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CALCULATED ELECTRIC NEAR FIELDS OF NAVY SHIPBOARD HF ANTENNAS

Electric near fields of trussed-whip, twin-whip,
discone-cage, and bottom-fed fan antennas

JC Logan and JW Rockway
16 March 1978

Final Report: July 1977 - January 1978

Prepared for
Naval Electronic Systems Command

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CHAPTER 1. INTRODUCTION

BACKGROUND

Because shipboard operations are carried out within fixed (small) distances from hf transmitting antennas, the Navy has a unique and long-standing operational problem: the radiation from these antennas can be hazardous to personnel, ordnance, fuel, and electronic equipment because of the intensity of the fields close to the radiating element.

Accordingly, the Navy has been pursuing the study of the near fields of antennas for a number of years. However, the near field structure is complex, and previous theoretical analysis has been practical only for simple antennas in uncomplicated geometrical settings. With the advent of the modern high-speed computer, approximate solution techniques such as the method of moments used by the Numerical Electromagnetic Code become practical (ref 1).

SCOPE OF THE STUDY

A previous study provided the electric near fields of standard Navy hf whip antennas (ref 2). This study completes that effort by presenting the electric near fields of the trussed-whip, twin-whip, discone-cage, and bottom-fed fan shipboard hf antennas. At this time, the analytical model of the top-fed fan antenna has not been completed.

Chapter 2 is a discussion of the importance of the electric near fields of hf transmitting antennas to the Navy. Chapter 3 presents the analytical approach used in this study. Chapter 4 discusses the near field characteristics of hf antennas on an extended ground plane. This discussion is supported by appendices A and B. A general description and installation guidance for each of the hf antennas are given in appendix A. The results of the near field calculations are presented in appendix B. Chapter 5 discusses the near field characteristics of hf antennas in a structured environment. This discussion is supported by appendices C and D. The particular configurations of the structured environments are given in appendix C. The results of the near field calculations for these environments are given in appendix D. Finally, in chapter 6 a near field extrapolation algorithm is developed. With this algorithm, the calculated near fields for antennas on an extended ground plane can be used to predict a bound on the near fields that will occur in a shipboard environment for these hf transmitting antennas.

-
1. NOSC TD 116, "Numerical Electromagnetic Code (NEC)- Method of Moments," by GJ Burke and AJ Poggio, 18 July 1977
 2. NELC TR 1872, "Calculated Near Fields of Navy HF Whip Antennas," by JW Rockway and PM Hansen, 24 April 1973

CHAPTER 2. GENERAL NEAR FIELD CRITERIA

The near fields of Navy hf antennas are primarily important as radiation hazards (RADHAZ). There are essentially three types of radiation hazards:

RADHAZ to Personnel (HERP)
RADHAZ to Ordnance (HERO)
RADHAZ to Fuel (HERF)

These hazards and their general near field criteria are discussed in the following sections.

Near fields are also important to the technical discipline of Electromagnetic Vulnerability (EMV) (ref 3). EMV is concerned with the undesirable effects of electromagnetic energy entering electronic/electrical components, equipments, and systems through paths other than intended antennas. Near fields are the shipboard electromagnetic environment necessary for defining the EMV design criteria. Since EMV uses no general design criteria, it is not discussed here in further detail.

HAZARDS OF ELECTROMAGNETIC RADIATION TO PERSONNEL (HERP)

Most Navy platforms possess systems and equipments which radiate energy in some portion of the electromagnetic spectrum. The radiation can constitute a hazard to personnel. The degree to which personnel are exposed to the radiation depends on the type of platform, the systems installed, the location of the systems (particularly their antennas), the possibility of directive antennas illuminating areas occupied by personnel, etc.

The effects of exposure to this radiation can be classified into two categories, direct and indirect. Direct radiation is defined as the energy impinging directly on the body. Indirect radiation is defined as the capture of EM energy by a metallic object. Resulting voltage and currents cause burns when these metallic objects are contacted by personnel.

With certain reservations, physiologists and biologists generally agree that damage to personnel from direct radiation is primarily a heating effect.

In recent years, however, many distinctly nonthermal effects have been documented, some of which have been shown to be dependent on peak powers whose average value is not great enough to produce heating. Frequency dependence, with no heating, has also characterized many of the observed effects. While the full significance of these effects as human hazards has not been established, the fact that they occur at average power levels considered to be negligible suggests that, at the least, an awareness of their existence should be assumed. Some recorded nonthermal effects listed in MIL-HDBK-238(NAVY) of 10 August 1973 (ref 4) are:

-
3. TESSAC Final Report for EM Vulnerability, Naval Surface Weapons Center, 2 June 1977
 4. MIL-HDBK-238, "Electromagnetic Radiation Hazards," 10 August 1973

1. Minor changes in human blood properties upon exposure to EM energy of proper frequency and intensity.
2. Auditory response. Certain people hear a buzz when exposed to microwave radiation. The sensation of sound is probably not the microwave frequency but response to the pulse repetition frequency.
3. Abnormalities of the chromosome structure occurring upon exposure.
4. Movement, orientation, and polarization of protein molecules in pulsed rf fields.
5. Unexplained response of man to radar. Epigastric distress, emotional upsets, and nausea may occasionally occur at as low as 5-10 mW/cm² and are most commonly associated with the frequency range from

$$8 \times 10^3 \quad \text{to} \quad 12 \times 10^3 \quad \text{MHz.}$$

Changes in the transport rate of materials across the blood-brain barrier in humans and animals have also been observed. The significance of these changes is not yet understood.

The development of a safety instruction for microwave radiation hazards is the responsibility of the Bureau of Medicine and Surgery (BUMED) of the US Navy. In order to develop and validate the safety criteria for the BUMED instruction, the Naval Medical Research and Development Command (NMRDC) sponsors research in the area of electromagnetic radiation on biological materials. The present criteria are delineated by BUMED INST 6470.13A of 28 January 1977 (ref 5).

"Personnel shall not be exposed to a power density which, when averaged over any 0.1 hour period, exceeds 10 mW/cm² in the frequency domain of 10 MHz - 100 GHz. Neither the root mean squared electric field strength (E) nor the root mean squared magnetic field strength (H) may exceed the following values when averaged over any 0.1 hour period:

$$E = 200 \frac{\text{Volts}}{\text{Meter}}$$

$$H = 0.5 \frac{\text{Ampere-turns}}{\text{Meter}}$$

(These are the electric and magnetic field strengths roughly corresponding to electromagnetic waves in free space to which a value of power density of 10 mW/cm² may be assigned.) For a condition where exposure is not regular in time or continuous in level over the 0.1 hour period, the equivalent energy fluence level of 1 mW-h/cm² may be used as the limit of exposure for any 0.1 hour period. In situations where measurements of two or more quantities are available, the most restrictive shall be used as the limiting factor. For power density constant in time, the basic standard is shown in figure 1."

For the hf region, the 200-V/m level is generally believed to be too conservative

5. BUMEDINST 6470.13A, "Microwave and Radio Frequency Health Hazards," 28 January 1977

(ref 4). For example, on the basis of their analysis and experimental work, Rogers and King (ref 6) suggest that under plane-wave conditions (far field) an electric field strength of 1000 V/m be considered the safety limit for continuous exposure to radio-frequency radiation in the range below 30 MHz.

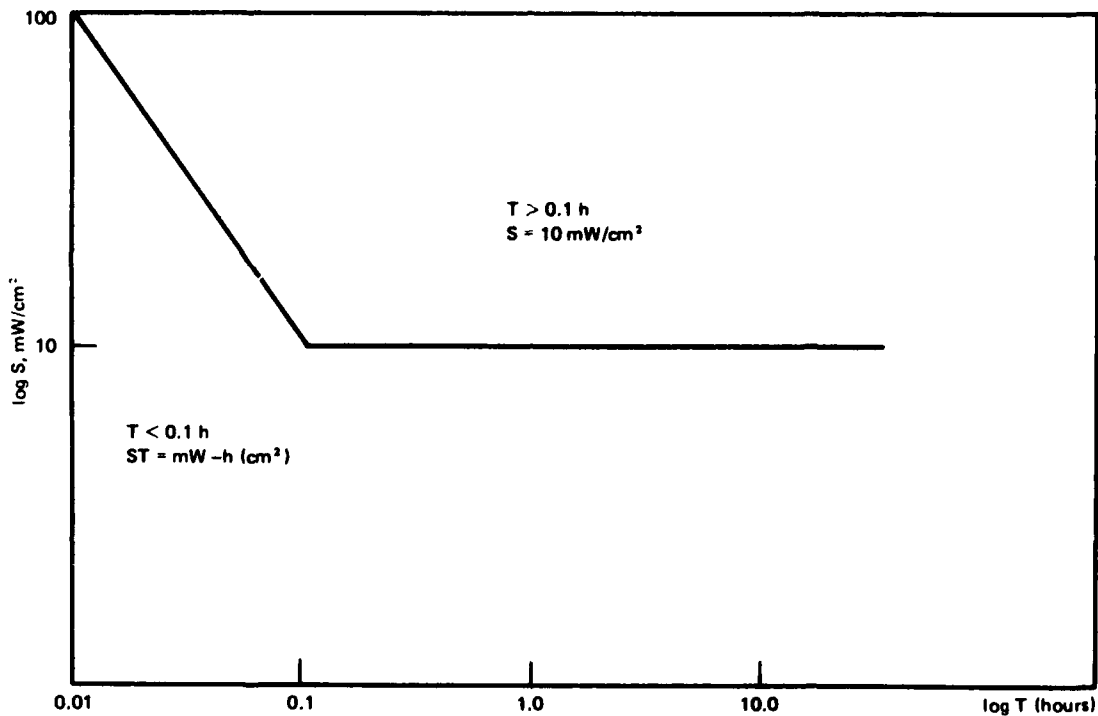


Figure 1. Duration of exposures (T) at power density (S) (ref. 5).

Rf burns constitute an indirect radiation effect. Ship communication transmitters induce voltages on various metallic structures such as underway replenishment gear, booms, and loading hooks. The voltages are capable of causing painful burns to personnel who come in contact with these structures. The problem is encountered most often on logistic support ships such as AO, AOR, AOE, and AS and aviation facility ships such as FF and LPH.

The presently accepted level to prevent rf burns has been empirically developed by the Naval Ship Engineering Center (ref 7). It has been established that 140 volts or greater, measured from the object to ground, can cause burns to persons touching the object.

6. Rogers, SJ and King, RS, "Radio Hazards in the MF/HF Band," Non-Ionizing Radiation, vol 1, p 178-189, 1970
7. Roman, J, "RF Burn Hazards Aboard Navy Ships," NAVSEA Journal, Naval Sea Systems Command, September 1974

HAZARDS OF ELECTROMAGNETIC RADIATION TO ORDNANCE (HERO)

Hazards of electromagnetic radiation to ordnance (HERO) stem from the use of sensitive electroexplosive devices (EEDs) in ordnance systems. The principal emphasis is on protecting electroexplosive devices such as squibs, detonators, explosive switches, and ejection cartridges. Premature actuation of some of these devices can, of course, have dire consequences, such as rocket ignition or warhead detonation on a flight deck. Premature actuation by rf can also impact the reliability of a system, as for example when the power supply for a missile guidance system is expanded inadvertently by the rf initiation of a squib switch. In addition, EED firing characteristics can be altered by electromagnetically induced heating.

For the above reasons NAVMAT Instruction 5101.1 requires that weapon systems and devices containing EEDs be reviewed and tested (if deemed necessary) and positive certification obtained that they can be handled with impunity in the maximum predicted electromagnetic environment before introduction for service use. Three classifications pertinent to HERO for ordnance items have been established. The classifications are based on weapon susceptibility. The degree of susceptibility is dependent upon the electromagnetic environment, the potential for the induction of electromagnetic energy into the ordnance system, and the characteristics of the EED. Items that are negligibly susceptible and require no field intensity restrictions beyond general requirements during all phases of normal employment are classified as HERO SAFE ORDNANCE. Items that are moderately susceptible and require moderate field intensity restrictions for at least some phases of employment are classified as HERO SUSCEPTIBLE ORDNANCE SYSTEMS. Items that are highly susceptible and require severe field intensity restrictions for some or all phases of employment are classified as HERO UNSAFE ORDNANCE (ref 8).

An extensive testing program exists to define HERO problem areas and ensure the safety and reliability of ordnance items. Tests are conducted in the maximum rf environments to which ordnance items will be exposed during the stockpile-to-launch sequence. Table 1 contains the criteria environment (ref 8). This implies that HERO SAFE ORDNANCE items have been tested to be safe and reliable in the criteria environments.

HAZARDS OF ELECTROMAGNETIC RADIATION TO FUELS (HERF)

The possibility of accidentally igniting gasoline at shore facilities and aboard aircraft carriers and other ships handling fuel has been considered when rf-induced sparks have been observed (ref 9). Many years ago the Navy conducted extensive tests and investigations of this problem both in laboratories and on ships. The tests showed that the probability of ignition of fuel vapors by rf-induced sparks was small because the following conditions must occur simultaneously for ignition to take place.

-
8. NAVELEX 0101,106, "Electromagnetic Compatibility and Electromagnetic Radiation Hazards," August 1971
 9. TESSAC Electromagnetic Safety Study Group Final Report, NAVSEC, 31 May 1977

- Fuels must be heated above their flash points. Flammability ranges (flash point ranges) of commonly used fuels are presented in figure 2. Fuels will not ignite unless oxygen is provided in certain specific and exact proportions. Fuels will also not detonate unless certain exact proportions of oxygen and fuel are maintained.
- Sufficient energy must be provided to sustain ignition. Although radiated energy is the primary source of energy associated with HERF phenomena, no mechanism exists by which this energy can interact directly with the fuel. Radiated energies are capable of causing arcing in susceptible structures. It is these arcs which produce ignition of the fuels.

An arc is a voltage breakdown between two fixed electrodes. It takes a certain amount of voltage to break down the dielectric between the electrodes, but it takes energy behind this source of voltage to sustain the arc for sufficient duration to ignite fuel mixtures. A spark, on the other hand, is formed when two metallic objects in electrical contact are separated and there is sufficient energy between these electrodes to sustain the spark and thus cause ignition. This is similar to the situation in which a fueling nozzle is withdrawn from the tank opening when an aircraft is being fueled. The radiation field intensity in the proximity of a radiating antenna could be sufficient to induce the required energy.

From actual measurements, it has been determined that a spark of energy of 50 V-A is required to ignite gasoline in an explosive vapor test device. Recently, some attempt has been made to relate the fuel hazard to electric field intensity. The primary result has been to show that the igniting electric field intensity is a function of frequency and is minimal in the upper hf band.

Table 1. Criteria environment.

FREQUENCY	ELECTRIC FIELD (V/M)	MAGNETIC FIELD (ampere-turns/meter)	AVG POWER DENSITY (mW/cm ²)
Communications Equipment			
250-535 kHz	300	0.5	
2-32 MHz	100	0.5	
100-156 MHz			0.01
225-400 MHz			0.01
Radar Equipment			
200-225 MHz			10
400-450 MHz			1
1. 0-1.3 GHz			1
2. 7-3.6 GHz			10
5. 4-5.9 GHz			100
8. 5-10.3 GHz			100

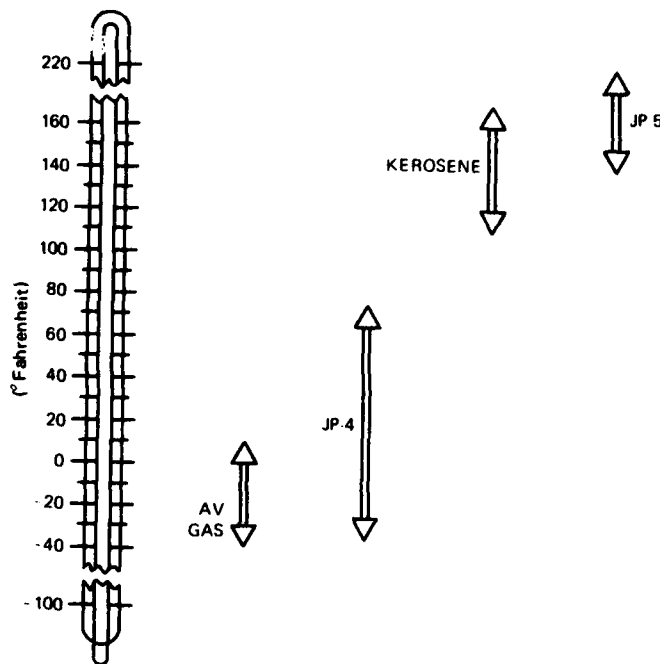


Figure 2. Flammability ranges for commonly used fuels.⁴ $(t^{\circ}\text{F} - 32)/1.8 = t^{\circ}\text{C}$.

In recent years, the probability of occurrence of this particular hazard has been further decreased with the following advances in technology.

Ship Design. In the design of ship topside arrangements, the location of fuel handling stations, fuel vents, etc, is considered relative to the placement of rf transmitting antennas. Every effort is made to locate these antennas away from fuel stations and vents.

Fuel Nozzle Modifications. Heat shrinkable tubing is applied to nozzles used in conventional gasoline fueling. This prevents metal-to-metal contact between the nozzle and the filler tube, thus eliminating the possibility that a spark will occur. Another hazard-reducing development in the aircraft refueling area has been the introduction of the pressurized fueling approach. In this procedure, the fuel nozzle contacts the metallic filler tube of the aircraft prior to the opening of the valve to the tank. Thus, if a spark should occur, there would be no flammable fuel-air mixture to ignite.

Fuel. The type of fuel now being most extensively used is JP-5, which has low volatility compared to gasoline. This is shown in figure 2. Because JP-5 does not have the volatility of gasoline, it is not likely to produce flammable fuel-air mixtures under accidental circumstances. This has done much to reduce the fuel hazard aboard ships. The fuel oil which powers the ships themselves is still less flammable than JP-5.

CHAPTER 3. APPROACH

NUMERICAL ELECTROMAGNETIC CODE

The Numerical Electromagnetic Code (NEC) is a user-oriented computer code for the analysis of the electromagnetic response of antennas and other metal structures. It is built around the numerical solution of integral equations for the currents induced on the structure by sources or incident fields. This approach avoids many of the simplifying assumptions required by other solution methods and provides a highly accurate and versatile tool for electromagnetic analysis.

The code combines an integral equation for smooth surfaces with one for wires to provide convenient and accurate modeling of a wide range of structures. A model may include nonradiating networks and transmission lines connecting parts of the structure, perfect or imperfect conductors, and lumped-element loading. A structure may also be modeled over a ground plane that may be either a perfect or an imperfect conductor.

The excitation may be either voltage sources on the structure or an incident plane wave of linear or elliptic polarization. The output may include induced currents and charges, near electric or magnetic fields, and radiated fields. Hence, the program is suited to either antenna analysis or scattering and Electromagnetic Pulse (EMP) studies.

The integral equation approach is best suited to structures with dimensions up to several wavelengths. Although there is no theoretical size limit, the numerical solution requires a matrix equation of increasing order as the structure size is increased relative to wavelength. Hence, modeling very large structures may require more computer time and file storage than is practical on a particular machine. In such cases, standard high-frequency approximations such as geometrical or physical optics, or geometric theory of diffraction may be more suitable than the integral equation approach used in NEC.

Part I of reference 1 includes the equations on which the NEC code is based and a discussion of the approximations and numerical methods used in the numerical solution. Part II: NEC Program Description describes the coding in detail. Part III: NEC User's Guide contains instructions for using the code, including preparation of input and interpretation of output.

The NEC program uses both an electric field integral equation (EFIE) and a magnetic field integral equation (MFIE) to model the electromagnetic response of general structures. Each equation has advantages for particular structure types. The EFIE is well suited for thin-wire structures of small or vanishing conductor volume while the MFIE, which fails for the thin-wire case, is more attractive for voluminous structures, especially those having large smooth surfaces. The EFIE can also be used to model surfaces and is preferred for thin structures which have little separation between front and back surfaces. Although the EFIE is specialized to thin wires, in this program it has been used to represent surfaces by wire grids with reasonable success for far field quantities but with variable accuracy for surface fields. For a structure containing both wires and surfaces the EFIE and

MFIE are coupled. The combination of the EFIE and MFIE was proposed and used by Albertsen, Hansen, and Jensen at the Technical University of Denmark (ref 10). Details of their numerical solution differ from those in NEC. A rigorous derivation of the EFIE and MFIE used in NEC is given by Poggio and Miller (ref 11).

In NEC, the EFIE and MFIE integral equations are solved numerically for the current distribution by a form of the method of moments. A general introduction to the method of moments can be found in reference 12.

Once the current distribution is computed, all effects of the antenna structure can be determined. The near field values are calculated by the method described by Adams, Baldwin, and Warren (ref 13). The peak electric field strength is not directly related to the sum of the squares and must be calculated by the method described by Adams and Mendelovicz (ref 14).

COMPUTATIONAL ACCURACY

The calculated impedances of the Navy shipboard hf transmit antennas compare well with measurements. References 15-17 show this comparison. These references verify this application of the Numerical Electromagnetic Code. The calculation of impedance and near fields requires significantly more accurate knowledge of the current distribution on the antenna structure than the calculation of the far field (ref 18). Similarly, the impedance requires more accurate current distribution than the near fields. Thus, for a given current distribution, accuracy of a field calculation improves rapidly with distance from the antenna.

In conjunction with analytical computations, near field measurements for a whip over an extended ground plane were made with an E-field sensor, EFS-1, manufactured by

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10. Albertsen, NC, Hansen, JE and Jensen, NE, "Computation of Spacecraft Antenna Radiation Patterns," The Technical University of Denmark, Lyngby, Denmark, June 1977
 11. Poggio, AJ and Miller, EK, "Integral Equation Solutions of Three-Dimensional Scattering Problems," chap IV, Computer Techniques for Electromagnetics, edited by R Mittra, Pergamon Press, New York, 1973
 12. Harrington, RF, Field Computation by Moment Methods, McMillan, New York, 1968
 13. Adams, AT, Baldwin, TE, and Warren, DI, "Electric and Magnetic Near Fields of Arrays of Straight Wires," 1972 IEEE International Electromagnetic Compatibility Symposium Record, 1972
 14. Adams, AT, and Mendelovicz, E, "The Near-Field Polarization Ellipse," IEEE Transactions on Antennas and Propagation, January 1973
 15. Burke, GJ and Poggio, AJ, "Computer Analysis of the Twin-Whip Antenna," Lawrence Livermore Laboratory, Report UCRL-52080, 1 June 1976
 16. Burke, GJ and Poggio, AJ, "Computer Analysis of the Bottom-Fed Fan Antenna," Report UCRL-52109, 19 August 1976
 17. Deadrick, FJ, Burke, GJ, and Poggio, AJ, "Computer Analysis of the Trussed-Whip and Discone-Cage Antennas," Report UCRL-52201, 6 January 1977
 18. King, RWP, "The Lingar Antenna Eight Years of Progress," Proceedings of the IEEE, vol 55, no 1, January 1967

Instruments for Industry, Inc (ref 19). Figure 3 compares these measurements with the numerical computations for the case of a 35-foot whip at 2 MHz. The comparisons are made at 1 meter above the extended ground plane. As indicated above, the accuracy of E improves with distance from the whip antenna. Thus, the increased discrepancy between measurement and calculation is attributable to measurement inaccuracy. With this consideration, the calculations compare well with the measurements.

The Numerical Electromagnetic Code can also be used to model the effect of the shipboard environment on the electric near field structure. The computational accuracy for this application is discussed in reference 20. This report presents the development of methodology for the utilization of the two presently available techniques for modeling ships in the hf range. One technique is referred to as wire grid modeling (ref 21-23) and the other as surface patch modeling (ref 24).

The wire grid modeling approach approximates the antennas and all surfaces on the ship with thin wires. Surfaces are represented as wire grids in which the grid cells are much smaller than the wavelength. In surface patch modeling, a two-dimensional field equation and appropriate surface boundary conditions are applied to solve for two components of current on small patches representing the actual surface. Either an electric field integral equation (EFIE) or a magnetic field integral equation (MFIE) may be used.

In reference 20, it is shown that either wire grid or surface patch modeling can provide data upon which engineering decisions can be based. Wire gridding provides a somewhat greater degree of confidence--ie, slightly more accurate data-- than does surface patch modeling. However, surface patch modeling offers approximately 30% savings in computer costs.

-
19. NELC TD 359, "Thin-Wire Modeling Techniques Applied to Antenna Analysis," by JW Rockway and JC Logan, 11 October 1974
 20. NELC TN 3284, "Computer Techniques for Shipboard Topside Antenna Modeling Below UHF," JC Logan and JW Rockway, 17 November 1976
 21. Lin, YT, and Richmond, JH, "EM Modeling of Aircraft at Low Frequencies," IEEE Transactions on Antennas and Propagation, vol AP-23, no 1, January 1975
 22. Forgan, DH, "Computation of the Performance of HF Aerials Mounted on Aircraft," Royal Aircraft Establishment Technical Report, TR 74077, August 1974
 23. Lin, JL, Curtis, WL, and Vincent, MC, "Radar Cross Section a Rectangular Conducting Plate by Wire Mesh Modeling," IEEE Transactions on Antennas and Propagation, vol AP-22, no 5, September 1974
 24. Albertson, NC, Hansen, JE, and Jensen, NE, "Computation of Spacecraft Antenna Radiation Patterns," The Technical University of Denmark, Lyngby, Denmark, June 1972

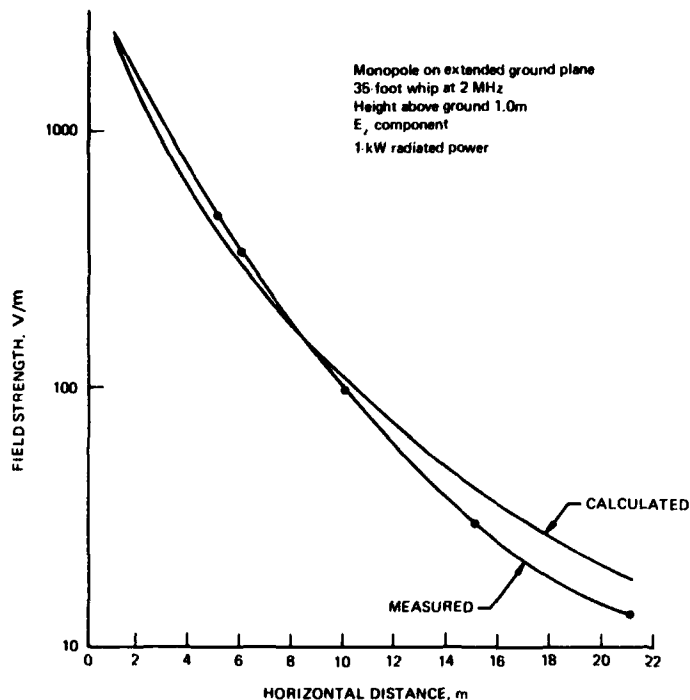


Figure 3. Comparison of measured and calculated peak electric near fields.

CHAPTER 4. NEAR FIELD CHARACTERISTICS OF HF ANTENNAS ON EXTENDED GROUND PLANE

The near fields of the five Navy shipboard antennas described in appendix A have been calculated by use of NEC, the code presented in chapter 3. The results of these calculations are plotted in appendix B. The plots show the peak electric fields in the antenna near zones at 1 and 2 meters above the ground plane for various frequencies between 2 and 30 MHz. The fields are produced by 1.0-kW radiated power but may easily be scaled to any desired radiated power.

These near field calculations show that Navy shipboard hf antennas have similar near field characteristics when mounted on a ground plane. The same characteristics were pointed out by Rockway and Hansen (ref 2) in an earlier study of the near fields of the 35-foot whip antenna.

Rockway and Hansen calculated the near fields of a 35-foot whip on a ground plane driven by a 1-kW transmitter through an AN/URA-38 tuner. They demonstrated the variation of the near fields with height and frequency. Similar calculations made for the current study concur with their findings.

Close to the 35-foot whip at frequencies from 2 to 6 MHz (below first resonance), the greatest field distribution occurs at a height of 1 meter. At higher frequencies, the location of the maximum varies. The height variation of the maximum near fields with frequency depends on the variation of the current distribution on the antenna as it passes through various resonances. It is also affected by the fact that the ground plane cancels horizontal electric fields.

The near fields also have an inverse relation to the distance in wavelengths from the antenna. In wavelengths, 1 meter is much closer to the antenna at 2 and 4 MHz than at higher frequencies. This means the lower hf band will have greater near fields than the upper band at 1 and 2 meters from the antenna.

Another important characteristic is that the near fields are minimal at resonant frequencies. In the case of the 35-foot whip, the first resonance occurs near 7 MHz. The near fields rise and fall as the frequency is increased above 7 MHz through these various resonances. As the frequency decreases below the first resonance, the Q of the antenna increases and the near fields also increase. The maximum near fields within 1 and 2 meters from the antenna occur at the lowest transmit frequency below first resonance. This is also the frequency at which the antenna Q is highest. The calculations of Rockway and Hansen show this is true for the 35-foot whip even when tuner loss is taken into account.

A similar case can be stated in turn for each of the five antennas in this study. In summary, for hf antennas on a ground plane:

1. The near fields are greatest in the lower hf band below the first resonance and close to the antenna. The maximum occurs at the lowest transmit frequency.
2. The shorter the antenna is electrically, the higher the near fields.
3. Minimal near fields occur at resonant frequencies.

CHAPTER 5. NEAR FIELD CHARACTERISTICS OF HF ANTENNAS IN A STRUCTURED ENVIRONMENT

The characteristics of the near fields of Navy shipboard whip antennas in a structured environment were previously investigated by Rockway and Hansen (ref 2). They considered a whip mounted on a ground plane near a conducting infinite vertical plane and the same whip mounted in a corner formed by the intersection of two infinite vertical conducting planes and the ground plane. They also used a method of moments approach to calculate the near fields. The present study is an extension of their work.

Rockway and Hansen showed how a whip antenna is detuned by the addition of a nearby large vertical surface. Below first resonance, as the antenna is moved closer to the vertical surface, the Q of the antenna increases and the near fields increase for a given level of radiated power. The most pronounced increase occurs in the space between the antenna and the vertical surface. However, the presence of the vertical surface increases the Q of the antenna as it is brought closer, resulting in increased tuner insertion loss for the case of the base-tuned Navy whips. Consequently, with fixed available transmitter power, the hazardous near field zone remains about the same with or without the vertical surface present.

The present study used NEC, described in chapter 3, to calculate the near fields of a 35-foot whip antenna in two structured configurations. The first configuration is a 35-foot whip mounted on a box which in turn is on an infinite ground plane. The box dimensions are similar to those of a deckhouse on a small ship. Both center mounting and edge mounting are considered. For convenience of easy reference, the details of each configuration are presented in appendix C and the results of the calculations are plotted in appendix D.

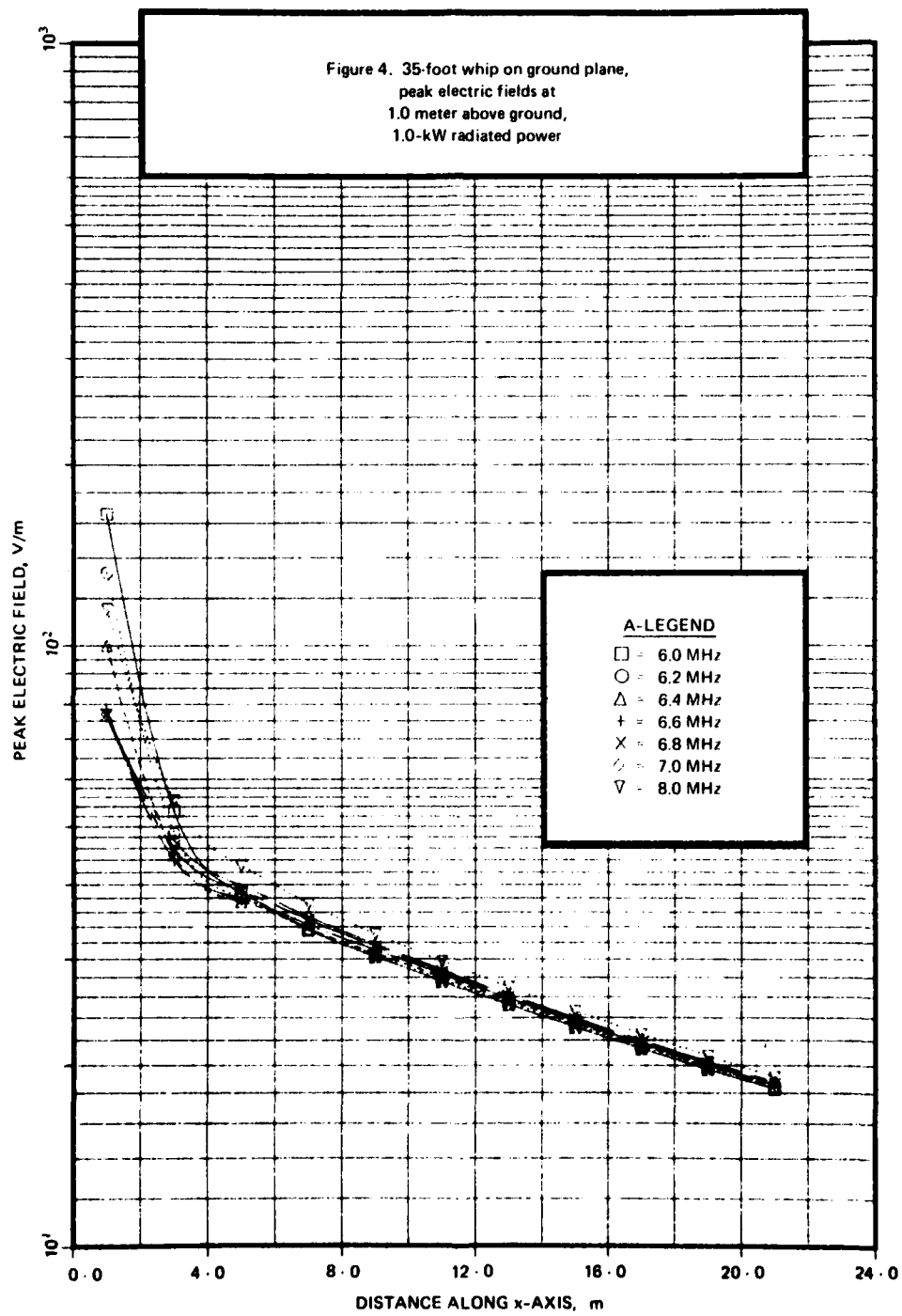
The near fields of a 35-foot whip mounted at the center of a deckhouse for various frequencies from 2 to 30 MHz are shown in figures D1 through D3. Figure C1 defines the coordinates and locations of the near field data. Figures D4 through D6 show the near fields when the whip is at the deck edge on top of the deckhouse. Figure C2 defines this configuration. Comparison between these sets of data and also, comparison to the near fields of the 35-foot whip alone on a ground plane (fig B1) lead to the following observations.

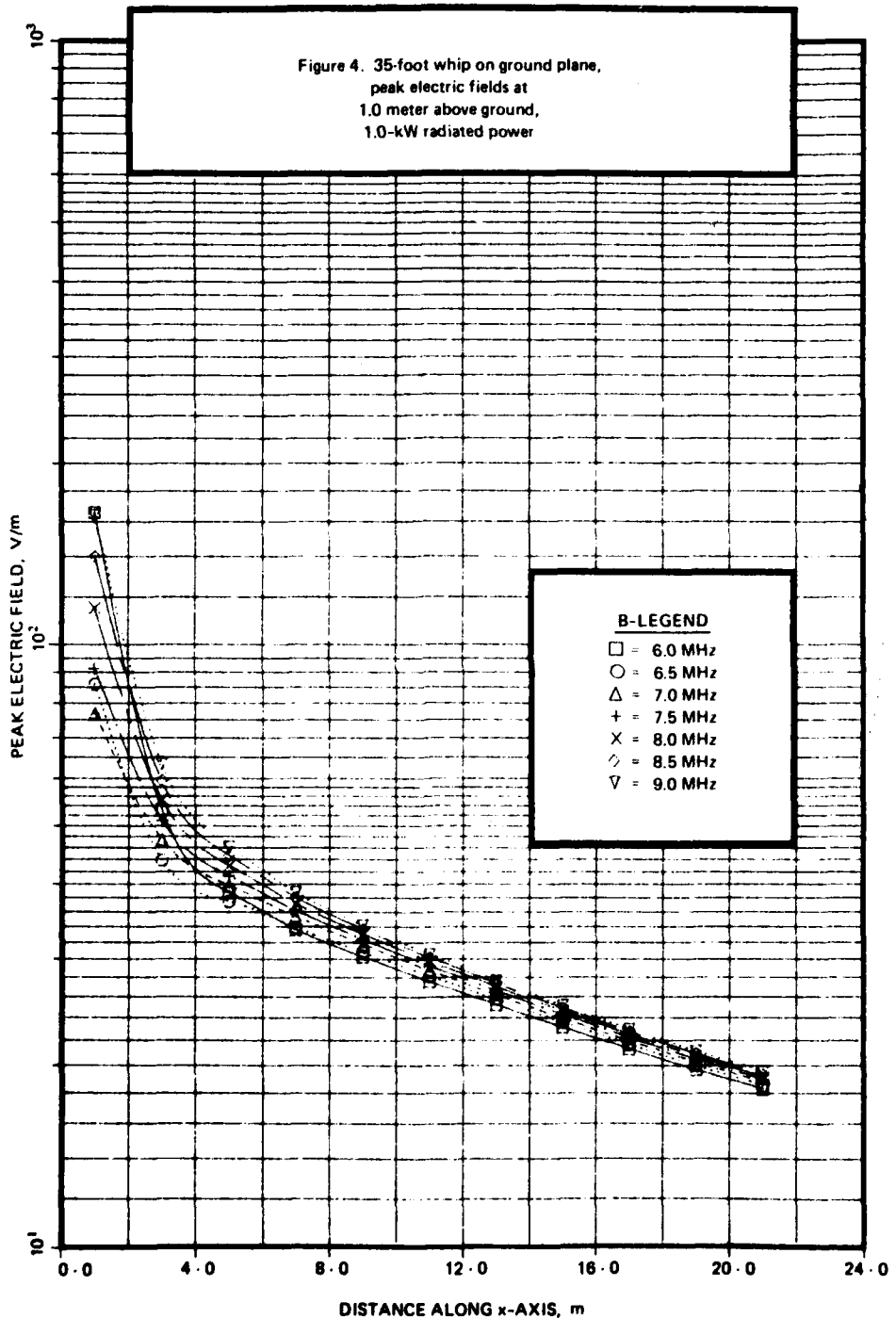
The maximum near fields occur close to the antenna near its base and at the lowest transmit frequency below first resonance. Since the near fields close to the antenna (1-2 meters) are in proportion to the current distribution, the highest near fields will occur in the vicinity of the highest currents. In the case of the whip, the highest currents are near the feedpoint below first resonance. Even when the antenna is mounted on the deckhouse edge, the highest currents are near its base, and this is where the maximum fields are found.

The effects of mounting the whip on a deckhouse are more pronounced when it is mounted on the deck edge than when it is mounted in the center. Away from the edge, the added vertical height is compromised by the horizontal surface about the antenna base. When the whip is mounted at deck edge, the currents on the vertical surface are greater and enhance radiation and lower the Q of the antenna. In practice, deck edge mounting lowers the first resonance frequency, in effect lengthening the antenna and decreasing its Q. The slight decrease in the Q of the antenna correlates to a slight decrease in the near field levels. The near fields below first resonance and close to the antenna are greatest for the antenna mounted alone on a ground plane.

The near fields of a 35-foot whip mounted on a ground plane with a parasite whip (undriven, grounded whip) close by are plotted in figures D7 through D12. Shown are the near fields for parasite lengths at various separation distances and frequencies from 6 to 8 MHz. These frequencies were chosen to be near the resonance of either the parasite or whip. The parasite lengths were chosen to resonate at the same frequency as the whip and at a slightly higher frequency. A brief description of the geometry used for the near field calculations is given in appendix C.

Some useful observations can be made by comparison of figures D7 through D12. A closely coupled parasite increases the Q of the transmitting antenna, resulting in higher near field levels close to the transmitting antenna. The smaller the spacing, the more pronounced the effect. Also, the effects of the parasite are greatest as it passes through resonance and, in fact, the fields near the parasite peak at its resonance.





The near fields produced by a 35-foot whip radiating the same power without a parasite are given in figures 4A and 4B. Compare figures D7 through D9 to figure 4A and compare figures D10 through D12 to figure 4B. The fields close to the parasite are higher than would be produced at the same distance from the whip without the parasite. The fields close to the whip are somewhat greater with the parasite than without. However, the greatest near fields still occur at the lowest frequency below first resonance of the transmit antenna, and the ground plane results without the parasite can be used for a bound on the expected near fields.

The findings of this chapter in summary are as follows:

1. The hazardous region about an hf antenna is not a strong function of the structure surrounding it.
2. Surrounding structure can cause an increase of the Q of an antenna.
3. Nearby structures that become resonant may cause an increase in near field levels between the antenna and structure above that found for the antenna alone but only at the resonant frequency of the parasite structure.
4. The most significant effect of mounting an hf antenna on an elevated platform such as a ship is to lengthen the antenna, thus lowering the frequency of its normal first resonance. This means that the near fields are reduced somewhat from that predicted for the ground plane case for a given frequency.

CHAPTER 6. A BOUNDING ALGORITHM FOR NEAR FIELDS

The analysis of a shipboard antenna configuration with respect to HERP, HERO, and HERF requirements can generally be performed without a precise and detailed survey of the near fields. For most engineering applications, the prediction of the maximum near fields is sufficient. A precise and detailed survey is generally too costly both in dollars and in time and provides minimal contribution towards the engineering decisions. In addition, the actual dimensions and shape of the ship may not be known early enough in the ship design cycle to make such a survey practical. The results of the previous chapters and the graphs of appendices B and D can be used to establish the upper bound on the near fields of Navy shipboard hf antennas and, thus, can be used at the onset of the ship design cycle.

The near field bounding algorithm consists of four principles. The first three are derived from the results of the previous chapters. The fourth is a principle of any linear medium.

- Principle 1:** The near fields closest to an antenna are maximum at the lowest transmit frequency below first resonance.
- Principle 2:** The near fields are as great or greater for an antenna mounted on a ground plane than for the same antenna aboard ship.
- Principle 3:** The near fields are not significantly changed by the addition of a parasite close to an antenna. The near fields are only slightly increased because of close-by parasites with the maximum effect between the antenna and the parasite. The field about the parasite reaches a maximum at the first resonant frequency of the parasite.

Principle 4: The near fields are directly proportional to the square root of the power radiated.

Some additional remarks are necessary for the appropriate application of these principles.

Navy hf antennas for shipboard applications fall into two categories: (1) high-Q, tuned antennas driven by a single transmitter, and (2) low-Q, broadband antennas driven by up to five transmitters simultaneously through multicouplers. For given transmitter power, the near fields of the high-Q antennas depend on tuner loss and antenna environment. Tuner loss is a function of frequency and antenna environment. Likewise, the near fields of the low-Q antennas depend on the insertion loss of the multicouplers and the antenna environment. However, the multicoupler insertion loss is generally frequency independent with practically no influence from the antenna environment. The effect of mounting a high-Q antenna on a deck edge is to make the antenna appear longer, lowering the antenna Q from what it would be on a ground plane. This effect is somewhat less pronounced if the antenna is mounted away from the edge towards the deck center. The lower Q reduces the tuner insertion loss, providing potentially more power from the transmitter and higher near fields. But the increased effective length is equivalent to a downward frequency shift in the first resonance, resulting in reduced near fields. The latter is the dominant effect so that if the radiated power is known, the ground plane results would set the upper bound.

Usually, the power available from the transmitter is known rather than the radiated power. Determination of the radiated power for the antenna mounted on a ship can be expensive and time consuming. Also, using the near fields for the ground plane case corrected to the transmitter power level may be much too conservative. A closer estimate of the upper bound can be obtained by correcting the ground plane results for the tuner loss obtained in the ground plane configuration. The tuner loss can be determined from the impedance of the antenna on the ground plane, which most of the time is easily and readily obtained. Rockway and Hansen (ref 2) have shown that the transmitter power level and tuner insertion loss give an accurate bound to the near fields of the 35-foot antenna in a shipboard environment. This will also be true for other high-Q (tuned) hf antennas. The upper bound for a low-Q, broadband antenna is simpler to determine. Given the same power radiated, the near fields of the ground configuration set the upper bound. Since the multicoupler insertion loss is usually insensitive to frequency and loading, the correction of the near fields to the transmitter power level is the same for both the ground plane and shipboard configurations. Assuming all the power delivered to the antenna terminals is radiated, the near fields are corrected for the radiated power by using principle 4.

Topside structures such as masts and other hf antennas are closely coupled to a given antenna at the low end of the hf band and can affect the near fields. Fortunately, parasites have their maximum effect on the near fields at a frequency close to the quarter-wavelength resonance of the parasite. Neglecting other hf antennas, only one or two structures on a given ship will be quarter-wave resonant in the lower hf band. At higher frequencies the near fields are significantly lower and thus need not be considered in the bounding algorithm. In most cases the effects of the parasites can be ignored and the upper bound determined by appropriately scaling the near fields for the ground plane configuration. For those cases in which an important contribution to the near fields due to a struc-

ture or another hf antenna acting as a parasite is suspected, the antenna and the parasite should be modeled in the ground plane configuration and the results scaled to the appropriate power level. Problems of this type must be addressed on an individual basis. Care must be taken to identify potential problems due to parasites in any determination of the near field bound.

As an example of the application of the bounding technique, consider the following problem. A discone-cage antenna is to be mounted on the bow of USS GEORGE SPELVIN. A 1.0-kW transmitter will drive the antenna through an AN/SRA-57 multicoupler in the frequency range of 4 to 12 MHz. Some equipments which are susceptible to fields in this frequency range are to be located nearby about 1.0 meter above the deck. The equipments can tolerate fields up to 50.0 volts/meter. The problem is to determine the safety zone for locating the equipments.

According to principle 2, the near fields given in figure B13 can be used to bound this problem. Assuming the equipments will not be located very close to structures that may be quarter-wave resonant between 4 and 12 MHz, the effects of parasites may be neglected (principle 3).

The near field data in figure B13 are for odd frequencies starting at 3 MHz. The near fields dip at the first resonance near 5 MHz. Following principle 1, the fields at 3 MHz will be used. These fields are for 1000 watts of radiated power. Measurements indicate that the insertion loss of the AN/SRA-57 is about 2.0 dB; ie, about 631 watts will be radiated when driven by a 1-kW transmitter. Principle 4 can be used to scale the 50-volt/meter criterion to the 1000-watt level as follows:

$$50 \sqrt{\frac{1000}{631}} = 62.9 \text{ volts/meter.}$$

From B13, 62.9 volts/meter occurs at about X = 6.8 meters, or 22.3 feet. The conclusion is that the equipments should be located at least 22.3 feet from the center of the discone-cage.

APPENDIX A: HF ANTENNAS ON EXTENDED GROUND PLANE

This appendix discusses five hf transmit antennas configured on an infinite perfectly conducting or extended ground plane. The five antennas are:

35-Foot Whip Antenna
35-Foot Trussed-Whip Antenna
35-Foot Twin-Whip Antenna
Discone-Cage Antenna
Bottom-Fed Fan Antenna

A general description and installation guidance for each of these antennas are given in the following sections. The results of the near field calculations are presented in appendix B. Table B1 is a summary of the calculations.

35-FOOT WHIP ANTENNA

Both the NT-66047 and the AS-2537/SR are basically 35-foot whips (fig A1) (ref A1).

The NT-66047 has been for many years the standard Navy shipboard whip for transmitting and receiving at hf. It is constructed from aluminum in five tapered sections. The whip is mounted on the IL-18/U or IL-19/U ceramic insulator. The AS-2357 whips are replacements for the NT-66047. The AS-2537 is made in two fiber-glass sections bolted together with an integral mounting base of steel included in the lower section. The radiating portion of the antenna consists of six beryllium-copper strips laminated in fiber glass. In the AS-2537A, the two whip sections screw together and the insulator portion is also fiber glass.

Installation guidance for base-tuned hf transmitting whip antennas has the following general objectives:

- To locate the antenna so that its feedpoint impedance variations will be within the tuning range of the commonly used coupler (CU-938, AN/SRA-22, AN/URA-38).
- To achieve the pattern coverage required by the applicable design approach. Omnidirectional coverage is generally desired; however, when the number of whips to be located exceeds the number of locations which enable omnidirectional coverage, it may be necessary to accept complementary coverage for pairs of whips.

A1 NECL TD 356, "Shipboard Antenna and Topside Arrangement Guidance," by DW Dubrul and LM Peters, 1 September 1974

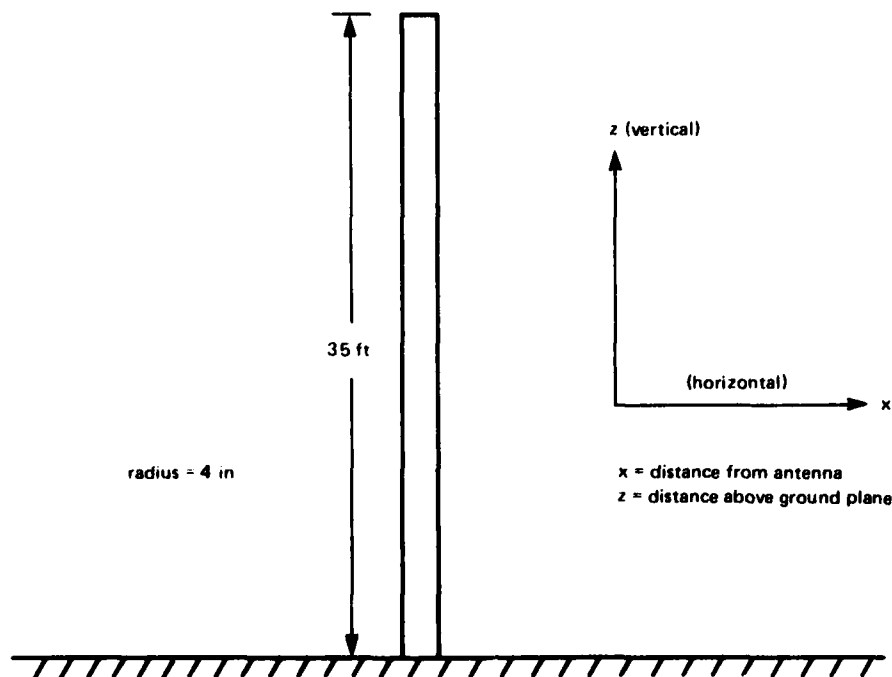


Figure A1. 35-foot whip antenna.

- To observe operating clearance requirements of other ship systems and helicopters.
- To avoid radiation and shock hazards to personnel.

The typical hf whip will usually have a range of feedpoint impedances within the tuning range of the available couplers if it is at least 35 feet from other antennas or structures higher than the whip base elevation. Experience indicates that whip antennas equipped with AN/URA-38 couplers may fail to automatically tune at certain frequencies if they are not separated by at least 30 feet.

The desirable separation distance between an hf transmitting whip and an hf receiving antenna depends on the equipment to which the receiving antenna is connected. When a multicoupler having good adjacent-channel rejection is used, there is less need for space isolation; however, if an AN/SRA-12 receiving filter is used or if an adjacent base-tuned whip is connected to a transceiver, greater space isolation is required. The tuners used with the base-tuned whip are primarily impedance-matching devices which do not have good adjacent-channel signal rejection. The AN/SRA-12 multicoupler has a series of bandpass filters which provide no discrimination between signals common to one of the several passbands. Both these equipments are liable to permit excessive rf power to be coupled into the associated receiver from on-board transmitters unless adequate space isolation exists between the respective antennas. In some cases, circuit components have

been damaged in the AN/SRA-12 filter unit because of high rf power from on-board transmissions.

Separation between hf receiving and transmitting whips will also be influenced by the design approach decision regarding the establishment of topside zones for locating receiving and transmitting antennas.

Satisfactory omnidirectional radiation patterns cannot be achieved for all frequencies in the 2-30-MHz band on any ship having a sizable mast structure above the mounting elevation of any particular antenna. Pattern degradation due to structural interference can be reduced by increasing the distance between the antenna and the structure.

Antennas centrally located on horizontal conducting plane surfaces are likely to have better overall patterns than antennas mounted on the edge. Antennas mounted on the edge of an elevated conducting plane will have the greatest low-angle gain in the directions for which the radiation crosses the plane surface.

The calculated electric near fields at frequencies of 2,4,6, and 10 MHz are shown in figures B1 and B3 for vertical heights, z , of 1 and 2 meters, respectively. At frequencies of 15, 20, 25, and 30 MHz, the electric near fields at vertical heights, z , of 1 and 2 meters are shown in figures B2 and B4, respectively. The radiated power is 1 kW. All figures are graphs of the peak electric field in volts/meter as a function of horizontal distance, x , in meters away from the antenna.

35-FOOT TRUSSED-WHIP ANTENNA

The 35-foot trussed whip is an NT-60047 or other type whip which has been broadbanded by the addition of wires around the antenna—usually trussed to spokes attached part way up the whip (ref A1). The diameter of the whip is increased to several feet (the diameter will vary) at the spokes with the wires tapering to the whip diameter at the bottom and upper attachment points of the trussing. Trussing improves the efficiency of a whip by lowering the mismatch loss to a 50-ohm system at the lower high frequencies. Figure A2 is the AS-2805/SRC, which is the AS-2807/SRC with trussing wires added. The installation guidance is the same as for the 35-foot whip antenna described in the previous section.

The calculated electric near fields of the AS-2805/SRC at frequencies of 2,4,6, and 10 MHz are shown in figures B5 and B7 for vertical heights, z , of 1 and 2 meters, respectively. At frequencies of 15, 20, 25, and 30 MHz the electric near fields at vertical heights, z , of 1 and 2 meters are shown in figures B6 and B8, respectively. The radiated power is 1 kW. All figures are graphs of the peak electric field in volts/meter as a function of horizontal distance, x , in meters away from the antenna.

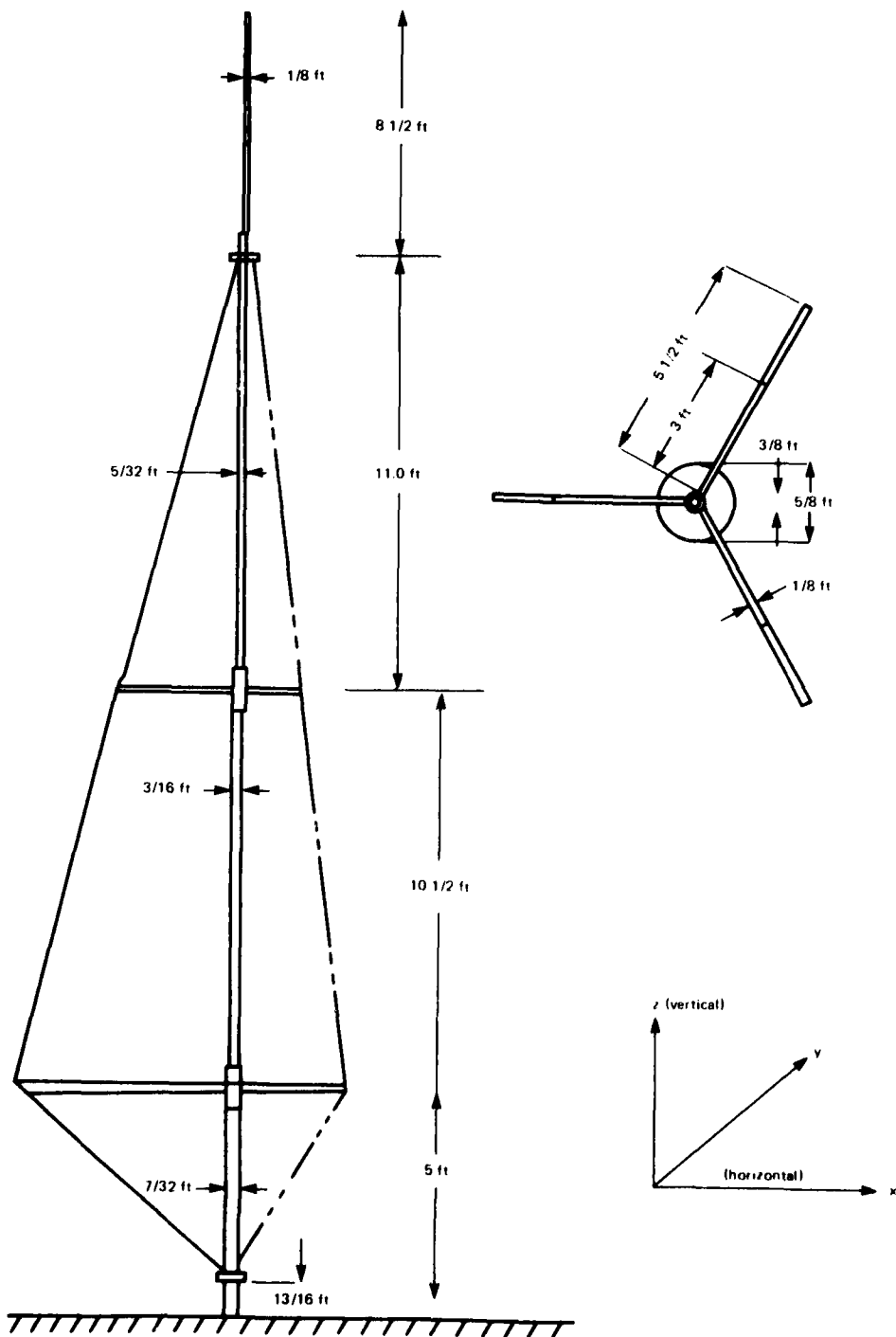


Figure A2. 35-foot trussed-whip antenna.

35-FOOT TWIN-WHIP ANTENNA

This antenna consists of two AS-2537/SR whips mounted approximately 10 feet apart, tied together at or near their feedpoints, and fed with a single coaxial feedline (ref A1). The impedance characteristics in a 50-ohm system are greatly improved over those of a single whip. A matching network is required when the antenna is used for transmitting but is optional for receiving. The twin-whip antenna is normally located on top of the pilot house, sometimes tilted 45 degrees towards the bow. The best location is on the centerline.

A schematic of the 35-foot twin-whip antenna is given in figure A3. The feed-point is at the origin of the depicted coordinate system. The antenna is aligned with the x-axis and perpendicular to the y-axis. The calculated electric near fields of this antenna are given in figures B9 through B12. The frequencies are 3, 5, 7, 9, 11, and 13 MHz. The radiated power is 1 kW. Again, all the figures are graphs of the peak electric field in volts/meter as a function of horizontal distance away from the antenna. Figures B9 and B11 are the electric near fields along the x-axis for vertical heights of 1 and 2 meters, respectively. Figures B10 and B12 are the electric near fields along the y-axis, again for vertical heights of 1 and 2 meters, respectively.

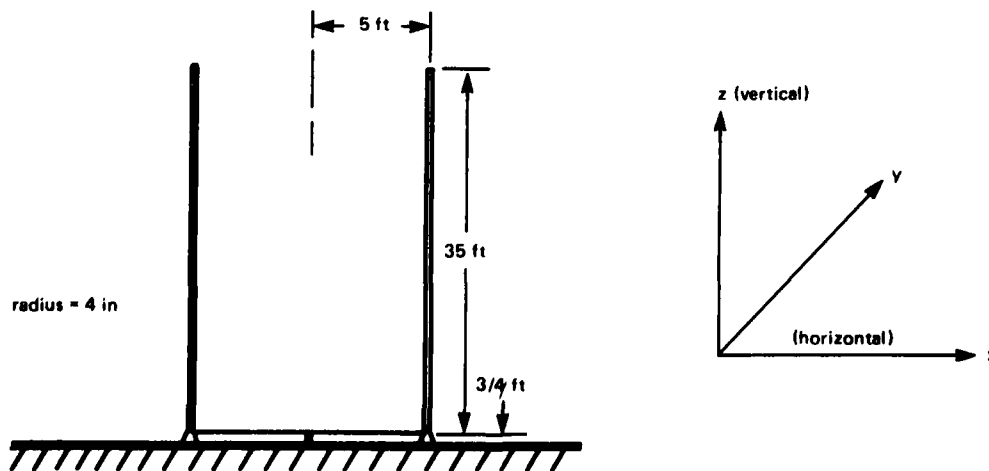


Figure A3. 35-foot twin-whip antenna.

DISCONE-CAGE ANTENNA

The discone-cage antenna is actually two antennas combined into one structure, each antenna having a separate feedpoint (ref A1). The highband antenna is of the discone type, utilizing an array of radial elements in a horizontal plane at the top of the cage as the disc and the upper section of the cage as the cone. The antenna is fed at the gap between the disc and the apex of the cone. The midband antenna consists of the entire cage section. The lower ends of the wires which form the cage are terminated on a collector ring which is insulated from the grounded supporting structure and used as the feedpoint.

Feedpoint impedance-matching networks are required for both sections. A shorted coaxial stub is built into the upper section of the supporting mast for matching the upper-band discone antennas to 50-ohm coax. It is occasionally necessary to add a series capacitor in the feedline, depending on antenna configuration details and the influence of antenna siting parameters. The matching network for the cage section is located in a deck-mounted enclosure at the feedpoint.

The discone-cage antenna must be located in a clear area. Adjacent structure will alter its radiation pattern characteristics and feedpoint impedances. One of the most successful locations has been on the bow of ships other than carriers. To avoid interference with anchor-handling requirements, the discone has been successfully installed on a bridge structure erected over the anchor machinery area. In other installations the antenna has been mounted on a pedestal, approximately 7 feet high, to reduce the electrical shock hazard to personnel.

Several versions of the hf discone-cage antenna have been developed and built by various shipyards. The electric near fields were calculated for the discone-cage antenna of figure A4. The antenna is mounted on a 7-foot pedestal. The calculated electric near fields of this antenna are given in figures B13 and B14. The frequencies are 3, 5, 7, 9, 11, and 13 MHz. The radiated power is 1 kW. Again, all the figures are graphs of the peak electric field in volts/meter as a function of horizontal distance, x , away from the antenna. Figure B13 presents the electric near fields for a vertical height of 1 meter off the extended ground plane, figure B14 the electric near fields for a 2-meter vertical height.

BOTTOM-FED FAN ANTENNA

The final antenna type of interest here is the fan (ref A1). The twin-wire rope fan antenna is used to induce rf currents on a portion of the superstructure so that the superstructure in effect becomes part of the radiating system. Consequently, the configuration of the superstructure has direct impact on the performance of the twin-fan antenna. Ship-board experience and model measurements have served to identify certain relationships between topside configuration and the performance of fan antennas, but there are, as yet, no rigorous methodologies for designing fan antennas.

The present twin-fan antenna has an open-wire feed system which is the most performance-sensitive portion of the installation. At the present time a valid analytical model of this feed region does not exist that is suitable for the calculation of the electric near fields. Work is continuing on the development of a valid model. Because of this analytical difficulty, only a bottom-fed fan antenna will be considered in this report.

The electric near fields were calculated for the bottom-fed fan antenna of figure A5. This particular antenna was configured for the patrol hydrofoil (missile) (PHM) (ref A2). The mast support is at the origin of the depicted coordinate system. The mast cross member is aligned with the y-axis. The calculated electric near fields of this antenna are given in figures B15 through B18. The frequencies are 2, 4, 6, 10, 15, and 25 MHz. The radiated power is 1 kW. Again, all the figures are graphs of the peak electric field in volts/meter as a function of horizontal distance from the antenna. Figures B15 and B17 are the electric near fields along the x-axis for vertical heights of 1 and 2 meters, respectively. Figures B16 and B18 are the electric near fields along the y-axis, again for vertical heights of 1 and 2 meters, respectively.

A2 NECL TD 269, "HF Antenna System design for Patrol Hydrofoil (Missile) (PHM)," by JL Lievens and IC Olson, 20 August 1973

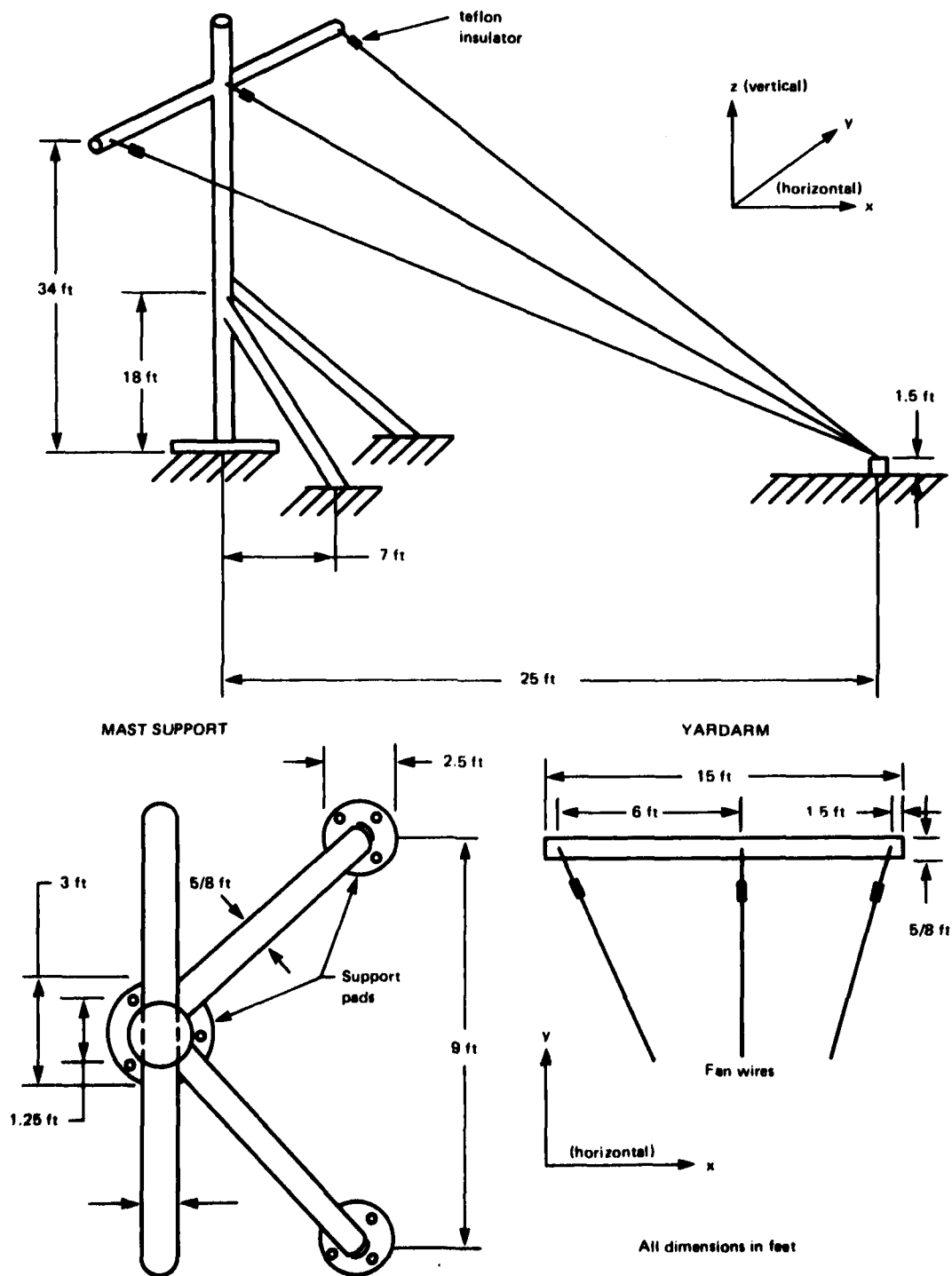
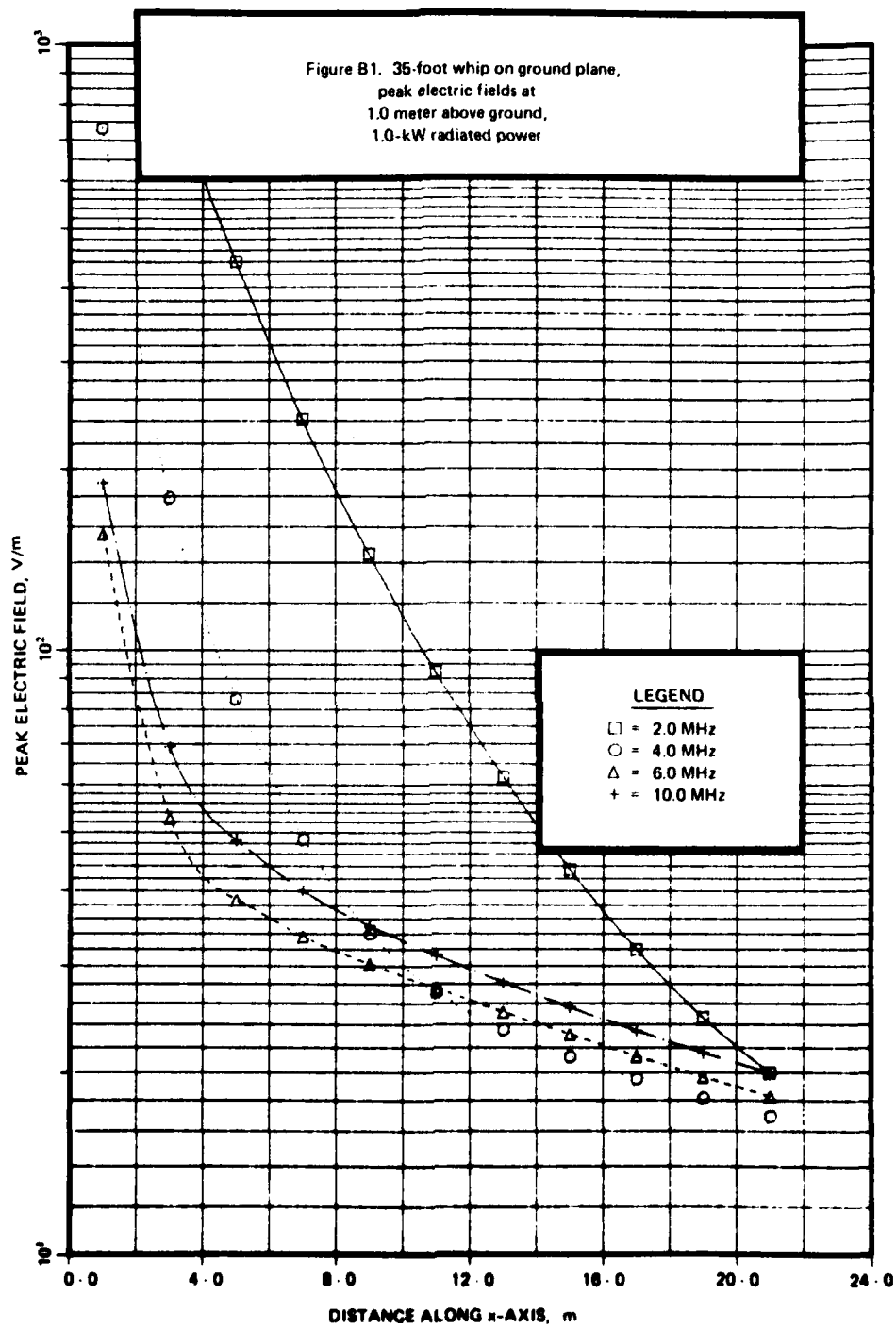


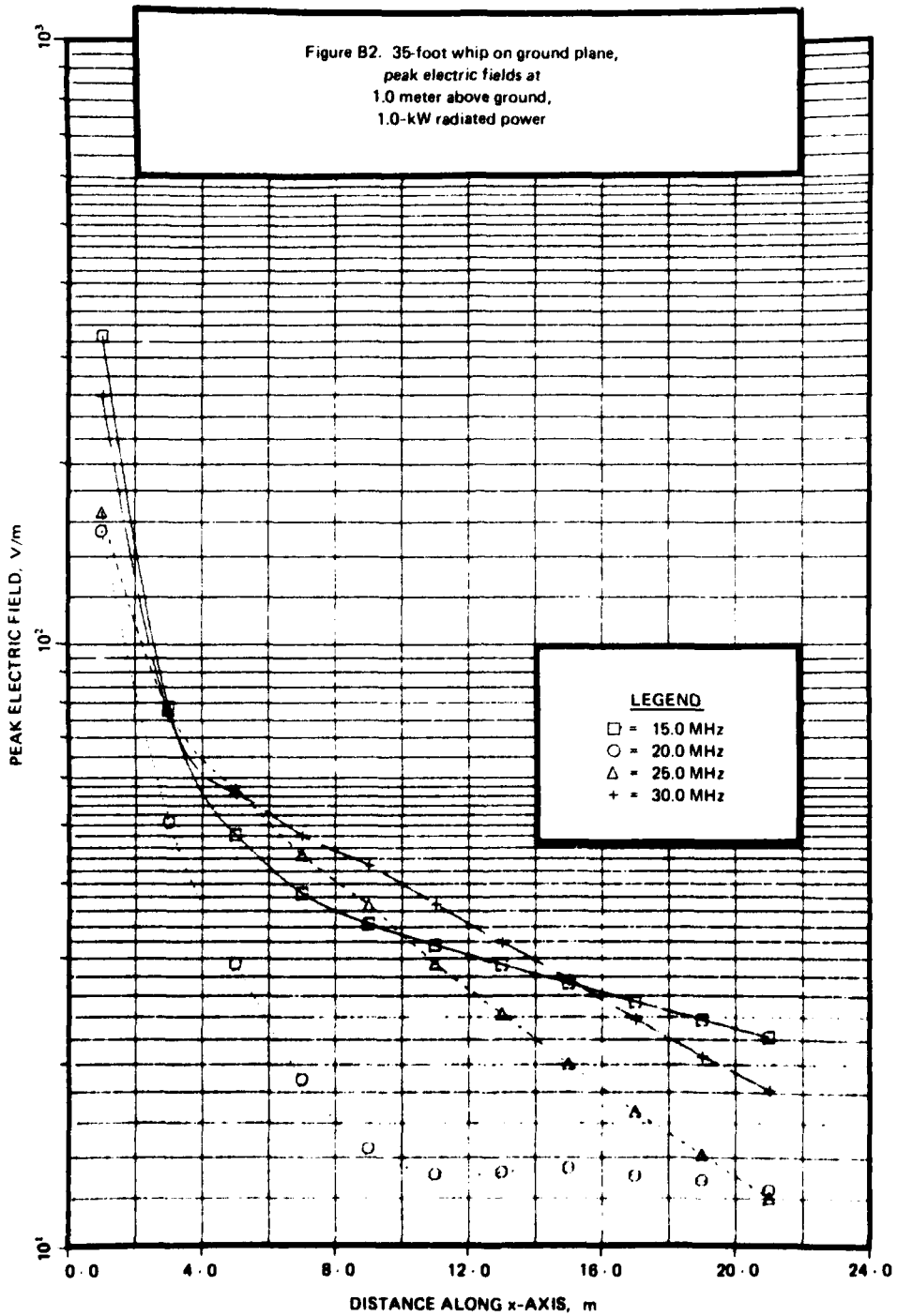
Figure A5. Bottom-fed fan antenna.

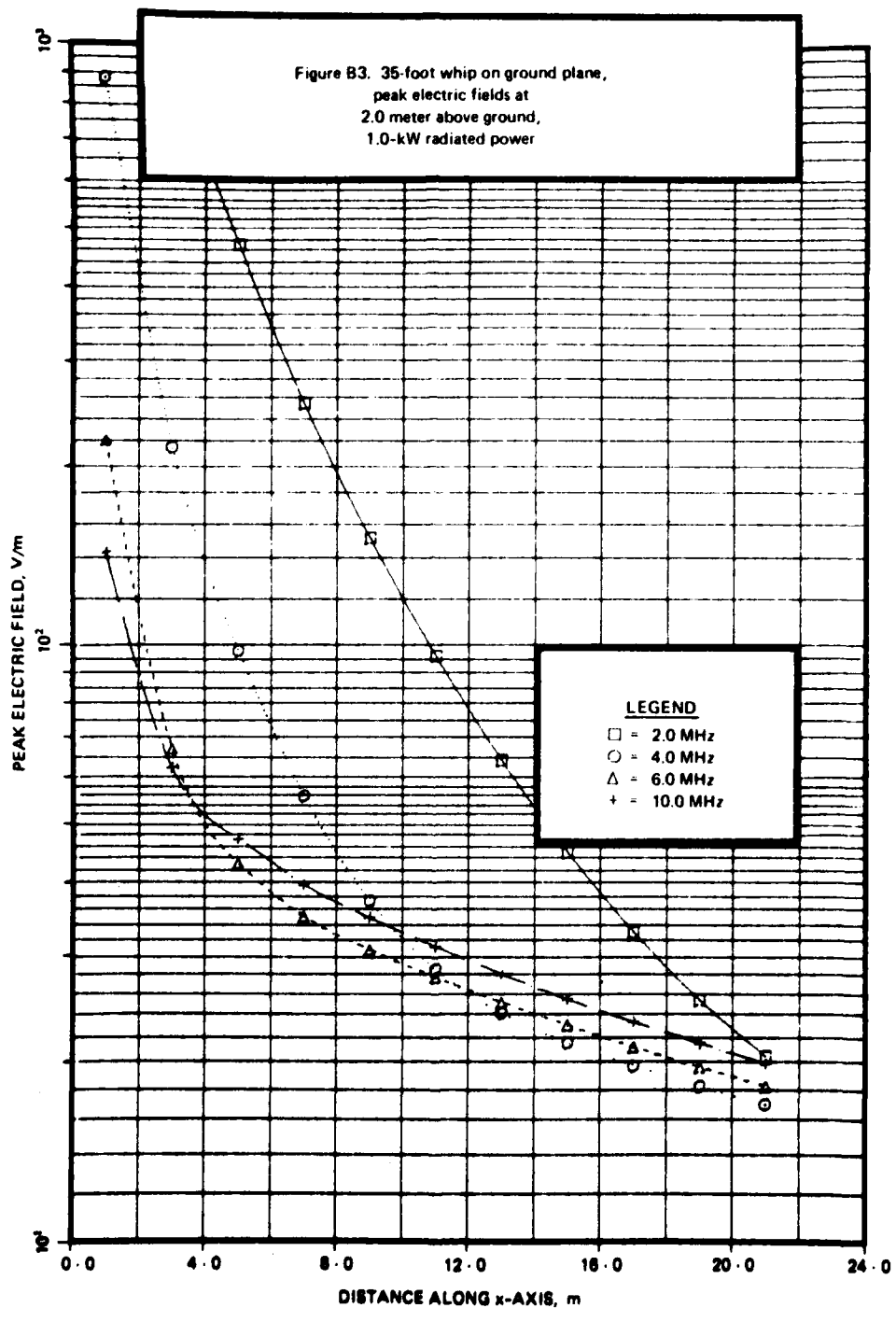
**APPENDIX B: NEAR FIELD CALCULATIONS OF HF ANTENNA
ON EXTENDED GROUND PLANE**

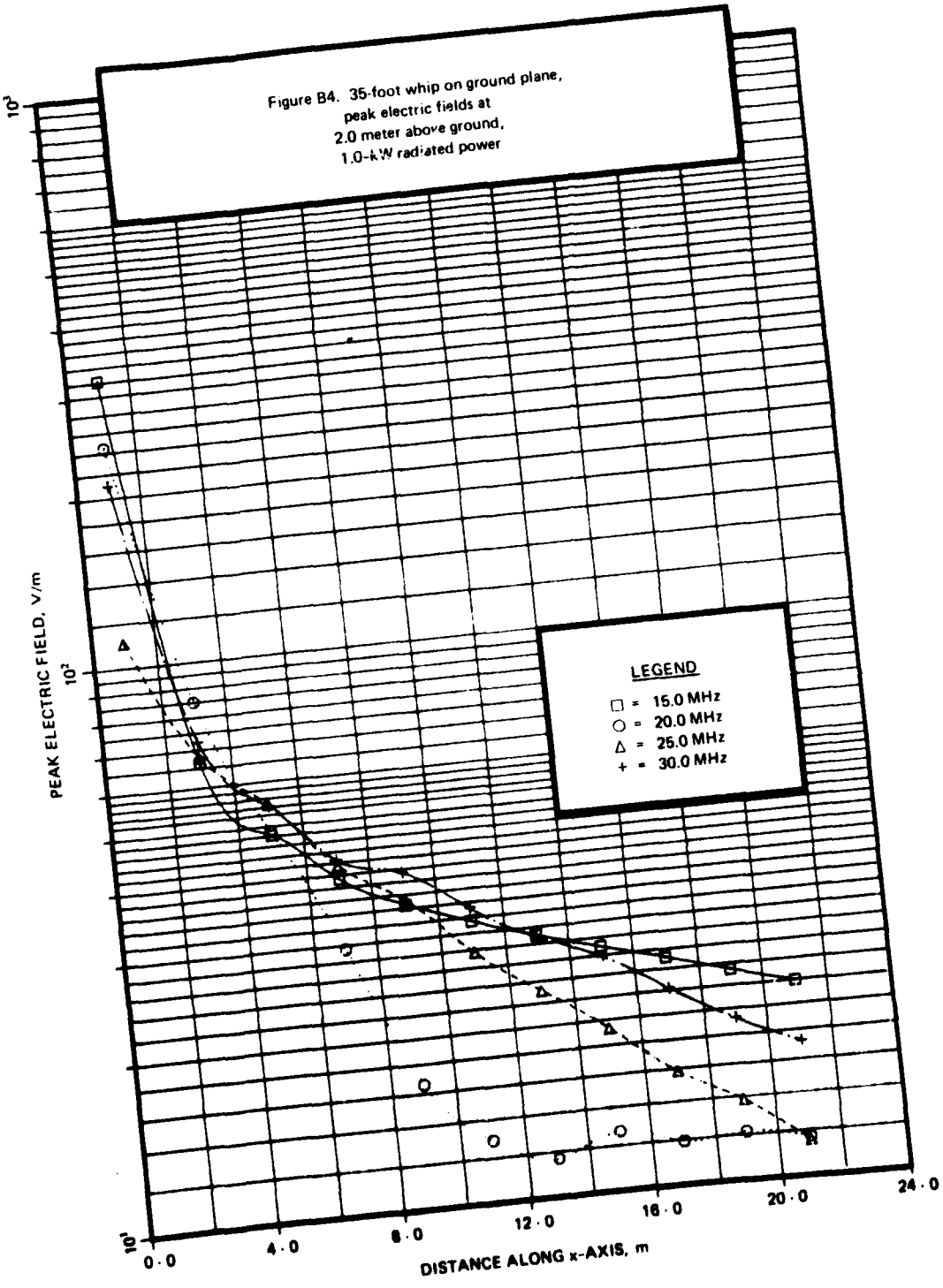
Table B1. Index of peak electric field calculations, antennas on extended ground plane,
1-kW radiated power.

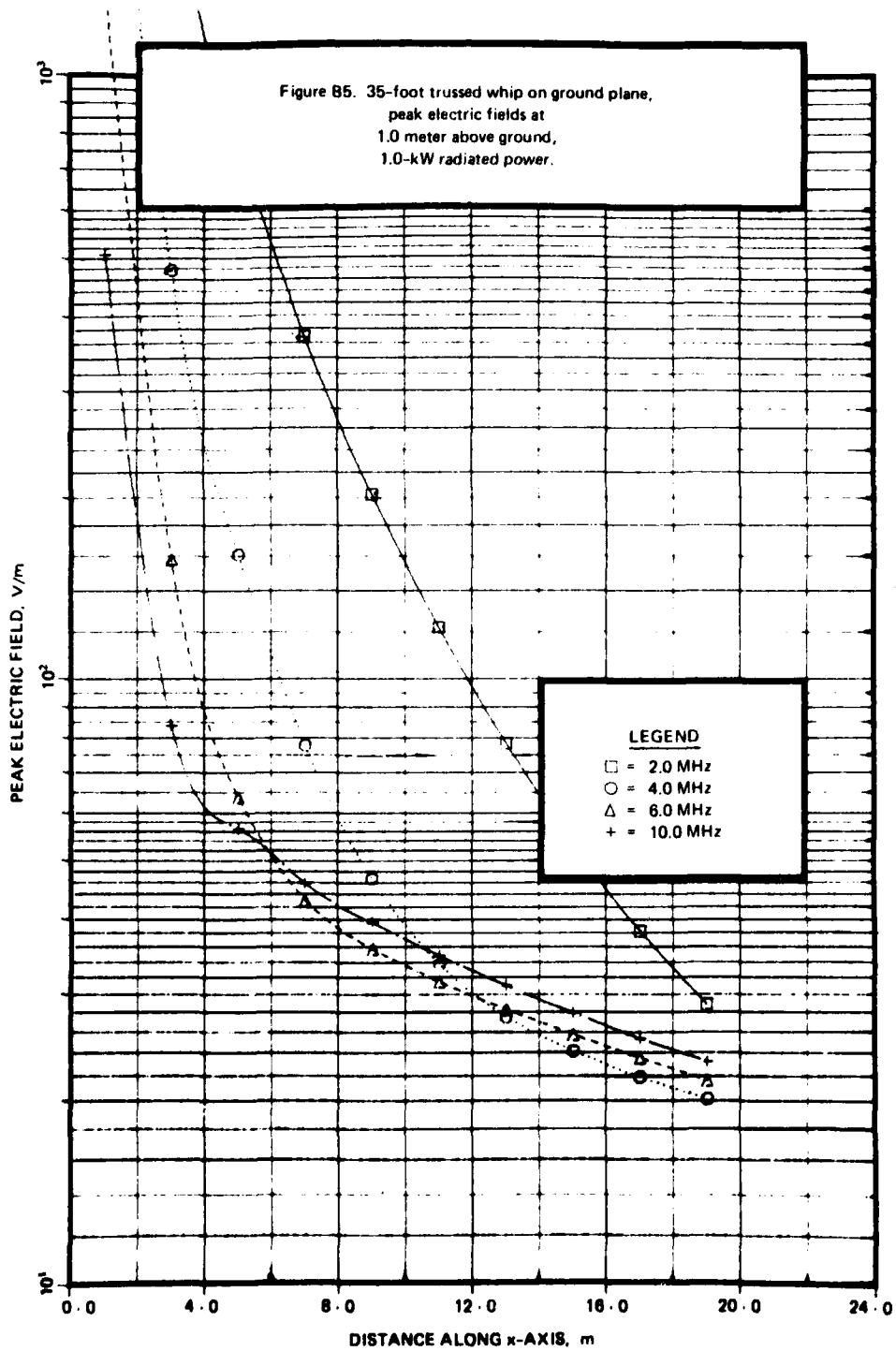
Antenna	Frequencies (MHz)	Spatial Variation (meters)	Figure
35-ft whip	2, 4, 6, 10	$z = 1.0\text{m}; x = 1.0\text{--}21.0\text{m}$ $y = 0.0\text{m}$	B1
	15, 20, 25, 30		B2
	2, 4, 6, 10	$z = 2.0\text{m}; x = 1.0\text{--}21.0\text{m}$ $y = 0.0\text{m}$	B3
	15, 20, 25, 30		B4
35-ft trussed whip	2, 4, 6, 10	$z = 1.0\text{m}; x = 1.0\text{--}19.0\text{m}$ $y = 0.0\text{m}$	B5
	15, 20, 25, 30		B6
	2, 4, 6, 10	$z = 2.0\text{m}; x = 1.0\text{--}19.0\text{m}$ $y = 0.0\text{m}$	B7
	15, 20, 25, 30		B8
35-ft twin-whip	3, 5, 7, 9, 11, 13	$z = 1.0\text{m}; x = 1.0\text{--}20.0\text{m}$ $y = 0.0\text{m}$	B9
		$z = 1.0\text{m}; y = 1.0\text{--}20.0\text{m}$ $x = 0.0\text{m}$	B10
		$z = 2.0\text{m}; x = 1.0\text{--}20.0\text{m}$ $y = 0.0\text{m}$	B11
		$z = 2.0\text{m}; y = 1.0\text{--}20.0\text{m}$ $x = 0.0\text{m}$	B12
discone-cage	3, 5, 7, 9, 11, 13	$z = 1.0\text{m}; x = 1.0\text{--}20.0\text{m}$ $y = 0.0\text{m}$	B13
		$z = 2.0\text{m}; x = 1.0\text{--}20.0\text{m}$ $y = 0.0\text{m}$	B14
bottom-fed fan	2, 4, 6, 10, 15, 25	$z = 1.0\text{m}; x = 1.0\text{--}20.0\text{m}$ $y = 0.0\text{m}$	B15
		$z = 2.0\text{m}; y = 1.0\text{--}20.0\text{m}$ $x = 0.0\text{m}$	B16
		$z = 1.0\text{m}; x = 1.0\text{--}20.0\text{m}$ $y = 0.0\text{m}$	B17
		$z = 2.0\text{m}; y = 1.0\text{--}20.0\text{m}$ $x = 0.0\text{m}$	B18

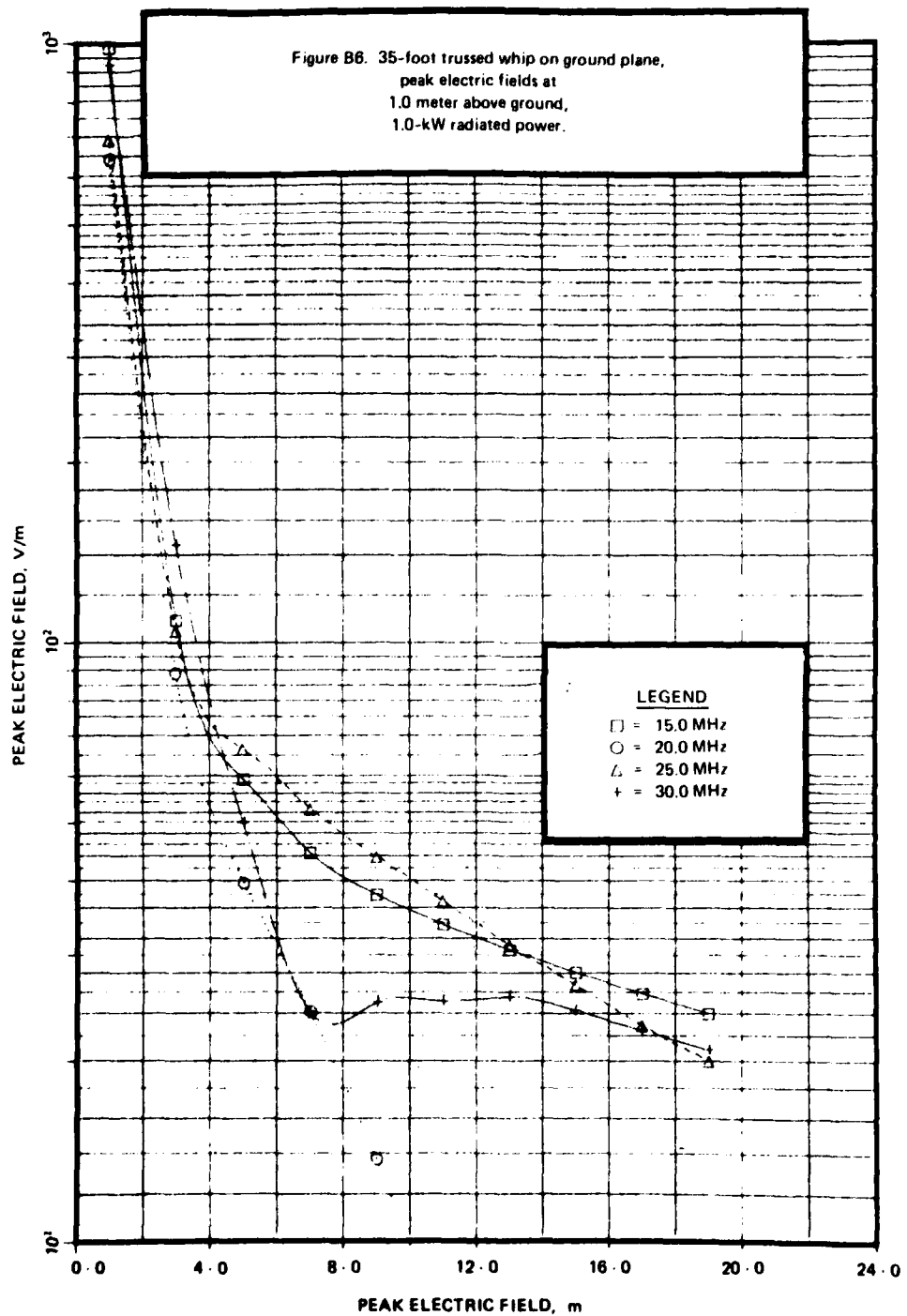


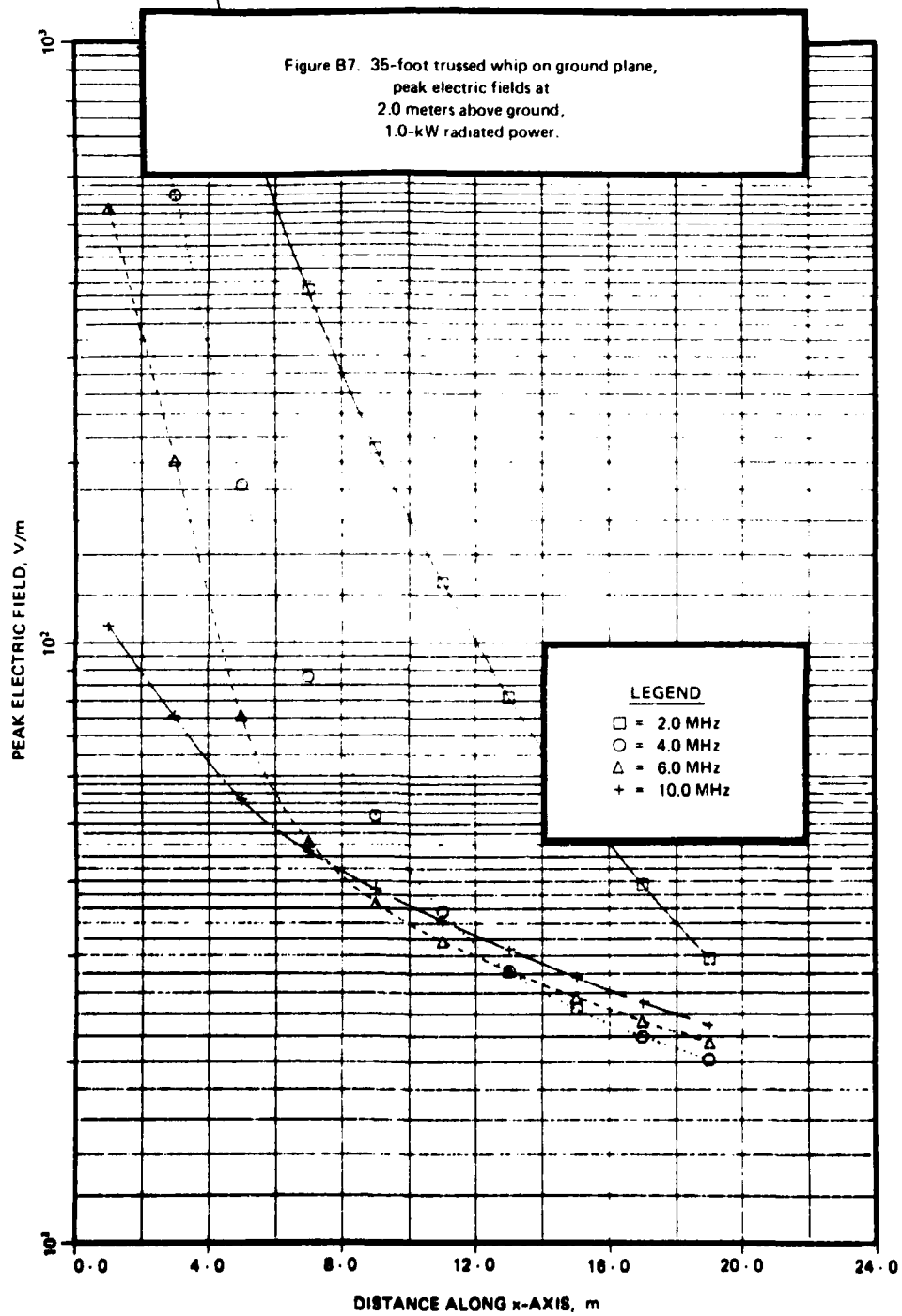


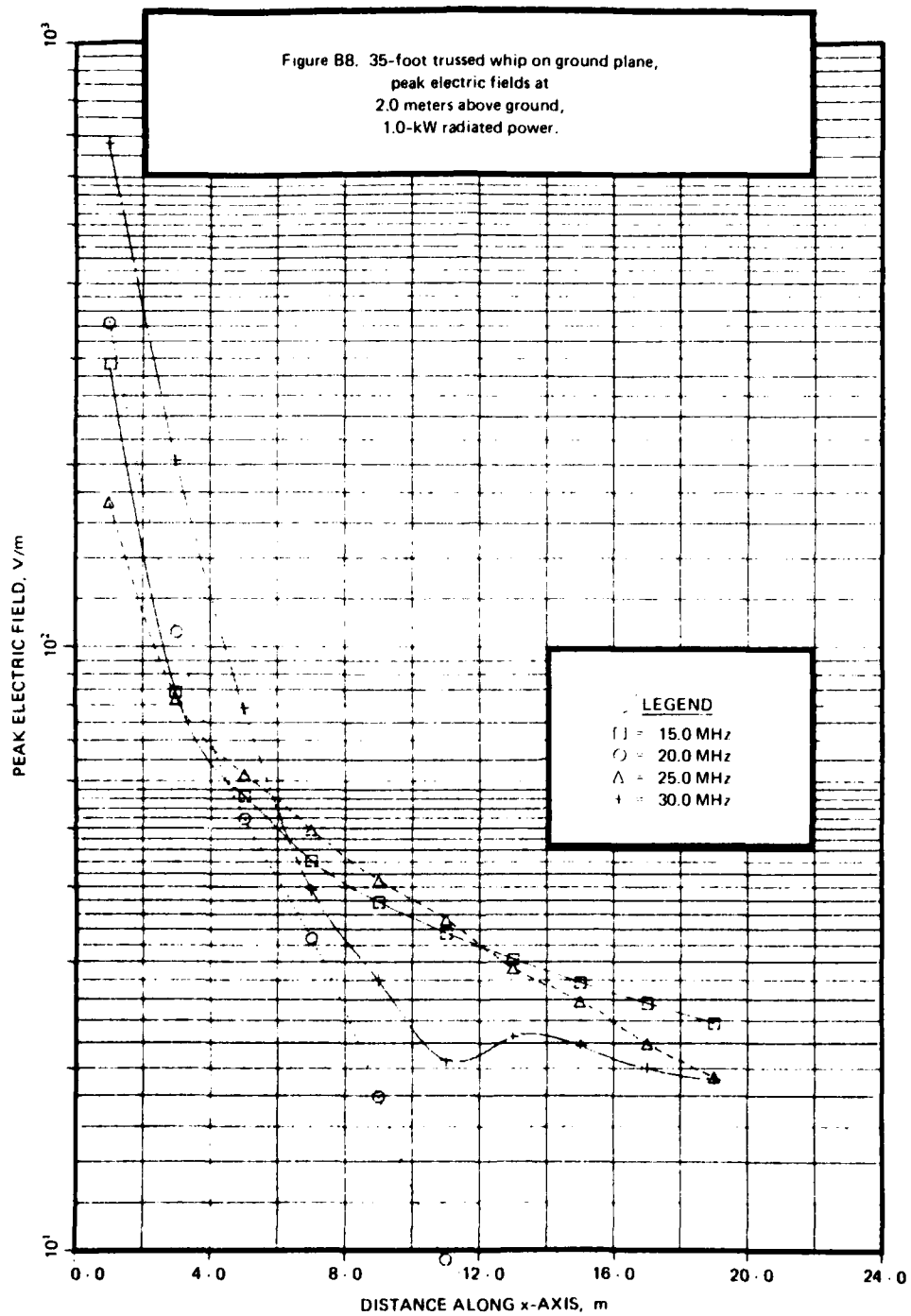


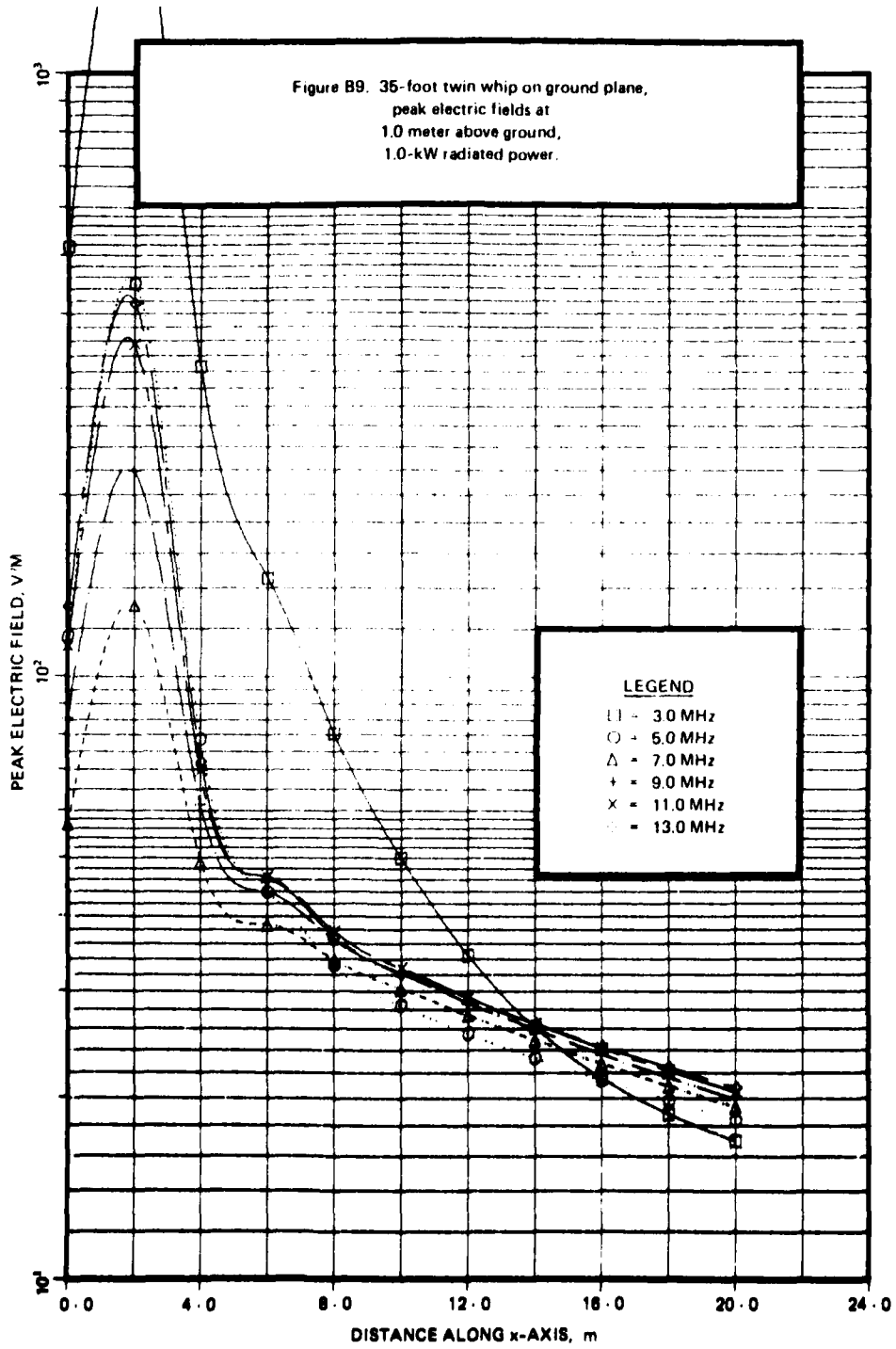


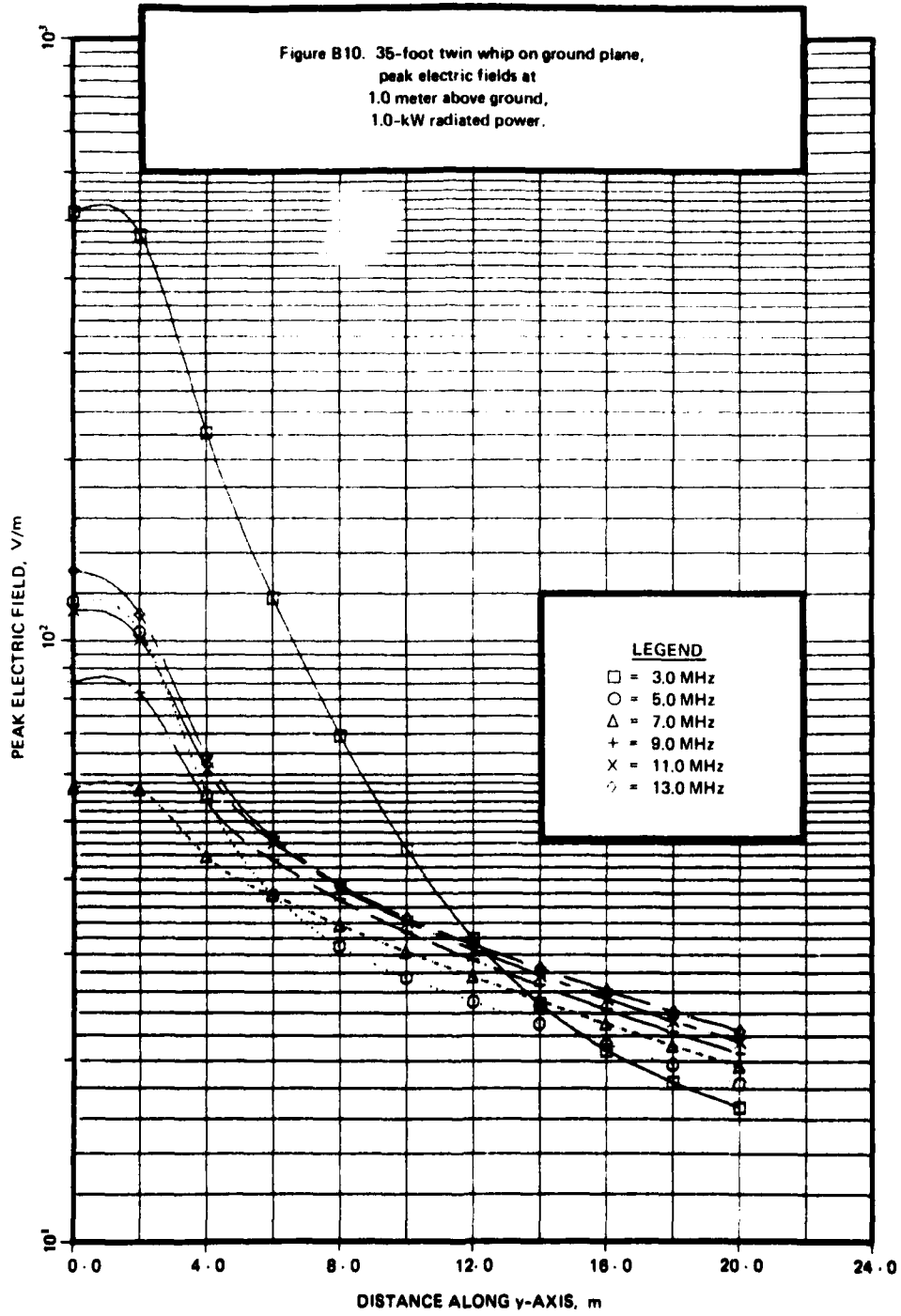


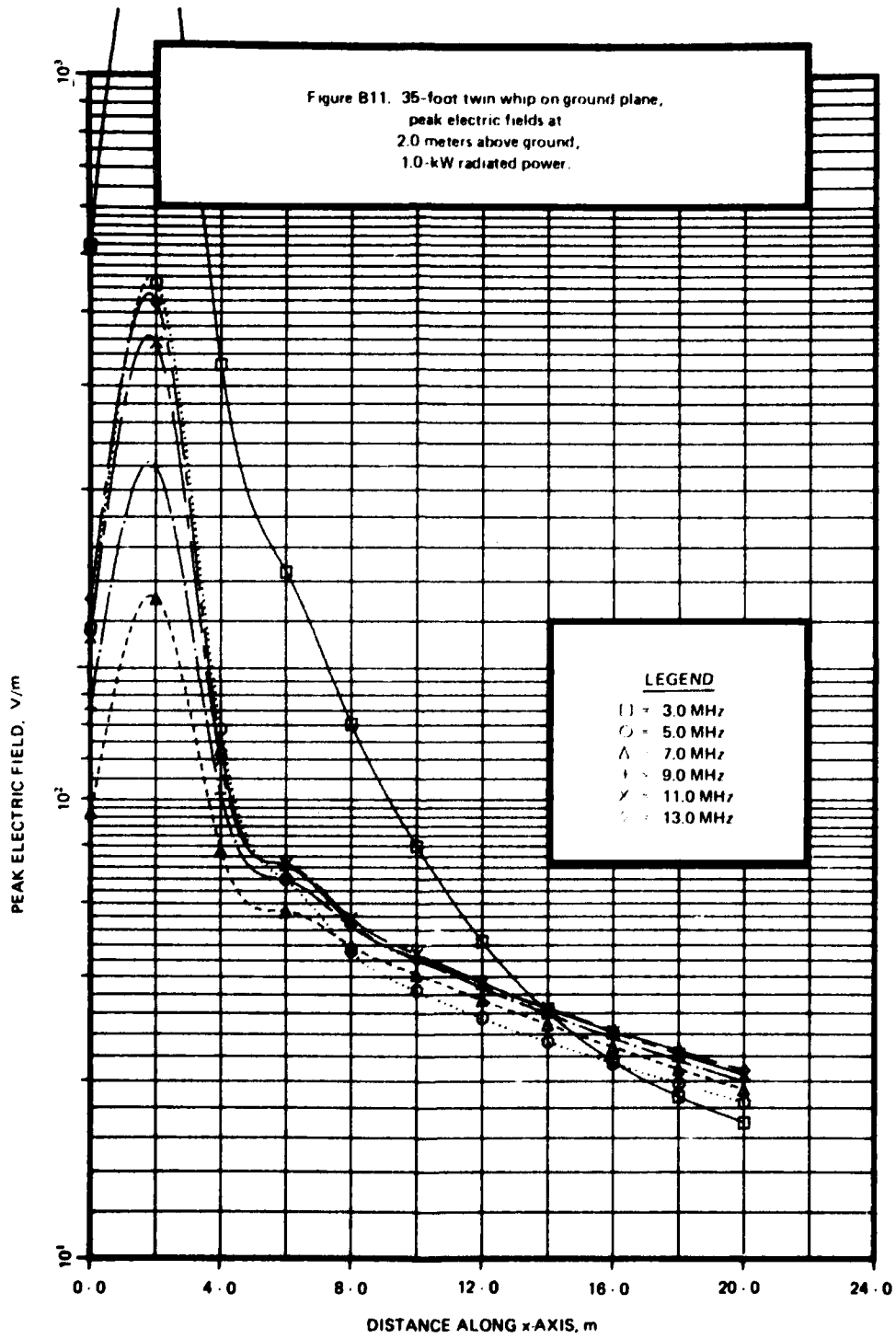


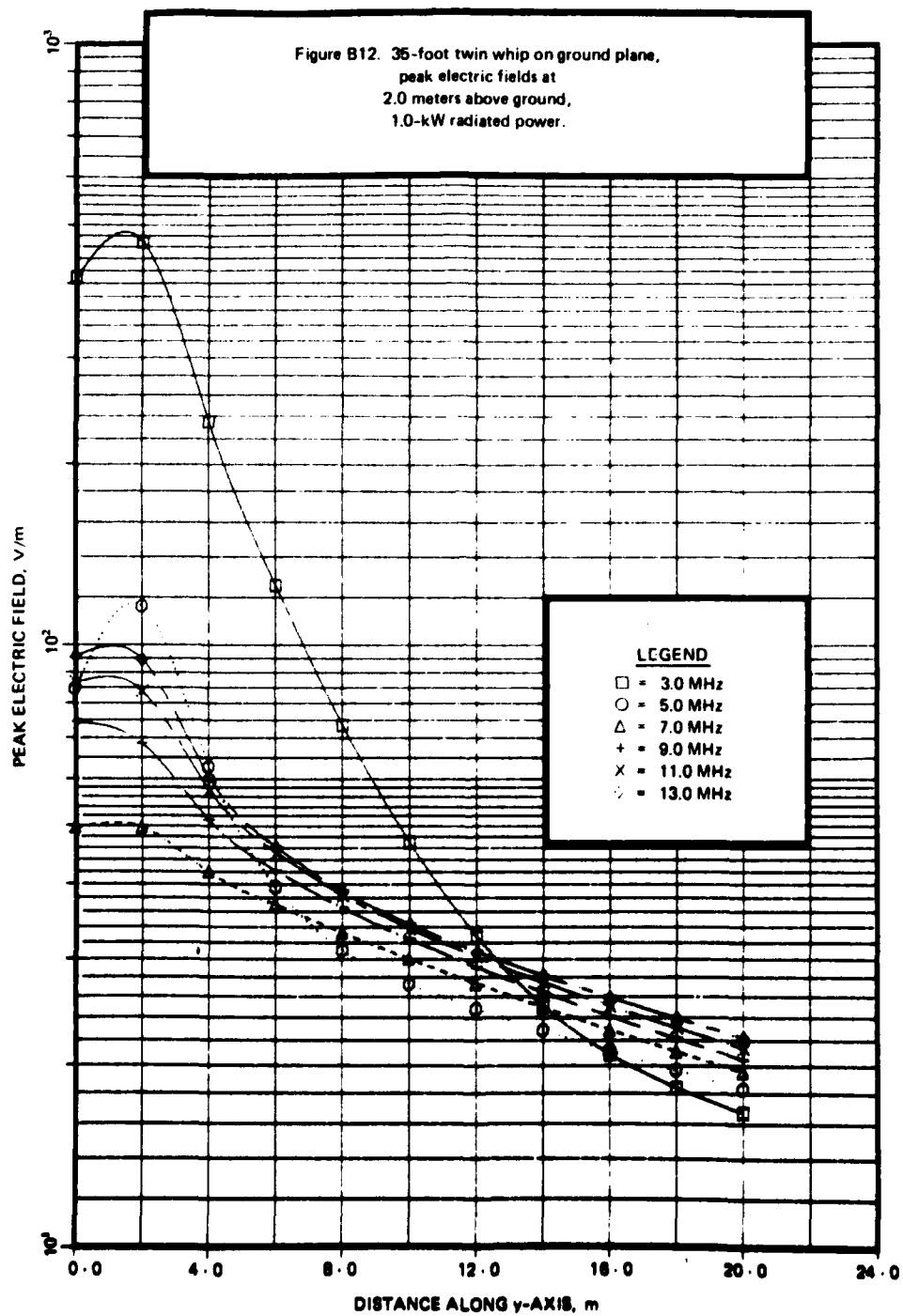


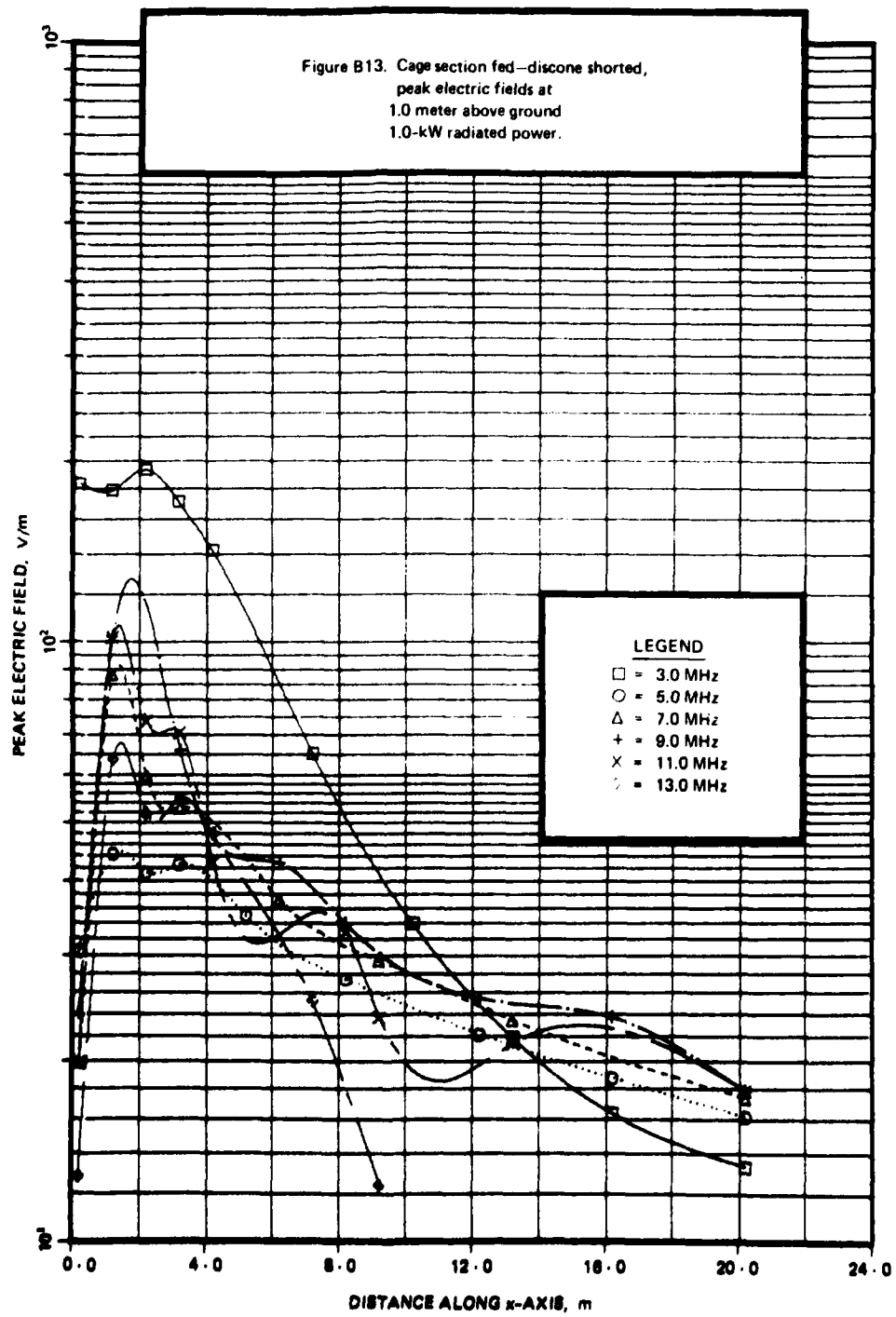


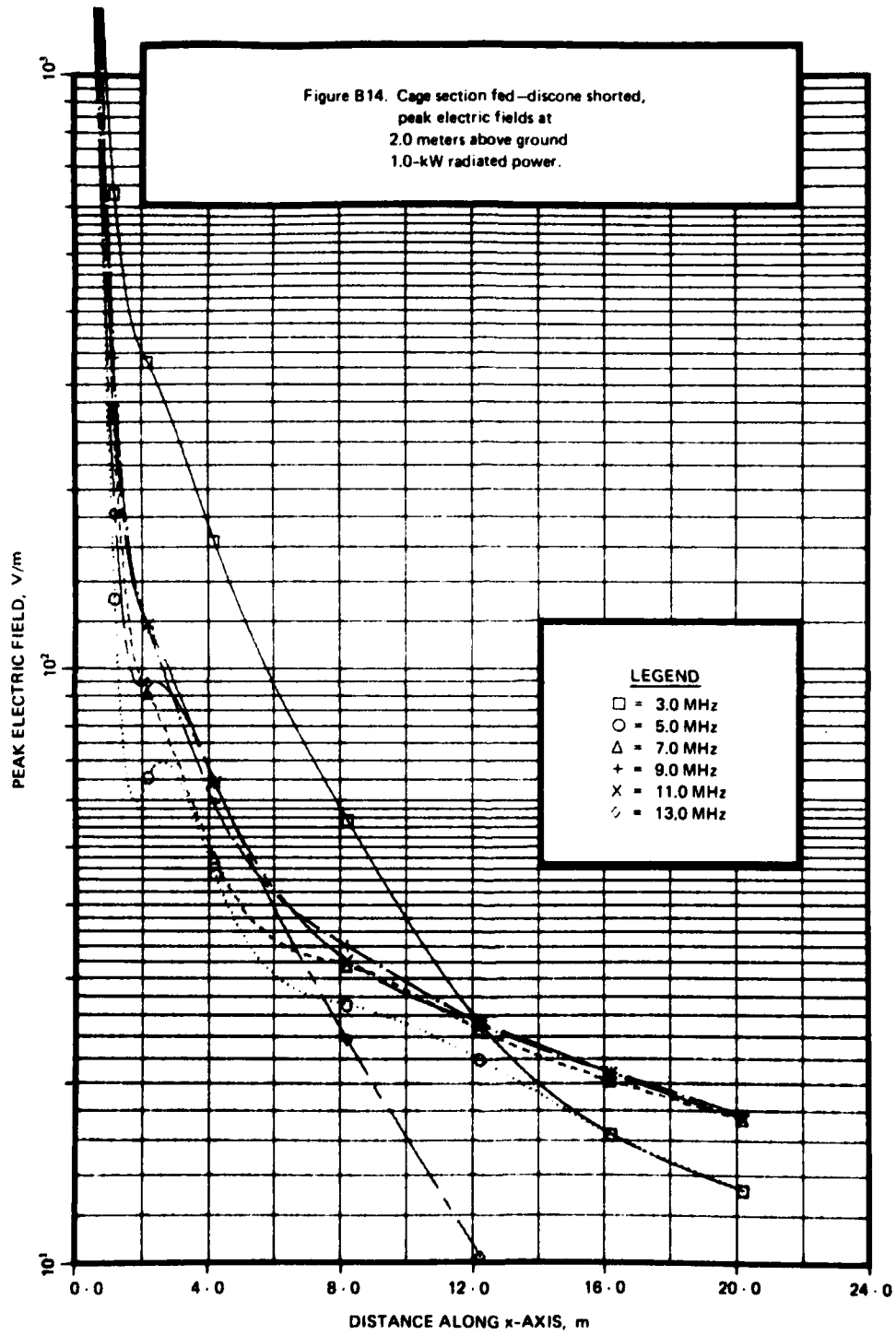


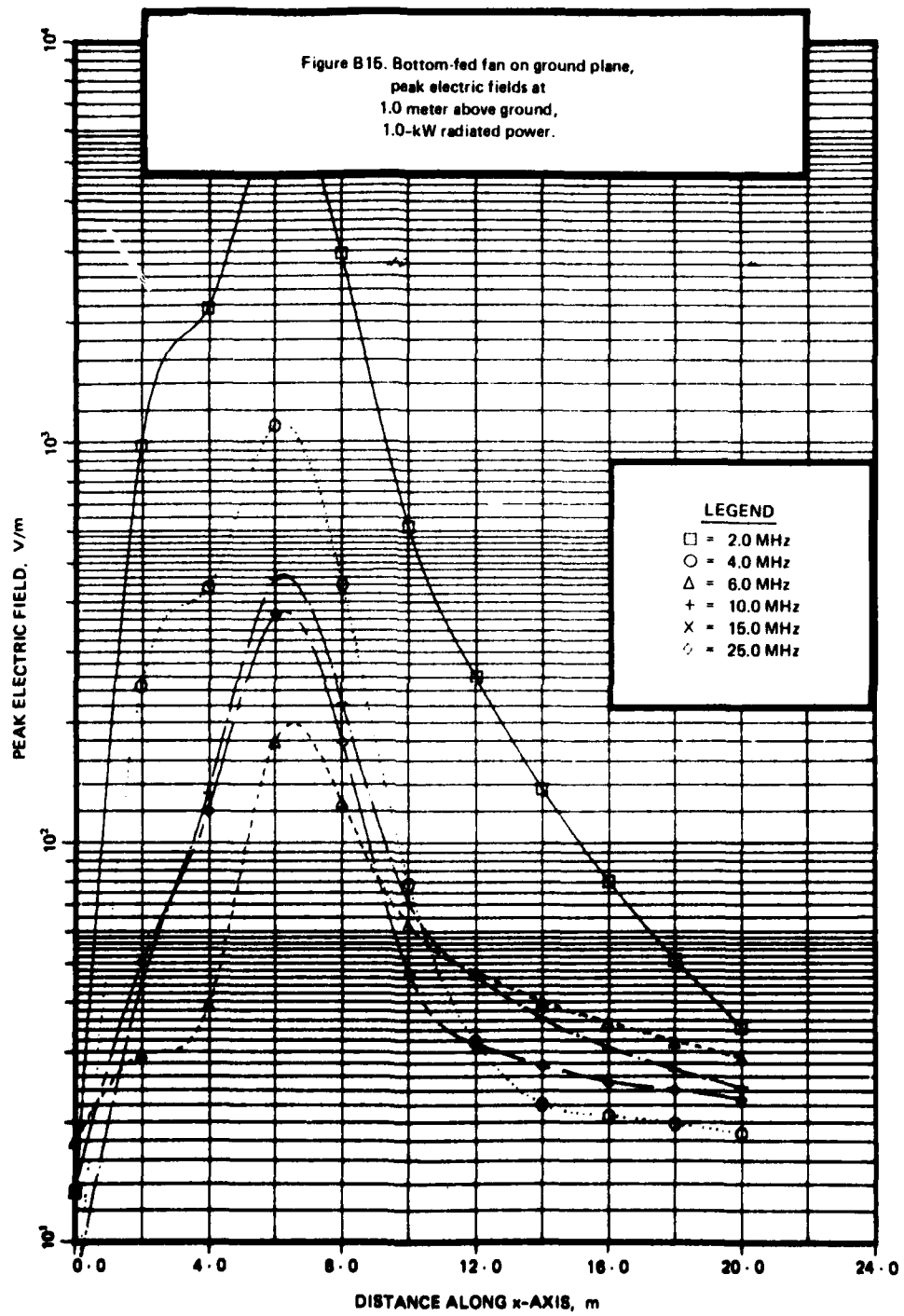


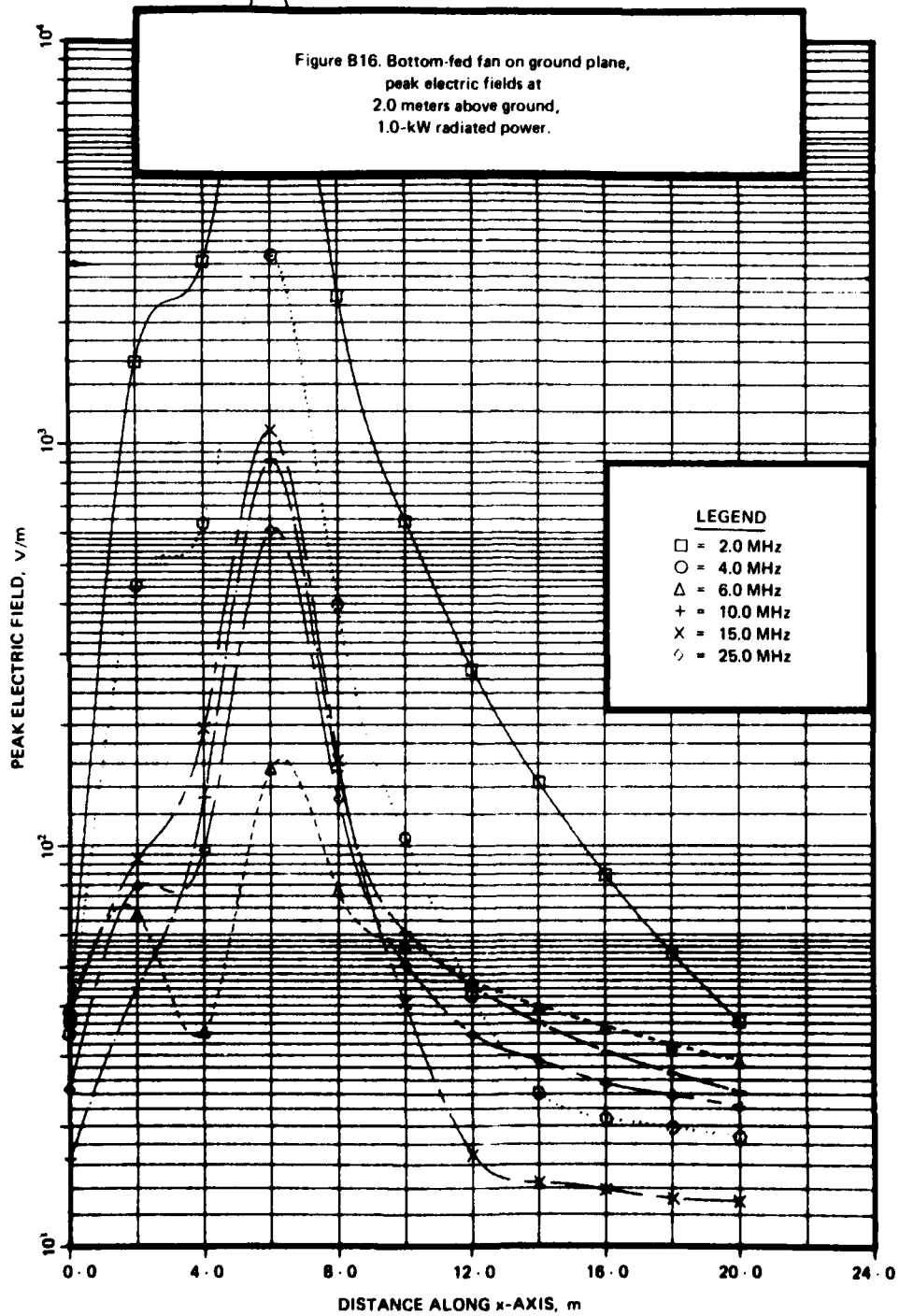


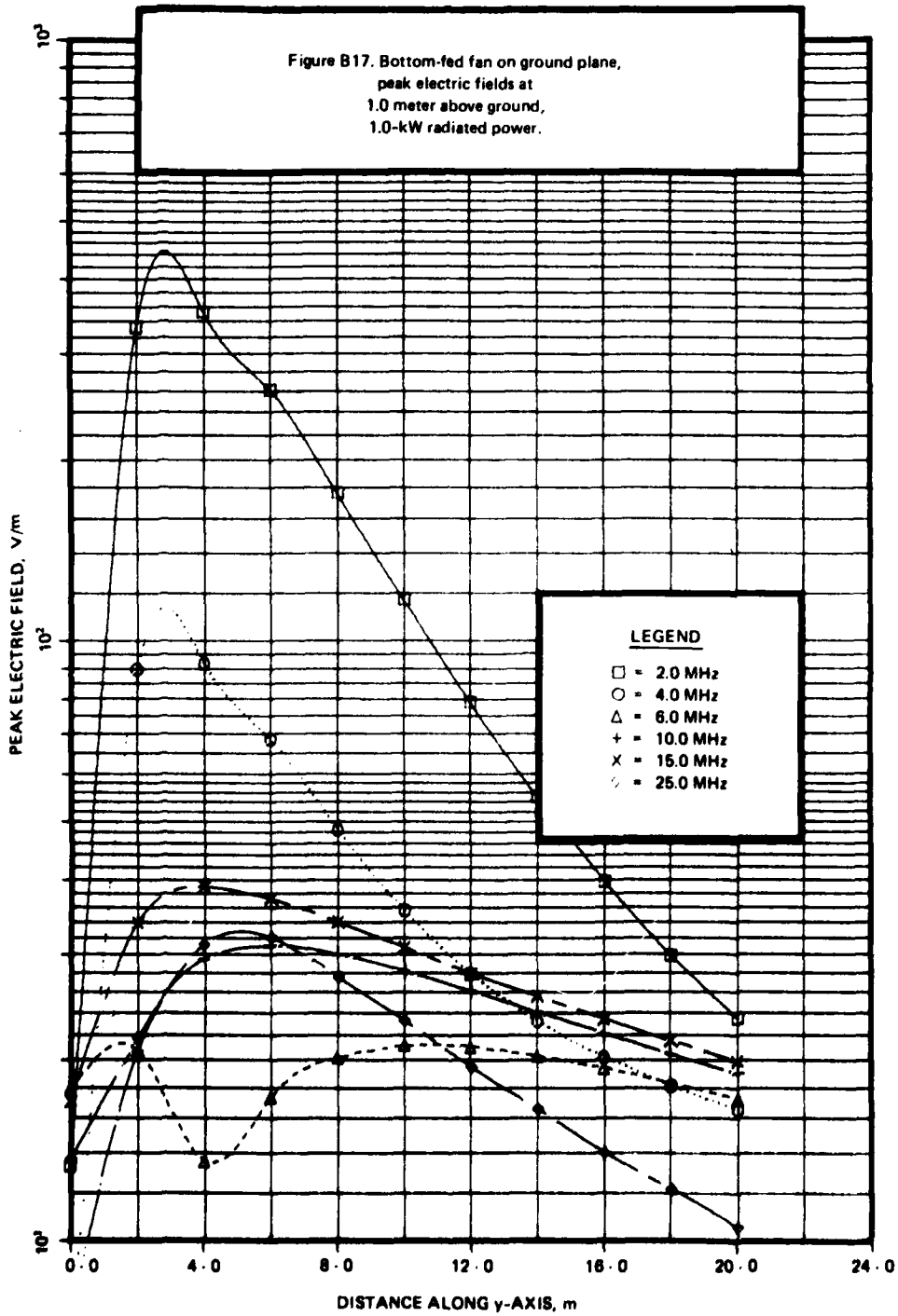


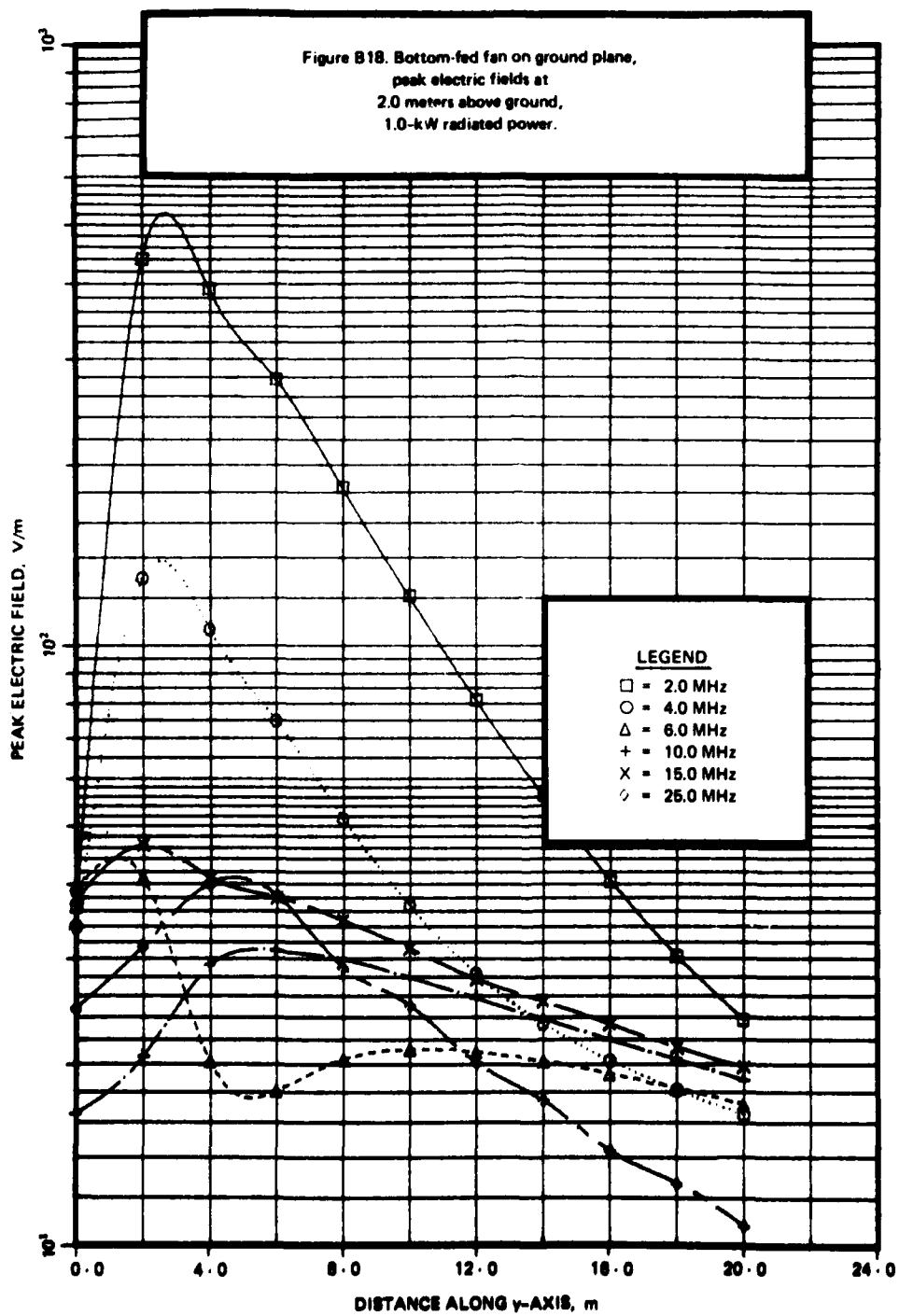












APPENDIX C: HF ANTENNAS IN A STRUCTURED ENVIRONMENT

In reference 2, an attempt was made to determine the effect of surrounding structure on the near field distribution. Two simple cases were considered. The first case was a 35-foot whip on a ground plane and near an infinite vertical plane. The second case was a 35-foot whip on a ground plane and near two infinite, vertically intersecting planes. In all cases, the antenna and the surrounding planes were perfectly conducting.

In this report investigation into the effect of surrounding structure is expanded. Two other cases are considered. In the first case, a 35-foot antenna is mounted on a deckhouse. The whip is positioned both at the center of the deckhouse (fig C1) and at the edge of the deckhouse (fig C2). In the second case, parasitic whips are positioned near the 35-foot transmitting whip antenna. Both 30-foot and 35-foot parasitics are used.

The results of the near field calculations for these two cases are presented in appendix D. The calculated electric near fields for the structured environment of figure C1 are given in figures D1 through D3. The frequencies are 2, 3, 4, 5, 6, 7, and 8 MHz. The radiated power is 1 kW. All the figures are graphs of the peak electric field in volts/meter as a function of horizontal distance, y . Figures D1, D2, and D3 are the electric near fields for vertical heights 1, 5.88, and 10 meters. The calculated electric near fields for the structured environment of figure C2 are given in figures D4 through D6. These figures are similar to the first three figures. Further, figures D4, D5, and D6 are the electric near fields for vertical heights of 1, 5.88, and 10 meters. The calculated electric near fields for a 35-foot whip near a 35-foot parasitic are given in figures D7 through D9. The 35-foot parasitic is also a 35-foot whip and both structures are perpendicular to the x -axis. The frequency range is 6.0–8.0 MHz. The radiated power is kW, and z is 1.0 meter. Again, all the figures are graphs of the peak electric field in volts/meter as a function of horizontal distance, x . Figures D7, D8, and D9 are the electric near fields for separation distances of 6, 10, and 14 meters, respectively.

The calculated electric near fields for a 35-foot whip near a 35-foot parasitic whip are given in figures D10 through D12. Both structures are perpendicular to the x -axis. The frequencies are 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, and 9.0 MHz. The radiated power is 1 kW, and z is 1.0 meter. Again, all the figures are graphs of the peak electric field in volts/meter as a function of horizontal distance, x . Figures D10, D11, and D12 are the electric near fields for separation distances of 6, 10, and 14 meters, respectively.

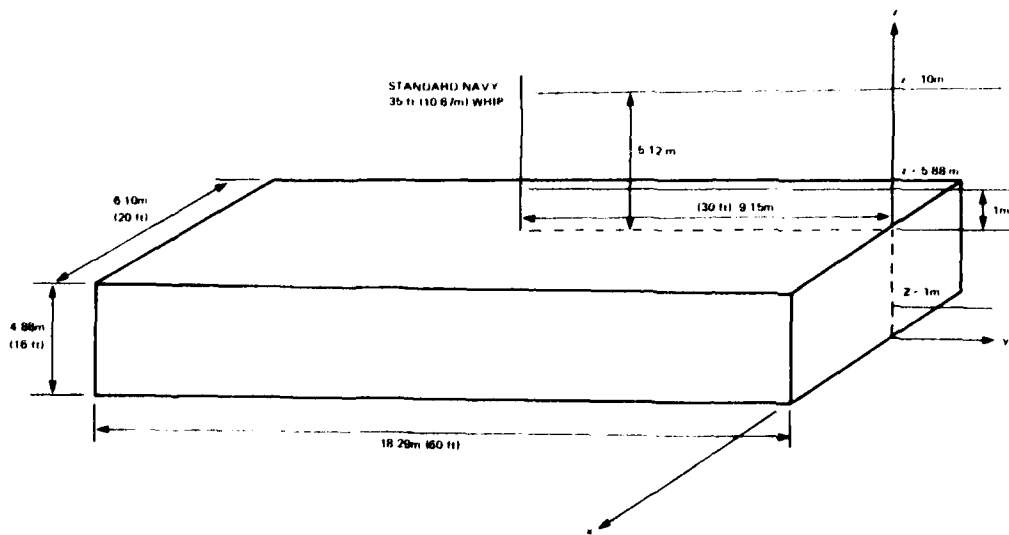


Figure C1. 35-foot whip mounted at center of deckhouse. Near fields have been calculated for points at $z = 1.0, 5.88,$ and 10.0 meters.

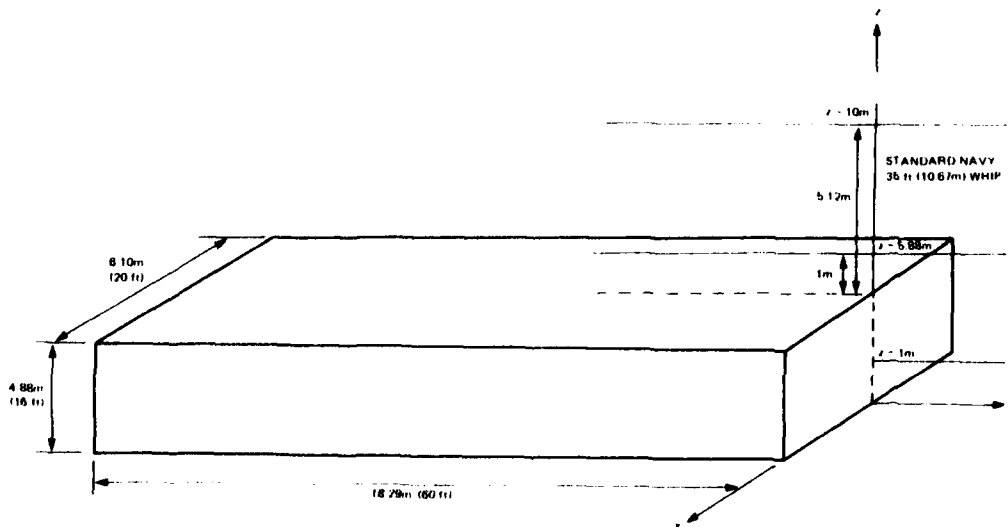


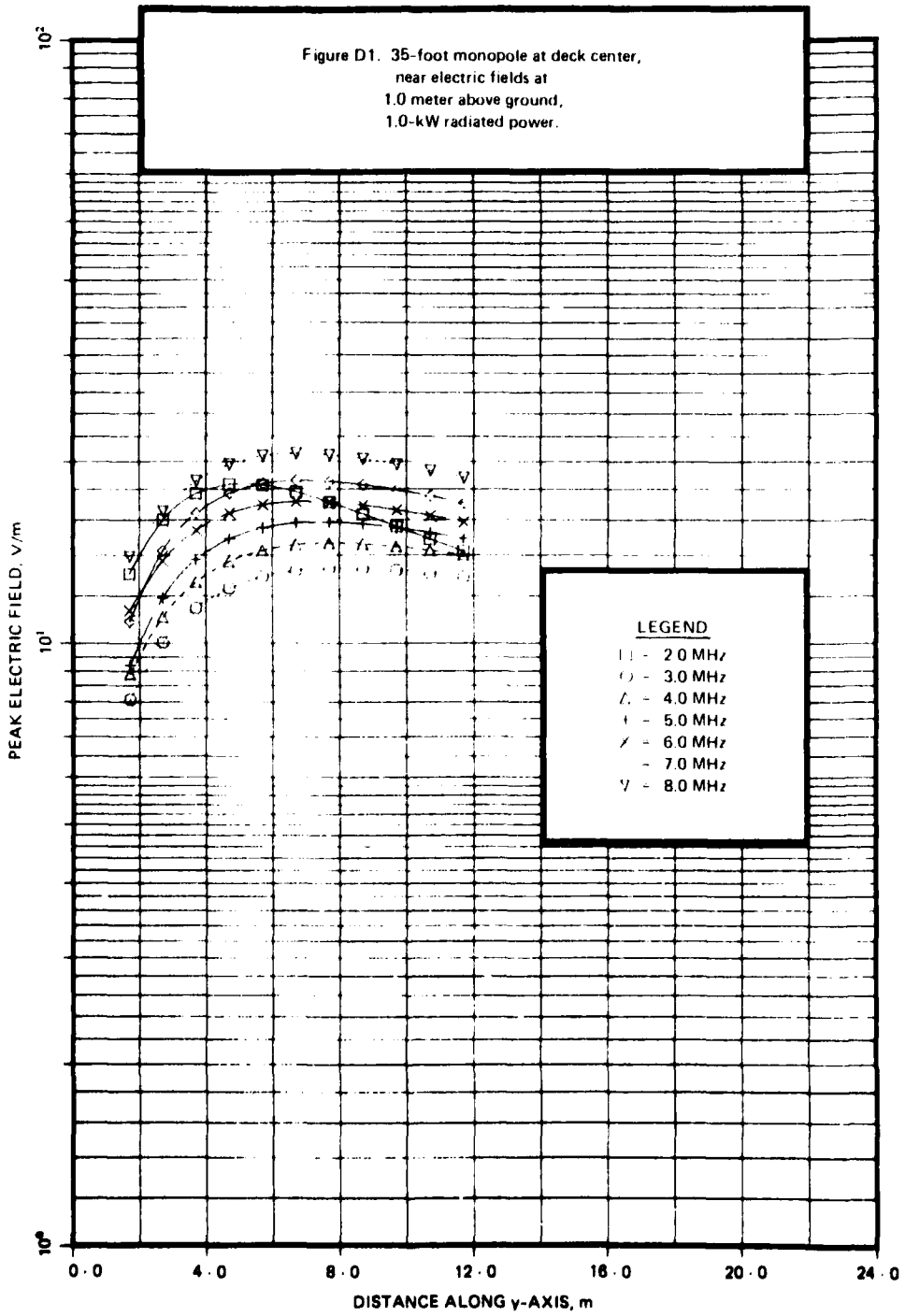
Figure C2. 35-foot whip mounted at deck edge of deckhouse. Near fields have been calculated for points at $z = 1.0, 5.88,$ and 10.0 meters.

**APPENDIX D: NEAR FIELD CALCULATIONS OF HF ANTENNA
IN A STRUCTURED ENVIRONMENT**

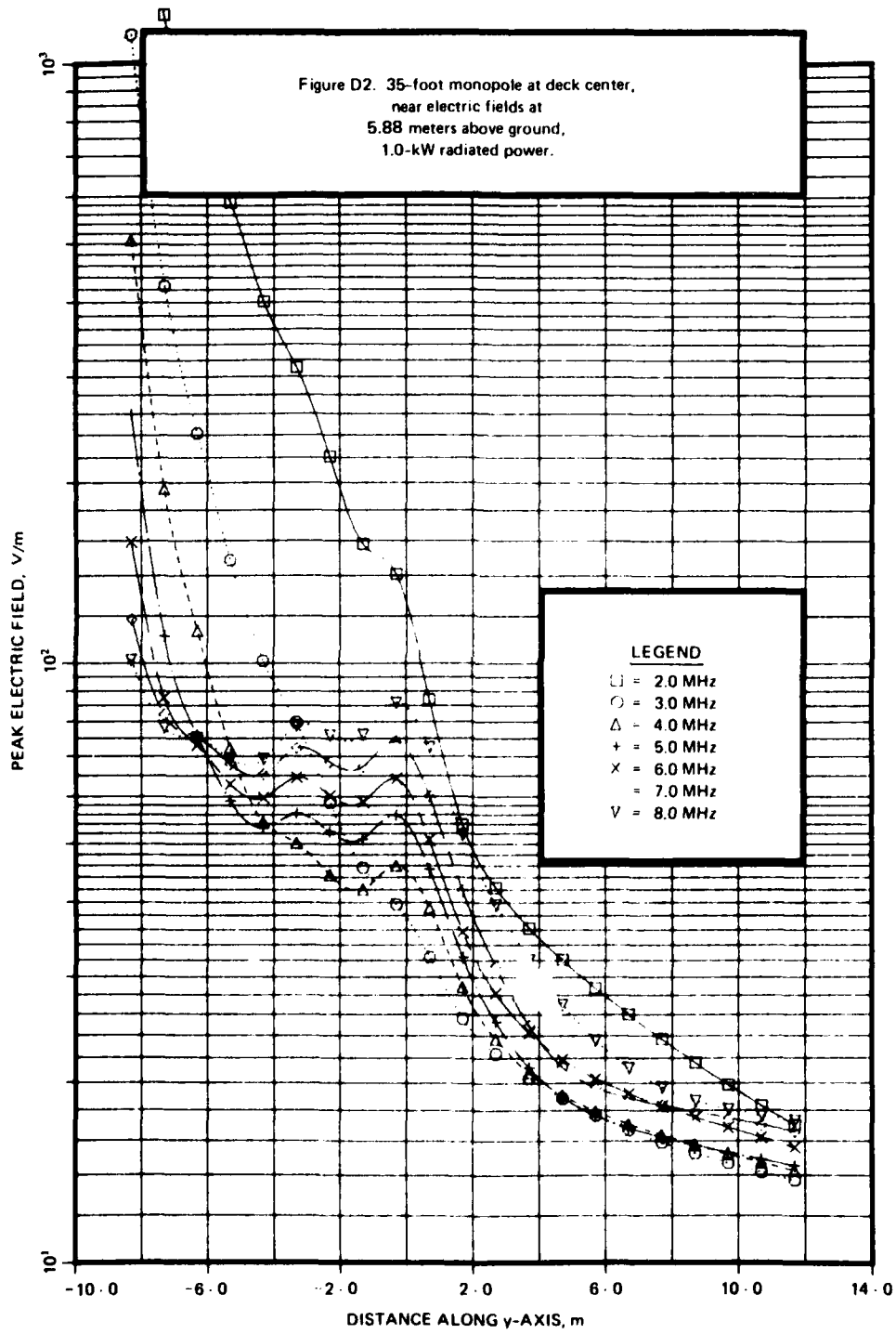
Table D1. Index of peak electric field calculations, 35-foot whip antenna in a structured environment, 1-kW radiated power.

Structured Environment	Frequencies (MHz)	Spatial Variation (meters)	Figure
35-ft whip mounted at center of deck house (fig C1)	2, 3, 4, 5, 6, 7, 8	z = 1.0m, y = 1.0 to 12.0m x = 0.0m	D1
		z = 5.88m, y = -9.0 to 12m x = 0.0m	D2
		z = 10.0m, y = -9.0 to 12m x = 0.0m	D3
35-ft whip mounted at deck edge of deck house (fig C2)	2, 3, 4, 5, 6, 7, 8	z = 1.0m, y = 1.0 to 12.0m x = 0.0m	D4
		z = 5.88m, y = -9.0 to 12m x = 0.0m	D5
		z = 10.0m, y = -9.0 to 12m x = 0.0m	D6
35-ft whip with 35-ft parasitic-separation distance = 6m = 10m = 14m	6.0, 6.2, 6.4, 6.6, 6.8, 7.0, 8.0	z = 1.0m, x = -8.0 to 16.0m y = 0.0m	D7
	6.0, 6.2, 6.4, 6.6, 6.8, 7.0		D8 D9
35-ft whip with 31-ft parasitic-separation distance = 6m = 10m = 14m	6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0	z = 1.0m, x = -8.0 to 16.0m y = 0.0m	D10
			D11
			D12

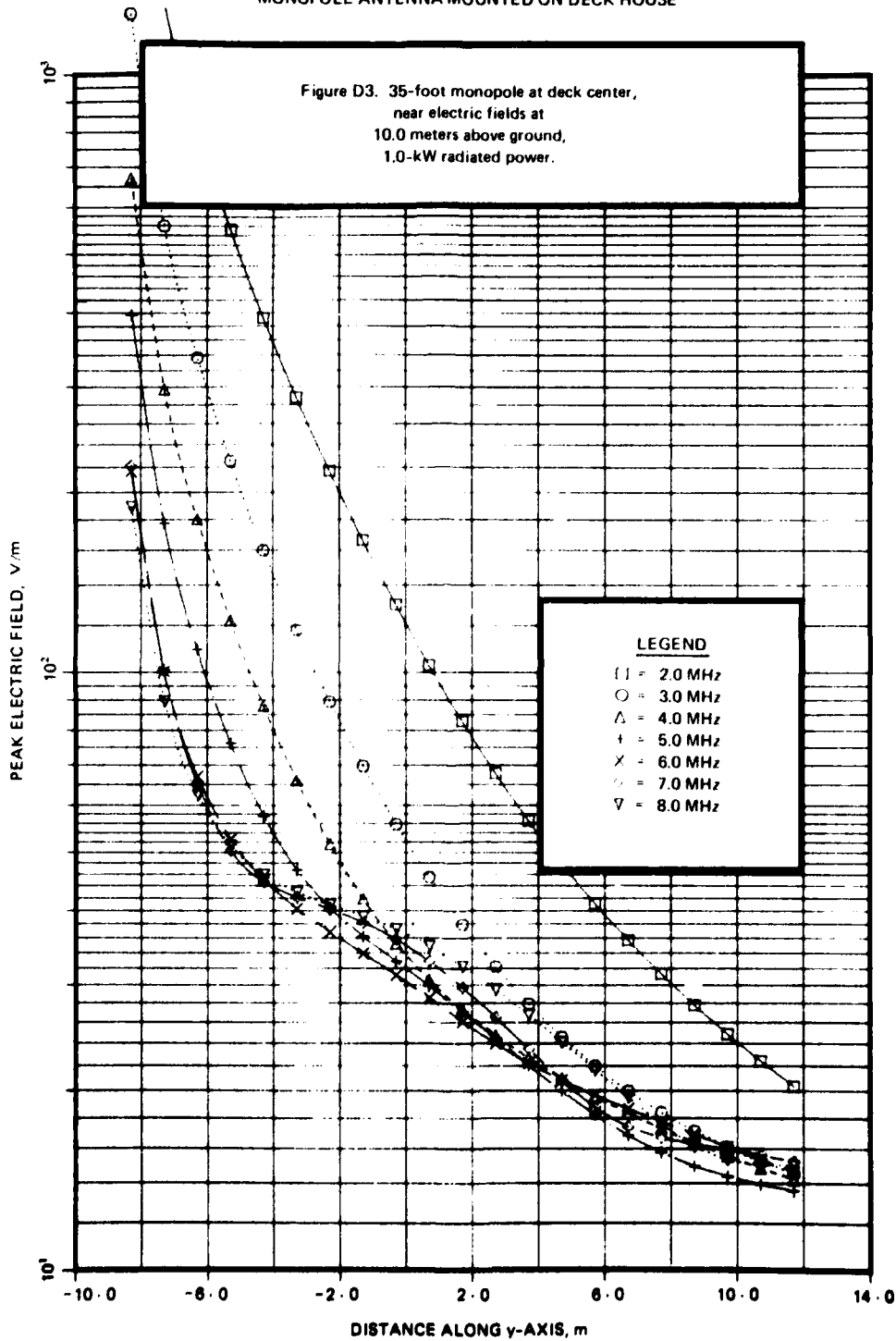
MONOPOLE ANTENNA MOUNTED ON DECK HOUSE



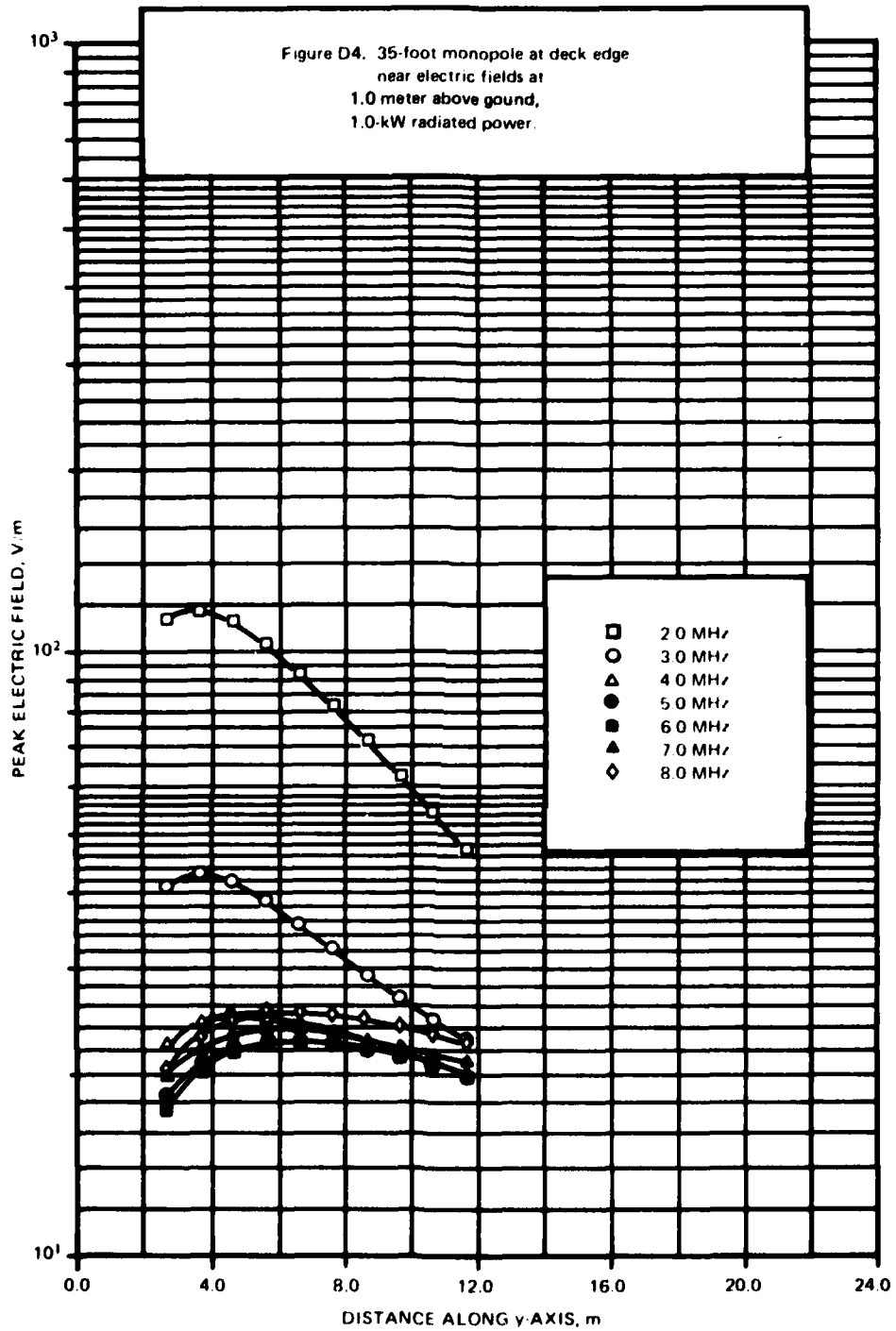
MONOPOLE ANTENNA MOUNTED ON DECK HOUSE



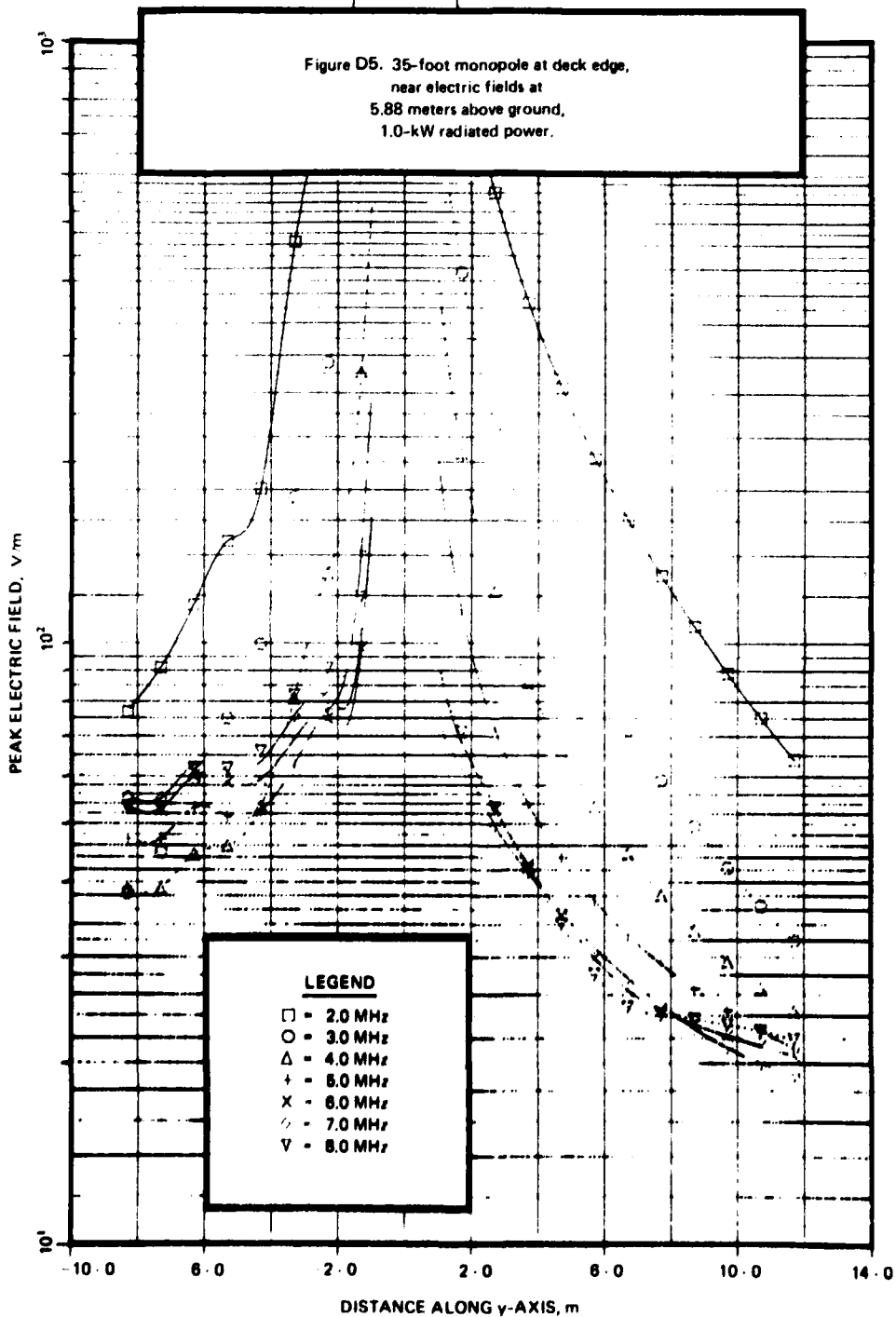
MONOPOLE ANTENNA MOUNTED ON DECK HOUSE



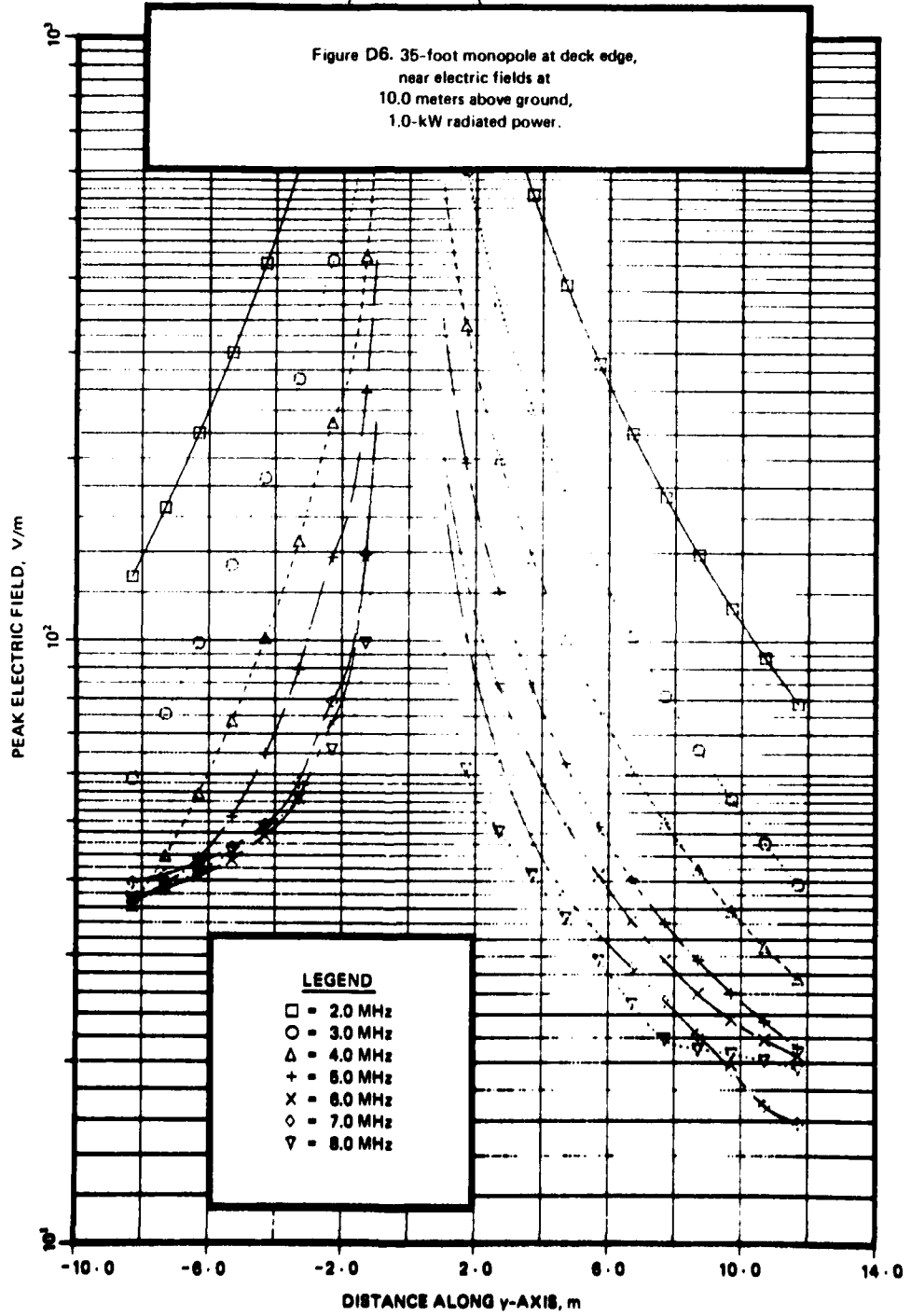
MONOPOLE ANTENNA MOUNTED ON DECK HOUSE



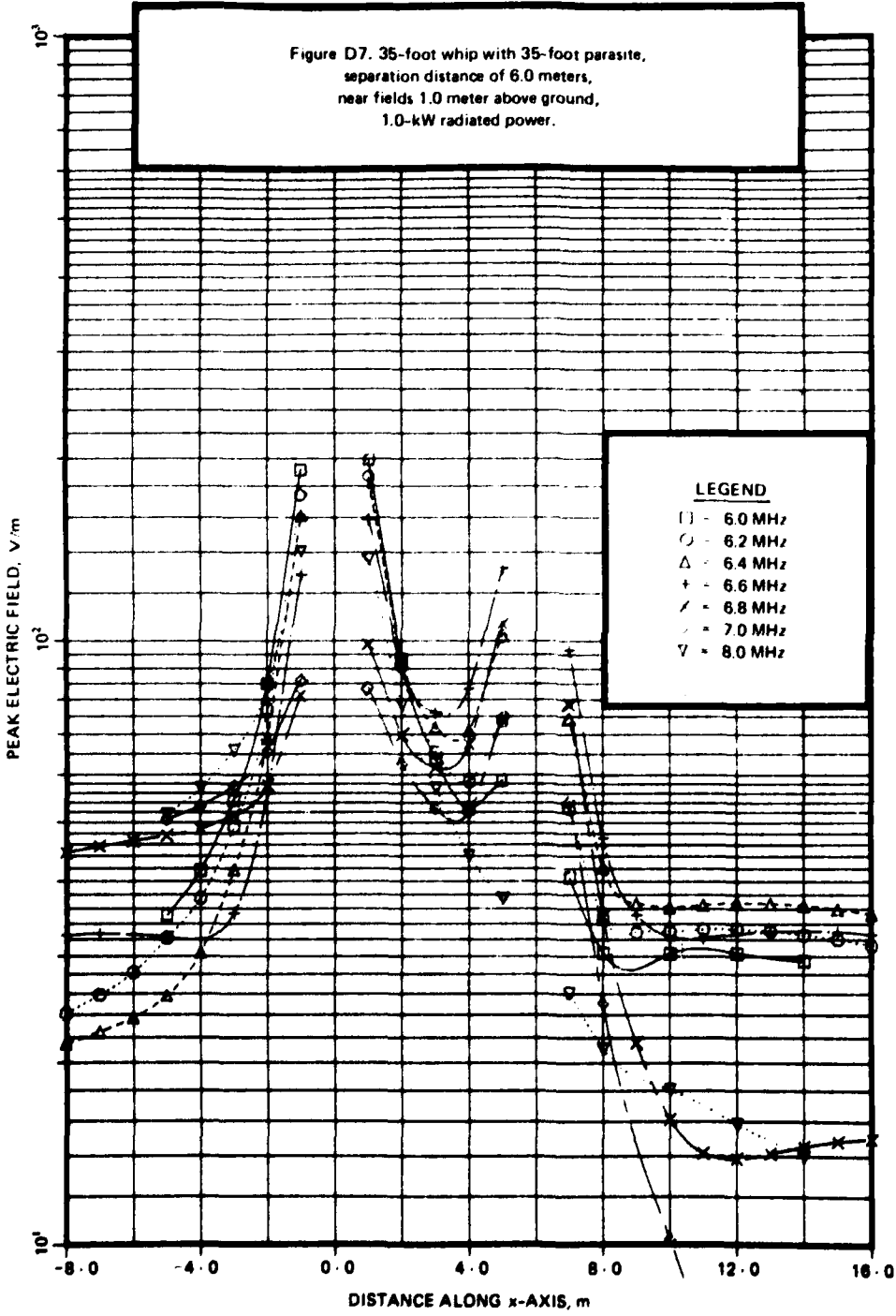
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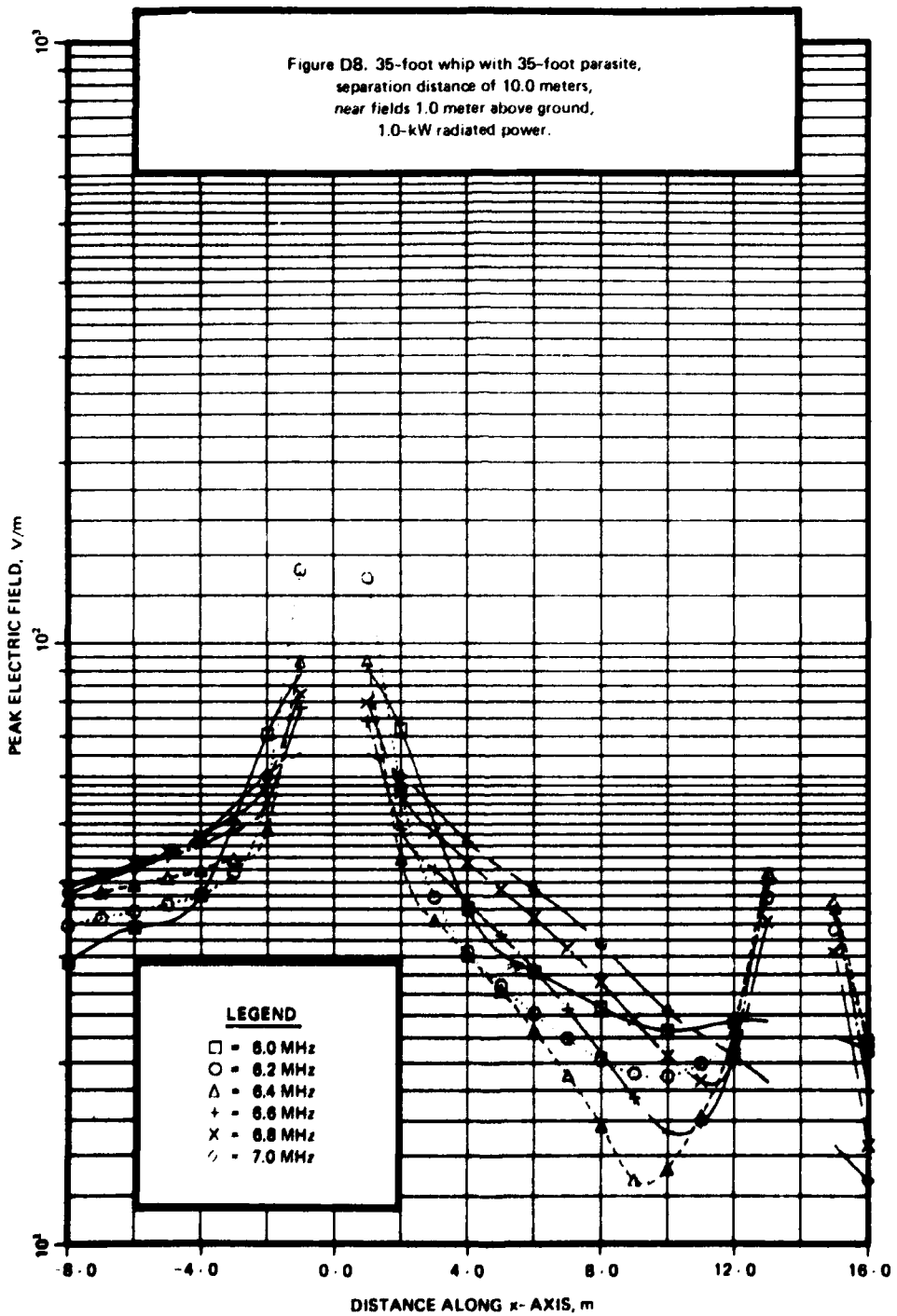
MONOPOLE ANTENNA MOUNTED ON DECK HOUSE



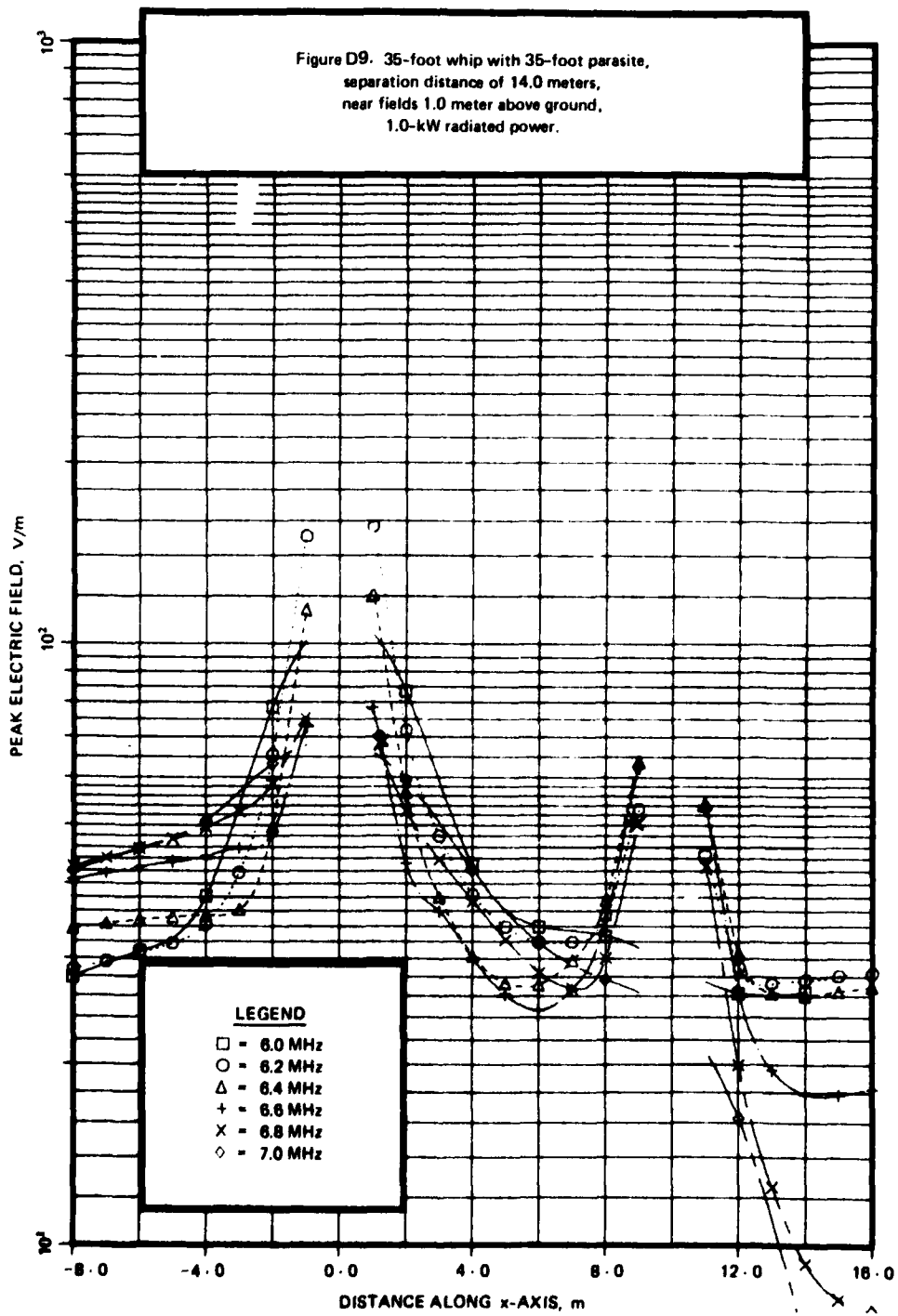
EFFECTS OF PARASITIC STRUCTURES



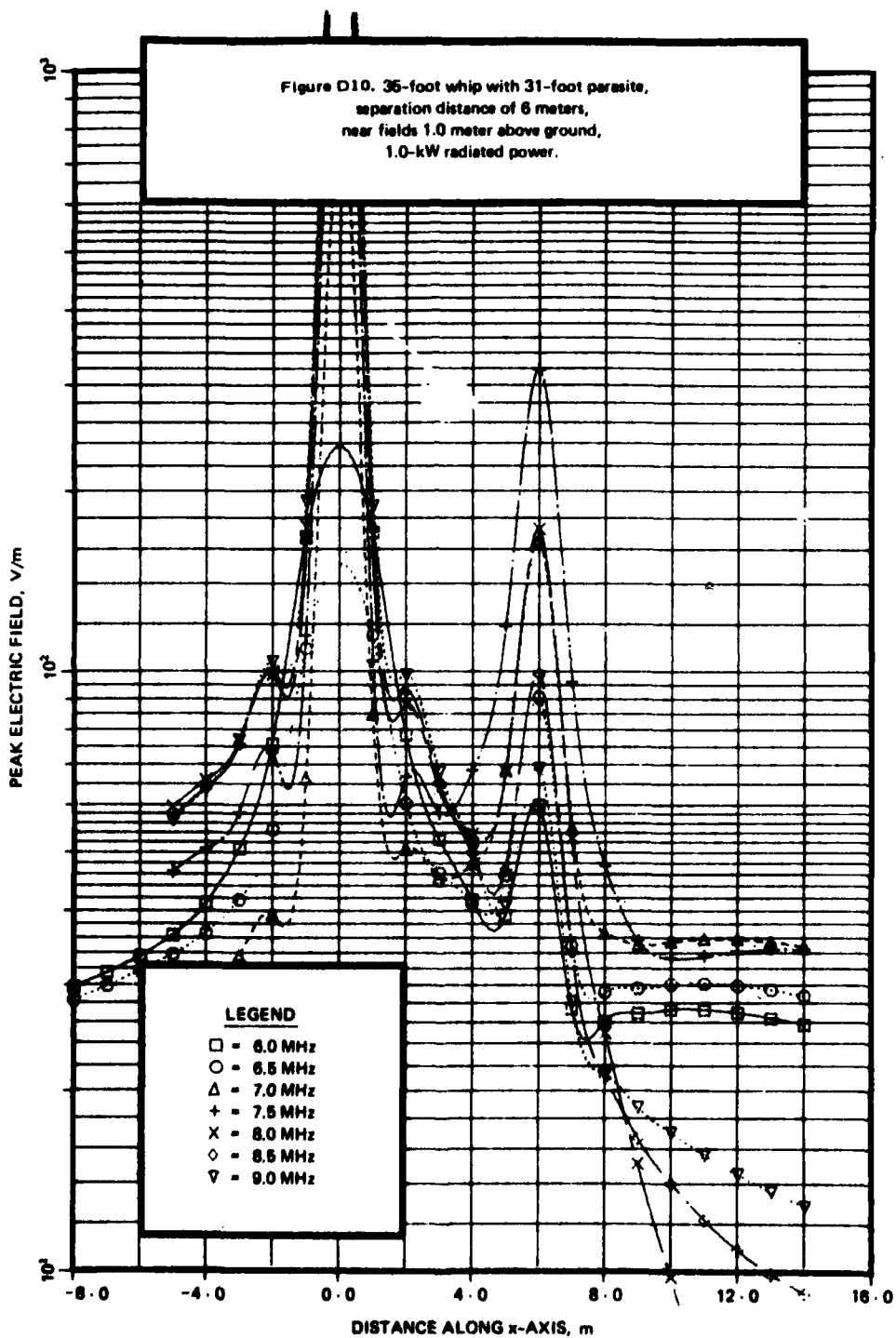
EFFECTS OF PARASITIC STRUCTURES



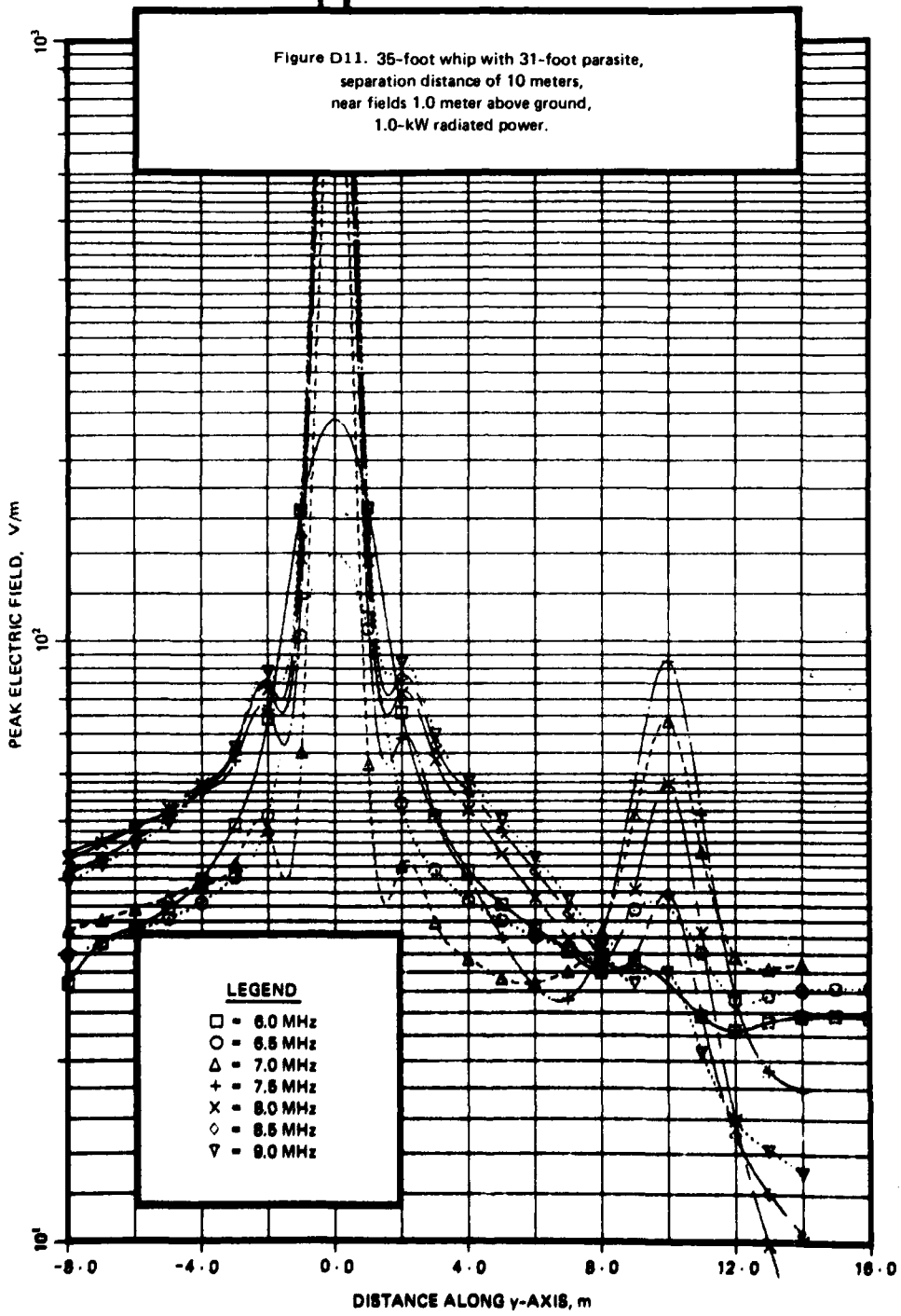
EFFECTS OF PARASITIC STRUCTURES



EFFECTS OF PARASITIC STRUCTURES

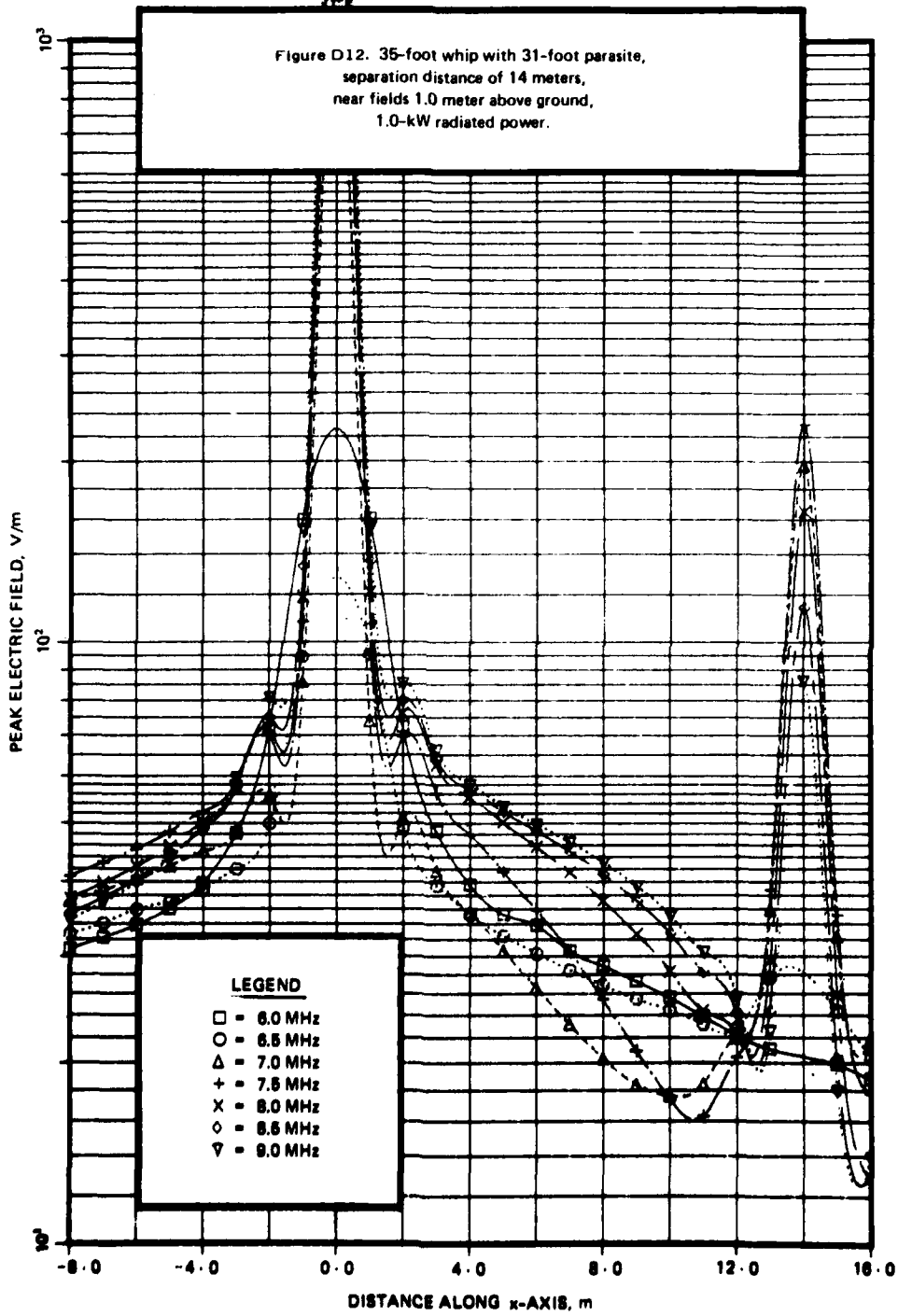


EFFECTS OF PARASITIC STRUCTURES



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