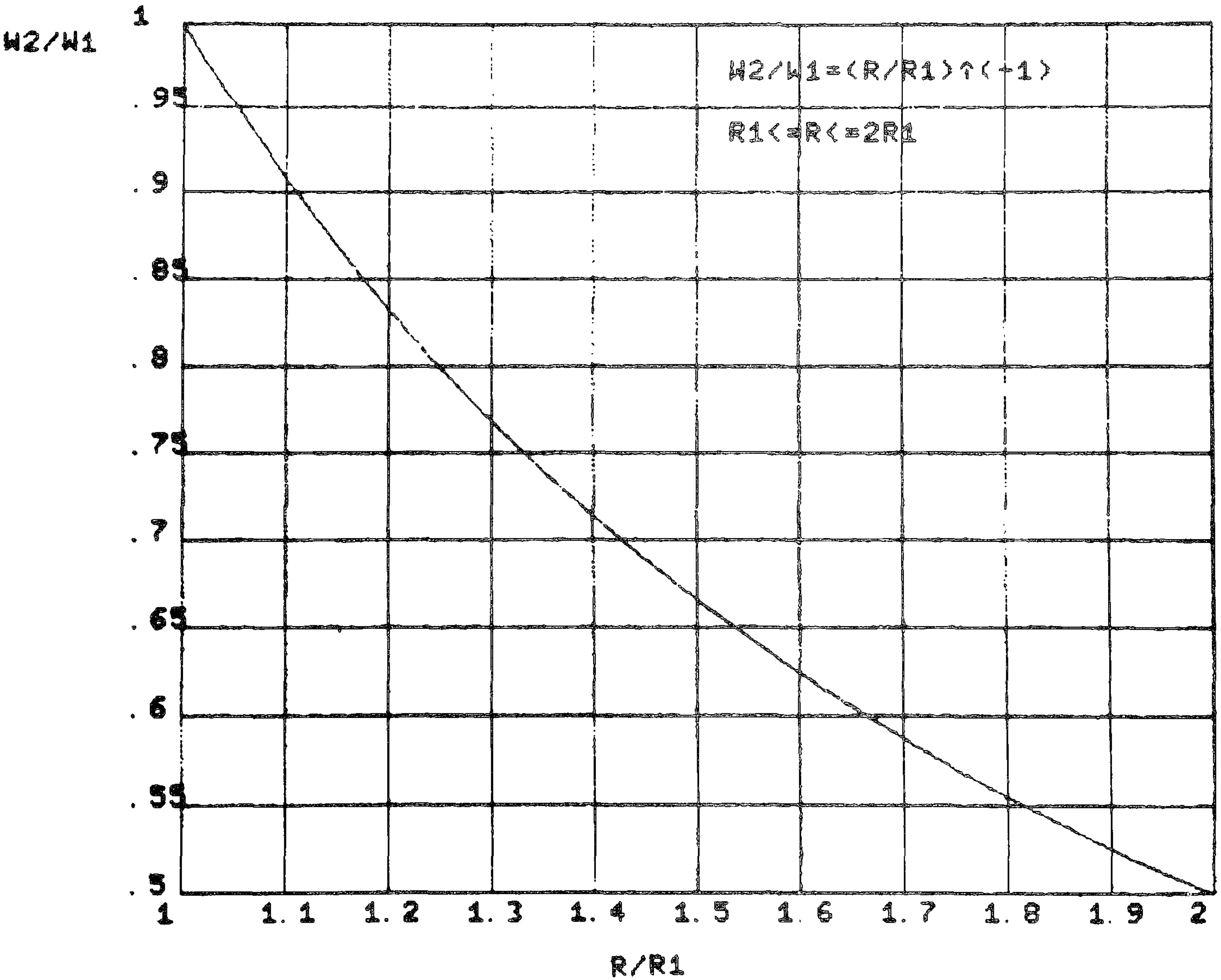


Figure 8 Intermediate Field Power Density/On-Axis Near Field Power Density vs. Distance from Antenna/Near Field Extent

Table 2

Paraboloidal Antenna Characteristics

DIAM(FT)	WAVELENGTH(CM)	GAIN(DB)	R1(CM)	W1(MW/CM↑2)
60				761372
	1	72.1769	590902	
	2	66.1562	295451	
	3	62.6343	196967	
	4	60.1356	147725	
	5	58.1974	118180	
	6	56.6137	98483.8	
	7	55.2747	84414.7	
	8	54.1149	73862.7	
	9	53.0918	65655.8	
	10	52.1766	59090.2	
	15	48.6548	39393.4	
	20	46.1559	29545.1	
	25	44.2177	23636.1	
	30	42.6341	19696.7	
	35	41.2951	16882.9	
	40	40.1353	14772.5	
	45	39.1122	13131.1	
	50	38.197	11818	
	55	37.3692	10743.6	
	60	36.6134	9848.36	

E= .5

The AN/TSC-54 comprises items 28 through 33 in the ECAC identification (1) of the most powerful CW sources, ranked on the basis of decreasing EIRP. The LET studied at Ft. Monmouth, an earth terminal used to communicate with an experimental communication satellite developed by the Lincoln Laboratories, was not identified in the ECAC source listings.

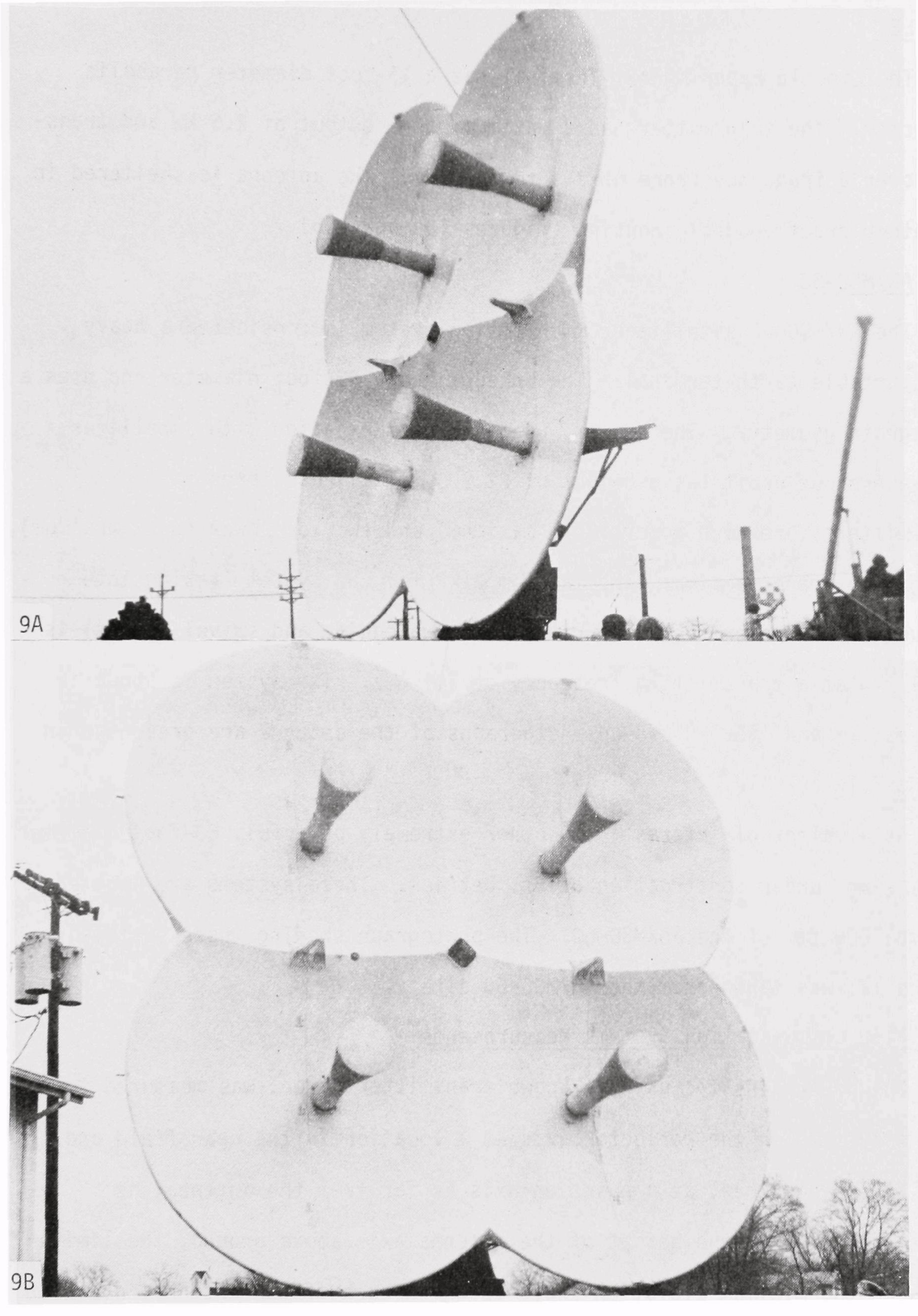
The system studied at Ft. Detrick, Maryland, the AN/MSC-60, had recently been constructed, was in the system calibration stage, and was not yet considered operational. Its EIRP, 5.0×10^9 W, makes it one of the most powerful in the U.S. with respect to EIRP (refer to table 1).

A system located at Ft. Monmouth, an AN/MSC-46, is listed in table 1 among the systems having the highest EIRP values. In fact, the systems numbered 13 through 20 are all examples of an AN/MSC-46 satellite communication system. It was one of the systems to be studied, but unfortunately was not operational at that time.

AN/TSC-54

The AN/TSC-54 satellite communication terminal is a part of the Defense Satellite Communication System. The system is transportable by air or vehicle, and provides the capability for tracking a near synchronous orbit communications satellite and for transmitting voice and teletypewriter communications through satellites to other communication facilities. It transmits in the frequency range from 7.9 to 8.4 GHz, and receives satellite transmission in the 7.25-7.75 GHz range.

The antenna consists of an array of four 10-foot diameter parabolic reflectors, each having a special high efficiency power feed in a Cassegrain geometry. Figures 9a and 9b are photographs of the antenna. The overall reflective surface area is approximately equal to that of a single 18-foot diameter reflector.



Figures 9A and 9B AN/TSC-54 Antenna Array

LET

The Lincoln Experimental Terminal has a 15-foot diameter parabolic reflector. The transmitter has a maximum power output of 2.5 kW and transmits over a frequency range of 7.9 to 8.4 GHz. The antenna is sheltered in a weather-proof geodesic housing (figures 10a and 10b).

AN/MSC-60

The AN/MSC-60 satellite communication system is considered a heavy transportable earth terminal. The antenna has a 60 foot diameter and uses a Cassegrain geometry. The system, used for communication with satellites in synchronous orbit (at a height of 22,300 miles), has three transmitters, one high power (8 kW maximum) and two low power (3 kW maximum), using only one at a time. The maximum EIRP for the system (taking into account a 3 dB power loss occurring in the waveguide and swivel joints) is 5.0×10^9 W at a transmitting frequency of 7.9 GHz. The system is shown in figures 11a and 11b. Close-up photographs of the antenna are presented in figures 11c and 11d.

As a matter of interest, two other extremely powerful, 60-foot diameter systems are under construction at Ft. Detrick. These systems are located within 1000 ft. of the AN/MSC-60. The photograph showing these systems, figure 12, was taken from the AN/MSC-60 site.

Satellite Communication Systems Measurements

The power density, using a known transmitter power, was measured for each of the systems on the reflector axis at a location in the near field and also, where possible, at a point on-axis as far from the antenna, as practical. Due to the height of the antenna axis above ground, the limitations on the minimum elevation angle to which each of the antennas could be

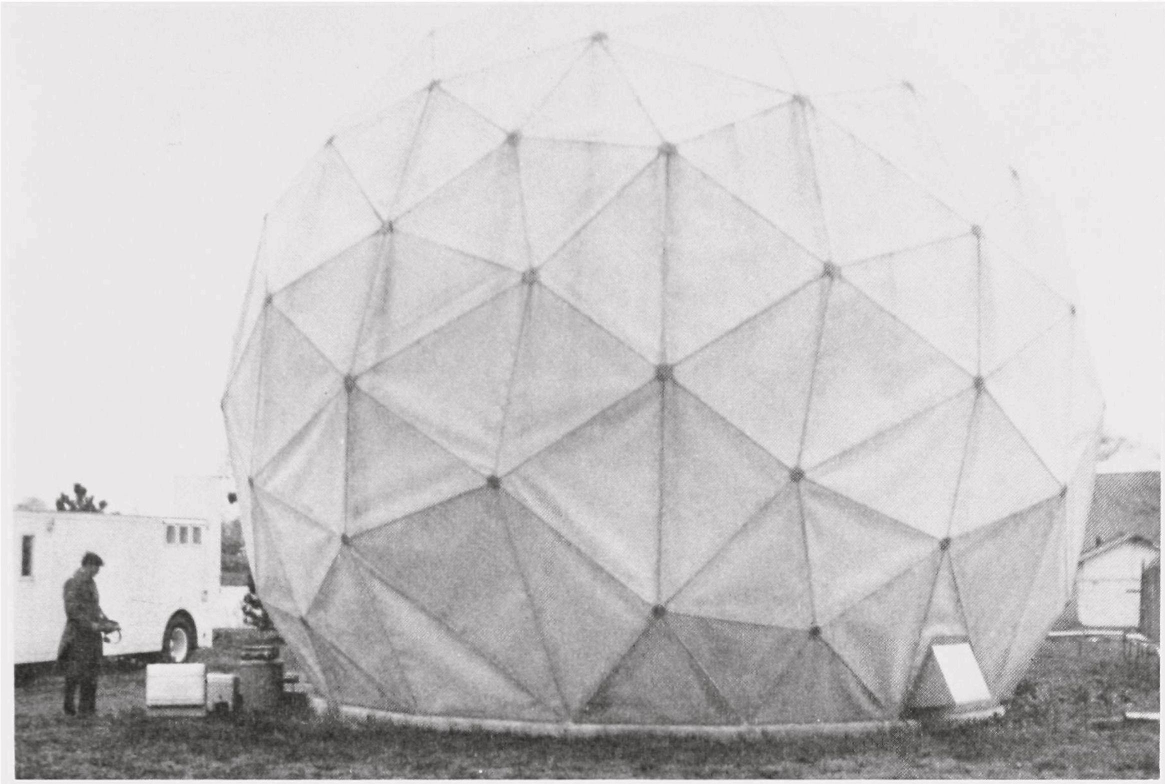


Figure 10A LET Geodesic Housing

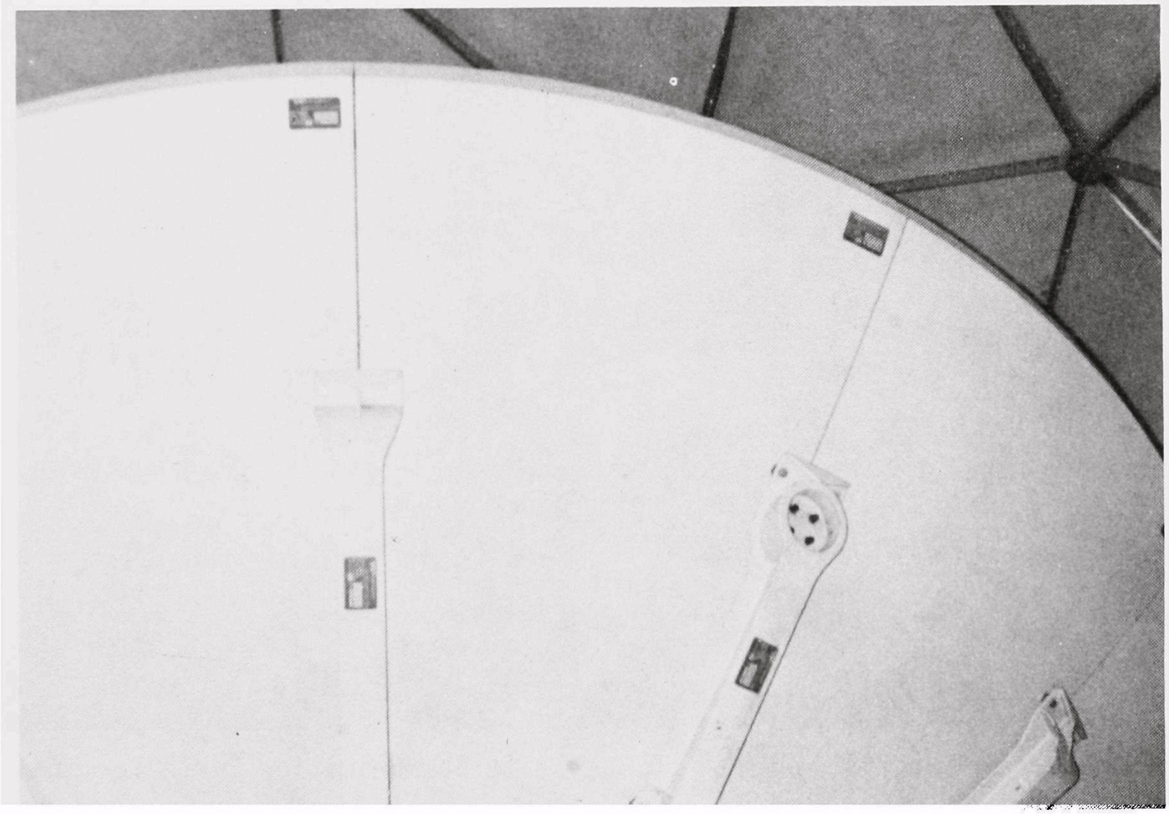
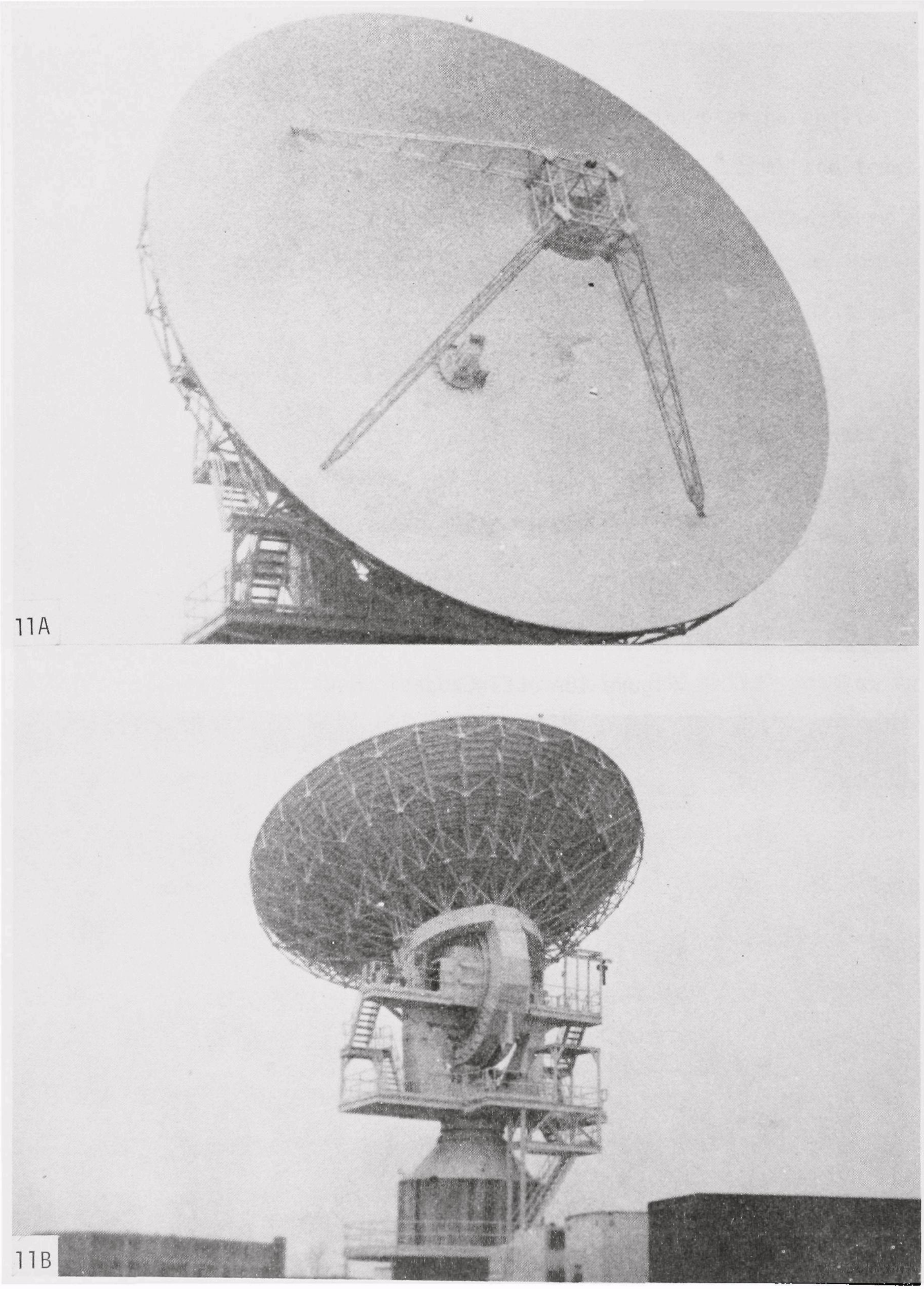
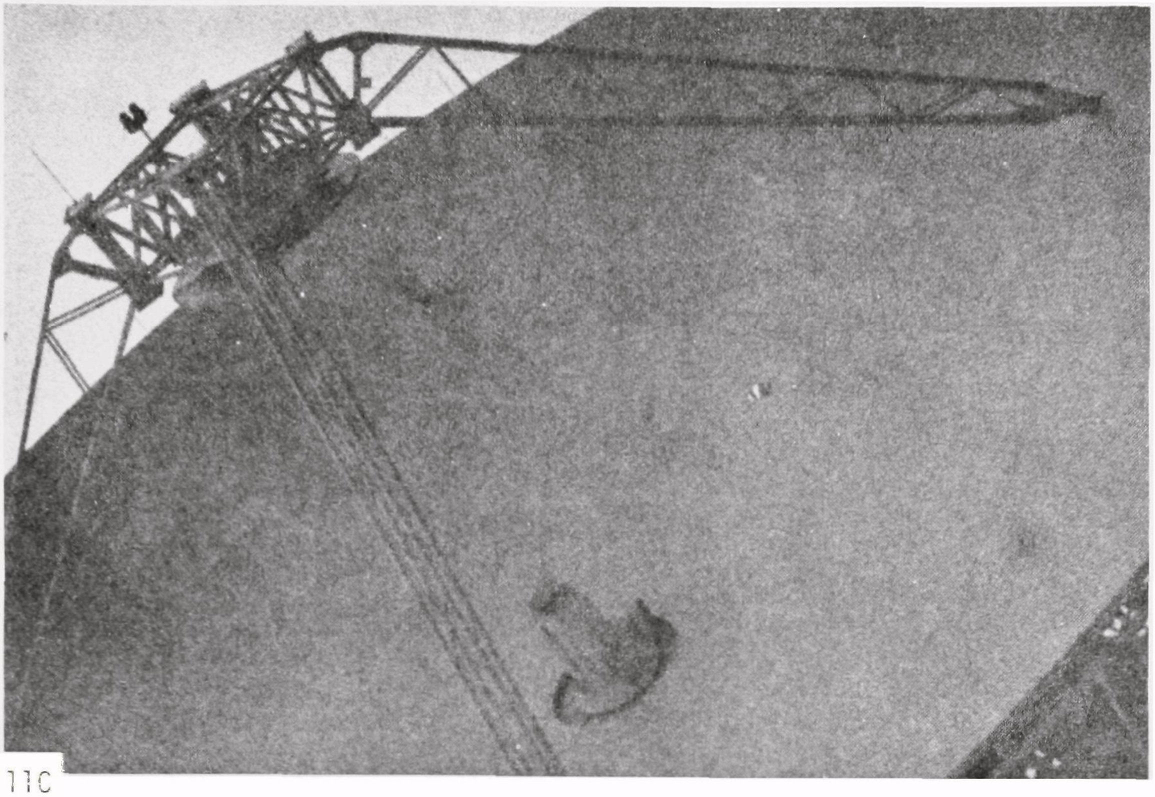


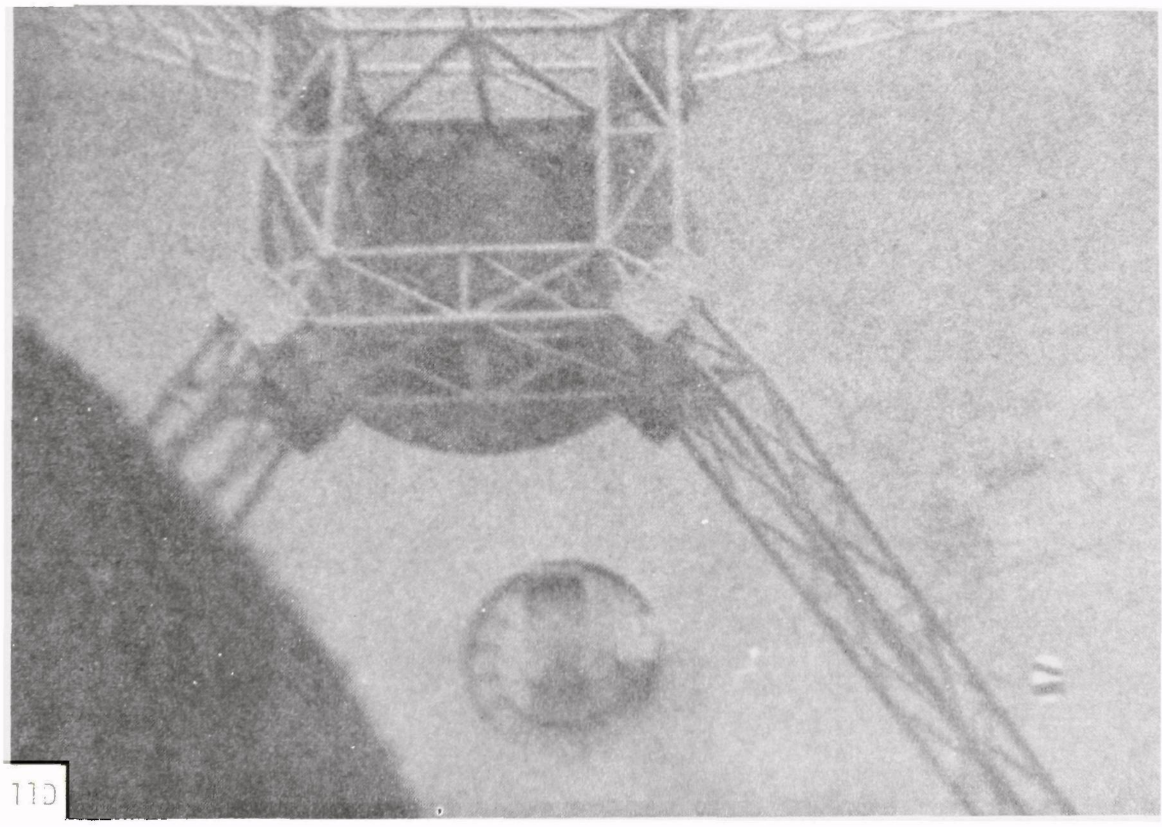
Figure 10B LET Antenna (Rear View) In Housing



Figures 11A and 11B AN/MSC-60 Satellite Communication Earth Terminal



11C



11D

Figures 11C and 11D Close-up Views of the AN/MSC-60 Antenna

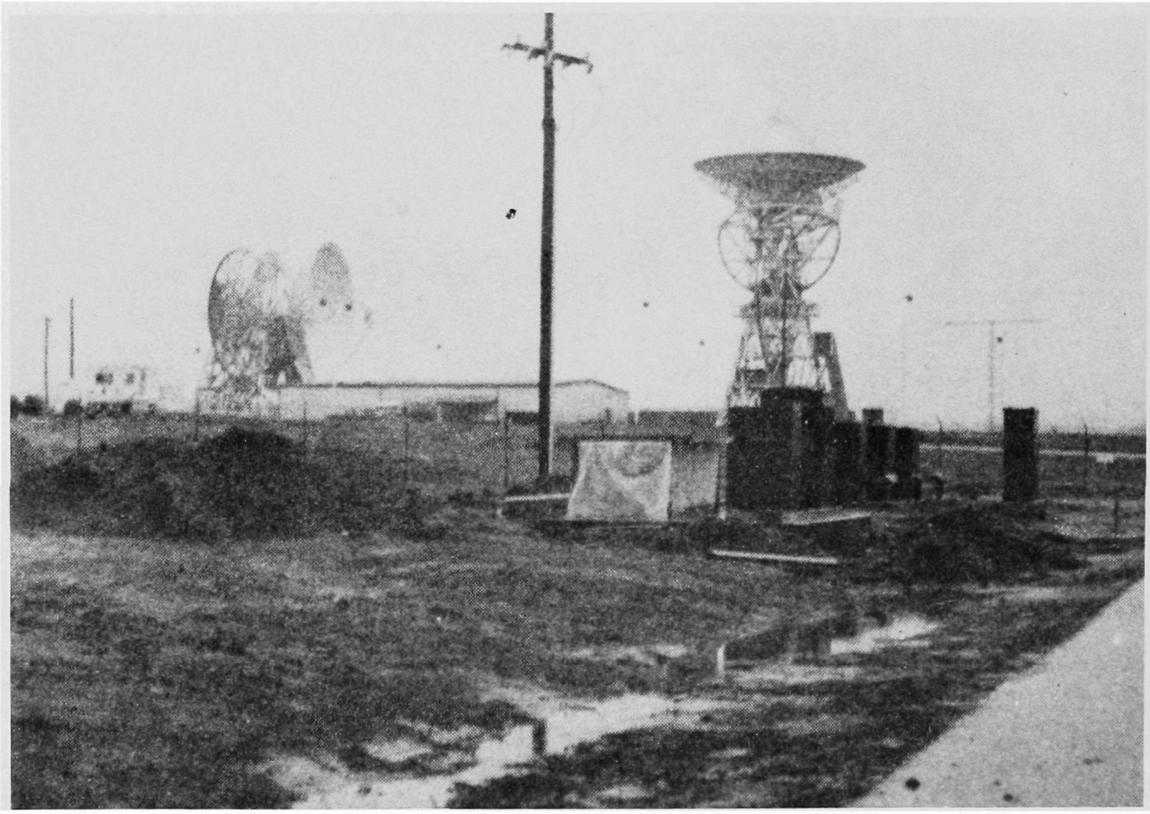


Figure 12 Satellite Communication Earth Terminals under Construction at Fort Detrick, Md.

Table 3

Summary of Pertinent Characteristics for
Selected Satellite Communication Systems

	LET	AN/TSC-54	AN/MSC-60
Antenna			
Type	Cassegrain	Cloverleaf Array Using 4 Modified Cassegrain Reflectors	Cassegrain
Diameter (ft)	15	18 (eff)	60
Aperture Efficiency	.50	.75	.50
Gain (dB)	48	52	61
1/2 Power Beamwidth (deg)	.58	.5	<.1
Polarization of Transmitted radiation	RHC	RHC	RHC
Height from center of antenna to ground (ft)	∿15	∿16	63
Transmitter power output (kW) (Maximum)	2.5	8.0	8.0
Frequency (GHz)	7.9-8.4	7.9-8.4	7.9-8.4
System EIRP (10^9 W)	.161	1.27 .63*	10.0 5.0*

*Includes 3 dB power loss in waveguide and swivel joints.

oriented, and the means available to elevate personnel and instrumentation to the system axis, the number of locations at which measurements can be made is severely restricted. For the measurements of the LET and AN/TSC-54 systems at Ft. Monmouth, the only practical way for personnel to reach the height at which the maximum power density could be measured was to use buildings to which access was possible. A "cherry picker" was available for the measurements of the AN/MSC-60 system at Ft. Detrick, however, the number of locations at which it could be situated was limited because of structures and streets in the area, and the availability of suitable ground which could provide a stable base.

In all measurements, the antenna is oriented so as to illuminate the measuring instrumentation, and the maximum power density is found by moving the instrumentation until the maximum reading is obtained.

The geometry for the measurements is generally illustrated in figure 13. The information specifying the distances, elevation angle, and detector used for each measurement is given in table 4.

The on-axis power density generated by the LET system was measured at two locations: one in the near field, on a metal staircase on the outside of a building with a brick exterior; the second measurement in the intermediate field at the second story window of a wooden building. The location for the near field power density measurement is shown in figure 14.

The measurement of the near field maximum power density generated by the AN/TSC-54 system was the only on-axis measurement attempted. The system's operating personnel limit the minimum elevation angle to 7.5° to avoid any possibility of creating a potentially hazardous exposure situation,

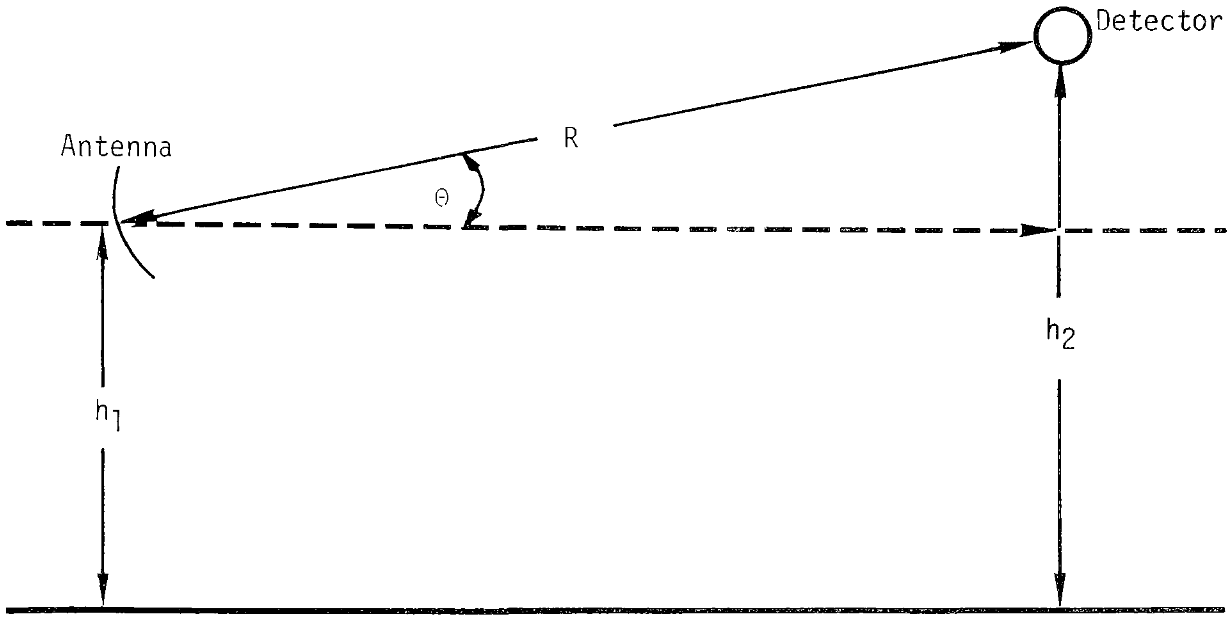


Figure 13 Geometry for On-Axis Power Density Measurements

Table 4

Measurement Geometry and Instrumentation

System	R (ft)	Θ (deg)	h_1 (ft)	h_2 (ft)	Instrumentation
LET	∿200	∿4	15	∿28	Narda 8323 probe
LET	∿600	0.3	15	∿18	HP 432A power meter, AEL APN101A antenna
AN/TSC-54	50	7.5	16	∿22	Narda 8321 probe
AN/MSC-60	60	0	63	63	Narda 8321 probe
AN/MSC-60	360	0	63	63	Narda 8321 probe

and for this reason the measurement could be performed only on the roof of the wooden building which housed the transmitters and electronic systems of the AN/TSC-54. Figure 15 illustrates the actual measurement in progress.

The on-axis power density measurement of the microwave radiation transmitted by the 60-foot diameter reflector of the AN/MSC-60 was possible only with the use of a "cherry picker" which elevated the measurement personnel and instrumentation to the height of the center of the antenna for an elevation angle of 0°. The fiberglass basket could accommodate two persons and their hand-held instruments. The antenna was oriented so as to direct its radiation at the basket, and then the "cherry picker" boom was moved and the basket oriented in order to intercept the on-axis beam.

The extent of the near field for this antenna, 1.6×10^3 m, made it impossible to measure power density beyond the near field. Measurements were made at two different locations with respect to the antenna, but both were in the near field. The antenna and measuring personnel are shown in figure 16.

Instrumentation Description

The instrument primarily used in performing these measurements was the NARDA 8300 which employs the model 8321 broadband isotropic probe for measurements of power density <20 mW/cm^2 and the 8323 broadband isotropic probe for measurements of power density >20 mW/cm^2. The Hewlett Packard power meter, model 432A, with calibrated thermistor mount and calibrated antenna, sensitive to the frequency emitted by each satellite communication system, was used in one of the measurements (see table 4).

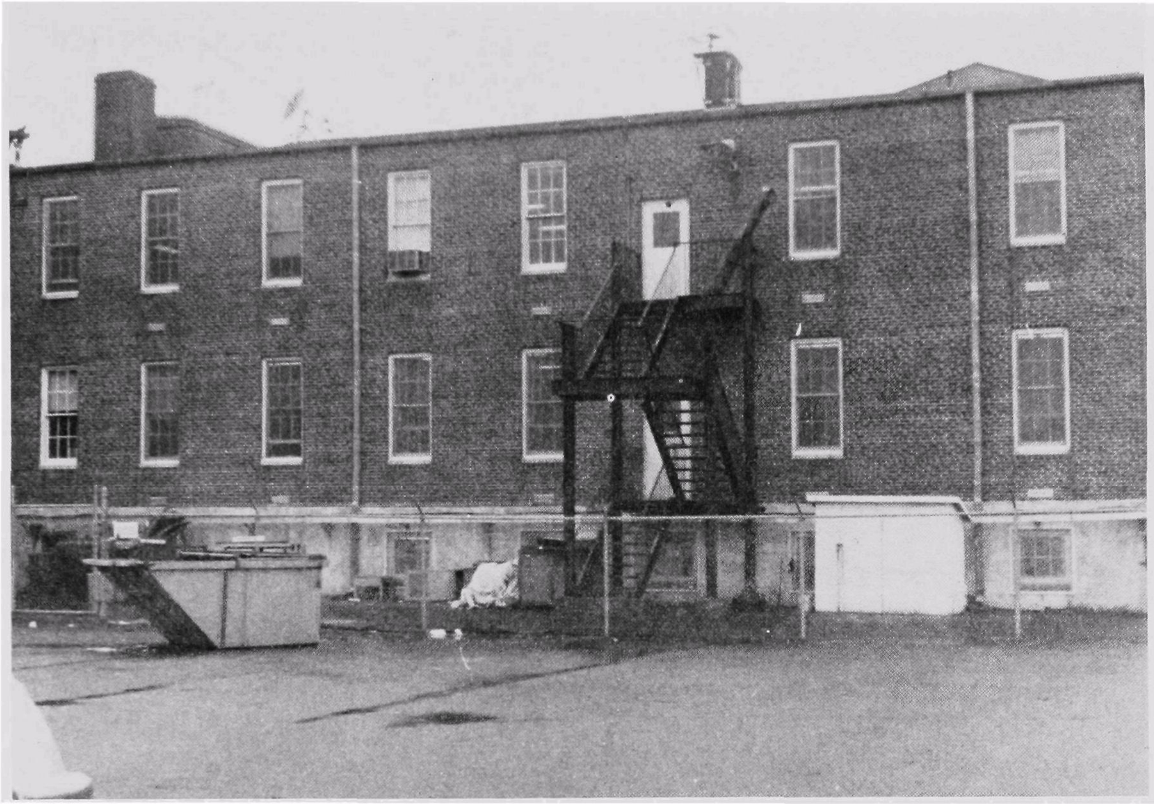


Figure 14 Staircase Location for LET Near Field Measurement

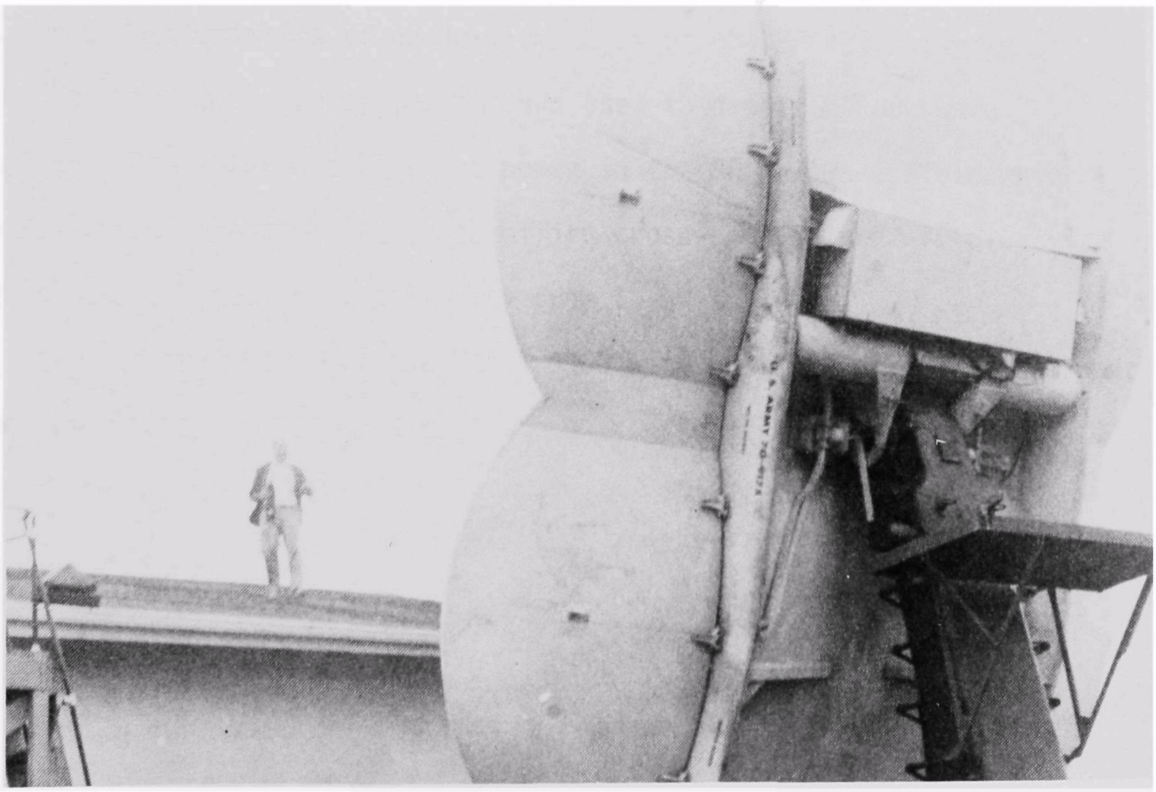


Figure 15 Measurement of AN/TSC-54 Near Field Power Density

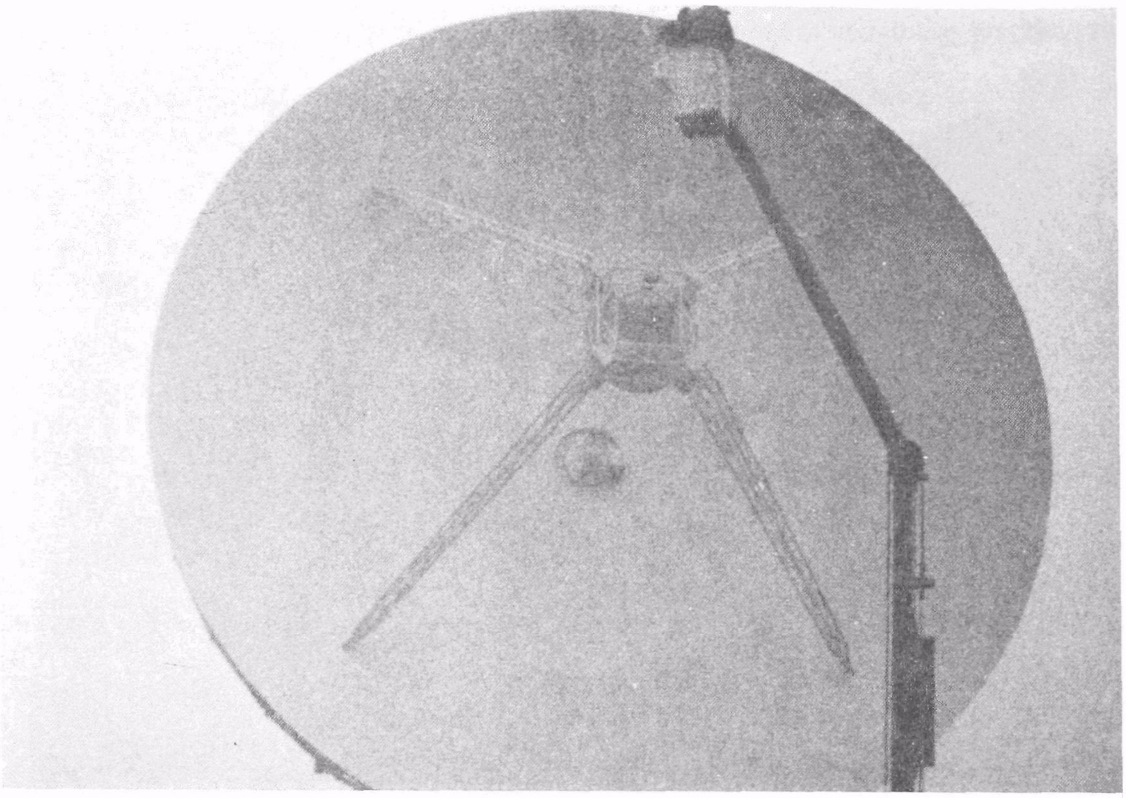


Figure 16 Measurement of AN/MSC-60 Near Field Power Density

The NARDA broadband isotropic monitor responds to the electric field component of radiation, in the frequency range of 300 MHz to 18 GHz, with equal sensitivity over all polarizations and direction of propagation, and can measure the power density accurately in the near and far field. This isotropic response characteristic is derived from the probe design employing thin film resistive thermocouple dipoles arrayed in three mutually perpendicular planes.

The HP-432A power meter uses a log periodic antenna as the radiation sensor. The antenna must be oriented to maximize the signal generated by the detected radiation. The maximum signal measured must be multiplied by a factor of 2 in order to correct for the measurement of power density for the circularly polarized radiation radiated by the satellite communication systems measured; or measurements of power density must be made in two orthogonal directions and then added.

The characteristics of an instrument using the HP-432A power meter depend to a great degree on the antenna used to detect RF or μwave radiation. The meter displays the power in the RF or μwave field which was detected by an antenna having a specified cross-section and efficiency. The 432A has 7 ranges of sensitivity from 10 μW to 10 mW.

The characteristics of the NARDA 8300 with the 8321 and 8323 isotropic probes are presented in table 5 (5).

Table 5

NARDA Isotropic Probe Characteristics

	8321	8323
Frequency range (GHz)	0.3 to 18	0.3 to 18
Power reading ranges (full scale)	2 mW/cm^2 & 20 mW/cm^2	10 mW/cm^2 & 100 mW/cm^2
Frequency sensitivity (dB)		
1 to 12 GHz	±0.5	±0.5
0.85 to 16 GHz	+0.5 to -1	+0.5 to -1
0.30 to 18 GHz	+0.5 to -3	+0.5 to -3
Isotropic responses	±0.5 dB from energy incident in any direction (excluding handle)	
Accuracy	±3% of full scale	
Overload threshold		
CW (mW/cm^2)	100	300
Peak (W/cm^2)	20	60
Power source	battery	battery
Weight	∿4 pounds including carrying case	

A problem which existed in the NARDA probes, especially the more sensitive 8321, was the effect of static charge buildup on the 4-inch diameter sphere of foamed polystyrene which contains the probe elements. The amount of static charge present causes deflection of the meter indicator above the zero level, and may be responsible for inaccuracies in low-level power density readings, observed in field measurements, of ∿±0.8 dB at 2 mW/cm^2. The amount of static charge varies continuously and cannot be accurately compensated for by the zero control. It appears possible to have up to ∿±2 dB maximum error in measured power density for the most sensitive scale. The manufacturer has recently eliminated the static charge buildup problem with a design change.

Measurement Results

The results of the measurements performed to determine the on-axis power density levels generated by the three satellite communication system earth terminals studied are presented in table 6. The values of near field, on-axis, power density predicted by the model are given for a transmitter power of 1 kW. In addition, the predicted on-axis power density levels at the point of measurement are given for the actual transmitter power used. The physical geometry and instrumentation involved are as presented in figure 13 and table 4.

The maximum on-axis near field, power density for each system was calculated using eq 2, the antenna diameter, transmitter power used, and antenna efficiencies of 0.50 for the LET and AN/MSC-60 systems and 0.75 for the AN/TSC-54. The only measurement of on-axis power density made beyond the near field extent of an antenna was that for the LET at a distance of 1.5×10^2 m to 1.8×10^2 m. Equation 5 was used in calculating the expected power density. In addition, the near field extent was calculated for all systems, using eq 3, because of its importance in the calculation of power density variation with distance from the antenna at distances beyond the near field.

Table 6

Results of On-axis Power Density Measurements

	LET		AN/TSC-54	AN/MSC-60		
Diameter (ft)	15		18 (eff)	60		
Near Field Distance (m)	9.3×10^{1}		1.4×10^{2}	1.6×10^{3}		
Predicted Maximum Near Field On-Axis Power Density (mW/cm^2) for 1 kW Transmitter Power	12.2		12.7	.76 .38[b]		
Transmitter Power (kW)	2	2	1	.500	6.7	6.0
R, Distance from Antenna (m) to Point of Measurement	1.5×10^{2} to 1.8×10^{2}	6.1×10^{1}	1.5×10^{1}	1.8×10^{1}	1.8×10^{1}	1.0×10^{2} to 1.1×10^{2}
Measured Power Density (mW/cm^2)	12	50*	7	∿.3	∿2.2	∿3
Predicted Power Density (mW/cm^2) at R	15.1 to 12.6	24.4	12.7 6.4**	.38 ∿.19**	5.1 2.5**	4.6 2.3**

*Measurement performed on metal staircase (see figure 14).
**Includes a 3 dB loss of power into waveguide and swivel joints not originally known but discovered after an inquiry was made to operations personnel about the discrepancy between the measured values and those predicted.

Section 4 - Discussion and Evaluation

Measurement Considerations

The measurement procedure used in performing an on-site measurement of potentially hazardous environmental levels of power density requires that the system must be operated in a manner consistent with good safety practices which consider the system characteristics, so that the transmitter power, antenna orientation, and system activation be under the control of the persons performing the measurement.

The determination of the procedure used in measuring the power densities generated by any given satellite communications system involves: a calculation of the environmental power density levels generated by the system based on reflector and transmitter characteristics, knowledge of the distances from the centerline of the reflector to ground for the minimum elevation angle of the system at possible measurement locations, location of structures in the vicinity of the system, a need to avoid the exposure of persons other than personnel involved in measurements, provisions for the means to elevate personnel and equipment to the proper height above ground for the measurement, and the need for a reliable communication link between measurement personnel and the system operators.

The calculation of maximum near field power density (on-axis) per kW transmitter power and near field extent specifies the transmitter powers (other than maximum) to be used during a measurement of system characteristics and the distances at which measurements may be considered. The selection of measurement locations also involves consideration of the minimum antenna elevation angle possible, the need to avoid exposure to other persons, the location of structures and the associated effects due to reflection of radiation, terrain characteristics which affect the height above ground at which it may be necessary to locate measurement personnel, and the availability of a means to reach that height.

As antenna diameters increase, and therefore the near field extent also increases, it becomes more impractical to measure power density beyond the near field for elevation angles significantly greater than zero degrees.

The initial analysis used in the selection of systems to be investigated, and the preliminary determination of instrumentation needs and measurement procedure was based upon the data residing in the ECAC information inventory and the use of an idealized model. However, there are factors which could modify this analysis and impose other requirements which must be satisfied. After an initial evaluation has been made, complete and accurate characteristics of the identified systems should be obtained. Recent system modifications, i.e., transmitter power capability, may not have been included in the data obtained from ECAC.

The data resident in the ECAC information inventory includes the site location, system frequency, transmitter power, antenna or system gain, antenna diameter, system nomenclature, antenna height above ground, a qualitative description of the terrain, and the name of the operating agency. However, there is much information which could be of use, does not exist in the data file, and must be obtained from the persons operating the source prior to a measurement. This information concerns power losses which occur between the transmitter and the antenna, the coupling efficiency between the antenna feed and reflector, the minimum antenna elevation angle, and the normal operating power of the transmitter. The maximum power capability of a transmitter and its usual operational power may be much different, however, the maximum transmitter power should be used in evaluating a system as a potential hazard prior to its measurement.

The source must be operated with particular considerations being given to safety so that the personnel performing measurements are not exposed to excessive levels of radiation and that exposure of persons not involved in the measurement be avoided. Thus an understanding of the measurement procedure and purpose by the satellite communication system operators is extremely important, as is a reliable system for communication between the measurement personnel and the system operators. This direct communication link and the source operator's knowledge of the measurement procedure facilitates the measurement and results in knowing all of the pertinent source operating characteristics at the time of each measurement.

The instrumentation used to measure the power density from satellite communication systems under less than ideal conditions (from a roof-top or "cherry picker" basket) must not only have the necessary sensitivity over the desired frequency range, but must be portable, lightweight, physically small, extremely reliable, battery powered, thermally stable, and easily read. The effect of various weather conditions on the operation of an instrument must be considered in determining its suitability during the measurement.

An important requirement is that the measured power density be directly indicated by the instrument so that possible complications affecting the measurement may be immediately obvious instead of being detected at a later time. This requirement also serves to protect both the measurement personnel and instrumentation from possible exposure to excessive or hazardous levels which could be accidentally produced.

Evaluation of Model Applicability

The model used in predicting characteristics and on-axis power density levels for satellite communication systems earth terminals having circular paraboloidal reflectors cannot be entirely validated by the measurements reported because relatively few measurements were made, and of these, none were made in the far field. However, the results obtained, table 6, lend support to the use of the model for predicting on-axis power density.

If the on-site measurements agree with the anticipated values derived through use of the model within the expected measurement accuracy of the instrumentation used, the model can be used for preliminary determinations of maximum on-axis power density at any distance from the antenna for satellite communication systems. If all sources of instrument error would add to produce the maximum possible error, deviations between measured and actual power densities of up to ∿40%, are possible. A difference of 30% between measured and power densities predicted by the model would be acceptable.

There are certain complicating factors not taken into account which will cause the predictions based on the model to deviate from the actual on-site measurements. These complications include the effect on power density of interfering structures, and the power losses which occur before power is introduced to the antenna system. In addition, there is a possible degradation in antenna gain due to geometrical considerations, but this latter factor is infrequently encountered since most systems have undergone rigorous testing prior to operation. However, it is conceivable that deviations from the idealized antenna geometry can occur, especially for systems which are assembled in the field, i.e., the smaller transportable systems.

The effect of interfering structures and the discrepancy between system transmitter power and the power fed to the antenna were demonstrated in the satellite communication system measurements. The effect of interfering structures on measured power density was seen in one of the LET system measurements. The near field measurement of power density yielded a maximum value of 50 mW/cm^2 as compared to a maximum theoretical value of 24.4 mW/cm^2 for the transmitter power used. The measurement was made on the metal staircase shown in figure 15 and undoubtedly the high value of power density was due to reflected radiation interfering constructively with incident radiation. While this measurement has no value as far as confirming the validity of the model, it is a fine example of the potential effect of structures having good reflective characteristics.

The predicted system characteristics, including near field power density, for the AN/MSC-60 system had been determined on the basis of the antenna diameter and an assumed aperture efficiency of .50. During the measurements, it was noticed that the predicted values of on-axis, maximum near field power density were a factor of ~ 2 greater than the measured values of power densities significantly greater than zero; i.e., 2.2 and 3 mW/cm^2.

The discrepancy was pointed out by the system operators as being due to a 3 dB power loss in the waveguide and swivel joints of the system. This power loss is typical of large systems where the antenna is massive and the distance between the transmitter and antenna power feed is relatively large.

The near field measurement of power density produced by the AN/TSC-54 system yielded a maximum value of ~ 7 mW/cm^2 as compared to an anticipated value of 6.4 mW/cm^2, based on the assumption that the power losses incurred prior to the antenna power feed is 3 dB and confirmed by persons having experience with this system.

System documentation and ECAC data do not necessarily provide information describing the power loss which occurs in waveguide and swivel joints, but may only specify maximum transmitter power and antenna gain from which a theoretical maximum EIRP may be calculated. The maximum on-axis power density should be calculated using known values of antenna power or including the effect of power losses between transmitter and antenna.

The results of the satellite communication systems measurements lend support to the use of the model for calculation of on-axis maximum power density in the near and intermediate field for the initial hazard evaluation of these systems. Unfortunately, because of the limited number of systems measured and the difficulty in placing personnel and instrumentation at the antenna axis during the on-site hazards surveys performed, only three near field measurements and one intermediate field measurements were possible.

The extensive near field region associated with the AN/MSC-60 system and the minimum elevation angle of 7.5° possible for the AN/TSC-54 system made it impractical to make measurements beyond the near field for these antennas. The definition of near field extent cannot be substantiated because the model based calculation of near field extent is much greater than the actual separation distance involved in the measurement. The valid LET system measurement was made at approximately the transition region between the intermediate and far fields as defined by the model.

The comparisons between the measured values of on-axis power density and the calculated values of maximum on-axis power density, based upon the model are given in table 7. The AN/MSC-60 measurement made with a transmitter power of .5 kW (table 6) must be disregarded because of the inherent inaccuracy of the isotropic probe at the low end of its most sensitive scale. Static charge buildup effects can add significantly to small indicated readings. Measurements of low power densities whose value is within an order of magnitude of inherent inaccuracies in instrument performance, show large percent errors for relatively small deviations.

Table 7

Comparison of Measured and Calculated Values of On-Axis Power Density

	LET	AN/MSC-60		AN/TSC-54
Measured Power Density (mW/cm^2)	12	∿2.2	∿3	7
Calculated Power Density (mW/cm^2)	15.1 to 12.6	2.5	2.3	6.4
% difference	26 to 5	14	23	9

The agreement shown supports the use of the USAEHA model for initial hazards evaluations of satellite communication systems in the near and intermediate fields. More measurements are needed to validate the model in these regions and in the far field, but in order to illustrate the ideas considered in the remainder of this report, the model will be used.

Anticipated Environmental Levels of Power Density for Simulated Satellite Communication Systems

The mathematical model previously described has been used to determine expected characteristics of various diameter circular paraboloidal reflectors assuming 5 kW transmitter power. This combination of antenna and transmitter simulates satellite communication system earth terminals. The characteristics are determined using realistic aperture efficiencies, transmitted wavelengths, and system power losses which occur between the transmitter and antenna feed.

These anticipated characteristics are presented in table 8 for reflector diameters which range from 15 feet to 100 feet. The gain, maximum on-axis near field power density, EIRP, and distances at which on-axis power density would reach selected levels have been calculated for two typical aperture efficiencies for antenna diameters where they may apply.

While these systems are simulated, they represent approximations to some satellite communication systems which are in use so far as antenna diameters are concerned. Transmitter power capability for actual systems may be different than the 5 kW selected for the illustration being as low as 1 kW for some tasks, however, this value may be typical for the power output of transmitters during usual system operation.

The contents of table 8 generally identify potentially hazardous systems directly from their maximum near field power densities and the distance intervals (with respect to antenna location) over which power densities exceed a selected threshold. The values in the table show magnitudes of expected maximum near field power density, for a given transmitter power and wavelength, and that the power density levels close to the antenna (in its near field) are more hazardous for smaller diameter antennas even though the EIRP increases with antenna diameter. However, the distances over which levels exceed a selected threshold increase with diameter, but generally not at the rate shown by EIRP.

Anticipated Environmental Levels of Power Density for Selected Systems

Calculations have been made, for the expected characteristics of

Table 8

Anticipated Characteristics of Simulated Satellite Communication Systems

Antenna Diameter (ft)	η	Gain* (dB)	Maximum Near Field Power Density (mW/cm^2)** 5 kW Transmitter Power	Near Field Distance* (m)	EIRP (10^9 W) $P_T \cdot G$	EIRP (10^9 W) $P \cdot G$ **	Distance (m) from Antenna for Power Densities of: 10 mW/cm^2	1 mW/cm^2	100 $\mu W/cm^2$	10 $\mu W/cm^2$
15	.5	48.1	60.9	9.23x10	0.32	-	3.20x10	1.01×10^3	3.20×10^3	1.01×10^4
	.75	49.8	91.4		0.48	-	3.95×10^2	1.25×10^3	3.95×10^3	1.25×10^4
20	.5	50.6	34.3	1.64×10^2	0.57	-	4.25×10^2	1.34×10^3	4.25×10^3	1.34×10^4
	.75	52.4	51.4		0.87	-	5.27×10^2	1.67×10^3	5.27×10^3	1.67×10^4
30	.5	54.1	7.61	3.69×10^2	1.28	0.64	-	1.44×10^3	4.55×10^3	1.44×10^4
	.75	55.9	11.4		1.94	0.97	4.21×10^2	1.76×10^3	5.58×10^3	1.76×10^4
40	.5	56.6	4.28	6.57×10^2	2.28	1.14	-	1.92×10^3	6.08×10^3	1.92×10^4
	.75	58.4	6.42		3.44	1.72	-	2.36×10^3	7.45×10^3	2.36×10^4
60	.5	60.1	1.90	1.48×10^3	5.11	2.56	-	2.82×10^3	9.13×10^3	2.89×10^4
90	.5	63.7	0.846	3.32×10^3	11.7	5.86	-	-	1.37×10^4	4.32×10^4
100	.5	64.6	0.685	4.10×10^3	14.4	7.2	-	-	1.52×10^4	4.80×10^4

*Assuming 4 cm μwave radiation transmission.
**3 dB loss between transmitter and power feed for reflectors with diameters ≥30 ft.

several existing satellite communication systems operating at maximum transmitter power. In each case, the distances from the antenna at which power densities of 10 mW/cm^2, 1 mW/cm^2, 100 $\mu W/cm^2$, and 10 $\mu W/cm^2$ are expected have been determined. The results are given in table 9.

The points of interest are, that for these systems having antenna diameters which vary from 15 feet to 210 feet, the near field, R_1, increases from approximately 100 meters to almost 6×10^3 meters. With the exception of the Intelsat system, the on-axis near field power densities, W_{nf}, are significant relative to 10 mW/cm^2. Examination of the distances from the antenna at which various on-axis power densities occur, shows the increase in the spatial extent, over which significant power densities exist, as the antenna diameter and near field extent increase.

The larger systems are included in the list of CW sources having the highest values of EIRP with the exceptions of the AN/MSC-60 and the two deep space communication systems. These more recent arrivals would not be expected to appear in the ECAC listing.

Potential Hazard Evaluation

A potential hazard evaluation assesses the potential of a source of radiation to produce a hazardous exposure level relative to a defined threshold for some selected exposure criterion. Potentially hazardous sources may be identified through an examination of the ECAC inventory. The inventoried sources may be evaluated relative to one another and assigned a priority for further examination.

An initial evaluation of the potential hazards of an individual satellite communication system may be performed by determining its worst

Table 9

Anticipated Characteristics of Selected Satellite Communication Systems

System	Antenna Diameter (ft)	λ (cm)	Gain (dB)	P_T (kW)	EIRP (10^9 W) $P^*\cdot G$	R_1 (m)	W_{nf} (max) (mW/cm²)	Distance (m) from Antenna for Power Densities of:			
								10 mW/cm²	1 mW/cm²	100 μW/cm²	10 μW/cm²
LET**	15	3.7	48.8	2.5	.189	9.98x10	30.4	2.46×10^2	7.79×10^2	2.46×10^3	7.79×10^3
AN/TSC-54**	18(eff)	3.7	52.1	8	.651	1.44×10^2	50.8	4.58×10^2	1.45×10^3	4.58×10^3	1.45×10^4
AN/MSC-46	40	3.7	57.3	10	2.68	7.10×10^2	8.56	-	2.94×10^3	9.29×10^3	2.9×10^4
AN/MSC-60**	60	3.7	60.8	8	4.82	1.60×10^3	3.04	-	3.94×10^3	1.25×10^4	3.94×10^4
AN/FSC-9	60	3.7	60.8	20	12.0	1.60×10^3	7.61	-	6.23×10^3	1.97×10^4	6.23×10^4
Intelsat	97	4.8	62.7	5	4.68	3.22×10^3	.728	-	-	1.23×10^4	3.88×10^4
Goldstone Venus***	85	12.6	53.8	450	54.0	9.43×10^2	97.3	4.16×10^3	1.32×10^4	4.16×10^4	1.32×10^5
Goldstone Mars***	210	12.6	61.9	450	348	5.76×10^3	16.8	9.68×10^3	3.34×10^4	1.06×10^5	3.34×10^5

*Includes a 3 dB loss of power into waveguide and swivel joints.
**Systems measured.
***These are not satellite communication systems, but systems which are used to communicate with space vehicles on planetary exploration missions.

case (on-axis) power density capability and the distance from the system at which the power density may equal a selected threshold value of interest. Simplified models exist which can calculate reasonably well the significant radiation characteristics of a source from basic characteristics; i.e., the reflector diameter, radiation frequency, aperture efficiency, and the maximum power which can be introduced into the antenna system for subsequent radiation into space.

If the potential hazard evaluation of satellite communication system were carried further to include other factors, i.e., operational procedures and site characteristics, power density produced at any location relative to the source would be predicted with greater accuracy. However, these factors are difficult to incorporate into calculations and they may be the factors responsible for significant differences between measured and calculated radiation field characteristics. In addition, biological effects information is inadequate for quantitative biological effects hazard analysis. The analysis depends on the power density at which effects occur and their frequency dependence, the exposure time, and the characteristic and distribution of the exposed population.

A simple illustration of the technique of applying a selected threshold value in a potential hazard evaluation of the inventoried satellite communication systems treated in this paper is presented in a graphic display (figure 17). Sources whose on-axis power density is greater than any imposed threshold are identified and their near field distances are immediately available for use in further analysis.

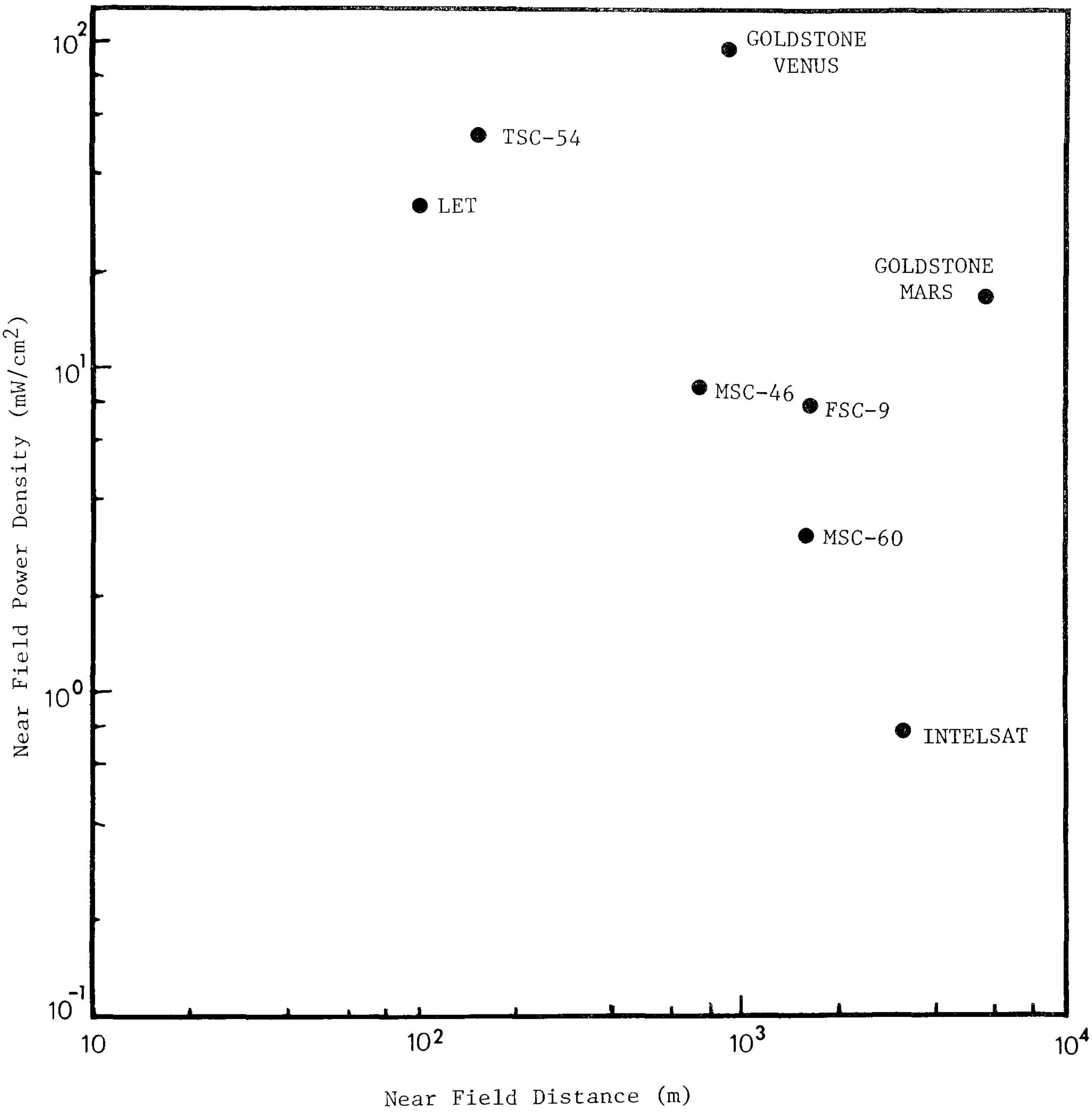


Figure 17 Possible Method of Identification of Satellite Communication Systems

Once this initial identification has been made, the sources can be comparatively ranked using chosen criteria. One method of comparing sources is based upon the distance from the source at which a selected on-axis power density exists. The results shown in table 9 can be used. Another method can be based upon the on-axis power density which exists at a selected distance from the source. It must be remembered that these evaluations do not take frequency, power density, and exposure time into account; they are based upon a model used for calculational purposes and assume a threshold value for power density.

Procedures which can be used to perform these evaluations for systems using modified circular paraboloidal reflectors and other types of antennas are available, although more complex, so that the evaluation techniques can be applied more generally.

The factors which must be considered in a realistic evaluation of the potential environmental hazard of any particular system include the transmitter power used in its regular operation (generally much less than the maximum possible), the procedures employed in system operation, the distance between the center of the antenna and ground, terrain characteristics, the minimum elevation angle of the antenna below which the system cannot operate, and the distribution of population within the area for which power density equals or exceeds the selected threshold level.

The operational transmitter power may not equal the transmitter power capability, resulting in power densities produced during operation which are less than the maximum possible. The power densities vary directly as transmitter power, so that if P_T (used)/P_T (max) = 0.1, the power densities produced will be one-tenth of that calculated for use of maximum transmitter power.

Many satellite communication systems cannot operate at elevation angles less than a specified angle relative to horizontal. The knowledge of that angle and other system and site characteristics; i.e., terrain features, antenna height above ground, population distribution, location and height of structures, and sidelobe radiation characteristics of the antenna, will realistically determine the possibility for exposure of persons within a radius for which the power density exceeds or equals the threshold level.

A system may produce significant power densities, and still not constitute a hazard if there is no possibility for exposure.

It is apparent that measurements of existing radiation levels are necessary to a realistic hazard evaluation. A potential hazard evaluation may be most useful in identifying those systems to be studied by measurement, to assist in assigning a priority to them for a more intensive evaluation, and to analytically determine radiation characteristics for a specified source. However, it is necessary to quantitatively measure the environmental levels of power density in a realistic evaluation due to the difficulty of incorporating into an analytical evaluation the factors which may significantly affect the results.

ECAC as a Resource in the Identification and Evaluation of Potentially Hazardous Sources

The value of potential hazard evaluations depends on the quality of the information which resides in the computerized data inventory. The

Electromagnetic Compatibility Analysis Center has the most extensive inventory of sources containing most of the system characteristics required, but the quality of the information is not always consistent. The organizations operating the systems have the responsibility to provide accurate information to ECAC but there are inaccuracies and inconsistencies.

The effective radiated power determined by ECAC and used in ranking sources, usually the maximum EIRP for the systems considered, uses the maximum transmitter power capability and, in many cases, the theoretical system gain, not the actual system gain. EIRP may be reported as defined in eq. (9), but usually as $G \cdot P_T$, where P_T is the maximum output power capability of the transmitter. EIRP reported in this manner may be a factor of two greater than that which includes losses in the system.

The extent to which the ranking of systems would be affected by inclusion of actual system gain characteristics needs to be determined, but the effectiveness in identifying sources or categories of sources according to their potential for creating potentially hazardous environmental radiation levels may not be affected.

Section 5 - Conclusions and Summary

This study applies in general to the concept of potential hazard evaluations involving sources of environmental microwave radiation, and specifically to satellite communication earth terminals. The general conclusions reached are that:

1) In general, satellite communication systems, operated in accordance with prescribed system operational procedures, should not constitute a thermal effects hazard. The possibility of exposure of persons (not

employed in system operation) should be extremely small because radiation is directed generally upward. The avoidance of population exposure is intended, as indicated by the minimum elevation angles specified. Certain satellite communication systems, if operated improperly, can create thermally hazardous situations due to the large on-axis power densities which can be produced at great distances from the antennas.

2) Models exist which predict, under ideal conditions, maximum on-axis near field power density, and appear to be applicable in defining the intermediate and far field zones and on-axis power density as a function of distance from the antenna.

3) The calculated values of on-axis near field power density, near field extent, and on-axis power density as a function of distance from the source can be applied to a method for potential hazard evaluation. A selected power density threshold can be used as a basis for the identification of potentially hazardous systems, assigning a relative ranking to them, and in the initial evaluation of a system with regard to its potential as a source of hazardous exposure levels.

4) Effective isotropic radiated power is not the most directly applicable characteristic to be used in the potential hazard evaluation. Small diameter antennas, having lower gain characteristics, can produce greater on-axis near field power densities, for equal transmitter powers and radiation wavelengths than larger diameter systems.

5) A more realistic hazards evaluation will include other criteria defining the exposure problem in addition to power density; i.e., the population exposed and the exposure duration.

6) A true hazard evaluation will not be possible until effects are identified, thresholds defined, and the relationships between the degree of effect to radiation frequency, power density, and exposure as a function of time are known.

7) Nonthermal effects hazard evaluations would give greater importance to the off-axis power density characteristics of satellite communication systems.

8) A potential hazard evaluation procedure can be used to identify those systems to which priority can be assigned for a more realistic hazard evaluation. Factors exist which significantly affect the results of an analytical evaluation, and make measurement a necessary part of a realistic hazard evaluation.

The requirements and uses for hazard evaluations are summarized in table 10.

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Table 10

Hazards Evaluation Summary

Potential Hazard Evaluation:

1. Used to identify potentially hazardous sources on the basis of a selected power density threshold
2. Systems can be ranked according to selected criteria
3. Uses existing simplified models to calculate:

   near, intermediate, and far field regions

   power density (on-axis) vs. distance from source

Realistic Hazard Evaluation requires:

1. Quantitative identification of biological effects; i.e., determining for each effect
   a. dependence upon frequency, power density, exposure time
   b. threshold values
2. Knowledge of the population exposed, including
   a. unique characteristics
   b. distribution
3. Measurement of significant radiation field characteristics for those sources identified; i.e., power density as a function of frequency and time.

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16. ABSTRACT

Selected satellite communication (SATCOM) systems are evaluated analytically and, for some of these systems, through measurement of the microwave radiation power densities generated by them. The evaluation is directed toward assessing the radiation exposure hazards which exist for specific systems and generally for SATCOM systems as a class of high power nonionizing radiation source. The paper includes determinations of anticipated maximum power density levels as functions of distance from the source, a description of the analytical method used, and the results of measurements of the power densities produced by certain SATCOM systems. Included also is a discussion of potential hazard analysis and its uses in identifying systems which may constitute environmental hazards.

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