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Special Technical Report 41

A STUDY OF ELECTROMAGNETIC PROPERTIES OF AN ISOLATED TREE

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By: VICHIT LORCHIRACHOONKUL

Prepared for:

U.S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY 07703

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SRI Project 4240

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ERRATA

For: "A Study of Electromagnetic Properties of an Isolated Tree," by V. Lorenirachoonkul, Special Technical Report 41, Contract DA 36-039 AMC-00040(E), Order No. 5384-PM-63-91, SRI Project 4240, Stanford Research Institute, Menlo Park, California (February 1968).

The titles of Figs. 11 and 12 were inadvertently reversed. Changes should be made as follows:

Page vii: substitute the title of Fig. 11 for that of Fig. 12, and the title of Fig. 12 for that of Fig. 11.

Page 28: The title of Fig. 11 should read as follows:

SIGNALS RECEIVED AS TRANSMITTER MOVES ON DIRECT PATH TOWARD RECEIVER

Page 28: The title of Fig. 12 should read as follows:

SIGNALS RECEIVED AS TRANSMITTER MOVES ON A RADIAL AT 60° TO THE DIRECT PATH FROM TREE TO RECEIVER

The figures are correct in all other respects.

ABSTRACT

The objective of this report is to establish an electrical model to represent an isolated tree. Representation of an isolated tree by a perfectly conducting cylinder of smaller radius is shown to be feasible. This leads to the concept of using the equivalent radius of the tree to link the unknown electromagnetic theories of the tree to the well-developed theories of the perfectly conducting cylinder.

Data from three kinds of experiments are analyzed to validate the electrical model:

(1) Patterns of radio waves scattered from an isolated tree and from an aluminum mast,

(2) Input impedance of a $\lambda/2$ vertical antenna in the vicinity of an isolated tree, and

(3) Patterns of an isolated tree as a shunt-fed, grounded radiator.

The frequencies used in the experiments were 50, 75.1, and 100 MHz; the polarization was vertical.

The variation of the input impedance of a $\lambda/2$ vertical antenna as it is moved close to a tree trunk is similar to that of a $\lambda/2$ horizontal antenna as it approaches a lossy ground. The directivity of a tree as a shunt-fed, grounded radiator is demonstrated experimentally, and the front-to-back ratio is about 16 dB.

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FOREWORD

The work described in this report was performed with the support, and using the facilities, of the Military Research and Development Center (MRDC) in Bangkok, Thailand. The MRDC is a joint Thai-U.S. organization established to conduct research and development work in the tropical environment. The overall direction of the U.S. portion of the MRDC has been assigned to the Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense, who, in 1962, asked the U.S. Army Electronics Command (USAECOM) and the Stanford Research Institute (SRI) to establish an electronics laboratory in Thailand to facilitate the study of radio communications in the tropics and related topics. The MRDC-Electronics Laboratory (MRDC-EL) began operation in 1963 [under Contract DA 36-039 AMC-00040(E)], and since that time the ARPA has actively monitored and directed the efforts of USAECOM and SRI. In Bangkok, this function is carried out by the ARPA Research and Development Field Unit (RDFU-T). The cooperation of the Thai Ministry of Defense and the Thailand and CONUS representatives of the ARPA and USAECOM made possible the work presented in this report.

I INTRODUCTION

It has been known since World War II that the attenuation of radio waves in the jungle is so great that communication with low-power manpack radios over distances greater than about one mile is very difficult. Herbstreit and Crichlow[1*] and others[2] measured signal attenuation with distance in forested terrain. More recently, the Jansky and Baily Division of the Atlantic Research Corporation has conducted a research program in Thailand to obtain experimental knowledge of radio propagation in tropical forests,[3] and data on antenna-vegetation effects and forest propagation have also been obtained by the Stanford Research Institute in Thailand.[4,5,6,7] These studies have dealt primarily with the trees in a forest considered as an ensemble. Indeed, a lossy dielectric slab-model for describing the gross features of forest propagation (e.g., path loss, height gain) has proven very successful.[8,9,10,11] Data obtained in these studies and in those by Josephson and Blomquist (Ref. 12, Fig. 3) have revealed rapid variation of received signal strength as the separation between transmitter and receiver is increased only slightly. This fading implies scattering from the trees, particularly those in the neighborhood of the antennas. Therefore, a study of the electromagnetic properties of isolated trees was undertaken on this contract to better define the effect of vegetation on radiowave propagation and antenna-vegetation interaction.

Before discussing the current study, let us review the earlier work pertaining to isolated trees, as contrasted with the work related primarily to the forest as an ensemble, referred to in the previous paragraph. Perhaps the earliest measurements were made by Josephson and Blomquist[12], whose study included mapping the vertically polarized fields in the vicinity of a pine tree (in a forest) at 35 MHz. They observed that a variation of 11 dB occurred within a distance of 1/3 wavelength from the tree.

---

* References are listed at the end of the report.

Steele and Barnum[13] studied the scatter cross-section of selected oak trees at 25.9 MHz and concluded that the echo center of these trees was the main trunk. A tree one-quarter-wavelength high was found to have a cross-section of about 0.6 that of a half-wave dipole (or about $\lambda^2/2$). Hagn et al.[14] observed significant scatter from a grove of eucalyptus trees and deep fading in the azimuth patterns of vertical monopoles. G. S. Parks, Jr., measured the driving-point impedance of a vertical halfwave 100-MHz dipole as a function of distance from an isolated eucalyptus tree (reported on in Ref. 15). The observed variation was similar to what one would expect from a two-element Yagi antenna as the distance between the driven element and the reflector is varied, and it was inferred that the tall vertical tree trunks can act as lossy conducting masts. Steele[16] commented that the roots of trees should provide good radio frequency coupling to the ground, and that trees may be considered as grounded vertical masts. In a later article on the effects of trees on HF backscatter from terrain, Steele points out: "A tree, however, can behave like an antenna receiving energy and radiating it again."[17] Additional dipole impedance measurements by N. K. Shrauger (reported on in Ref. 18), further confirm this idea.

Dickinson, et al.[19] measured the input impedance of a shunt-fed, "grounded" tree as a function of frequency. By comparing this with the imput impedance of a uniform lossy conducting cylinder, he obtained an estimate of the radio frequency conductivity of the tree of 0.24 mho/m. He concluded that although trees will function as grounded vertical radiators, they certainly are not an improvement over existing antennas, and he advised against any further research on trees as antennas. On 14 August 1967, independently of Dickinson's work, a 41-ft tree was used successfully in Thailand as an antenna in an HF communication link between SRI's Chumphon field site and Bangkok 500 km away.* The tree was shunt-fed as a grounded vertical mast and used on 9.1 MHz for both transmitting and receiving. Dickinson's analysis did not consider the possibility of a

* G. H. Hagn and H. W. Parker, "Test of Dr. Vichit's Tree as an Antenna," Internal Memorandum to SRI Project 4240 File, Bangkok, Thailand (14 September 1967).

tree possessing azimuth directivity, although this is suggested by its bulky shape and by some of the previous work.[12,13,16] Though the over-all efficiency of a tree as an antenna is lower than that of a conventional antenna, due to its imperfect conductivity, the directivity of a tree as an antenna--if it exists--would be a possible factor to offset its low efficiency.

The following measurements were performed in the current investigation of the radio-frequency characteristics of isolated trees:

(1) Patterns of an isolated tree and of an aluminum mast

(2) The input impedance of a vertical antenna in the vicinity of an isolated tree

(3) The radiation pattern of an isolated tree used as a grounded vertical antenna.

The theory behind the experiments is presented in Sec. II. It should be emphasized that this is the first attempt to establish some electrical and electromagnetic theories on an isolated tree. Most of the theories are based on the experimental results. Preliminary studies on an isolated tree at Chumphon test site are discussed in Sec. III. Details of experiments on an isolated tree and on an aluminum mast are described in Sec. IV. The results of each experiment are presented in Sec. IV, and the experimental and theoretical values are compared in Sec. V. Conclusions on the present study and recommendations for further research on related topics are discussed in Sec. VI.

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II THEORETICAL BACKGROUND

In this section, theoretical analysis of an electrical and electromagnetic model of an isolated tree is presented. From the study of the moisture content of living trees, it is found that the variation of the moisture content in the stem occurs mainly within the sapwood. The moisture content falls very rapidly across the xylary tissues situated between the vascular cambium and the outer limits of the transpiration stream.* This suggests that the conductivity along the circumference of xylary tissues between the vascular cambium and the outer limits of the transpiration stream is higher than the conductivity in the radial direction. Then if the tree is excited at a point A (see Fig. 1), the current flows

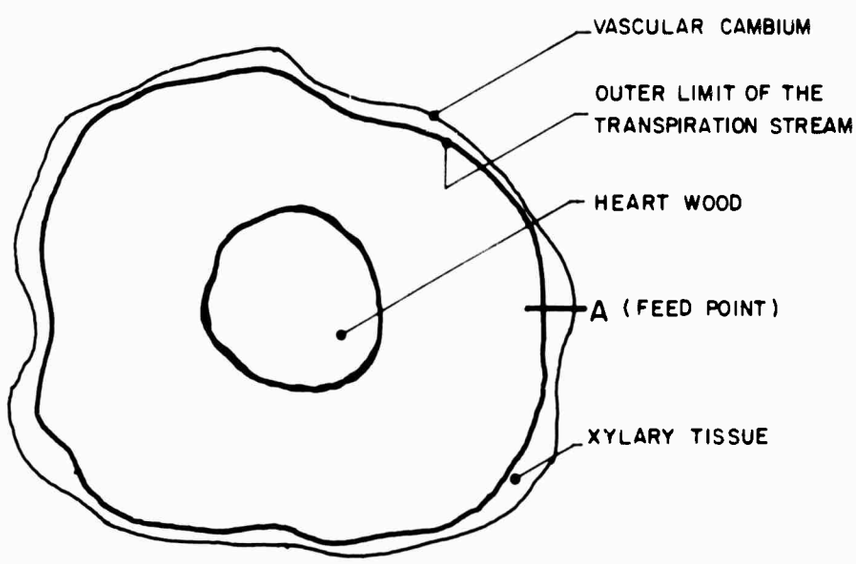

FIG. 1 CROSS-SECTION OF A TREE

* Definitions of the botanical terms are found in Ref. 20.

mainly in the xylary tissues between the vascular cambium and the outer limits of the transpiration stream. Based on this postulate, a hollow, perfectly conducting cylinder of radius a is used as a model for a tree. The equivalent radius of the tree is generally smaller than its actual physical radius, to compensate for the loss in the tree.

The first part of this section is concerned with the scatter field of an infinitely long, perfectly conducting cylinder. The cylinder of infinite length is used to simplify the mathematical difficulties. On the principal plane, i.e., perpendicular to the axis of the cylinder, the pattern of the field is the same whether the length of the cylinder is finite or infinite. The last part of this section deals with the characteristics of the impedance of an antenna in the vicinity of an isolated tree. An electrical description of the variation is discussed.

A. SCATTERING PROPERTY OF AN INFINITELY LONG CONDUCTING CYLINDER

Consider the electric field of an infinitely long line source carrying a current $Ie^{j\omega t}$. It is assumed that there is no change of magnitude or of phase from point to point along the line. For a point Q, a distance p in a principal plane from the line source, the z-component of the vector potential due to the current I in the infinitely long line source is:

$$A_z = \frac{\mu I}{4\pi} \int_{-\infty}^{\infty} \frac{e^{-j\beta r} dz}{r} \quad , \tag{1}$$

where $\beta = 2\pi/\lambda$ is a free-space wave number, and $r = (p^2 + z^2)^{1/2}$ is a distance from the current element to the point Q (see Fig. 2). It can be shown that the expression in the right hand side in Eq. (1) can be written in the closed form as:

$$A_z = -j \frac{\mu I}{4} H_o^{(2)}(\beta p) \quad , \tag{2}$$

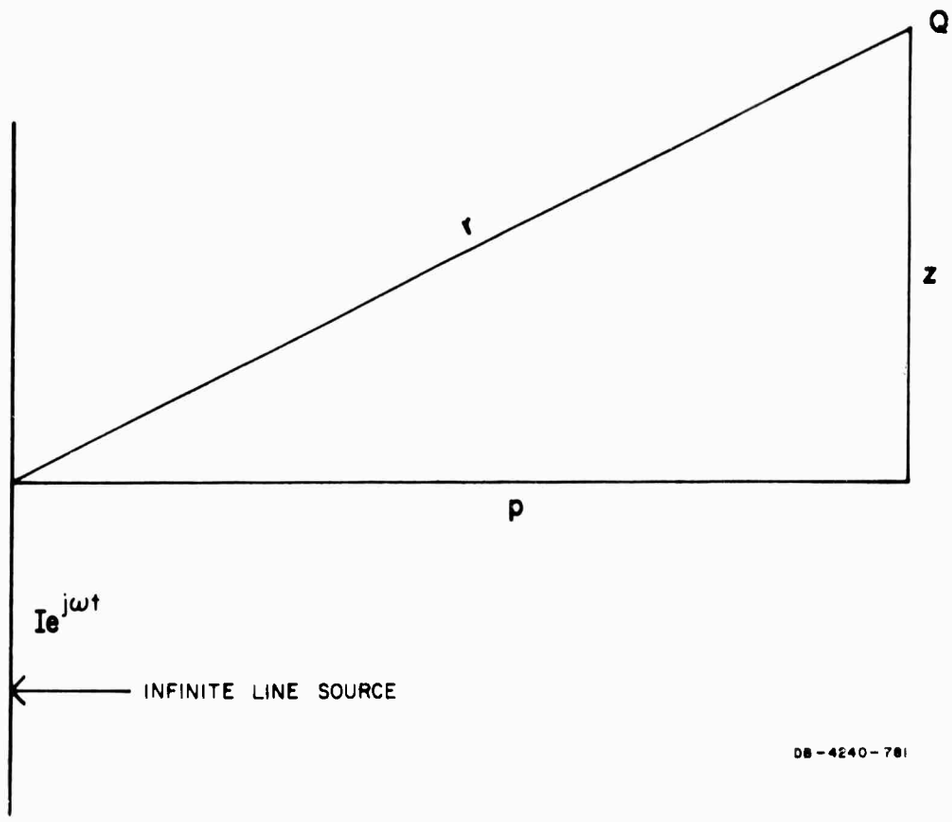

FIG. 2 COORDINATE SYSTEM FOR AN INFINITELY LONG LINE SOURCE

where $H_o^{(2)}(\beta p)$ is the zero-order Hankel function of the second kind. Then, for an infinitely long wire, an electric field E_o at a distance p can be expressed as:

$$E_o = -\frac{\omega\mu}{4} I H_o^{(2)}(\beta p) \quad . \tag{3}$$

If the argument βp of the Hankel function is sufficiently large (as at VHF), the Hankel function of Eq. (3) can be approximated by its asymptotic representation:

$$E_o = \begin{cases} -\frac{\omega\mu I}{4} (-1)^{n/2} H_n^{(2)}(\beta p) & \text{when n is even} \\ j\frac{\omega\mu I}{4} (-1)^{(n-1)/2} H_n^{(2)}(\beta p) & \text{when n is odd} \end{cases} \quad . \tag{4}$$

Now consider the case that an infinitely long line source carrying a uniform current $Ie^{j\omega t}$ is placed at a distance b away from the center of an infinitely long conducting cylinder of radius a, as shown in Fig. 3.

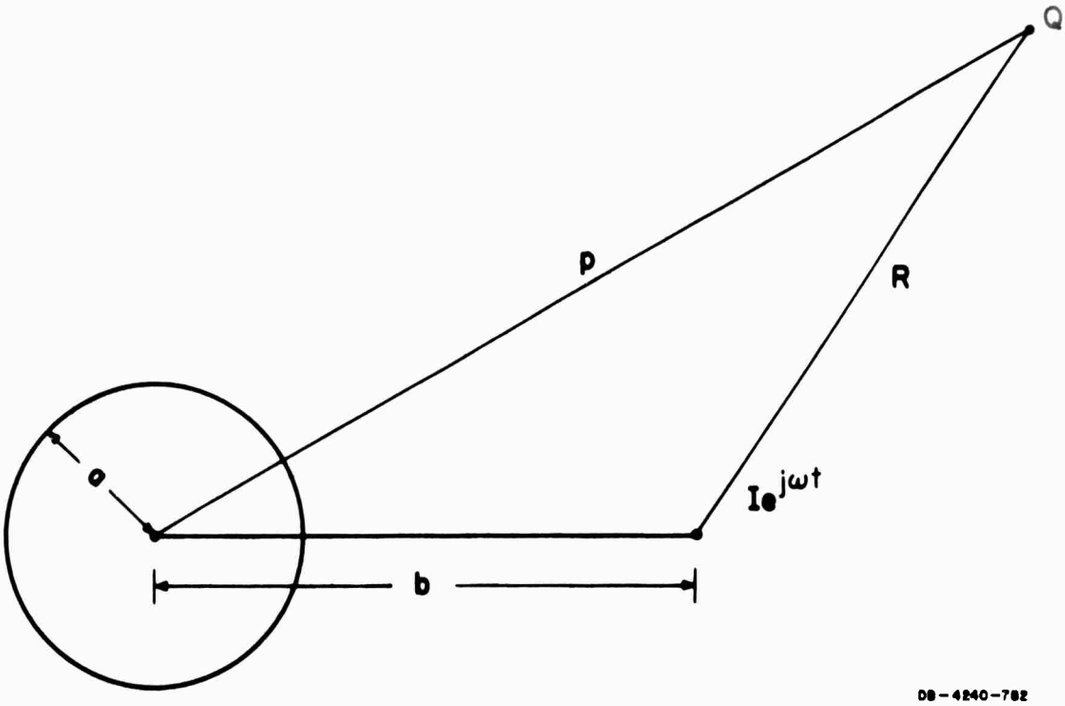

FIG. 3 GEOMETRY FOR AN INFINITELY LONG LINE SOURCE IN FRONT OF A PERFECTLY CONDUCTING CYLINDER OF RADIUS a

The solution of the problem of an infinitely long line source parallel to an infinitely long conducting cylinder is applicable to the case of a finite length line source parallel to a conducting cylinder of finite length in the principal plane, i.e., perpendicular to the axis of the cylinder, as long as b is small compared to the finite length, ℓ.

Let the linear distribution of the current density in the thin shell of the cylinder be represented by a Fourier series:

$$i_\phi = \sum_{n=o}^{\infty} i_n \cos n\phi \quad , \tag{5}$$

where i_n is the nth spatial harmonic of the distribution of the current density and its dimension is "per unit length."

For simplicity, consider first the case in which the distribution of the current density is independent of ϕ. In other words, the current is uniformly distributed on the shell of the cylinder of radius a.

As seen in Fig. 4, the difference in the propagation path between the point B_1 to the distant point Q and the point B_2 to the distant point Q is

$$2\ a \cos \alpha \cos \phi \quad . \tag{6}$$

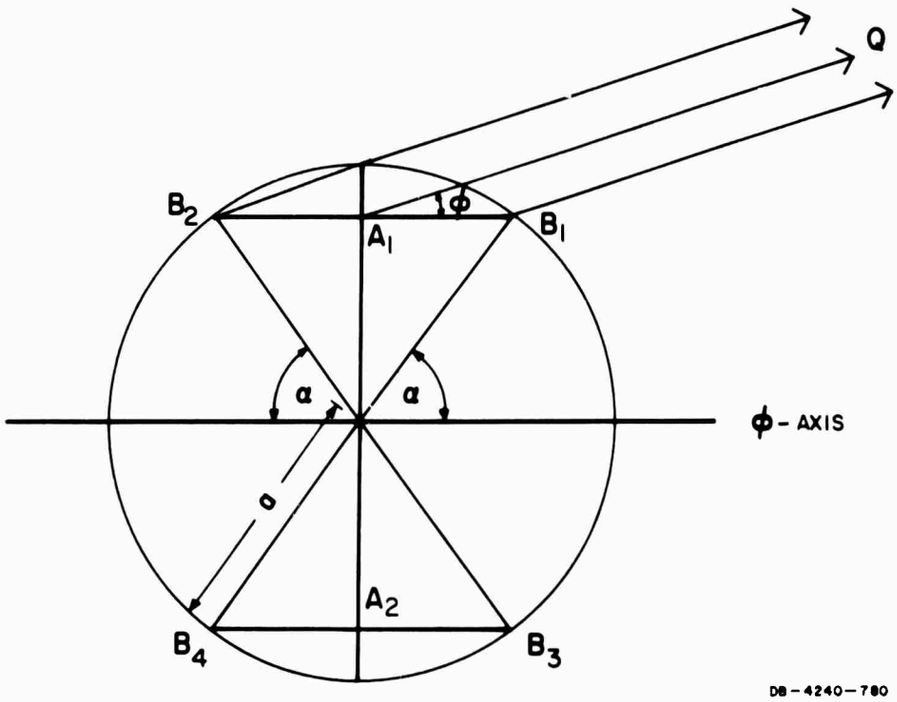

FIG. 4 NOTATION FOR DERIVING THE RADIATION FROM A PERFECTLY CONDUCTING CYLINDER

If the excitation of a point source alone would produce an electric field E_o at Q, then the two dipole moments of $i_o a\, d\alpha$ multiplied by the magnitude of symmetrical point sources at B_1 and B_2 produce an electric field:

$$2E_o \cos [\beta a \cos \alpha \cos \phi]\, i_o a\, d\alpha \quad , \tag{7}$$

which would arise from a fictitious current at A_1. Due to the symmetry about the ϕ-axis, the same field as in Eq. (7) resulting from the point sources at B_3 and B_4 would arise from another fictitious current at A_2. The path difference between the two fictitious point sources at A_1 and A_2 is

$$2a \sin \alpha \sin \phi \quad . \tag{8}$$

Then the resultant field due to four point sources at B_1, B_2, B_3, and B_4 is:

$$dE = \cancel{2}4E_o \cos [\beta a \cos \alpha \cos \phi] \cos [\beta a \sin \alpha \sin \phi]\, i_o a\, d\alpha \quad . \tag{9}$$

The total field at a distant point Q is:

$$E = \cancel{2}4E_o a i_o \int_o^{\pi/2} \cos [\beta a \cos \alpha \cos \phi] \cos [\beta a \sin \alpha \sin \phi]\, d\alpha$$

$$= 2\pi\, a E_o i_o J_o(\beta a) \quad . \tag{10}$$

Here, J_o is the zero-order Bessel Function of the first kind. The field in Eq. (10) is the same as that produced by a thin wire carrying a current $2\pi a i_o J_o(\beta a)$.

Next, if the distribution of the current density is

$$i_\phi = i_1 \cos \phi \quad , \tag{11}$$

the phase difference of signals from the points B_1 and B_2 becomes

$$\pi + 2\beta a \cos \alpha \cos \phi \quad . \tag{12}$$

The factor, π radians, is introduced in Eq. (12) because the current is flowing upwards in the first quadrant and downwards in the second quadrant. The resultant field due to the point sources at B_1 and B_2 is, then,

$$2E_o \sin [\beta a \cos \alpha \cos \phi] i_1 \cos \alpha \, a \, d\alpha \quad , \tag{13}$$

which is leading the field from the fictitious source at A_1 by $\pi/2$ radians. To use the same reference as in the previous case, Eq. (13) becomes

$$2jE_o \sin [\beta a \cos \alpha \cos \phi] i_1 \cos \alpha \, a \, d\alpha \quad . \tag{14}$$

Then the resultant field from the two fictitious sources at A_1 and A_2 is

$$\cancel{2}\,4jE_o \sin [\beta a \cos \alpha \cos \phi] \cos [\beta a \sin \alpha \sin \phi] i_1 \cos \alpha \, a \, d\alpha \quad , \tag{15}$$

and the total field at Q is

$$E = \cancel{2}\,4jE_o i_1 a \int_o^{\pi/2} \sin [\beta a \cos \alpha \cos \phi] \cos [\beta a \sin \alpha \sin \phi] \cos \alpha \, d\alpha$$

$$= j2\pi a E_o i_1 J_1(\beta a) \cos \phi \quad . \tag{16}$$

Similarly, if the distribution of the current density is

$$i_\phi = i_n \cos n\phi \quad ,$$

it can be shown that the total field from the cylinder of the radius a at the point Q is

$$E = (j)^n 2\pi a E_o i_n J_n(\beta a) \cos n\phi \quad . \tag{17}$$

Therefore, in general, if the distribution of the current density is given by Eq. (5), the electric field intensity at the point Q is

$$E = 2\pi a E_o \sum_{n=o}^{\infty} (j)^n i_n J_n(\beta a) \cos n\phi \quad . \tag{18}$$

Substituting the expressions of E_o from Eq. (4) into Eq. (18) yields

$$E = -\frac{\pi a \omega \mu I}{2} \sum_{n=o}^{\infty} i_n J_n(\beta a) H_n^{(2)}(\beta p) \cos n\phi \quad , \tag{19}$$

which is the field radiated from a perfect conducting cylinder of radius a at a distant point Q at distance p. The harmonics (i_n's) of the distribution of the current density are yet to be determined.

From the geometry in Fig. 3, the electric field at the point Q due to the line source alone is

$$E_1 = -\frac{\omega\mu I}{4} H_o^{(2)}(\beta R) \quad . \tag{20}$$

By Neumann's addition theorem in the theory of Bessel functions, Eq. (20) becomes

$$E_1 = \begin{cases} -\frac{\omega\mu I}{4} \sum_{n=o}^{\infty} \epsilon_n H_n^{(2)}(\beta b) J_n(\beta p) \cos n\phi \quad , & \text{for } p < b \\ -\frac{\omega\mu I}{4} \sum_{n=o}^{\infty} \epsilon_n H_n^{(2)}(\beta p) J_n(\beta b) \cos n\phi \quad , & \text{for } p > b \quad , \end{cases} \tag{21}$$

where ϵ_n is Neumann's number

$$\epsilon_n = \begin{cases} 1 & n = 0 \\ 2 & n \neq 0 \end{cases} \quad .$$

Then the total field at a distant point Q due to radiation from an infinitely long line source of current $Ie^{j\omega t}$ at a distance b away from the center of an infinitely long conducting cylinder of radius a is

$$E_T = \begin{cases} -\dfrac{\omega\mu I}{4} \displaystyle\sum_{n=o}^{\infty} \left[\epsilon_n H_n^{(2)}(\beta b) J_n(\beta p) + 2\pi a i_n J_n(\beta a) H_n^{(2)}(\beta p)\right] \\ \cos n\phi \quad , \qquad \text{for } p < b \\ -\dfrac{\omega\mu I}{4} \displaystyle\sum_{n=o}^{\infty} \left[\epsilon_n J_n(\beta b) + 2\pi a i_n J_n(\beta a)\right] H_n^{(2)}(\beta p) \\ \cos n\phi \quad , \qquad \text{for } p > b \quad . \end{cases} \tag{22}$$

At the surface of the perfectly conducting cylinder, the electric field is zero. Therefore, to satisfy this condition i_n must be

$$i_n = -\frac{1}{2\pi a} \frac{\epsilon_n H_n^{(2)}(\beta b)}{H_n^{(2)}(\beta a)} \quad . \tag{23}$$

The distribution of the induced current in the thin shell of the cylinder of radius a in the presence of an infinitely long line source at a distance b away is

$$i_\phi = -\frac{1}{2\pi a} \sum_{n=o}^{\infty} \frac{\epsilon_n H_n^{(2)}(\beta b)}{H_n^{(2)}(\beta a)} \cos n\phi \quad . \tag{24}$$

Substituting the expression for i_n in Eq. (23) into Eq. (22) yields:

$$E_T = \begin{cases} -\dfrac{\omega\mu I}{4} \displaystyle\sum_{n=o}^{\infty} \left[J_n(\beta p) - \frac{J_n(\beta a) H_n^{(2)}(\beta p)}{H_n^{(2)}(\beta a)}\right] \epsilon_n H_n^{(2)}(\beta b) \cos n\phi \quad , \\ \text{for } p < b \\ -\dfrac{\omega\mu I}{4} \displaystyle\sum_{n=o}^{\infty} \left[J_n(\beta b) - \frac{H_n^{(2)}(\beta b) J_n(\beta a)}{H_n^{(2)}(\beta a)}\right] \epsilon_n H_n^{(2)}(\beta p) \cos n\phi \quad , \\ \text{for } p > b \quad , \end{cases} \tag{25}$$

which is the expression to be evaluated to compare with the measurements in the experiment of scattered pattern of radio wave from an isolated tree or from an aluminum mast. A derivation of a similar expression for E_T is given in Ref. 21.

B. IMPEDANCE OF AN ANTENNA IN THE VICINITY OF AN ISOLATED TREE

As a transmitting antenna approaches a tree, a standing wave pattern is established in the signal received at a distant point. Assume that the reflection coefficient in the direct path between the tree, the transmitting and receiving antennas is $\rho e^{j\varphi}$. The signal received at a point along the direct path is then

$$E = E_o[f(r) + \rho e^{j\varphi} f(r + 2d)] \quad , \tag{26}$$

where $f(r)$ is the complex propagation law, dependent on the distance r, obeyed by the field in a certain arrangement; E_o is the field at a unit distance; and d is the distance between the tree and the transmitting antenna. Equation (26) can be viewed as a composite of two sources whose relative amplitudes are 1 and $\rho e^{j\varphi}$ at a 2d distance apart. In other words, the tree is replaced by a source whose amplitude in relation to that of the transmitting antenna is $\rho e^{j\varphi}$, situated at a distance 2d from the transmitting antenna.

If Z_m is the mutual impedance between the transmitting antenna and the fictitious antenna at a distance of 2d, the applied voltage at the antenna terminals is

$$V = I_1 Z_{11} + I_2 Z_m \quad , \tag{27}$$

where I_1 is the current in the transmitting antenna, I_2 is the current in the fictitious antenna, and Z_{11} is the self impedance of the transmitting antenna. Then the driving point impedance of the transmitting antenna under this configuration is

$$Z_1 = \frac{V}{I_1} = Z_{11} + \frac{I_2}{I_1} Z_m \quad . \tag{28}$$

The ratio of I_2/I_1 is given by the reflection coefficient $\rho e^{j\varphi}$. On the assumption that the current distribution in the fictitious antenna is sinusoidal, the mutual impedance can be written as

$$Z_m = 30\{2Ei(-j2\beta d) - Ei\,[-j\beta(\sqrt{4d^2 + L^2} + L)] - Ei[-j\beta(\sqrt{4d^2 + L^2} - L)]\} \quad , \tag{29}$$

where the exponential integral is given by:

$$Ei(jx) = \int_{-\infty}^{x} \frac{e^{ju}}{u}\, du \quad , \tag{30}$$

and L is the length of the antenna. Then the mutual resistance of the transmitting antenna and the fictitious antenna is

$$R_m = 30\{2Ci(2\beta d) - Ci[\beta(\sqrt{4d^2 + L^2} + L)] - Ci[\beta(\sqrt{4d^2 + L^2} - L)]\} \quad , \tag{31}$$

and the mutual reactance

$$X_m = -30\{2Si(2\beta d) - Si[\beta(\sqrt{4d^2 + L^2} + L)] - Si[\beta(\sqrt{4d^2 + L^2} - L)]\} \tag{32}$$

where

$$Ci(x) = \int_{-\infty}^{x} \frac{\cos u}{u}\, du \quad ,$$

and

$$Si(x) = \int_{-\infty}^{x} \frac{\sin u}{u}\, du \quad .$$

Substitution of the reflection coefficient for the ratio I_2/I_1 and of the expression of the mutual impedance in Eq. (29) into Eq. (28) gives the explicit form of the driving point impedance of an antenna in the vicinity of an isolated tree as a function of the distance between the tree and the antenna.

III PRELIMINARY STUDIES ON AN ISOLATED TREE*

Some preliminary studies on an isolated tree were performed at the Chumphon SRI field site in August 1967 for the purpose of studying its electrical properties and designing further experiments. The feasibility of representing a tree by a perfectly conducting cylinder of appropriate radius and the reflection of electromagnetic waves from an isolated tree were investigated.

The tree used in these experiments was about 40 feet high and was about 10 inches in diameter at a height of four feet above the ground. An area of about 40 feet radius around the tree was cleared. The effect of the tree on the amplitude of VHF signals received at a fixed point as a transmitter was moved in the vicinity of the tree was studied using the manpack VHF Xeledop system.

The manpack Xeledop, vertically polarized, was carried on the path between the tree and the receiving antenna, a 100 MHz sleeve antenna (cut for $\lambda/2$) situated in the top of the hut, which was 60 feet above the ground (see Fig. 5). The 100-MHz sleeve antenna, used to receive the signals of three frequencies (50, 75.1, and 100 MHz) from the manpack Xeledop, was connected by a 1000-ft. RG-8A/U coaxial line to three R-390 receivers. The AGC signals from each channel were recorded on a Sanborn recorder. The manpack Xeledop transmitter was carried from a point about 26 feet from the tree in the direct path between the tree and the receiving antenna to a point about 10 feet behind the tree. As the Xeledop transmitter was carried on the course, an observer with a handie-talkie several wavelengths away called check points to the operator at the Xeledop van, who noted the transmitter position. The distance between check points was 9.84 feet (one wavelength at 100 MHz). A definite

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* The earliest studies of a single tree performed under this contract are discussed in Refs. 15, 18, and 22.

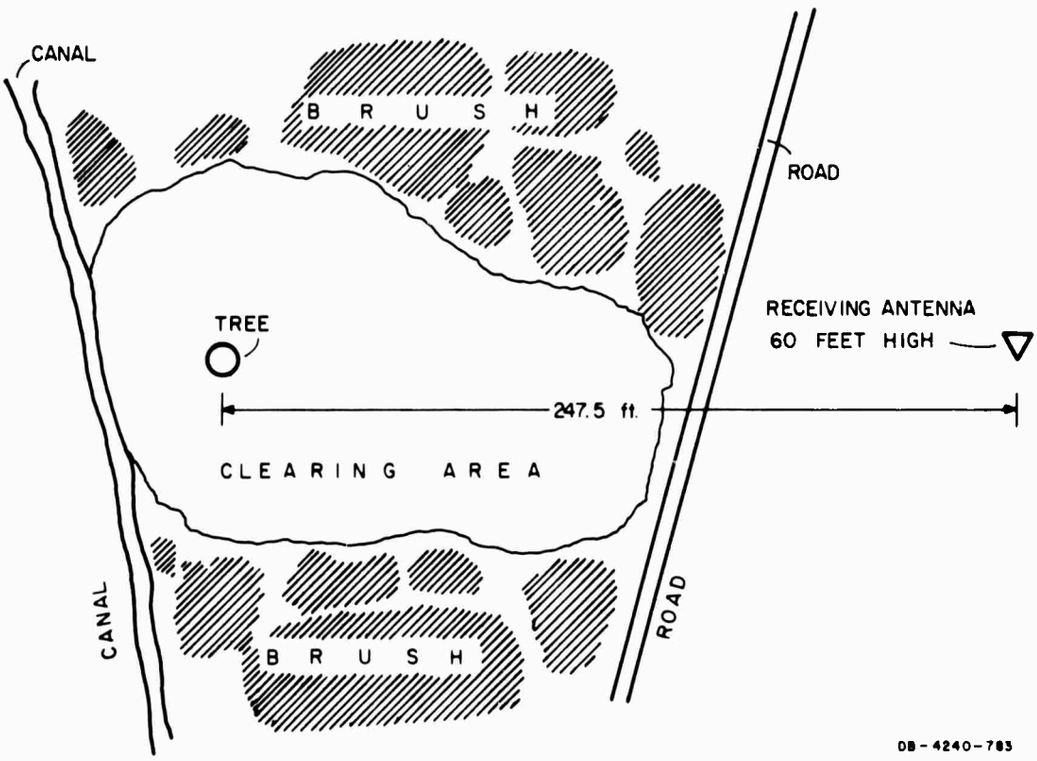

FIG. 5 LOCATION OF THE ISOLATED TREE AND THE RECEIVING ANTENNA AT CHUMPHON TEST SITE

standing-wave pattern (see Fig. 6) was observed in the received signal at all three frequencies. The distance between the maximum and the next minimum is approximately $\lambda/4$ in each case. The reflection coefficient of the tree in the direct path can be determined from

$$\rho = \frac{\left| \frac{E_{max}}{E_{min}} \right| - 1}{\left| \frac{E_{max}}{E_{min}} \right| + 1} , \tag{33}$$

and

$$\varphi = \begin{cases} 2n\pi + \frac{4\pi}{\lambda} S_{max} & n = 0, 1, 2, \ldots \\ (2n - 1)\pi + \frac{4\pi}{\lambda} S_{min} & n = 1, 2, 3, \ldots \end{cases} . \tag{34}$$

The ratio $|E_{max}/E_{min}|$ used in the calculation is the first peak-to-peak variation from the tree. The terms S_{max} and S_{min} are the distances of the maxima and minima from the tree.

The experimental results suggested the transmitter position should be located more accurately to give the precise locations of maxima and minima in the received signal. A more careful series of experiments was then planned.

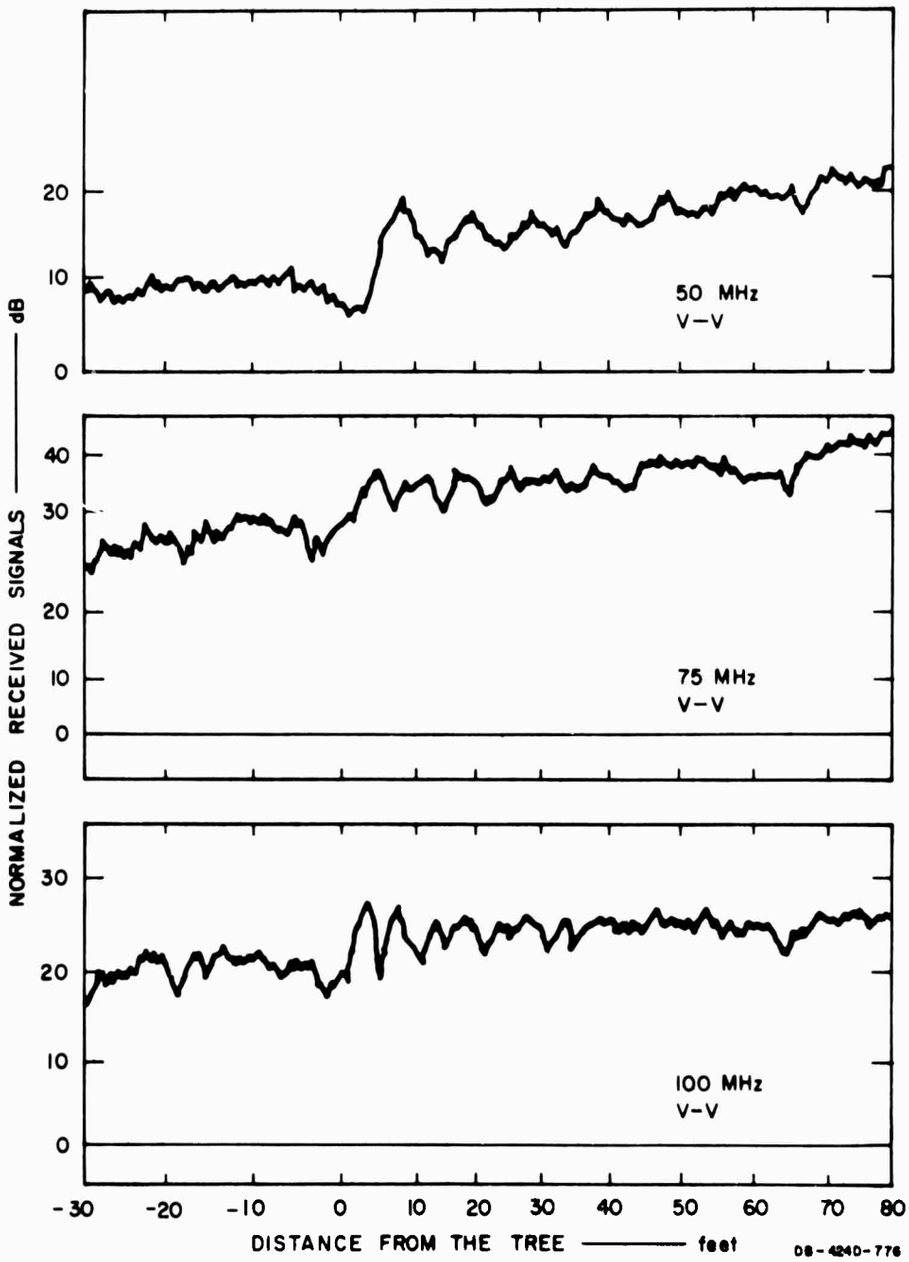

FIG. 6 SAMPLES OF THE RECEIVED SIGNALS IN THE PRELIMINARY STUDY OF THE SCATTERING PROPERTIES OF AN ISOLATED TREE

IV DESCRIPTION OF EXPERIMENTS

Three groups of experiments were performed to study electrical and electromagnetic properties of an isolated tree:

(1) Patterns of radio waves scattered from an isolated tree and from an aluminum mast,

(2) Input impedance of a $\lambda/2$ vertical antenna in the vicinity of an isolated tree, and

(3) Patterns of an isolated tree as a grounded vertical radiator.

The first group of experiments was designed to determine an equivalent radius of the tree in terms of the radius of the aluminum mast. With the equivalent radius, the cross-section and the scatter pattern of the tree can be evaluated theoretically. The second group of experiments was designed to determine the variation of the impedance of an antenna in the neighborhood of an isolated tree. From these measurements, the maximum distance between tree and antenna for which there is significant effect upon antenna impedance can be determined, and an area around the antenna in which trees could be replaced by appropriate sources can be estimated. The model of propagation of radio waves in a jungle might then be based on the distribution of the nearest-neighbor distance of trees and the density of trees in that forest. Discussion of this problem is postponed to the last section of this report. The last experiment was to determine the directivity of an isolated tree shunt fed as a grounded vertical radiator. The bulky shape of such a radiator suggests it will have significant gain. This is a possible factor to offset the low efficiency of a tree antenna as it was reported by Dickinson.[19]

Two isolated trees were chosen at Laem Chabang. One of them was a rubber tree, for convenience called tree "A". The height of tree A was approximately 65 feet. The diameter of the trunk at the point just above the ground was 26.8 inches and reduced to 19.2 inches at 4 feet above the ground. The area of 300 feet in radius around the tree was absolutely

cleared. The second tree ("B") was a mango, having a height of 30 feet and trunk diameter at the point just above the ground of 20.2 inches. Some bushes of less than 5 feet high were at a distance of 130 feet from tree B. However, the area within 130 feet from the tree was cleared.

In the first and last groups of experiments, the fields due to radiation from a vertical dipole in the vicinity of the tree or from the tree as a grounded vertical radiator were received by $\lambda/2$ vertical antennas connected to the equipment in the Xeledop van. Recordings were made simultaneously on three VHF channels (one of which is shown in Fig. 7).

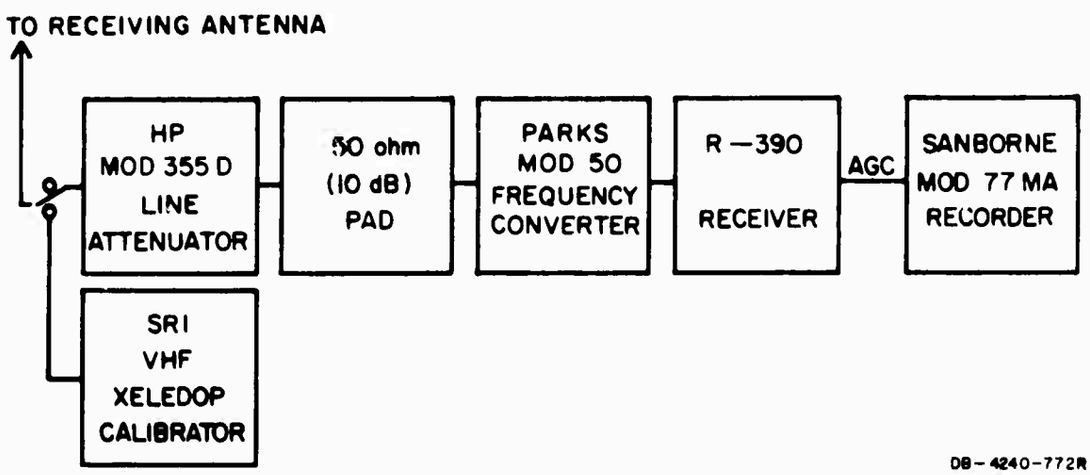

FIG. 7 ARRANGEMENT OF ONE CHANNEL OF RECEIVING EQUIPMENT HOUSED IN XELEDOP VAN

The recorder was first calibrated with the VHF Xeledop calibrator. The signal from the VHF Xeledop calibrator passed through the Hewlett Packard Model 355D line attenuator, 50-ohm 10-dB pad, Parks Model 50 frequency converter, and R-390 receiver. The AGC voltage was recorded at the Sanborne Model 7714A recorder. The 10-dB steps were marked on the chart recorder by setting the attenuation in the Hewlett Packard line attenuator. The recorder was calibrated at 50 MHz in the first channel, at 75.1 MHz in the second channel, and at 100 MHz in the last channel. Then all three

channels were used simultaneously to record the AGC voltages resulting from the terminal voltages at each $\lambda/2$ vertical antenna.

A. SCATTER OF RADIO WAVES FROM AN ISOLATED TREE AND FROM AN ALUMINUM MAST

The primary objective in this experiment was to study the pattern of radio waves scattered from an isolated tree. In addition, the feasibility of using a perfectly conducting cylinder of appropriate radius as a representation for a tree was investigated by repeating the same experiment with a grounded aluminum mast. The same arrangement for the experiment was set up at tree A and tree B. Twenty four dielectric strings of 49.2 feet in length were stretched around each tree. The angular spacing between adjacent strings was 15 degrees. Each string was marked at every 3.28 feet. The receiving antennas were 377 feet from the tree and spaced 37 feet apart. The antennas were connected to the Hewlett Packard Model 355D line attenuators in the Xeledop van. The arrangement of equipment in the Xeledop van was the same as previously described. The map of the area around tree A and tree B is shown in Fig. 8. Figure 9 shows the arrangement of the experiment in the area around the tree. The man who carried the manpack Xeledop pushed a button to transmit a signal to operate the event marker of the Sanborn recorder as he passed each mark on the string. The signal from the manpack Xeledop was then recorded as it was carried toward and away from the tree along each string. The experiment was performed at 50, 75.1, and 100 MHz, with vertical polarization arrangement of antennas. After the Xeledop had been carried along all twenty-four radii of tree B, this tree was cut down and removed from the site. Then, with exactly the same configuration at the receiving site, the experiment was repeated. The polar pattern after the tree was cut down is essentially a circle (see Fig. 10). The irregularity at the surface of the ground, if any, apparently did not have any significant effect on the measurement. Then a grounded aluminum mast was erected to replace tree B, and the experiment was repeated. The dimensions of the aluminum mast were 4 inches in diameter and 20 feet in height. Samples

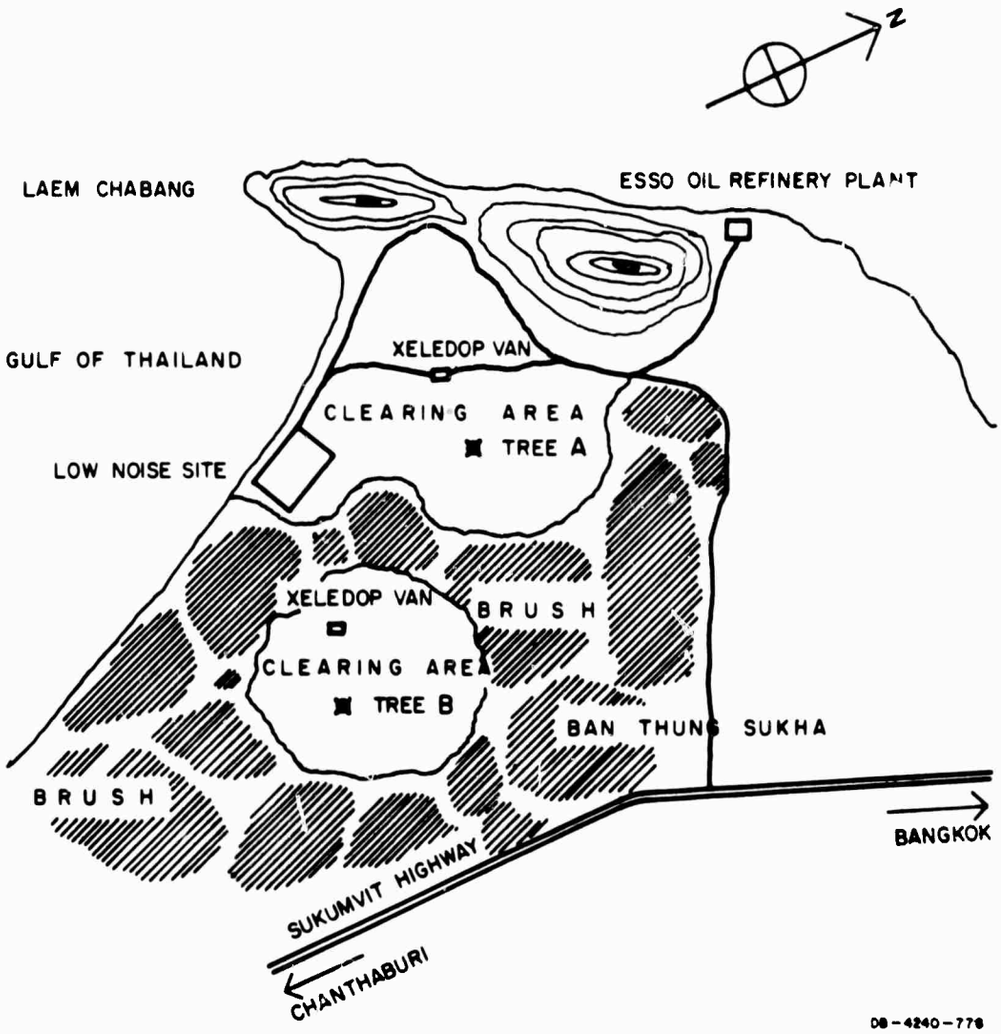

FIG. 8 PLAN VIEW SHOWING LOCATION OF TREE A AND TREE B RELATIVE TO LOW-NOISE SITE AT LAEM CHABANG, THAILAND

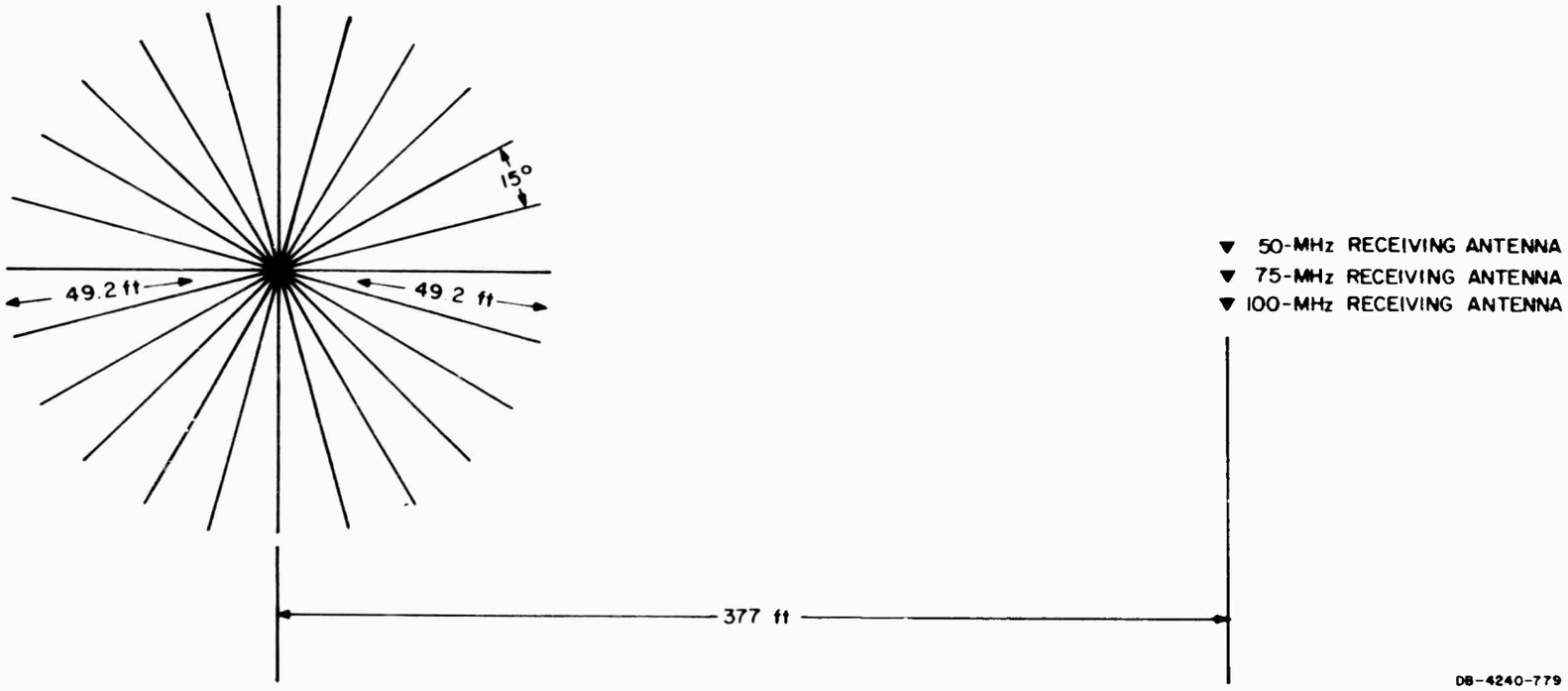

FIG. 9 ARRANGEMENT OF EQUIPMENT USED FOR MEASURING SCATTER PATTERNS OF ISOLATED TREE

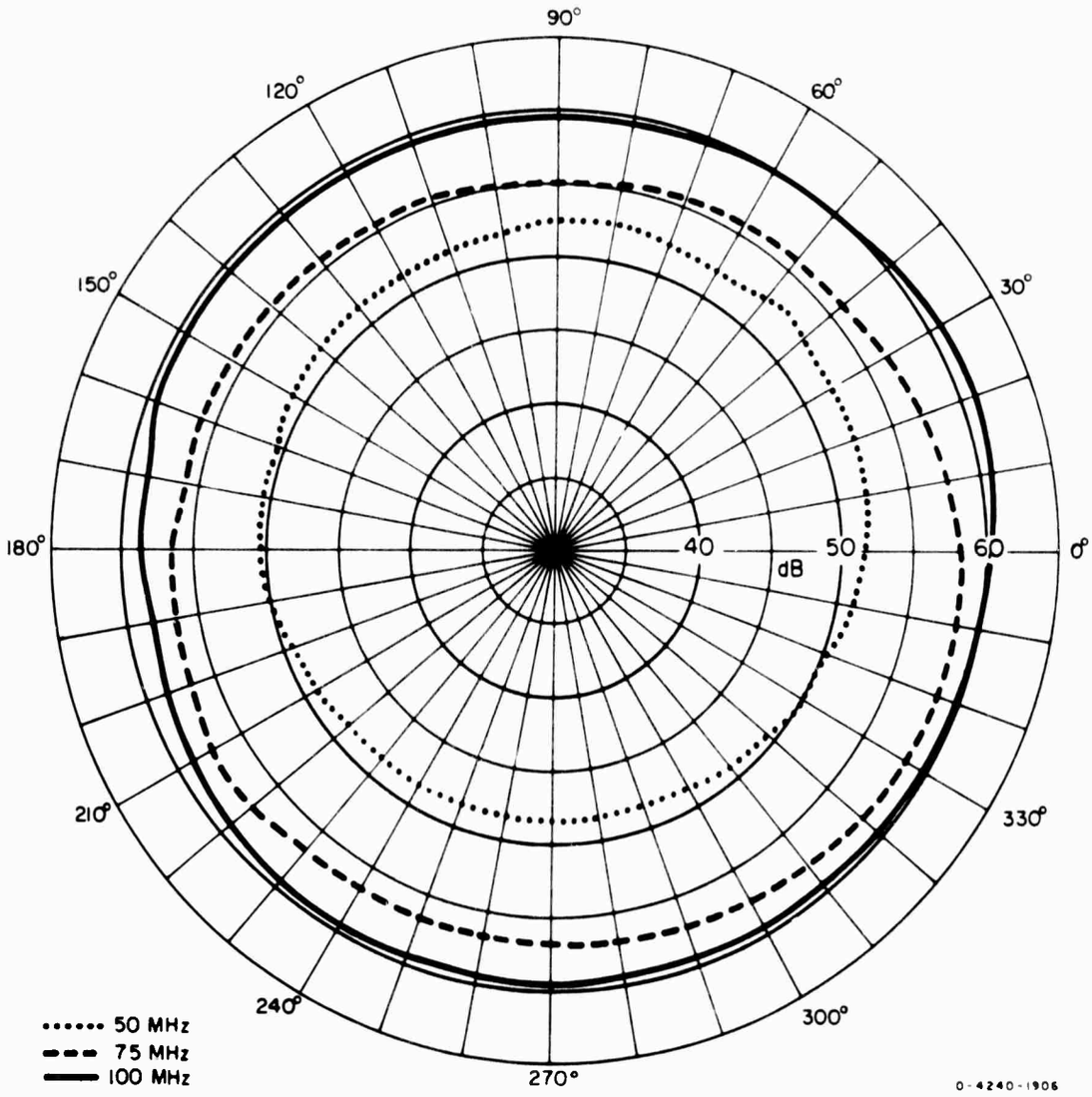

FIG. 10 POLAR PATTERNS AT SITE OF TREE B AFTER TREE WAS CUT DOWN

of the records in the experiment are reproduced in Figs. 11, 12, and 13. Figure 11 shows a standing wave pattern established in the received signal when the transmitting antenna was in the line between the tree and the receiving antenna, or, in other words, in the direct path. The distance between the maximum and the next minimum at each frequency was $\lambda/4$. The characteristics suggest the possibility of representing the tree in the direct path by another source with an appropriate amplitude. But as the transmitting antenna was moved away from the direct path (see Fig. 12), the distance between the maximum and the next minimum in the received signal increased. The simple model as suggested above fails to satisfy this characteristic. However, as seen later in the direct path, it is feasible to use the simple model to simplify the mathematical difficulties. Figure 13 shows the received signals when the tree was between the transmitting and receiving antennas, or, in other words, the receiving antenna was in the shadow zone. Only small variation was observed in the received signals. This implies that strong attenuation was incurred when the signal penetrated the tree. In all cases, most of the variations of the received signal occurred when the transmitting antenna was in the neighborhood of λ from the tree.

The manpack Xeledop transmitter was walked toward and away from the tree on each radial, and results from these two passes were averaged for the patterns. The difference in the received signals in the toward-and-away-from-the-tree runs in the order of 5 dB in the direct path, decreased to the value less than 1 dB when the transmitter, tree, and receiving antenna formed a right triangle, and it was negligible when the transmitter was obscured by the tree. Part of the difference was due to the effect of the body of the man who carried the Xeledop transmitter, and another part of the difference was, of course, due to experimental error.

The chart records for each of the twenty-four radial paths were scaled to digitize the signal strength, and the resulting data were replotted in polar form for six values of radial distance from the tree. Figure 14 shows an example of the signal amplitude data for signals scattered from tree A, tree B, and the aluminum mast, when the radial

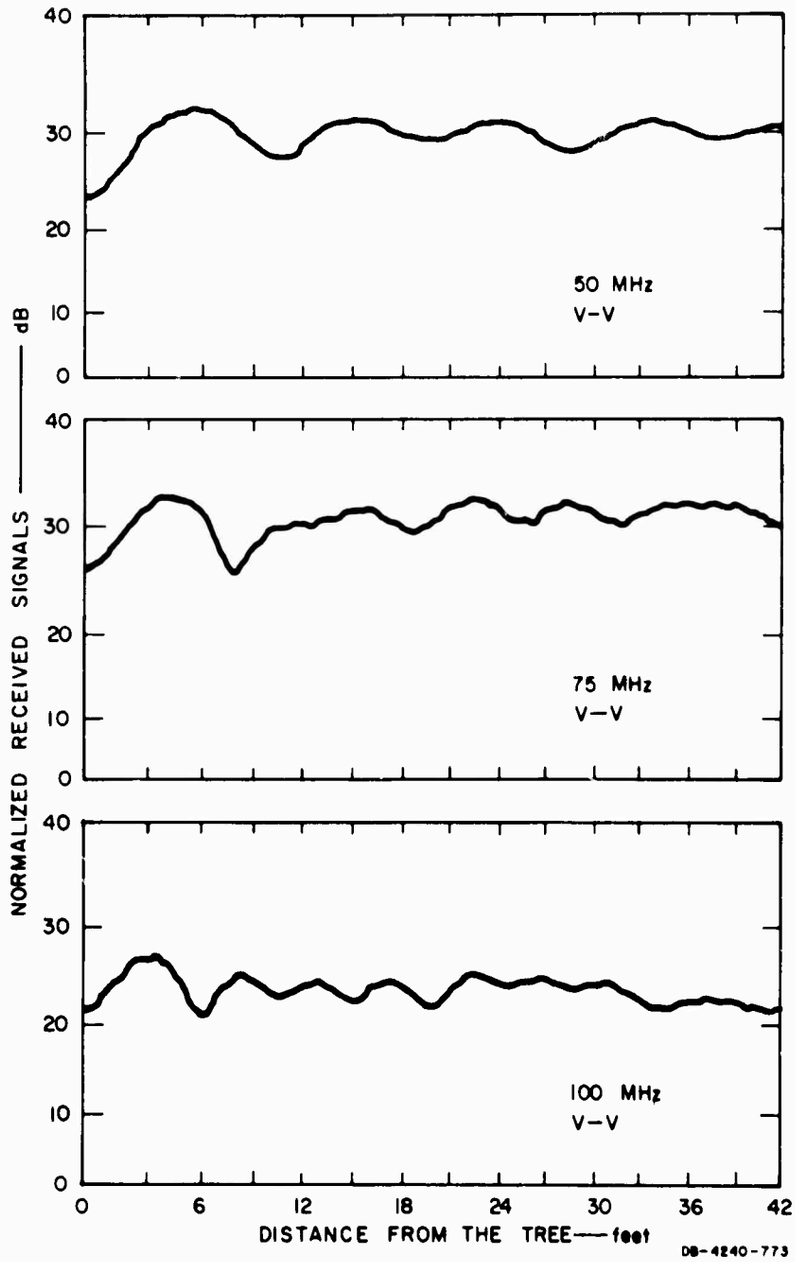

FIG. 11 SIGNALS RECEIVED AS TRANSMITTER MOVES ON A RADIAL AT 60° TO THE DIRECT PATH FROM TREE TO RECEIVER

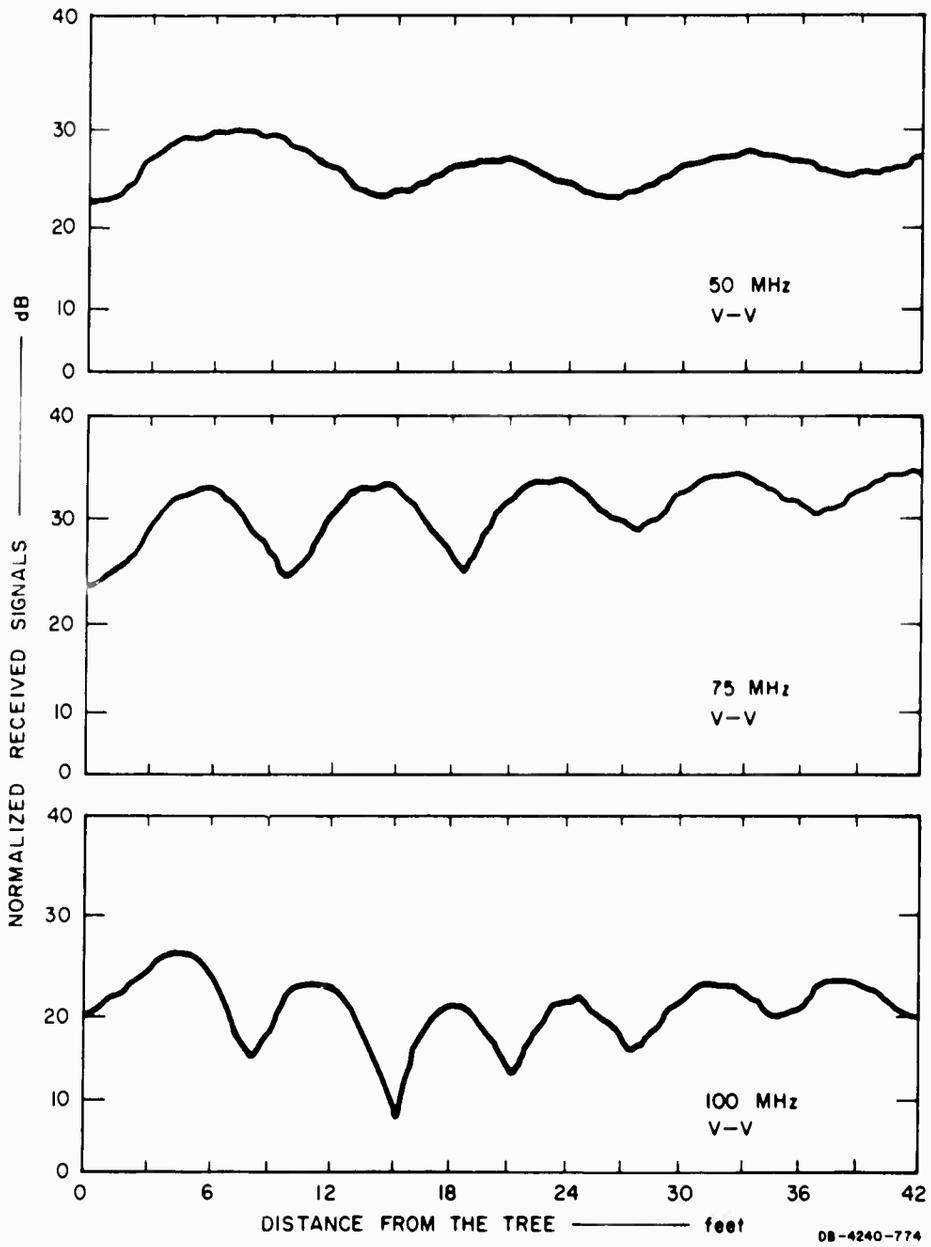

FIG. 12 SIGNALS RECEIVED AS TRANSMITTER MOVES ON DIRECT PATH TOWARD RECEIVER

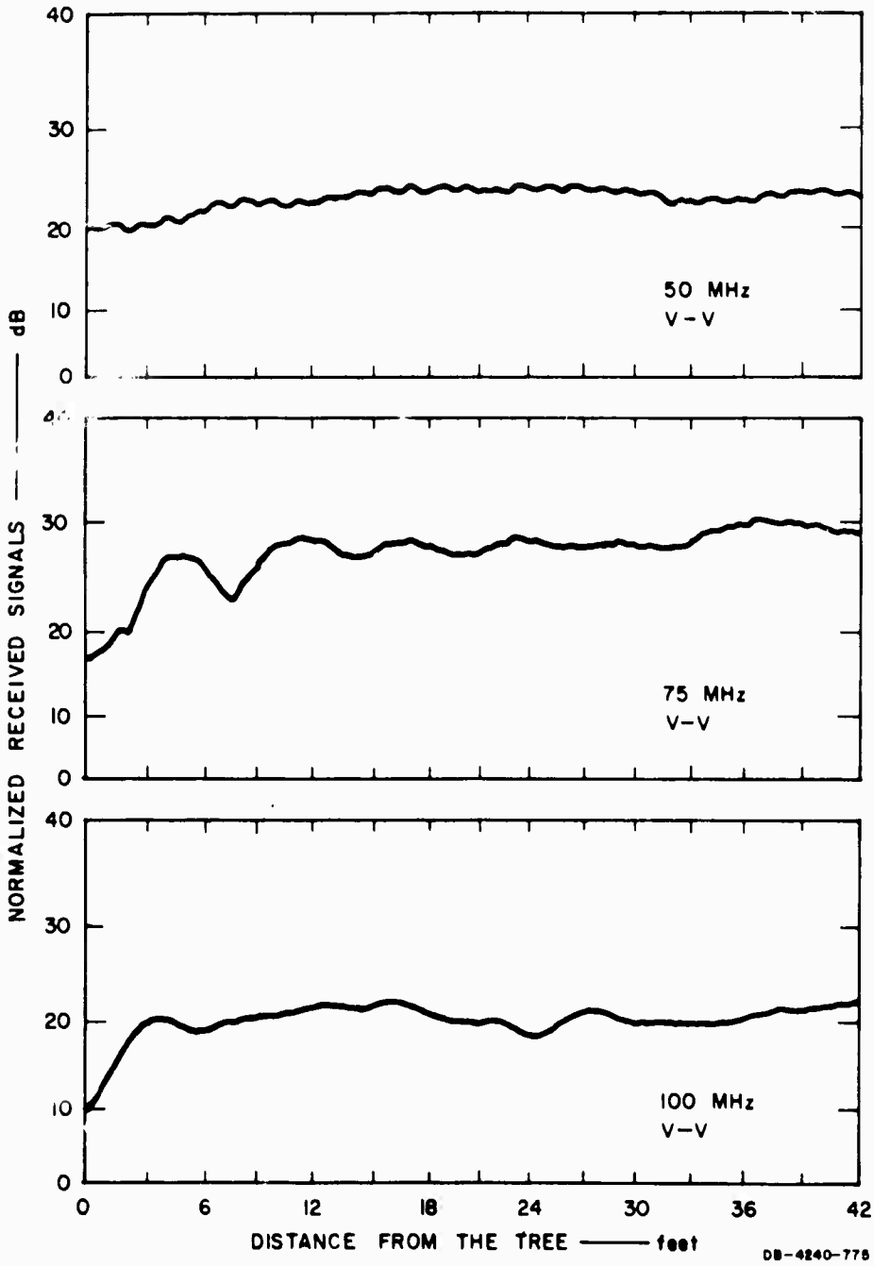

FIG. 13 SIGNALS RECEIVED AS TRANSMITTER MOVES DIRECTLY AWAY FROM TREE AND RECEIVER

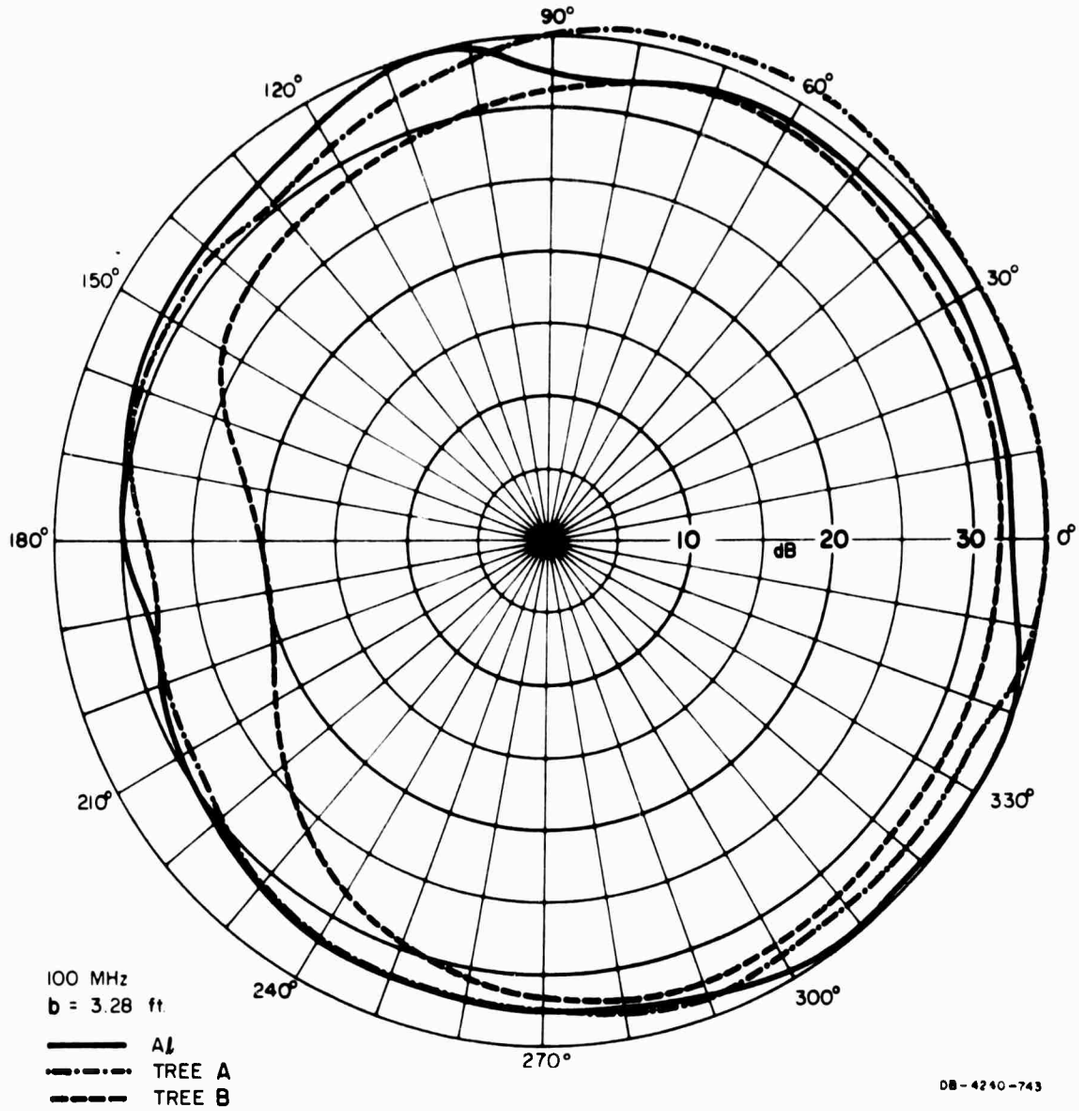

FIG. 14 SCATTER PATTERNS OF 100-MHz RADIO WAVES WHEN XELEDOP TRANSMITTER IS 3.28 FEET AWAY FROM THE SCATTERER

distance was 3.28 feet and the frequency was 100 MHz. Figures showing a comparison of the scattering from the two trees and the aluminum mast for all combinations of radial distance and frequency tested are presented in the Appendix. The data for all patterns were normalized to the maximum level received with the transmitter 3.28 feet from the aluminum mast.

It should be noted that the received signal in the experiment with tree A was stronger than that with tree B. Tree B was a dry, aged mango tree. The effect may be due to the moisture content in the tree. The received signal in the experiment with tree A was in the same order as that with the aluminum mast.

B. INPUT IMPEDANCE OF A $\lambda/2$ VERTICAL ANTENNA IN THE VICINITY OF AN ISOLATED TREE

Knowledge of the input impedance of an antenna in the vicinity of an isolated tree is of primary concern for determining variations of radiated power as the antenna is moved relative to the tree. This knowledge also helps to estimate empirically the area about the antenna that can be affected by the presence of a tree.

Both tree A and tree B (described in Sec. IV-A) were used in measurements of the effect of a single tree upon the input impedance of a vertical half-wave dipole. As in earlier work,[18] the antenna was mounted on a tripod that could be moved along a wooden track and then fixed at accurately known distances from the tree. For 75 and 100 MHz, measurements were made at points 0.5 foot apart, starting at 0.5 foot from the tree and terminating at a point about twenty feet away. The same range of distance was used for 50 MHz measurements, but adjacent positions were one foot apart. Measurements were made with the antenna feed-point at two heights above ground, namely ~~5.25~~ 4.92 and 6.56 feet.* At each height and each frequency, two measurement runs were taken, one starting very near the tree and moving away, and the other starting at the greatest distance and moving toward the tree. All measurements were made with the Smith Chart Impedance

* At 50 MHz it was necessary to raise the feed-point to 5.25 feet to let the lower end of the antenna clear the ground.

Plotter, manufactured by Dielectric Products Engineering Company. The plotter was calibrated by an SRI VHF Xeledop calibrator with 25, 50, and 100 ohm precision coaxial loads, to take into account the length and attenuation of the line between antenna and instrument.

The resistive and reactive components of the input impedance of the half-wave vertical dipole are plotted in Figs. 15 through 17.

Significant dependence of the vertical dipole impedance upon height of antenna feedpoint was seen only at 50 MHz, and the effect was the same for both trees. The spacing between adjacent ends of the vertical dipole and its image in the ground was zero and 0.133λ with the antenna feedpoint at 5.25 and 6.56 feet above the ground at 50 MHz. The mutual resistance of two parallel collinear $\lambda/2$ antennas was decreased by 15 ohms as the spacing between adjacent ends was increased from zero to 0.133λ.[23] But the mutual resistance was expected to be less than 15 ohms when the vertical antenna was above the lossy ground. It was found that the difference between the dipole impedances at two different heights at 50 MHz for both trees was 12 ohms.

When the spacing between adjacent ends of two parallel collinear $\lambda/2$ dipole was greater than 0.2λ, the mutual resistance was less than 5 ohms.[23] Then it could be hypothesized that the mutual effect of an $\lambda/2$ vertical antenna and its image in the ground would be negligible if the lower end of the antenna was more than 0.1λ above the ground. With the antenna feedpoint at 6.56 and 5.0 feet above the ground, the lower end of the antenna was more than 0.1λ above the ground at 75 and 100 MHz. Therefore, only the trunk of the tree should significantly affect the magnitude of the dipole impedance at 75 and 100 MHz, and no significant dependence of the vertical dipole impedance upon the height of the trunk was observed in the measurement.

Additional observations can be made from a study of these figures:

1. The largest effects on the dipole impedance were seen with tree A at 100 MHz.
2. Significant differences between the effects due to tree A and tree B were seen only at 100 MHz.

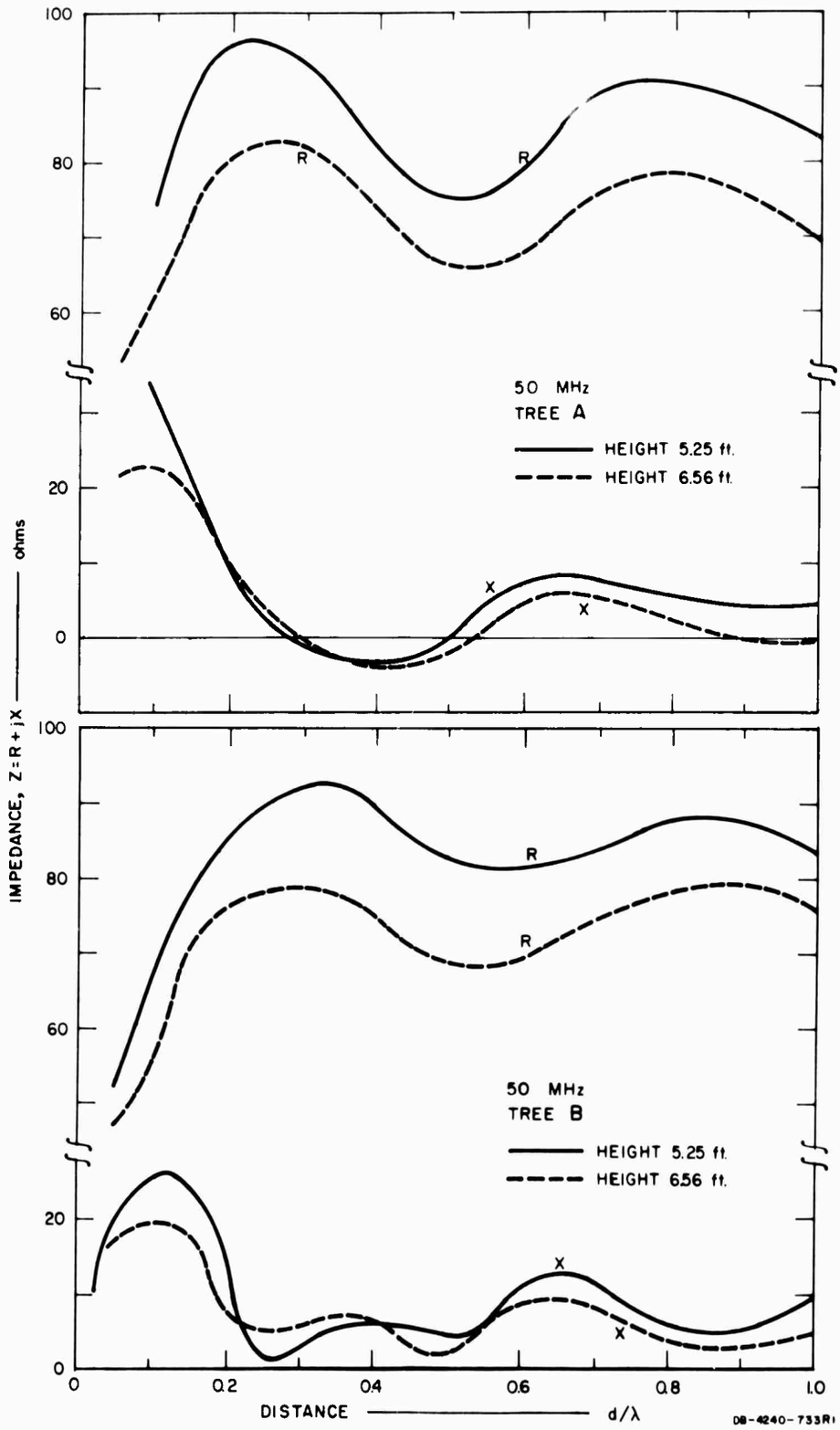

FIG. 15 INPUT IMPEDANCE OF 50-MHz $\lambda/2$ DIPOLE vs DISTANCE FROM TREES

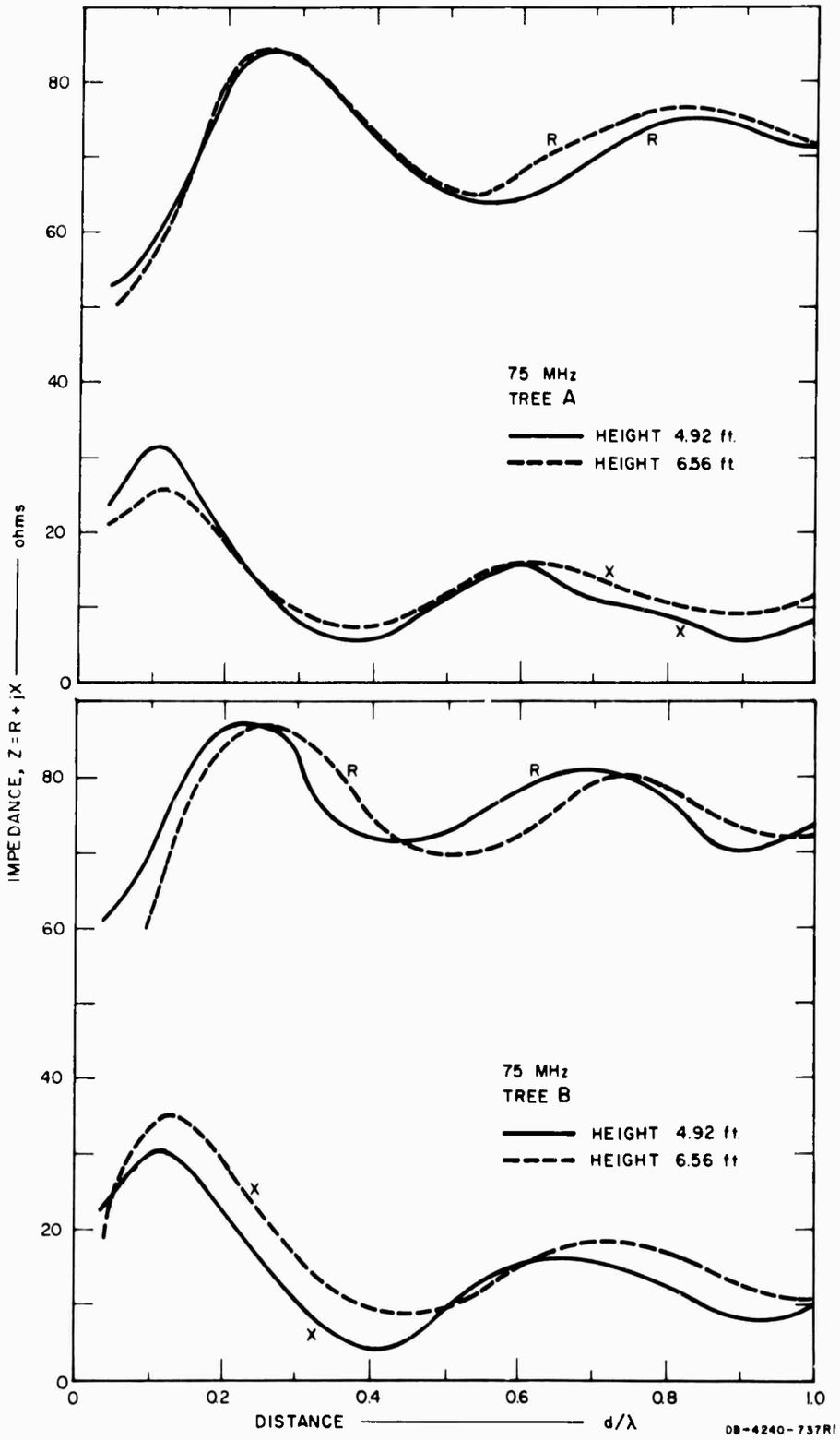

FIG. 16 INPUT IMPEDANCE OF 75-MHz $\lambda/2$ DIPOLE vs DISTANCE FROM TREES

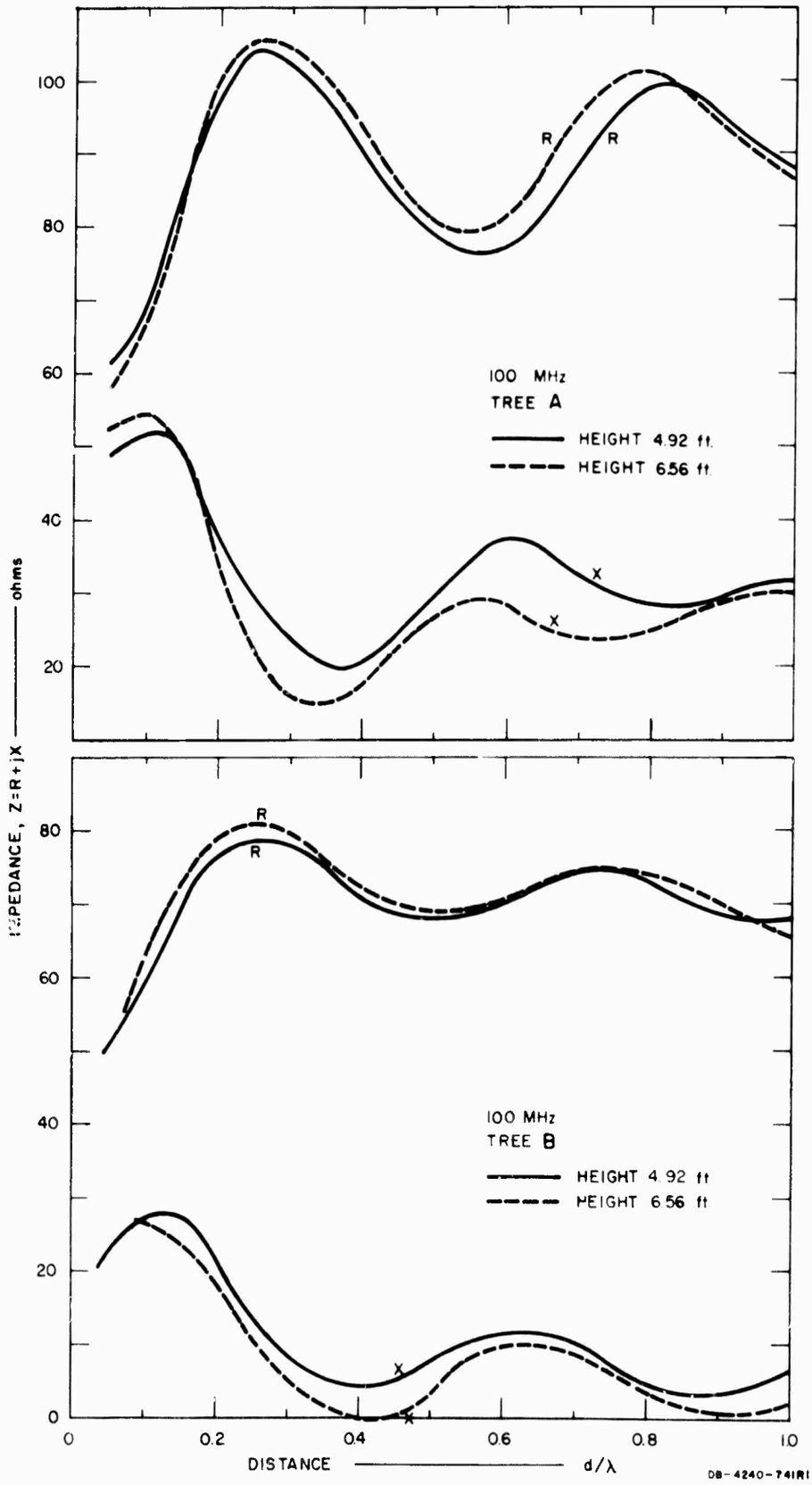

FIG. 17 INPUT IMPEDANCE OF 100 MHz λ/2 DIPOLE vs DISTANCE FROM TREES

3. Magnitude of the effects for tree A showed a positive (but weak) correlation with frequency, the largest effects being seen at the highest frequency.

4. Magnitude of the effects for tree B showed little variation with frequency.

C. RADIATION OF ISOLATED TREE "A" AS ANTENNA

To determine the appropriate feed point at the trunk of the tree, the input impedance as a function of the height of the feed point was measured. The result was also used to seek the requirements for any matching network.

Twelve four-inch-long nails were driven into the trunk of tree A at six-inch intervals. The dc resistance between two nails 6 inches apart decreased monotonically from 3200 Ω at the depth of penetration of 1/3 inch to 1750 Ω at the depth of penetration of 2 inches. The variation of the dc resistance was insignificant at greater depths of penetration. To eliminate any effect on the result due to the penetration of the nail, each nail was driven almost its length into the tree.

The configuration of the feed line used in impedance measurements is shown in Fig. 18. The outer conductor of the feed coaxial line was cut one-half wavelength from the termination, the shield of a half-wave coax stub was connected to the feed line outer conductor at one side of the cut, and the center conductor of the stub was connected to the feed line on the opposite side of the cut. This arrangement permitted shielding the ground wire connection to the nail at the bottom of the tree and produced a feed system with negligible shunting effect upon the load to be measured. Measurements at 48.5, 72.5, and 97 MHz showed that the input impedance of the λ-long feed line without the tree connected (i.e., open circuit) ranged between 7000 and 11000 ohms. The impedance of the tree was measured as a function of height of feed point (separation of fixed ground nail and movable "hot" nail) and frequency. The data taken with a Boonton Model 250A RX meter are tabulated in Table I. Note that the tree impedance was never more than ten percent of the input impedance of the feed line when the tree was not connected.

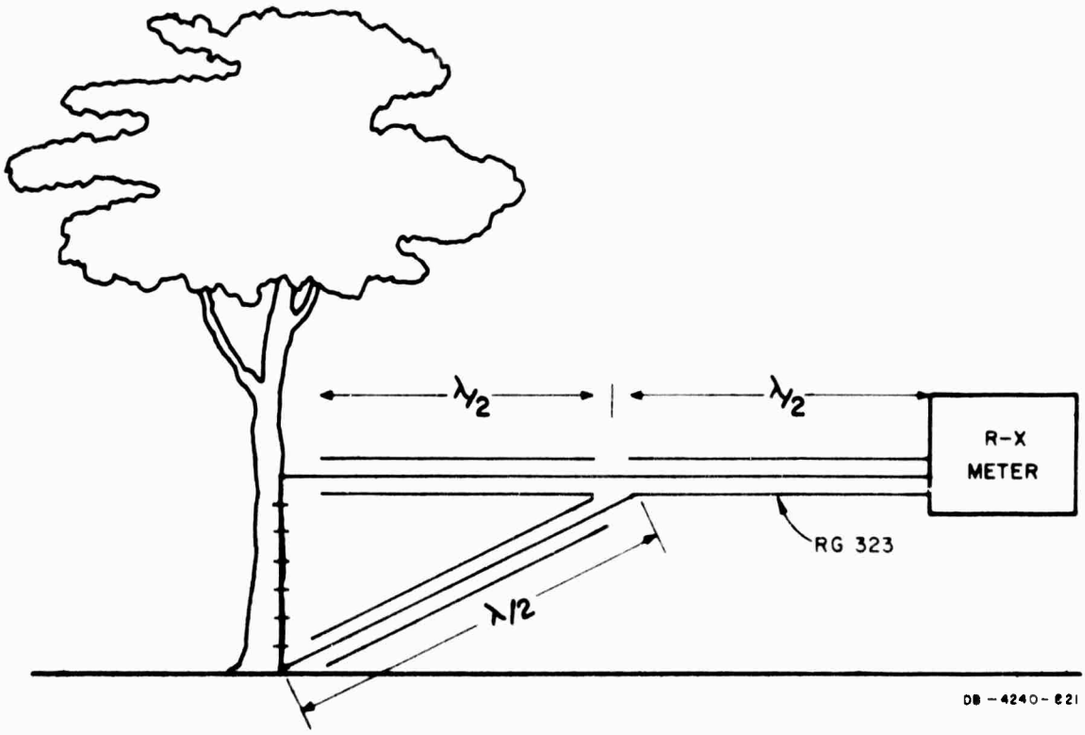

FIG. 18 FEEDLINE TO MEASURE THE IMPEDANCE OF THE TREE

Table I

INPUT IMPEDANCE OF SHUNT-FED TREE

Frequency (MHz)	Distance between the nails (inches)	R_L (ohms)			C_L (μf)		
		1st run	2nd run	Average	1st run	2nd run	Average
97	6	68	90	79	0.008	0.011	0.009
	12	355	355	355	0.017	0.025	0.021
	18	560	560	560	0.029	0.012	0.021
	24	600	715	657.5	0.029	0.021	0.025
	30	760	780	770	0.023	0.008	0.015
	36	760	820	790	0.038	0.024	0.031
	42	710	800	755	0.042	0.038	0.040
	48	760	785	772.5	0.043	0.038	0.041
72.5	6	780	840	810	0.084	0.09	0.087
	12	600	615	607.5	0.068	0.072	0.07
	18	490	508	499	0.048	0.051	0.049
	24	635	610	622.5	0.052	0.055	0.053
	30	715	680	697.5	0.056	0.055	0.055
	36	760	830	795	0.046	0.064	0.055
	42	830	885	857.5	0.074	0.075	0.074
	48	820	740	790	0.075	0.068	0.071
48.5	6	620	625	622.5	0.089	0.09	0.09
	12	355	400	377.5	0.054	0.06	0.057
	18	248	288	268	0.034	0.041	0.037
	24	235	234	234.5	0.008	0.022	0.015
	30	370	308	339	0.006	0.021	0.013
	36	460	418	439	0.027	0.019	0.023
	42	565	490	527.5	0.033	0.027	0.03
	48	520	600	560	0.044	0.041	0.042

The impedance data suggest the appropriate frequency to be 100 MHz and the appropriate feed point for a shunt-fed tree antenna to be the first two points where the input impedance is 79 ohms. It should be emphasized that the other points at the same or a different frequency could be used as the feed point, since a 10:1 transformer would be adequate to match the impedance for most of the points. The reactive component of the input impedance of the tree was negligible at the frequencies used in this experiment.

Before measurements of radiation from the tree were attempted, the radiation from the feed system was checked. The feed line was disconnected from the tree, and a one thousand ohm resistor was substituted to set up a standing wave on the line. The resulting SWR was larger than when the tree was connected. Measurement of radiated power with a half-wave vertical dipole at 19.7 feet from the tree gave a value of power 30 dB below that obtained with the tree terminating the drive line. This gave considerable confidence in the tree radiation data, because it showed that the received signal was mainly contributed by the tree, not by the feed system.

The VHF Xeledop calibrator was used as a source to drive the Boonton 230A power amplifier. With the direct feed from the power amplifier to the tree, the forward and reflected powers measured by the Bird wattmeter were 1 and 0.24 watts, respectively. When the signal was fed through the North Hill model 0501BB (300Ω:50Ω) wideband transformer, the forward and reflected powers were 1 and 0.235 watts. The arrangement of equipment is shown in Fig. 19. At the receiving site the Xeledop van was used. The arrangement of equipment there was the same as described previously.

With the power fed into the tree held constant, the signal received by a vertical half wave dipole was measured on a circle of 19.7 feet radius, with the tree at the center. The receiving antenna was hung from a wooden pole that was moved to twenty-four positions, fifteen degrees

FIG. 19 ARRANGEMENT OF EQUIPMENT TO LOAD TREE A AS A SHUNT-FED, GROUNDED RADIATOR

apart, on the circumference. At each position, measurements were made with the center of the vertical dipole* at 6.56, 9.84, 13.12, and 16.4 feet above ground. The radiation pattern of the tree, as a function of height of the receiving antenna, is plotted in Figs. 20 through 23. Note that the tree was fed at the line of zero degrees.

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* Previous measurements had shown that the impedance of the half-wave vertical dipole did not vary significantly for heights between six and sixteen feet, but stayed at approximately 70 + j7.5 ohms.

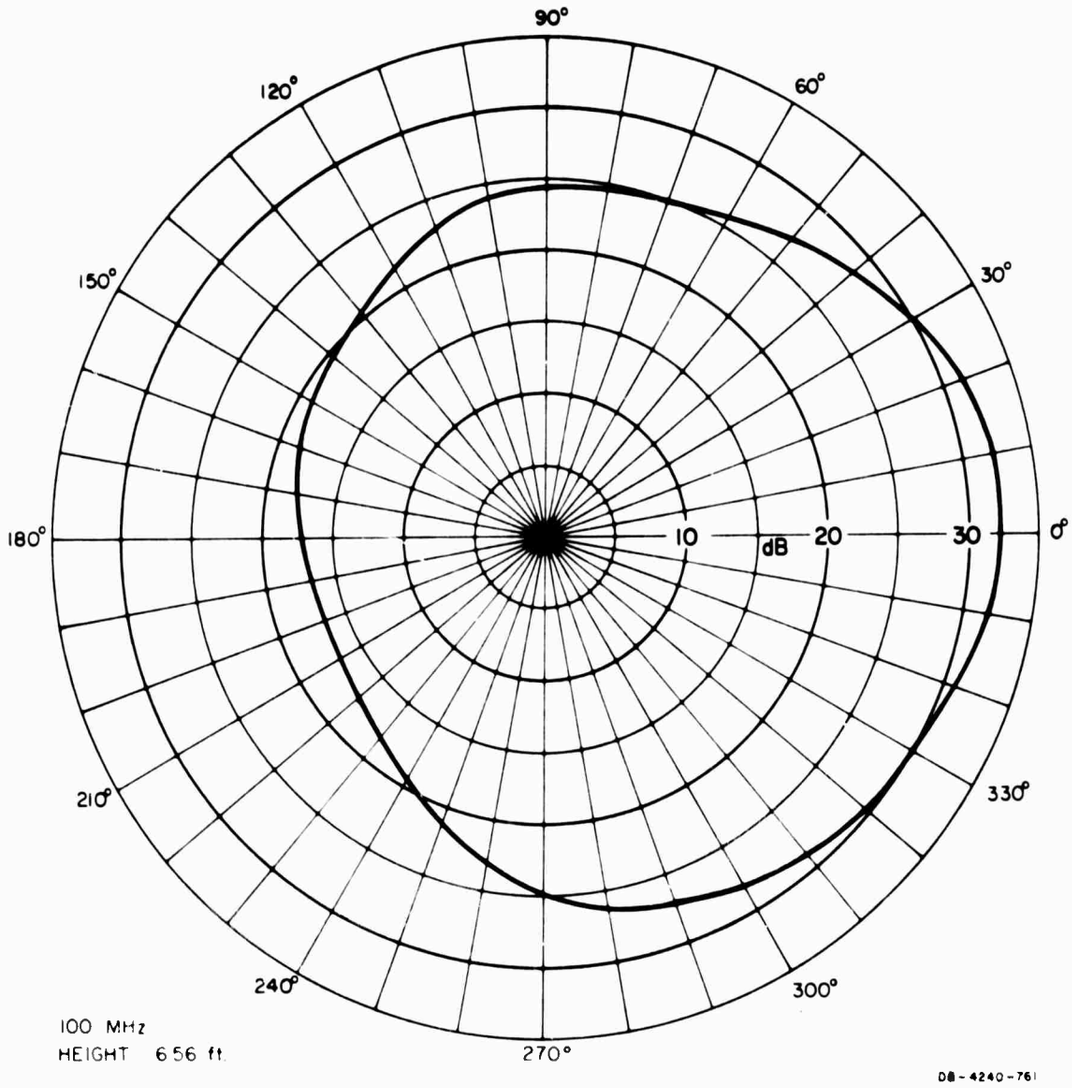

FIG. 20 SIGNAL RECEIVED FROM TREE A, TRANSMITTING ON 100 MHz, BY λ/2 VERTICAL DIPOLE AT 6.56 FEET ABOVE GROUND — AS A FUNCTION OF AZIMUTH

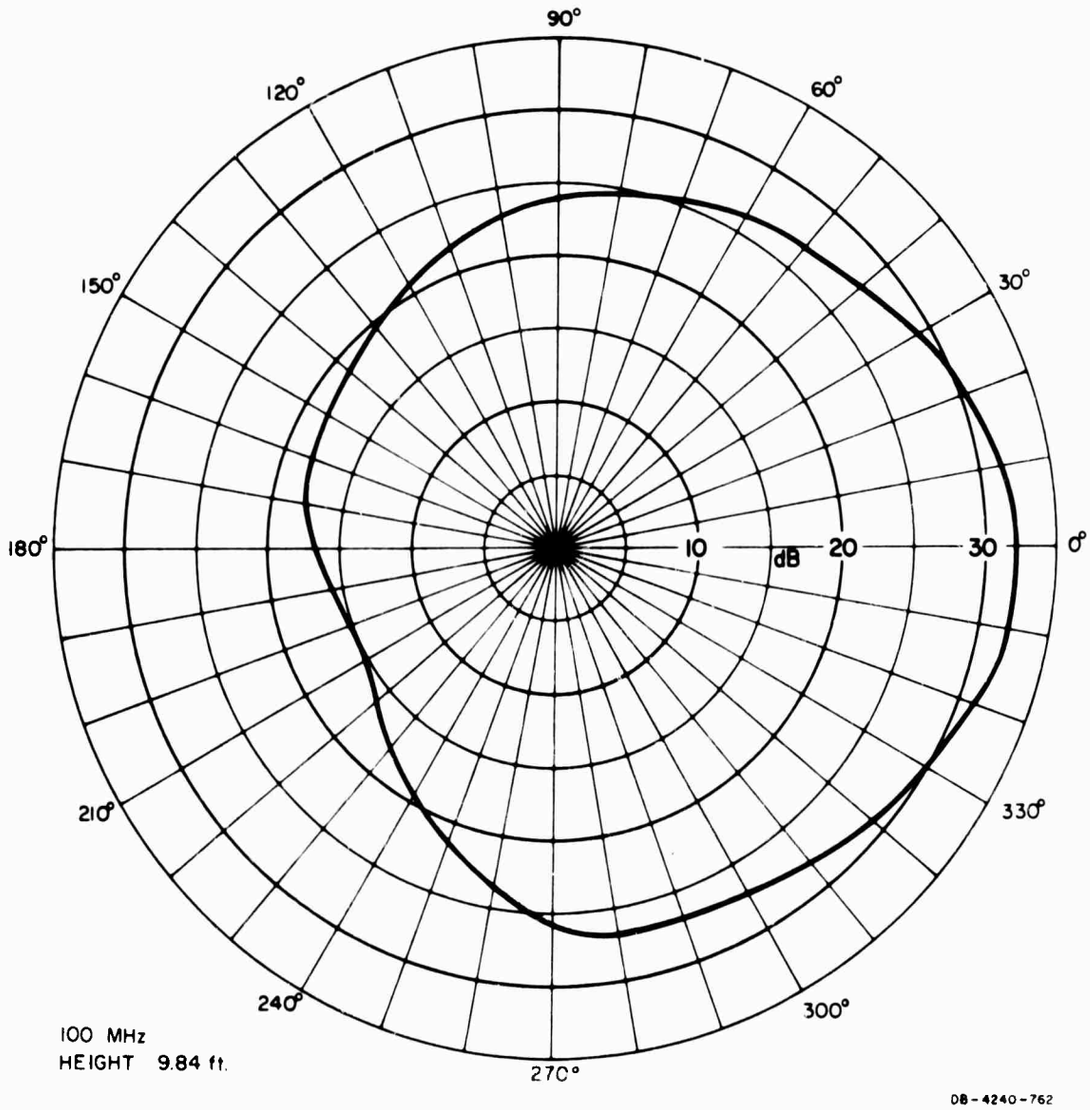

FIG. 21 SIGNAL RECEIVED FROM TREE A, TRANSMITTING ON 100 MHz, BY $\lambda/2$ VERTICAL DIPOLE AT 9.84 FEET ABOVE GROUND — AS A FUNCTION OF AZIMUTH

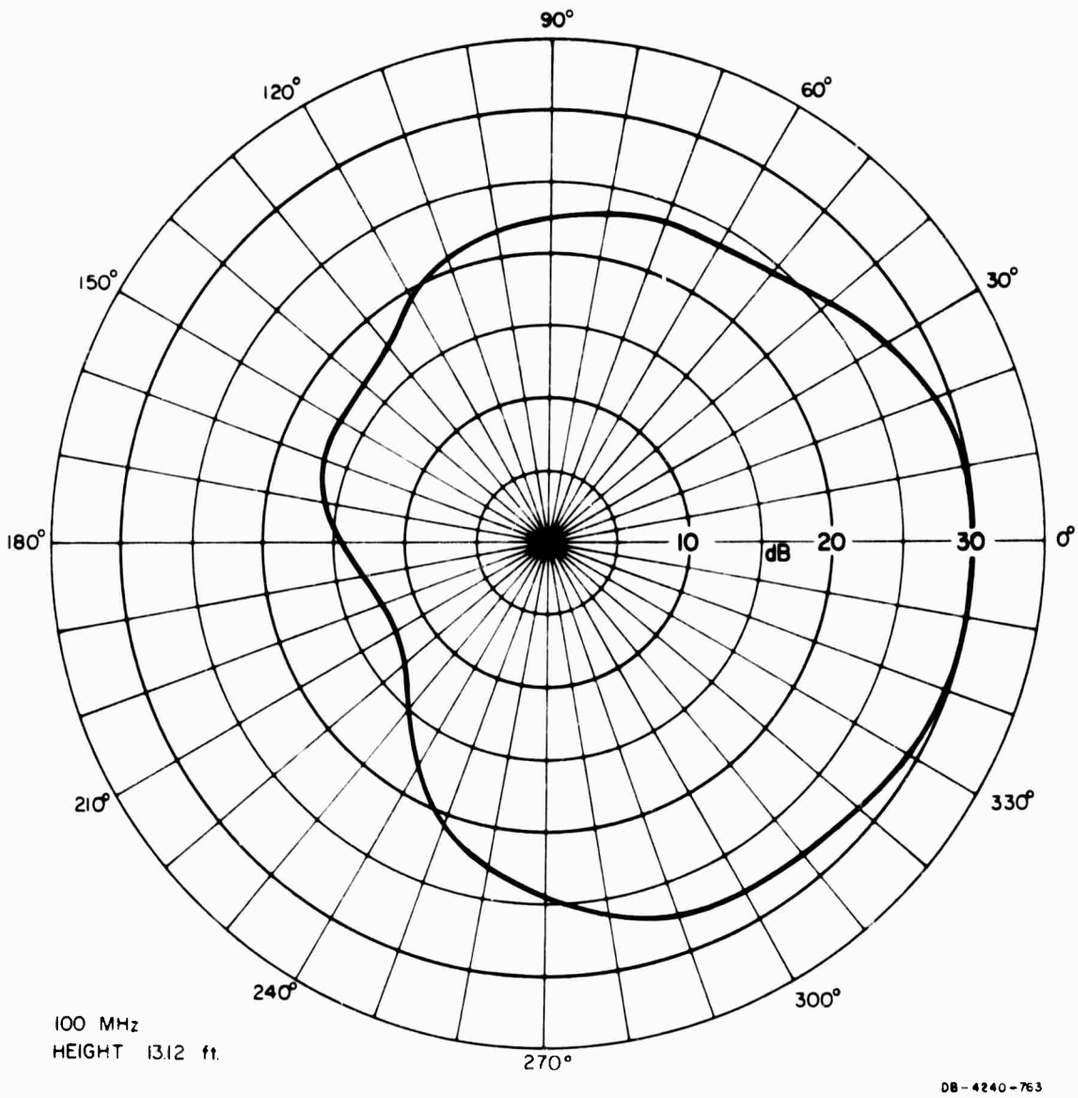

FIG. 22 SIGNAL RECEIVED FROM TREE A, TRANSMITTING ON 100 MHz, BY $\lambda/2$ VERTICAL DIPOLE AT 13.12 FEET ABOVE GROUND — AS A FUNCTION OF AZIMUTH

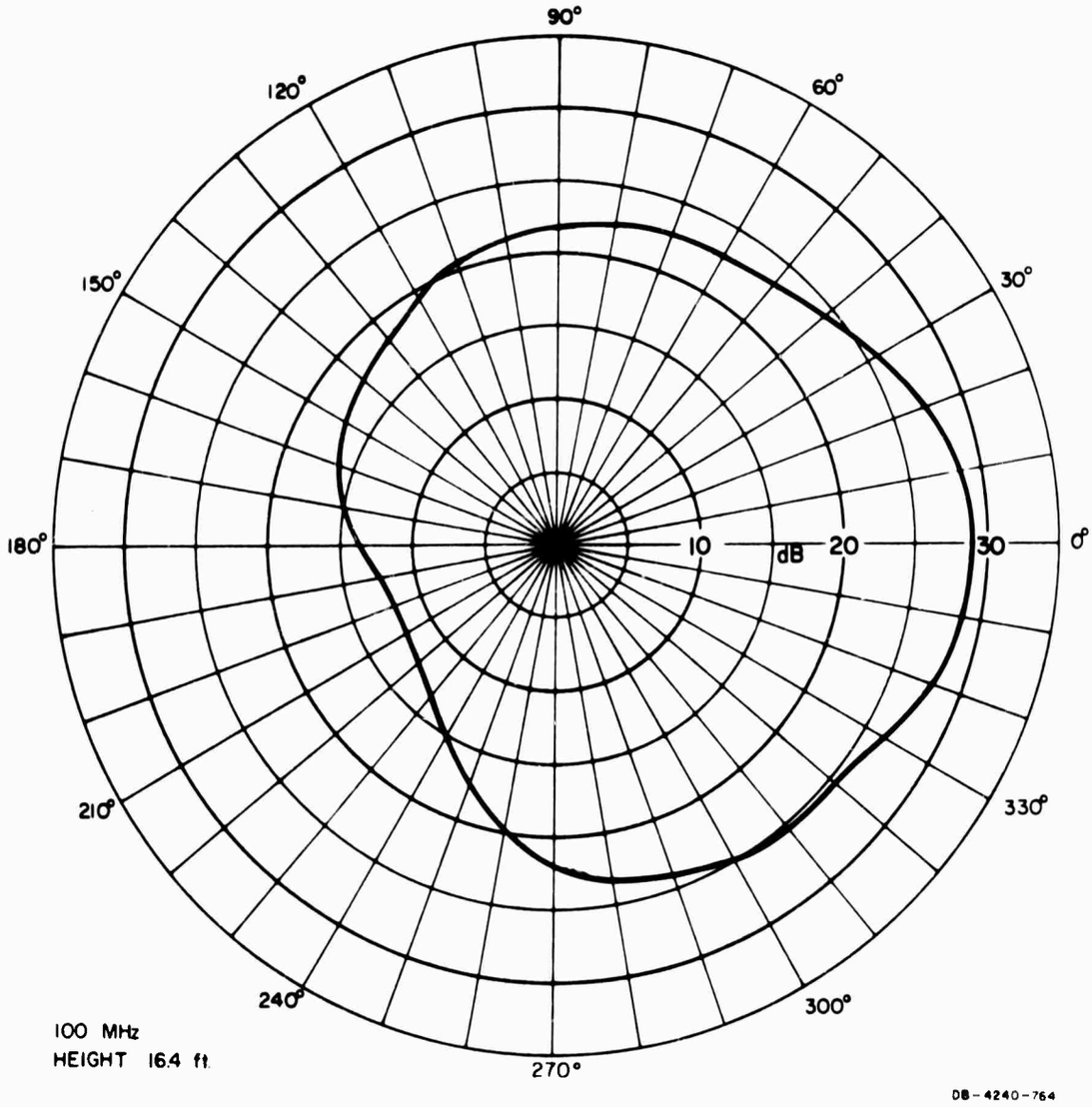

FIG. 23 SIGNAL RECEIVED FROM TREE A, TRANSMITTING ON 100 MHz, BY $\lambda/2$ VERTICAL DIPOLE AT 16.4 FEET ABOVE GROUND — AS A FUNCTION OF AZIMUTH

V COMPARISON BETWEEN THE THEORETICAL AND EXPERIMENTAL RESULTS

In the first part of this section, the measured results in the experiments of scattered patterns of radio waves from tree A, from tree B, and from an aluminum mast are compared with the theoretical results. The comparison of the model values and the experimental values of the impedance of a $\lambda/2$ vertical antenna in the vicinity of an isolated tree is discussed in the last part of this section. Because of the limited period of time, only a few experimental results are compared with the theoretical results. However, the comparison in this section should be adequate to support the theories in Sec. II.

A. SCATTERING FROM TREES

The measurements with tree A as a scatterer and with the aluminum mast as a scatterer show good agreement at all three frequencies. The measurements with tree B as a scatterer agree well with those with tree A and the aluminum mast as scatterers at 50 and 75.1 MHz. At 100 MHz some disagreement can be observed in the measurements in the shadow zone (see Figs. 14 and A14 through A18). It should be noted that the difference in the impedance of the vertical dipole between the effects due to tree A and tree B was observed at 100 MHz. This may be due to the low moisture content in the dry, aged tree B. Time did not permit carrying on further research on this phase. The reasonable agreement of the measurements in the experiments with tree A and the aluminum mast leads to the conclusion that the radius of the aluminum mast can be used as an approximation of the equivalent radius of tree A.

The expression of the combination of the incident and scattered fields in Eq. (25) [in Sec. II-A] is evaluated for a = 2 inches, b = 3.28, and 9.84 feet and p = 377 feet at 50, 75, and 100 MHz. Figures 24 through 26 compare the theoretical and experimental patterns of radio waves for the transmitting antenna at a distance of 3.28 feet from the scatterer.

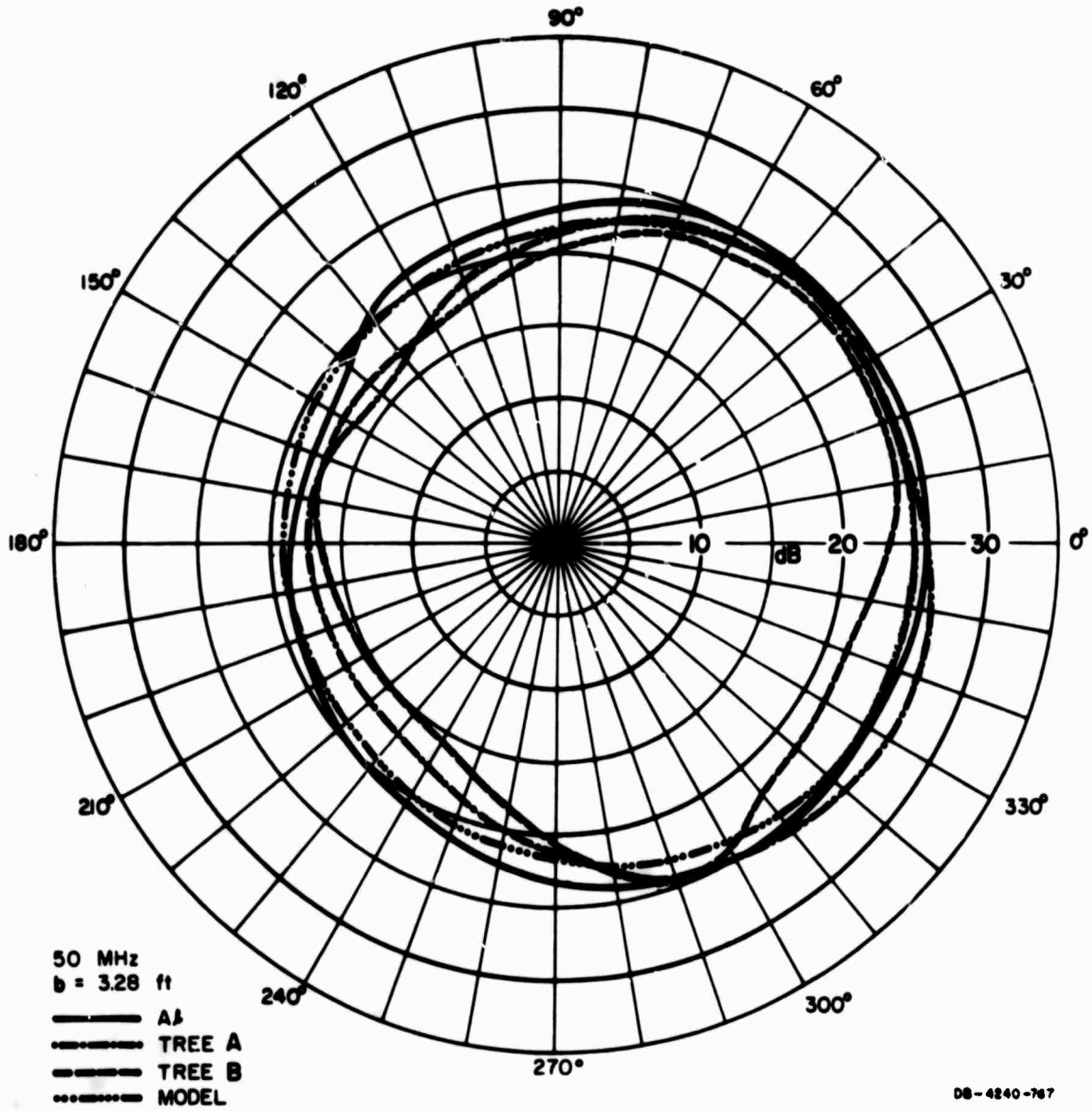

FIG. 24 COMPARISON OF THE THEORETICAL AND EXPERIMENTAL SCATTER PATTERNS FOR $\underline{b}$ = 3.281 FEET AT 50 MHz

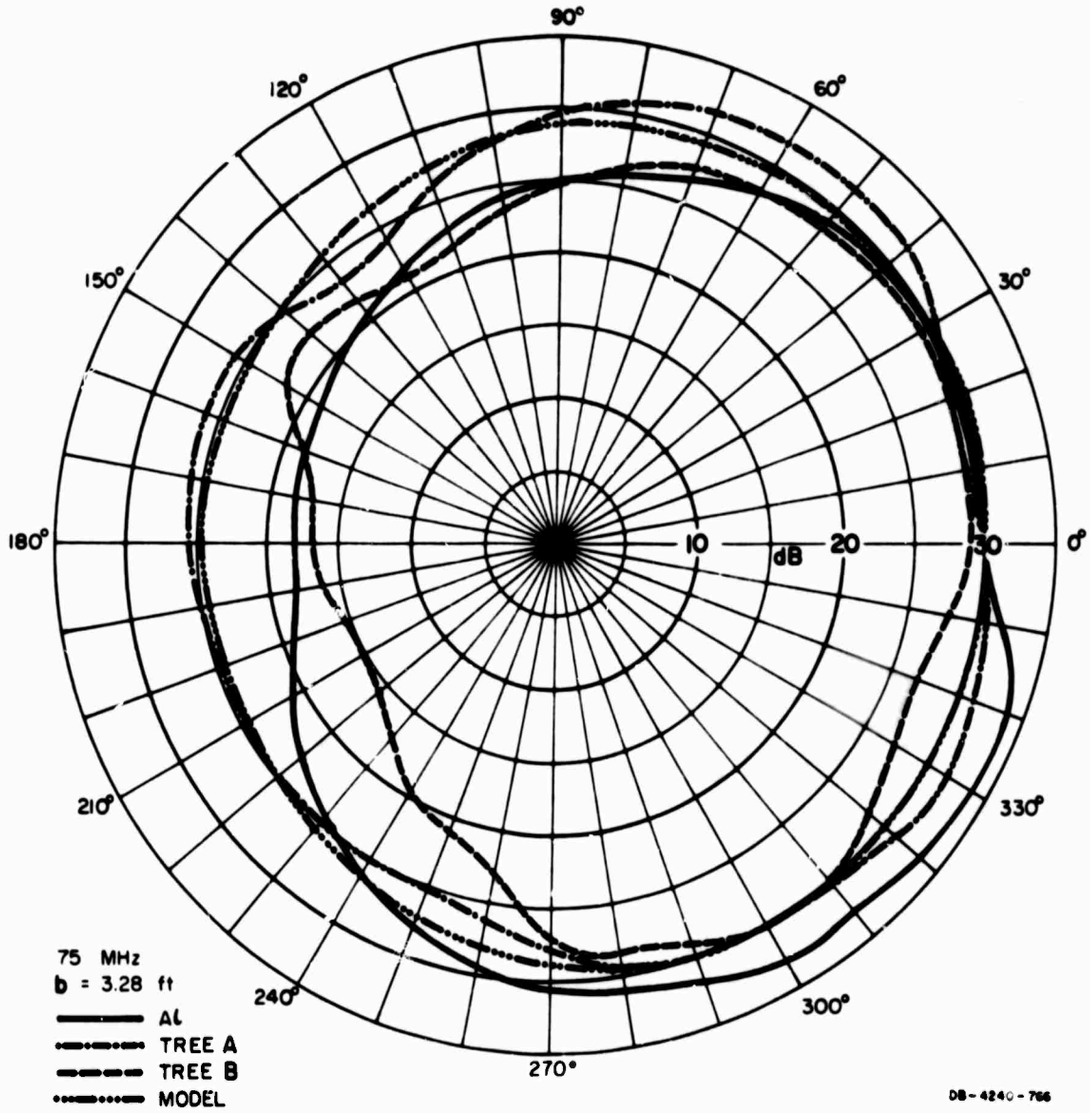

FIG. 25 COMPARISON OF THE THEORETICAL AND EXPERIMENTAL SCATTER PATTERNS FOR b = 3.281 FEET AT 75 MHz

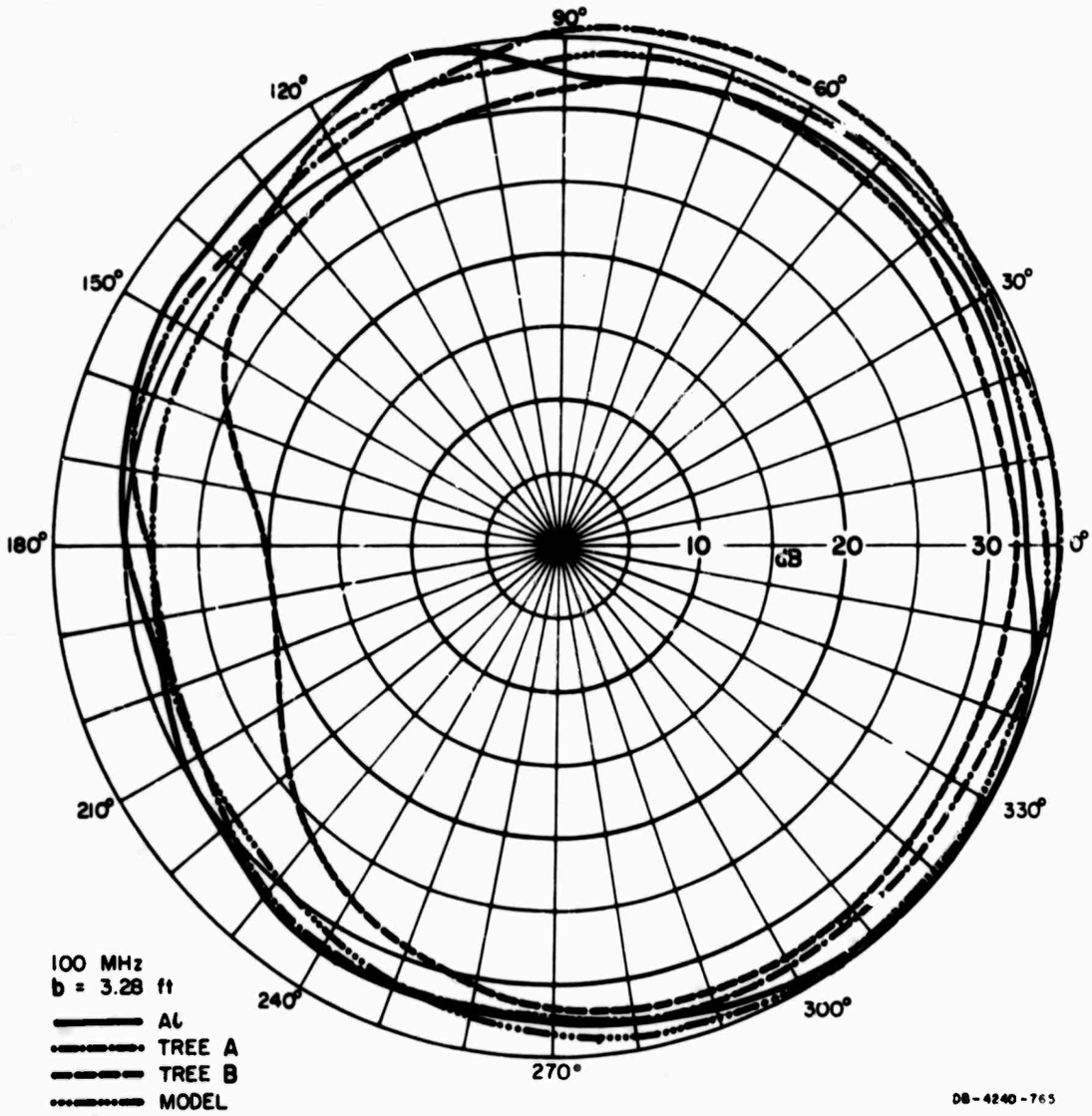

FIG. 26 COMPARISON OF THE THEORETICAL AND EXPERIMENTAL SCATTER PATTERNS FOR b = 3.281 FEET AT 100 MHz

Figures 27 through 29 compare those for the transmitting antenna at a distance of 9.84 feet from the scatterer. The general characteristic of the theoretical and the experimental curves is similar, and the theoretical and the experimental front-to-back ratios of the received signal are in the same order in all cases.

It can be concluded that the equivalent radius of the tree can be used to link the theories on scattering and radar cross-section of trees to the well-known theories on the corresponding topics of a perfect conducting cylinder. However, one might expect the equivalent radius of the tree to depend on the moisture content and, consequently, to be a function of the type of the tree.

B. IMPEDANCE OF ANTENNA IN VICINITY OF TREE

Before the expression of the driving point impedance of an $\lambda/2$ vertical antenna in Eq. (28) [in Sec. II-B] is evaluated, the reflection coefficients of the tree for each frequency in the direct path must be known. The reflection coefficient is determined from Eq. (33) and (34) [in Sec. III]. The ratio of $|E_{max}/E_{min}|$ used in evaluation of the magnitude of the reflection coefficient is the first peak-to-peak variation of the received signal from the tree in the direct path. The terms S_{max} and S_{min} are the distances of the maxima and minima of the received signal from the tree. In each run, the angle of the reflection coefficient is determined from the first three locations of these extrema from the tree. The reason that several locations of the extrema in the received signal are used to determine the angle of the reflection coefficient is to minimize the error in reading of locations of maxima and minima from the record chart. The mode of the calculated values of the angle of reflection coefficient is taken to be the value of the angle of the reflection coefficient. The reflection coefficients in the direct path at 50, 75.1, and 100 MHz are tabulated in Table II. Based on these values of the reflection coefficients at each frequency, the comparison of the theoretical and experimental values of the input impedance in the

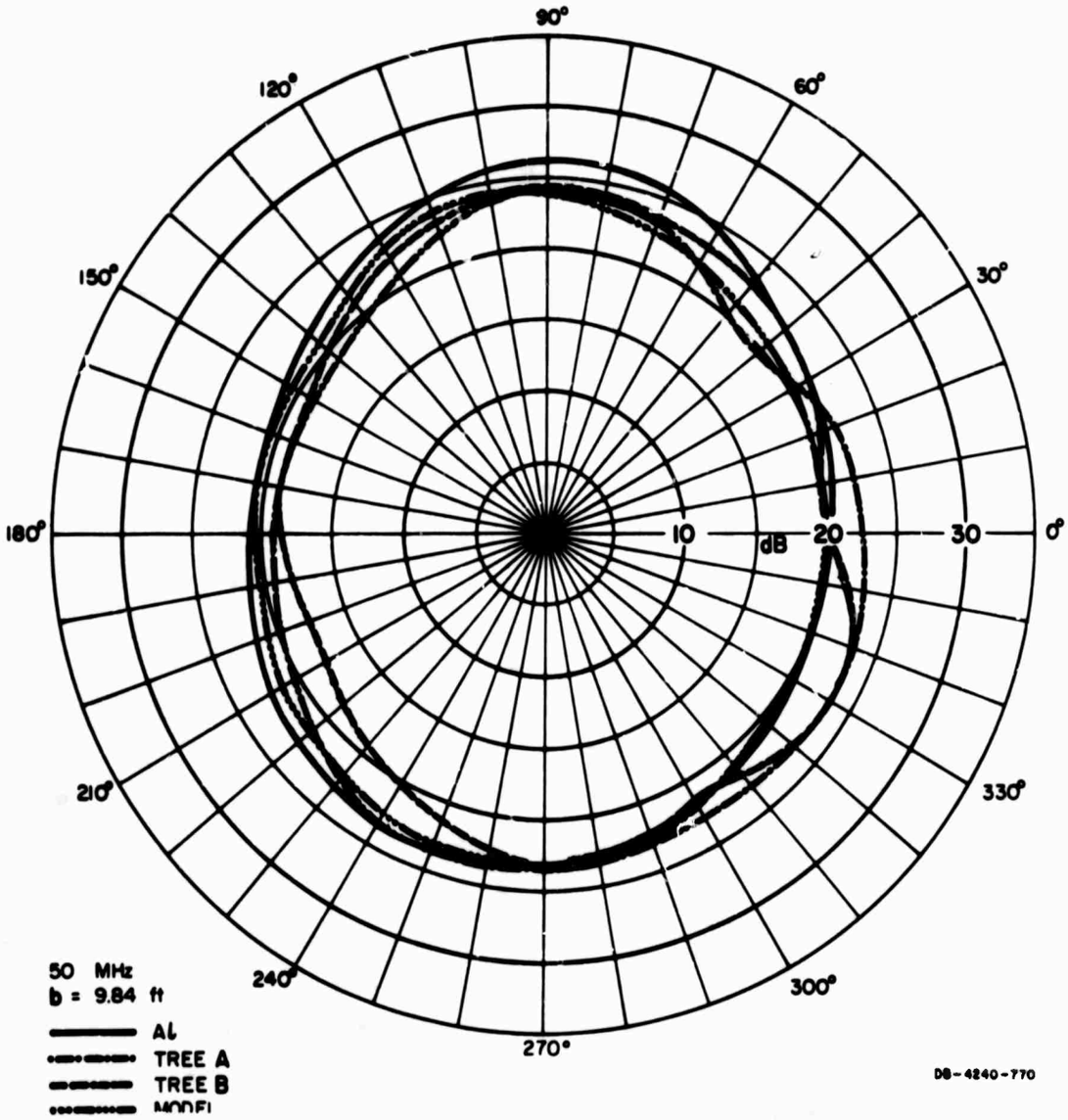

FIG. 27 COMPARISON OF THE THEORETICAL AND EXPERIMENTAL SCATTER PATTERNS FOR b = 9.843 FEET AT 50 MHz

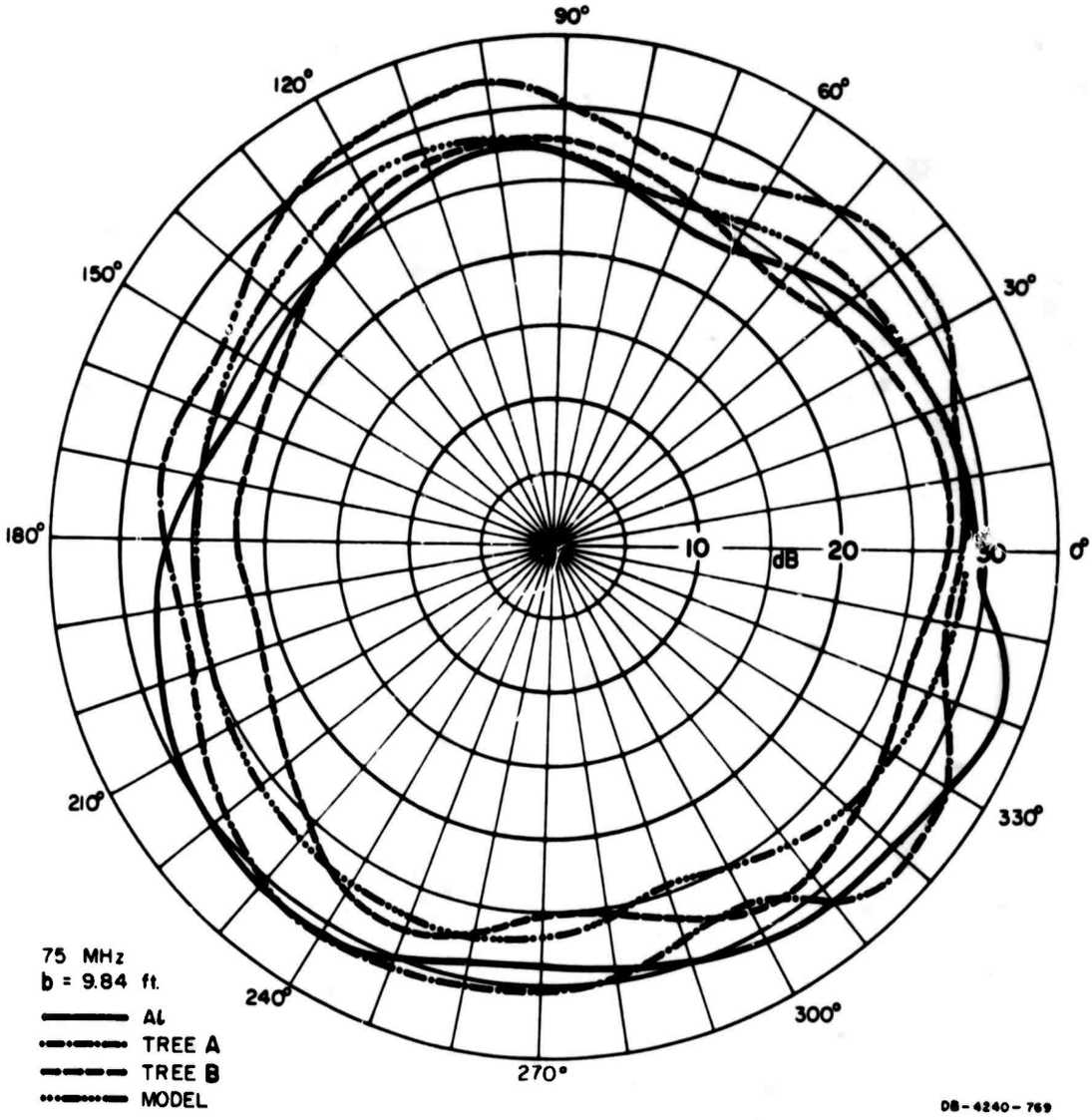

FIG. 28 COMPARISON OF THE THEORETICAL AND EXPERIMENTAL SCATTER PATTERNS FOR b = 9.843 FEET AT 75 MHz

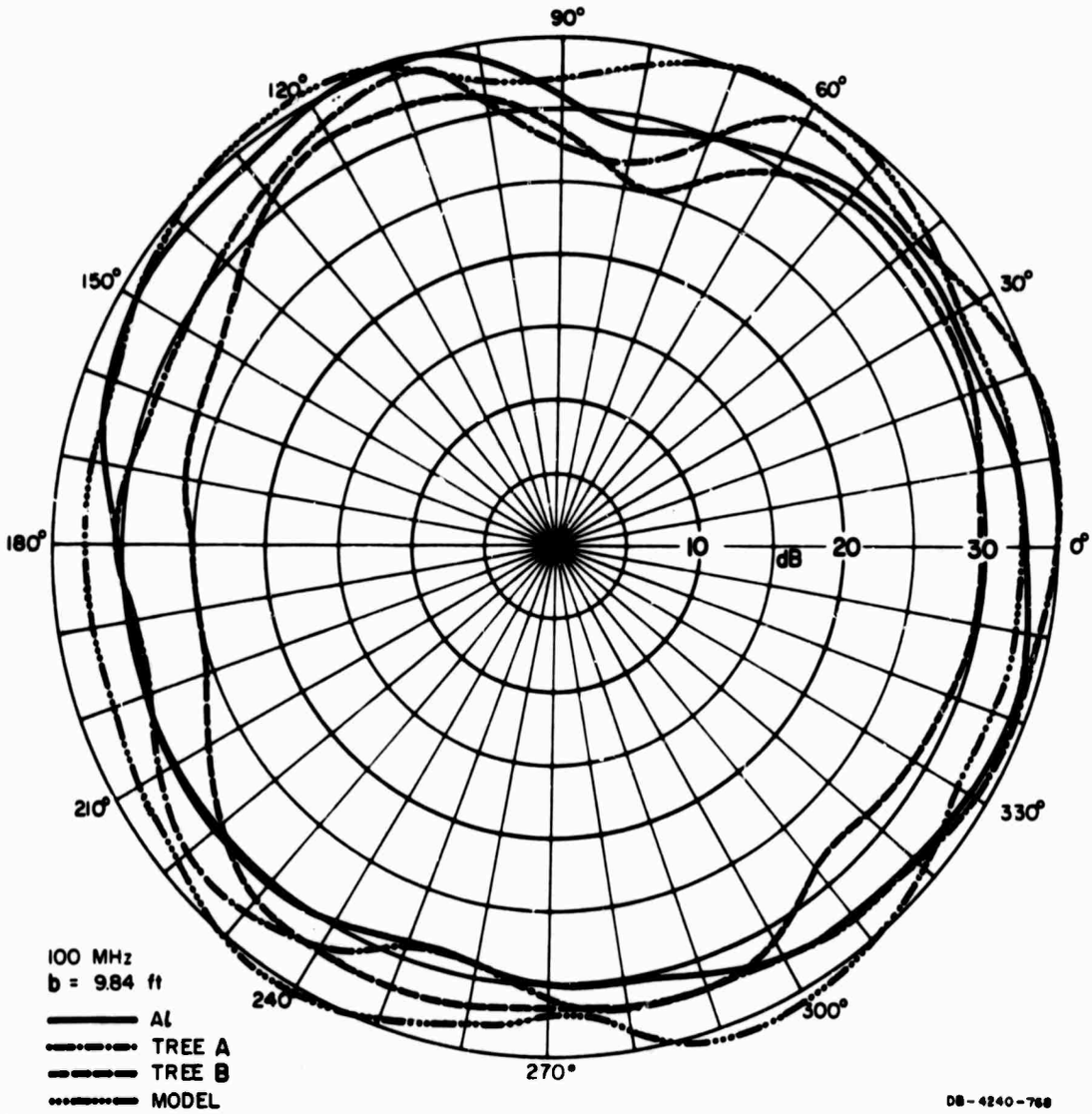

FIG. 29 COMPARISON OF THE THEORETICAL AND EXPERIMENTAL SCATTER PATTERNS FOR b = 9.843 FEET AT 100 MHz

Table II

AVERAGE REFLECTION COEFFICIENTS FOR THREE TREES

Frequency (MHz)	Reflection Coefficient
50	$0.32\angle 180^\circ$
75	$0.27\angle 180^\circ$
100	$0.38\angle 145^\circ$

vicinity of an isolated tree is shown in Figs. 30 through 33. At 75.1 and 100 MHz the theoretical values of the input impedance of the $\lambda/2$ vertical antenna are compared with the average values of the input impedances of a $\lambda/2$ vertical antenna at 5.25 and 6.56 feet, since the antenna impedance between the antenna and its image in the ground is negligible. But at 50 MHz the mutual impedance between the antenna and its image in the ground is still significant. Separate comparisons of the theoretical and experimental values at 5.25 and 6.56 feet are made at 50 MHz. Agreement between the experimental and model values is good, but it should be emphasized that this simple model is feasible to use only in the direct path.

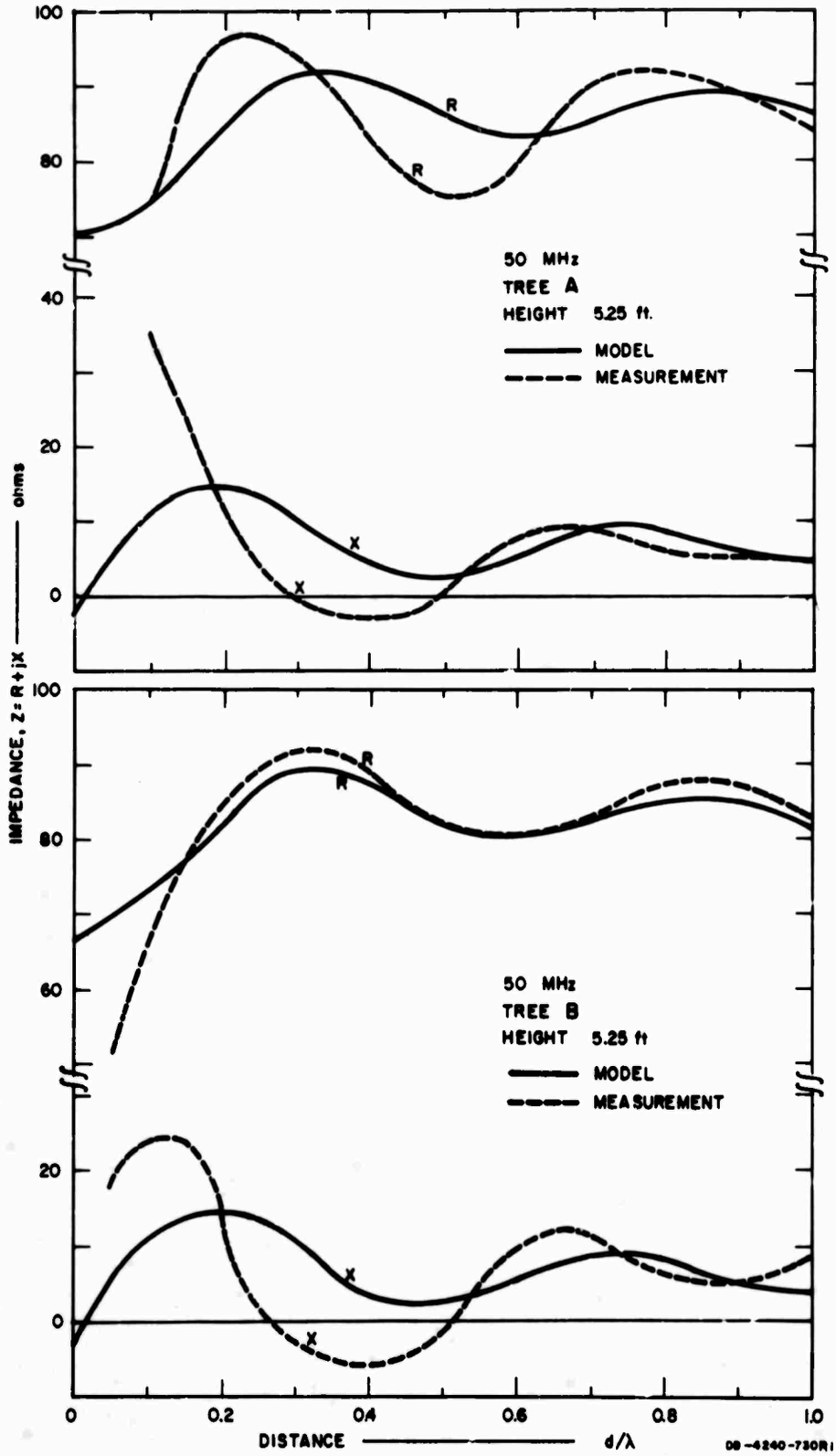

FIG. 30 MEASURED AND CALCULATED INPUT IMPEDANCE OF 50-MHz λ/2 DIPOLE vs DISTANCE FROM TREES (height = 5.25 feet)

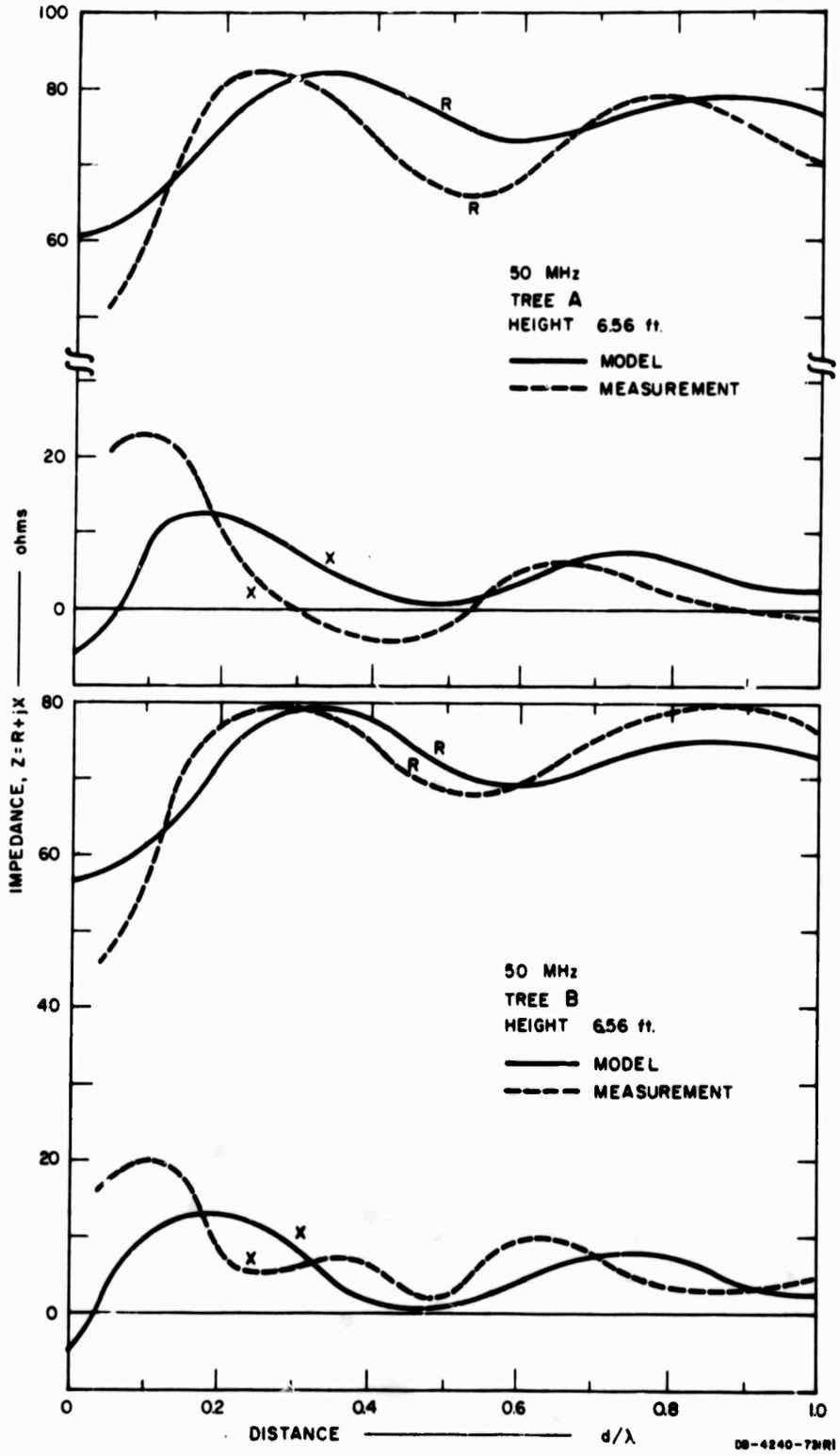

FIG. 31 MEASURED AND CALCULATED INPUT IMPEDANCE OF 50-MHz $\lambda/2$ DIPOLE vs DISTANCE FROM TREES (height = 6.56 feet)

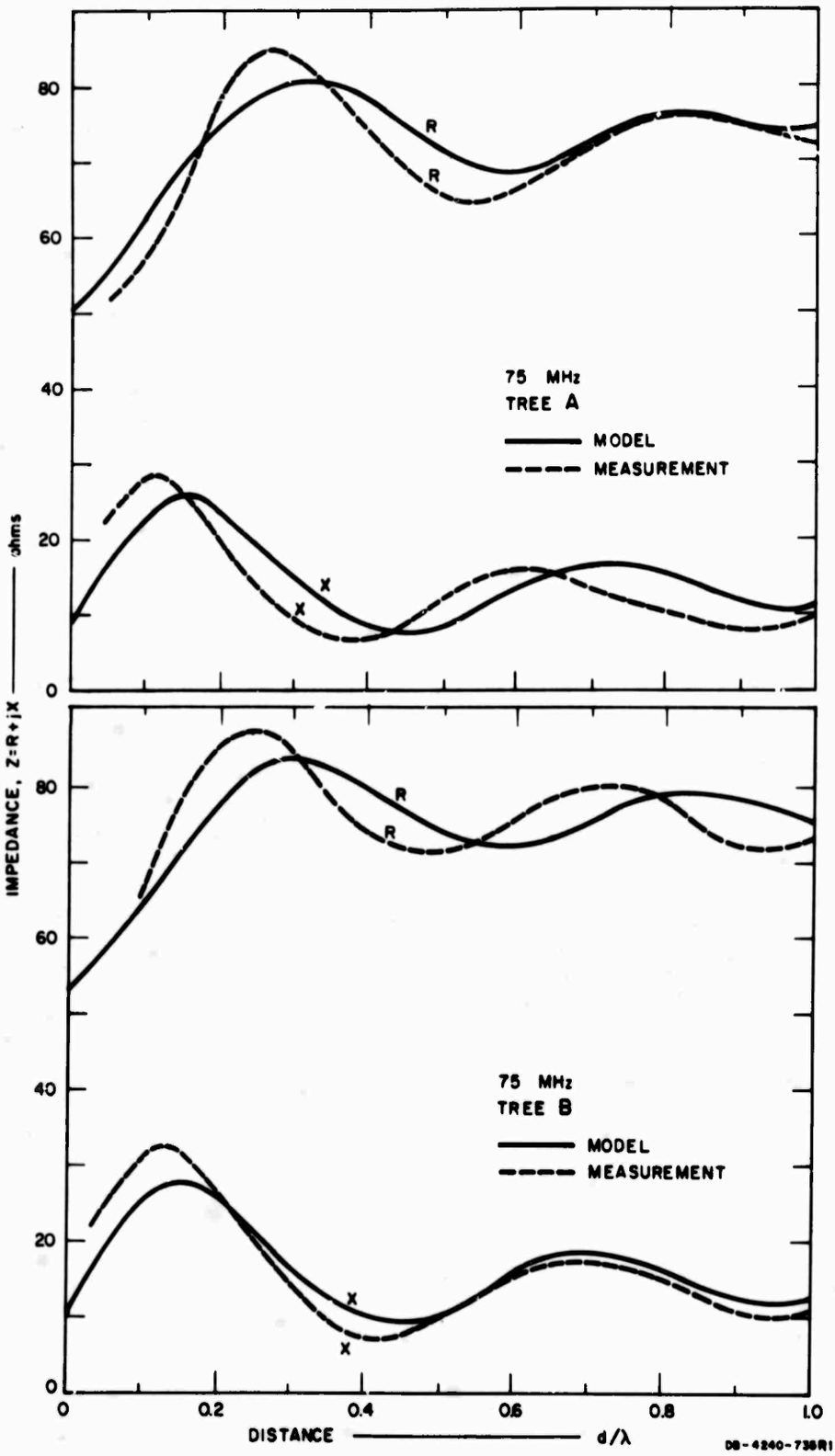

FIG. 32 MEASURED AND CALCULATED INPUT IMPEDANCE OF 75-MHz $\lambda/2$ DIPOLE vs DISTANCE FROM TREES

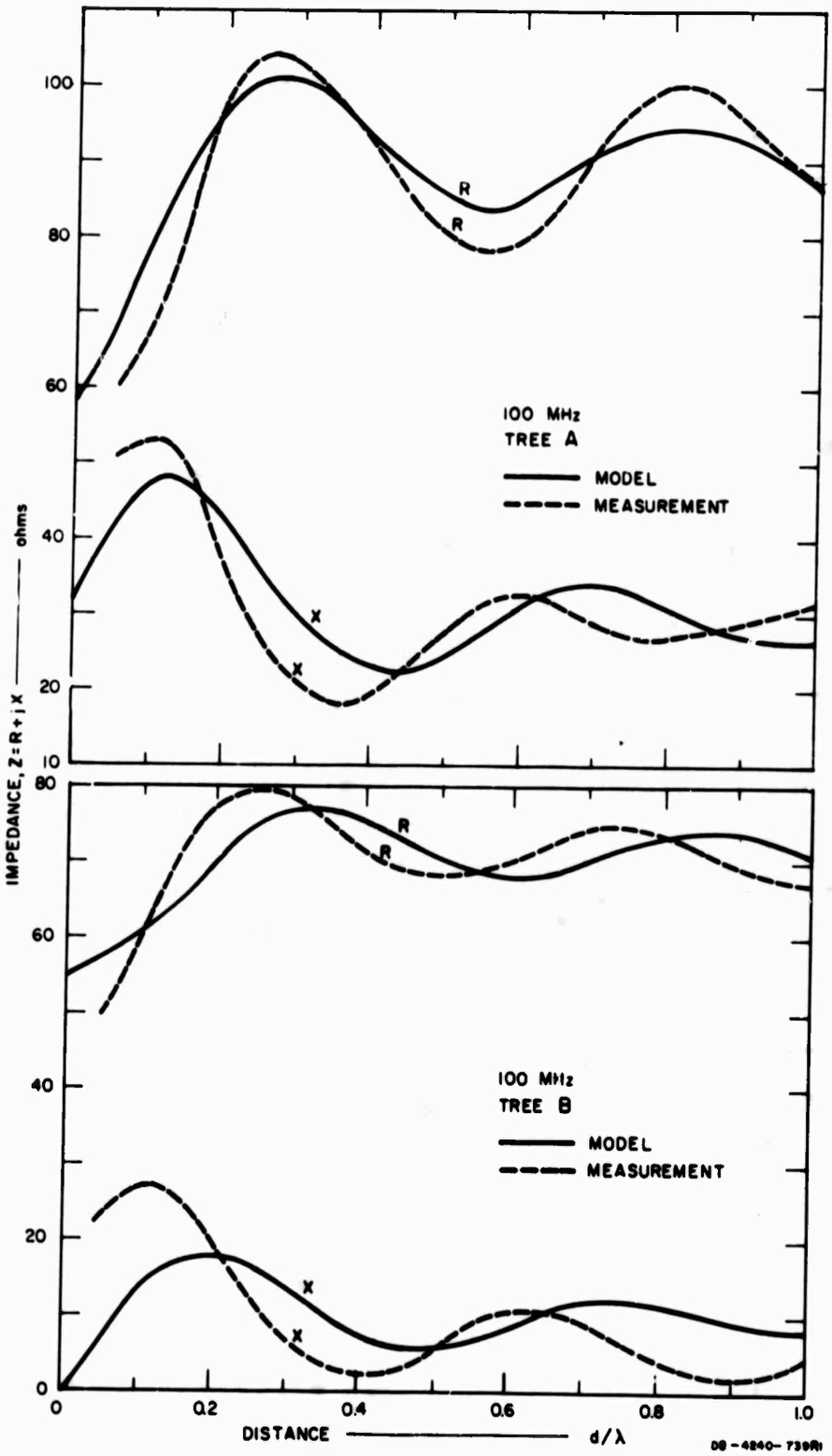

FIG. 33 MEASURED AND CALCULATED INPUT IMPEDANCE OF 100-MHz $\lambda/2$ DIPOLE vs DISTANCE FROM TREES

VI CONCLUSIONS AND SUGGESTED FUTURE RESEARCH

Four conclusions can be gathered from this report.

(1) A perfectly conducting cylinder of appropriate radius can be used to represent an isolated tree in a simple scattering model.

(2) Trees within one wavelength from the transmitting antenna can be considered as parasitic elements of the antenna.

(3) The characteristics of the driving point impedance of an antenna as it is moved close to a tree trunk are similar to those that would be obtained from a horizontal dipole antenna that is brought near lossy ground.

(4) The pattern of an isolated tree as a shunt-fed, grounded radiator is directive. This is a possible factor to offset its over-all low efficiency.

Based on the information gathered in this report, it can be concluded that in the VHF range, trees in the neighborhood of one wavelength from the transmitting antenna can be considered as parasitic elements. At each point in the jungle, the number and locations of trees could be generated by the distributions of the density and the nearest neighbor distance of trees in that jungle. As the transmitting antenna is being moved in the jungle, it is analogous to the change in the number and/or locations of parasitic elements. This hypothesis should explain the rapid variation and the high attenuation in radio waves that propagate through the jungle. The rapid variation in the signal is possible due to the sudden change in the number and locations of the parasitic elements of the antenna, and the high attenuation is possible due to the fact that the incident and scattering waves combine to form a wave that travels uniformly without scattering at a different velocity from the incident wave with attenuation. The theory of multiple scatterers is applicable, since the forest (as it appears to the radio wave in the VHF band) is no longer homogeneous and isotropic. Details of modeling VHF jungle propagation require further investigation.

In future research, it would be worthwhile to develop the empirical formulas of the equivalent radius of the tree. The frequency should extend to cover the entire range of VHF. The effect of an isolated tree on the horizontally polarized wave would be interesting and should be investigated.

The use of an isolated tree itself as a radiator would be a worthwhile topic for further research. The directivity of tree A as a shunt-fed, grounded radiator at 100 MHz exists and the front-to-back ratio is in the order of 16 dB. This encourages further investigation on this topic. As a first approach, the impedance of the tree as a shunt-fed, grounded radiator should be measured and the statistical relationship between the impedance and the dimensions and type of the tree developed. Knowledge of the statistical relationship between the impedance and the dimensions and type of tree is essential for the actual application of an isolated tree as a transmitting antenna. The feeding systems other than the shunt-feeding system should be investigated, since the radiation efficiency depends strongly on the feeding system.

Appendix

SCATTER PATTERNS OF VHF RADIO WAVES FROM TREES AND AN ALUMINUM MAST

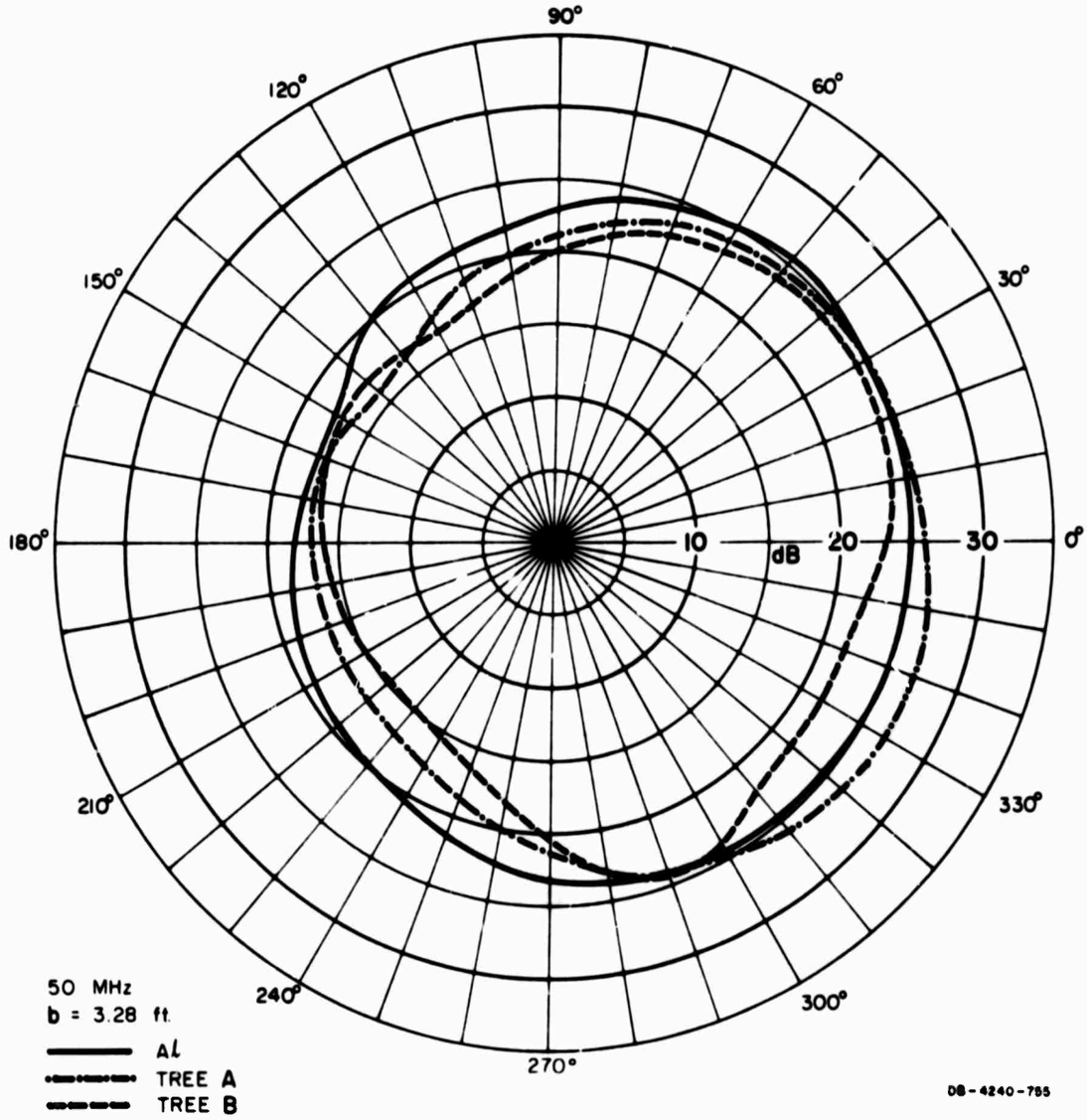

FIG. A-1 SCATTER PATTERNS OF RADIO WAVES AT 50 MHz WHEN THE XELEDOP TRANSMITTER IS 3.28 FEET AWAY FROM THE SCATTERER

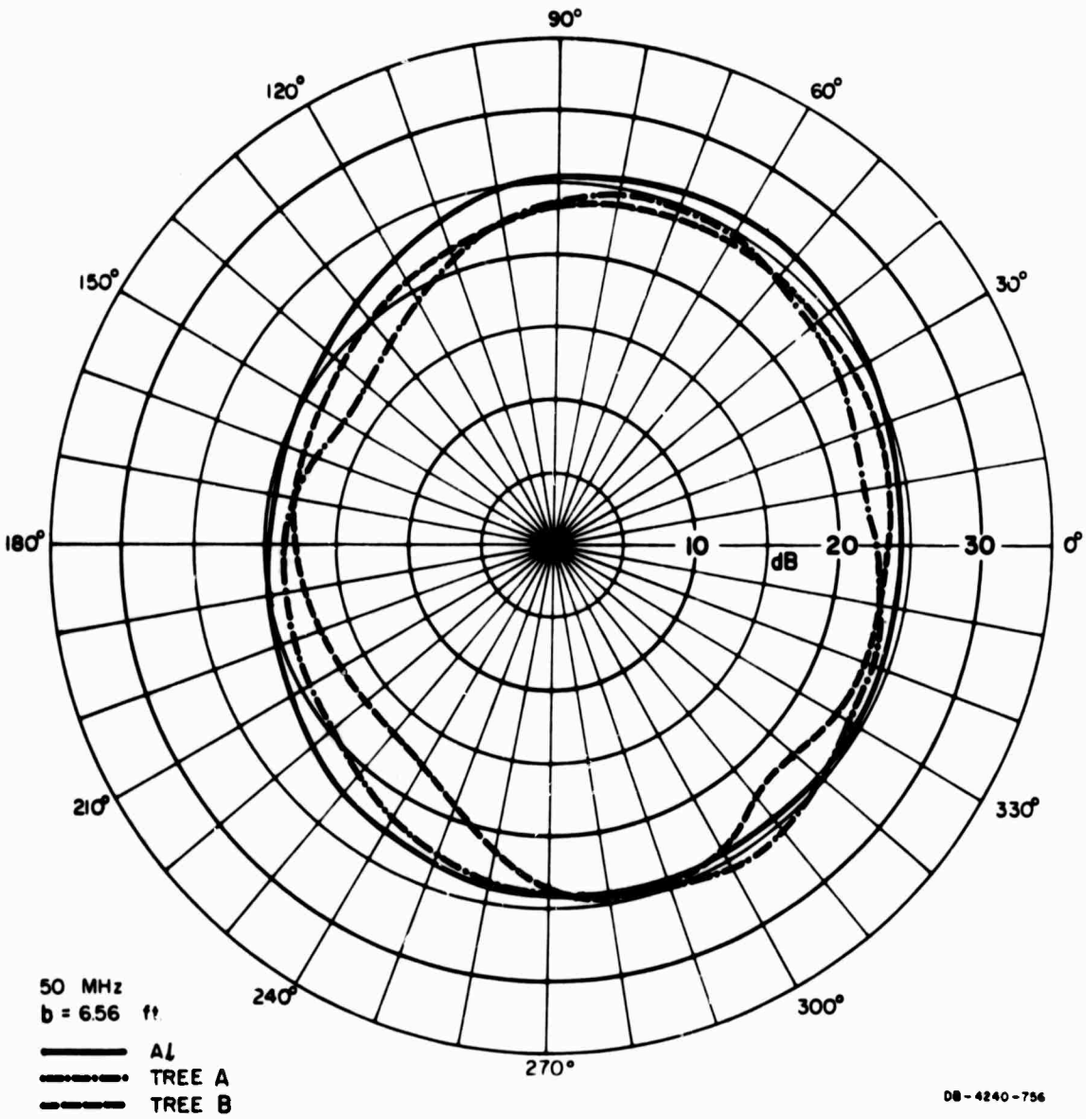

FIG. A-2 SCATTER PATTERNS OF RADIO WAVES AT 50 MHz WHEN THE XELEDOP TRANSMITTER IS 6.56 FEET AWAY FROM THE SCATTERER

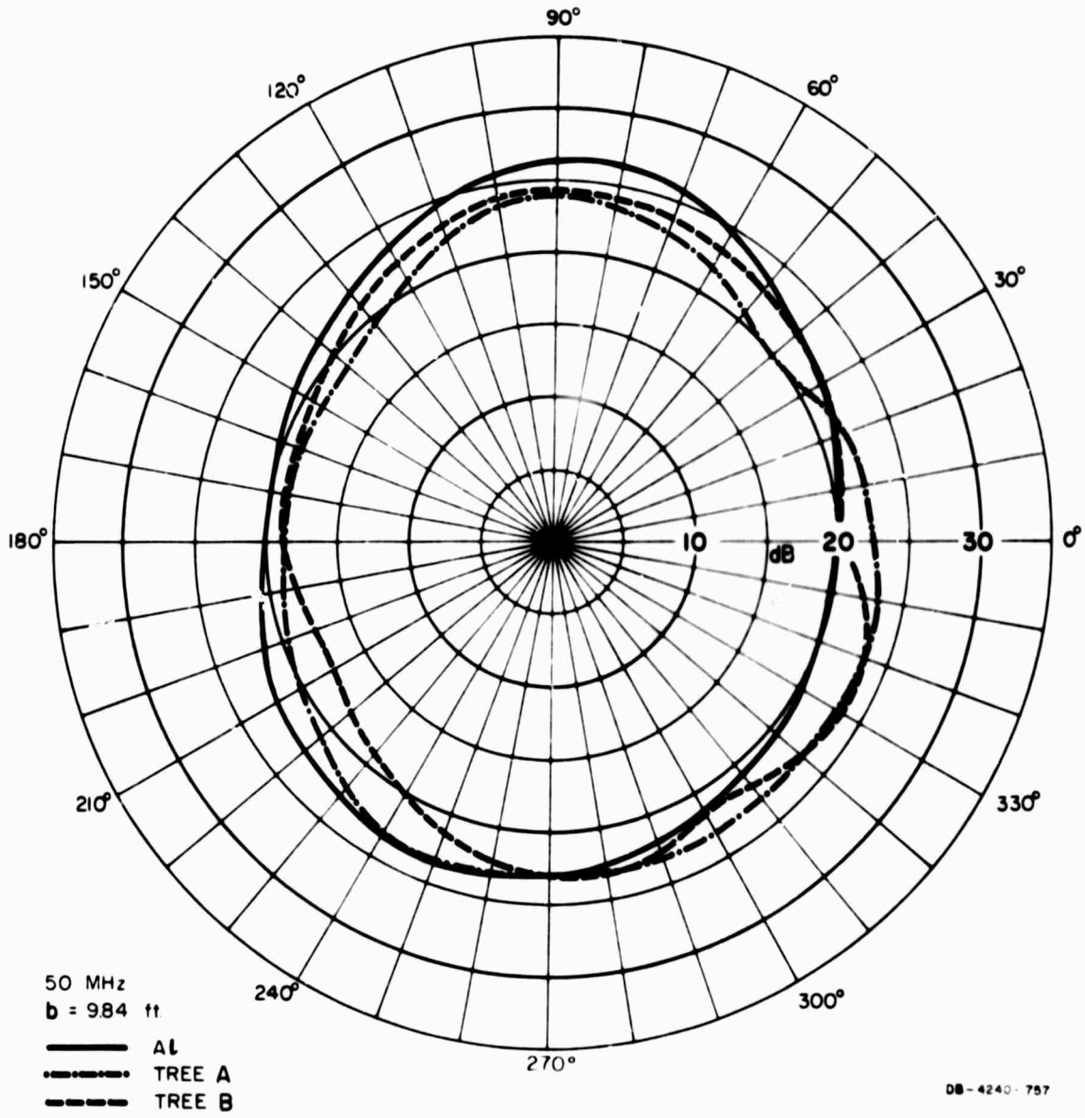

FIG. A-3 SCATTER PATTERNS OF RADIO WAVES AT 50 MHz WHEN THE XELEDOP TRANSMITTER IS 9.84 FEET AWAY FROM THE SCATTERER

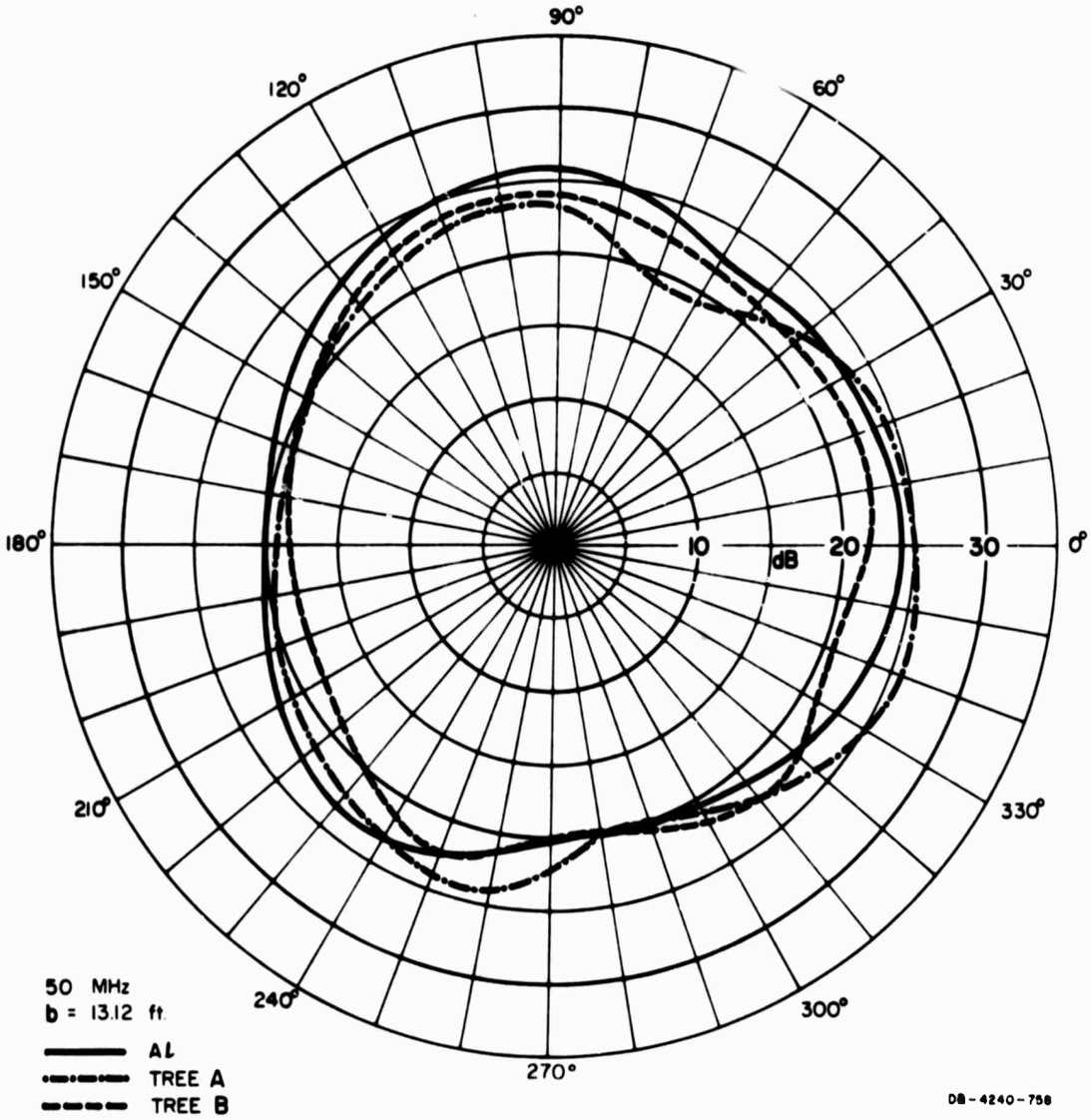

FIG. A-4 SCATTER PATTERNS OF RADIO WAVES AT 50 MHz WHEN THE XELEDOP TRANSMITTER IS 13.12 FEET AWAY FROM THE SCATTERER

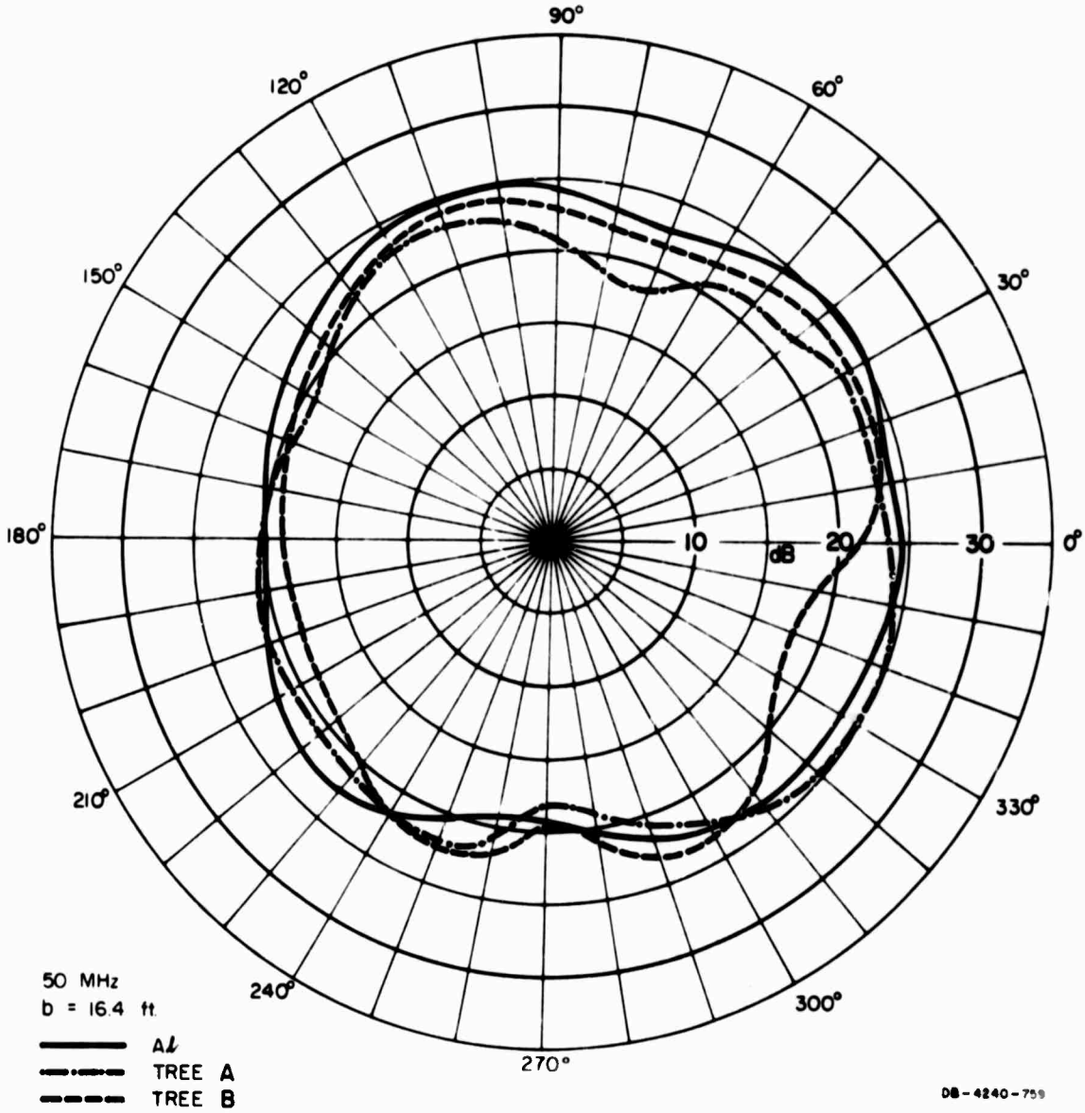

FIG. A-5 SCATTER PATTERNS OF RADIO WAVES AT 50 MHz WHEN THE XELEDOP TRANSMITTER IS 16.4 FEET AWAY FROM THE SCATTERER

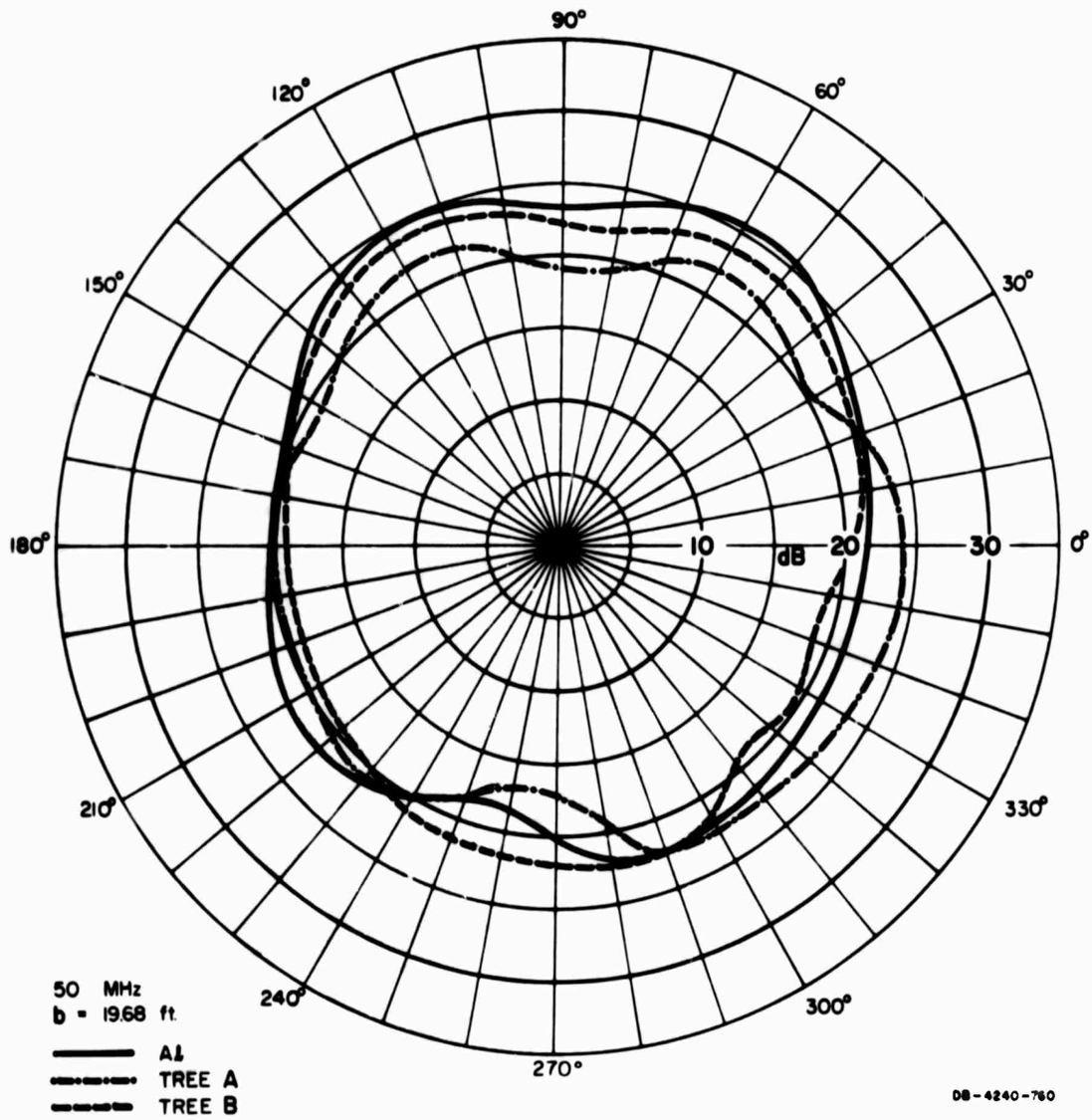

FIG. A-6 SCATTER PATTERNS OF RADIO WAVES AT 50 MHz WHEN THE XELEDOP TRANSMITTER IS 19.68 FEET AWAY FROM THE SCATTERER

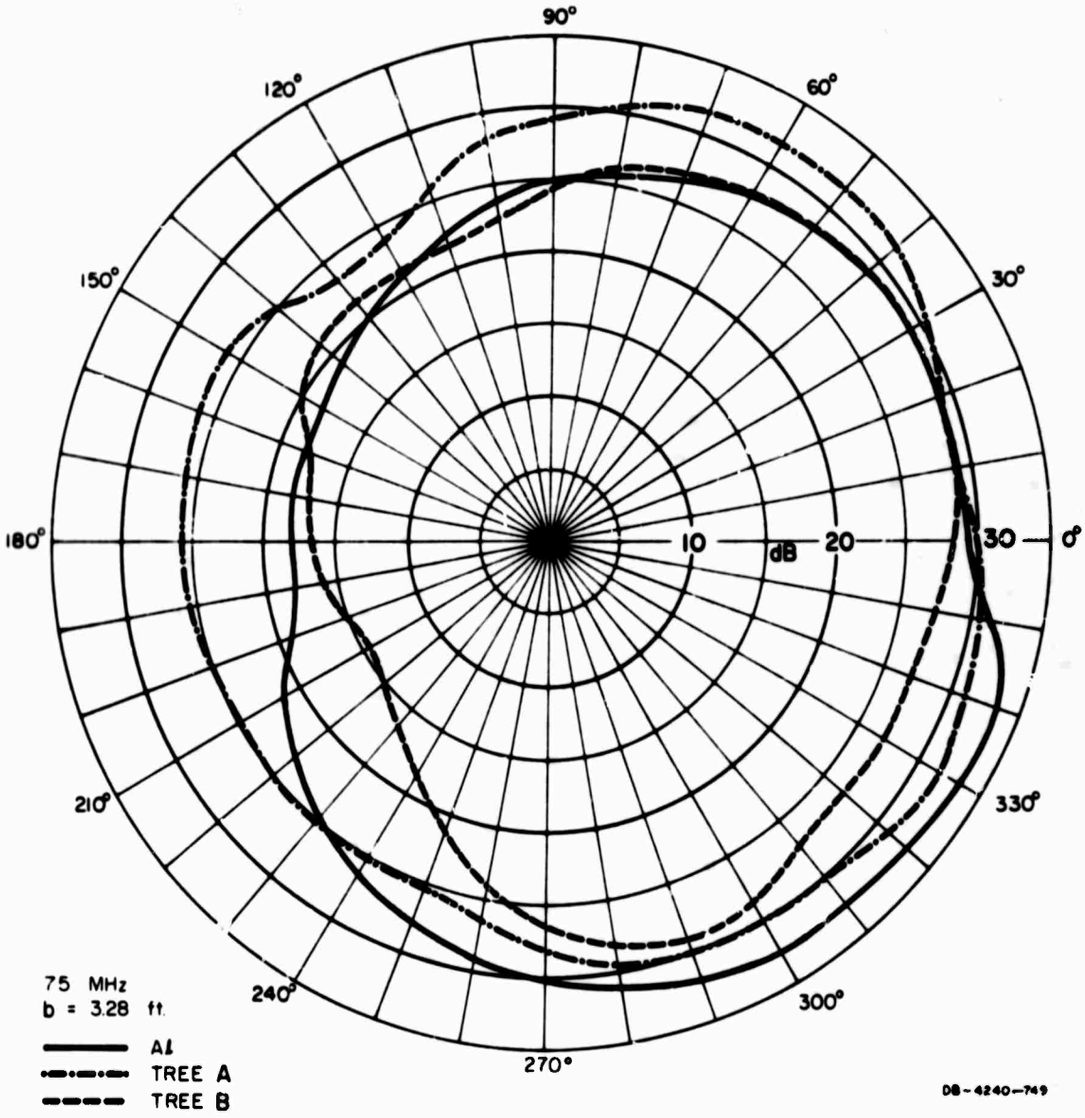

FIG. A-7 SCATTER PATTERNS OF RADIO WAVES AT 75.1 MHz WHEN THE XELEDOP TRANSMITTER IS 3.28 FEET AWAY FROM THE SCATTERER

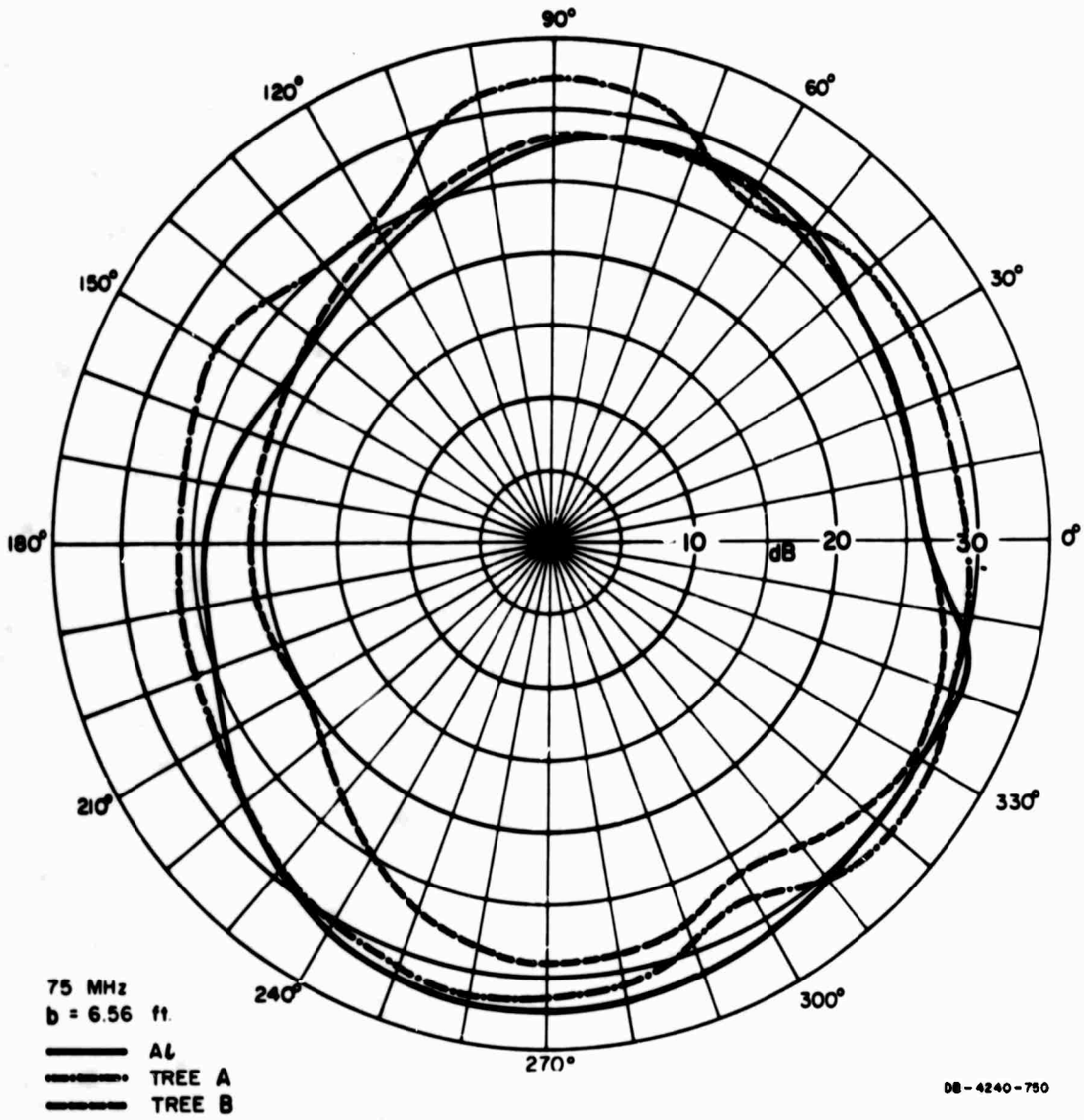

FIG. A-8 SCATTER PATTERNS OF RADIO WAVES AT 75.1 MHz WHEN THE XELEDOP TRANSMITTER IS 6.56 FEET AWAY FROM THE SCATTERER

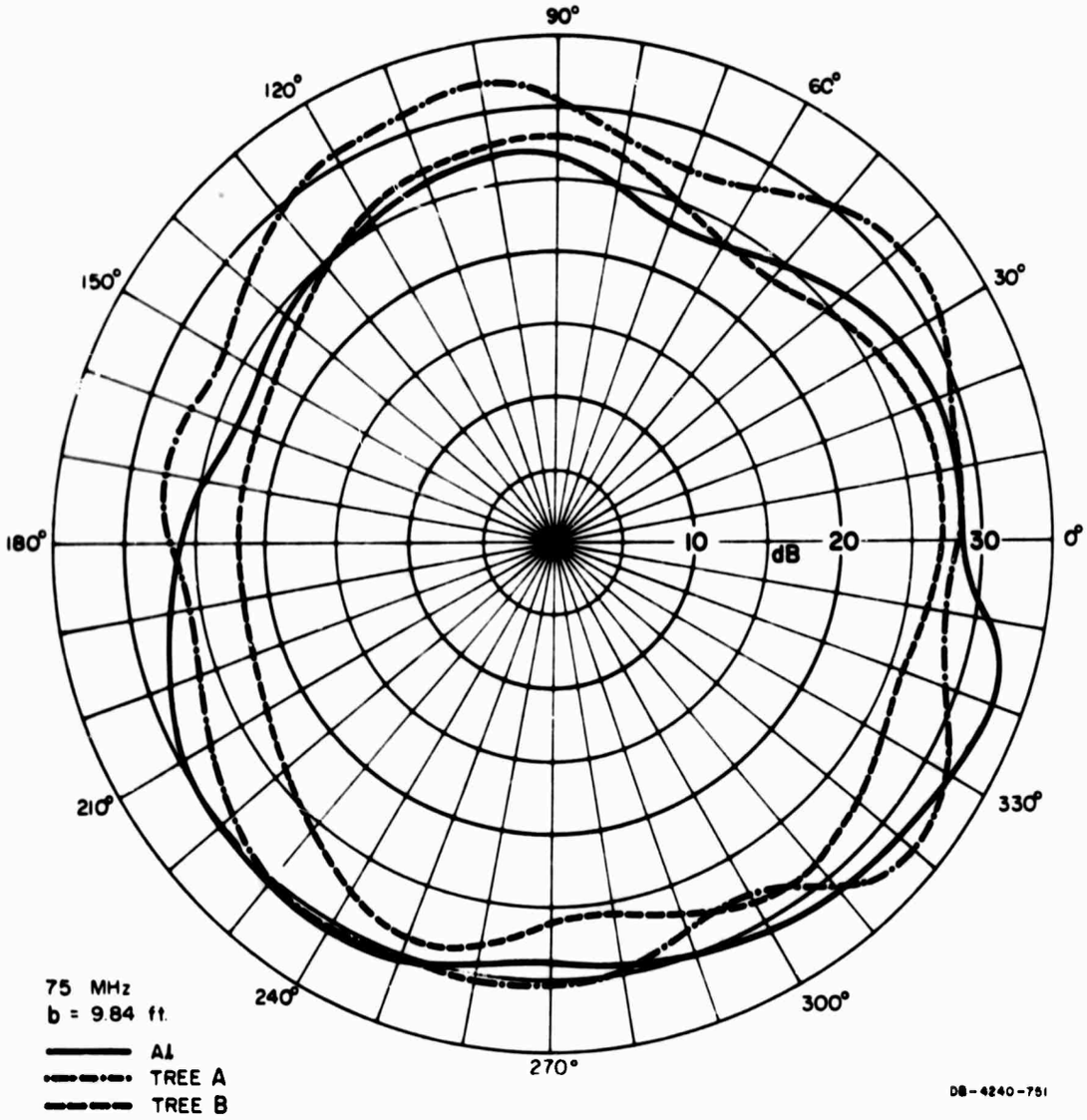

FIG. A-9 SCATTER PATTERNS OF RADIO WAVES AT 75.1 MHz WHEN THE XELEDOP TRANSMITTER IS 9.48 FEET AWAY FROM THE SCATTERER

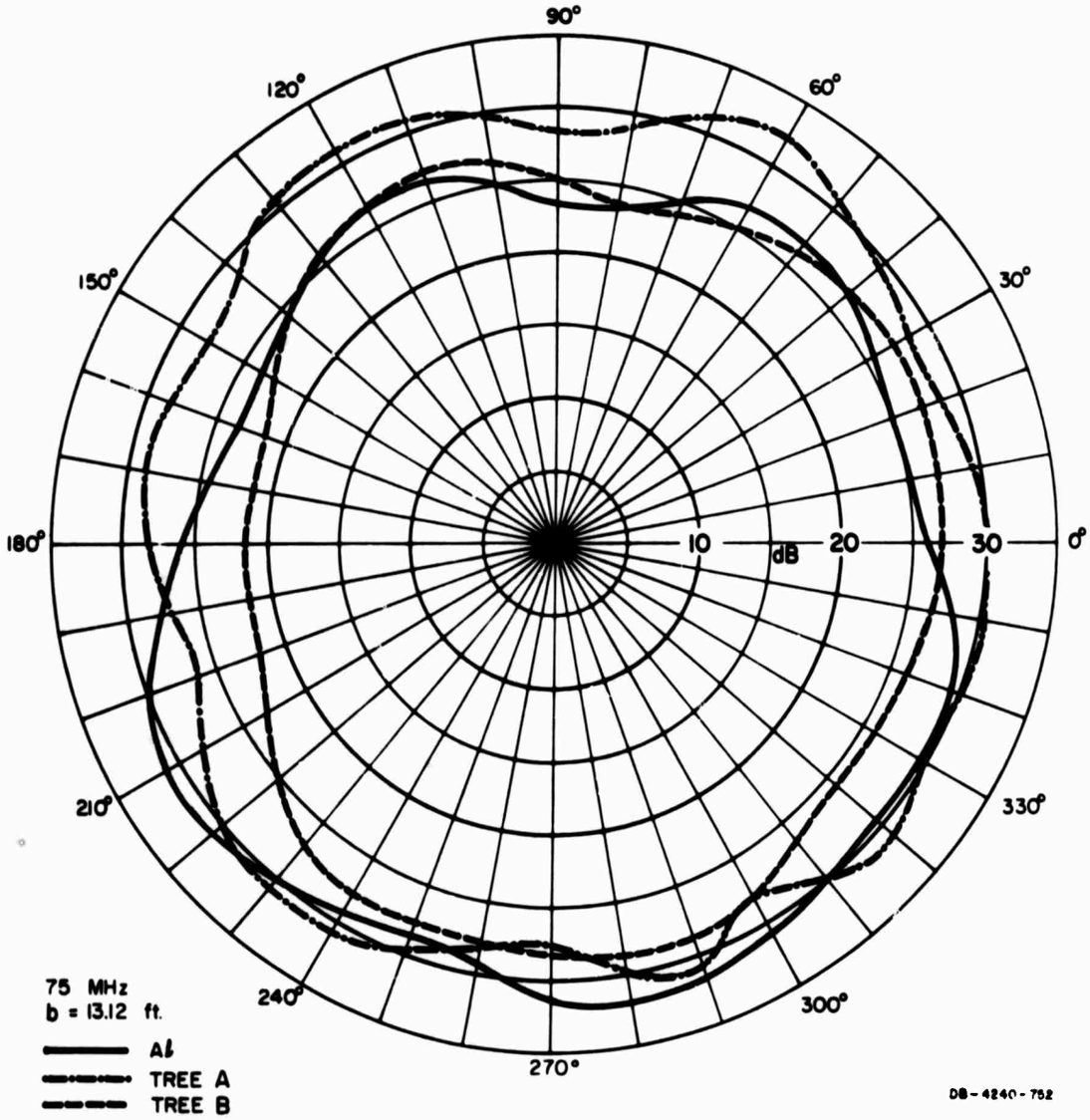

FIG. A-10 SCATTER PATTERNS OF RADIO WAVES AT 75.1 MHz WHEN THE XELEDOP TRANSMITTER IS 13.12 FEET AWAY FROM THE SCATTERER

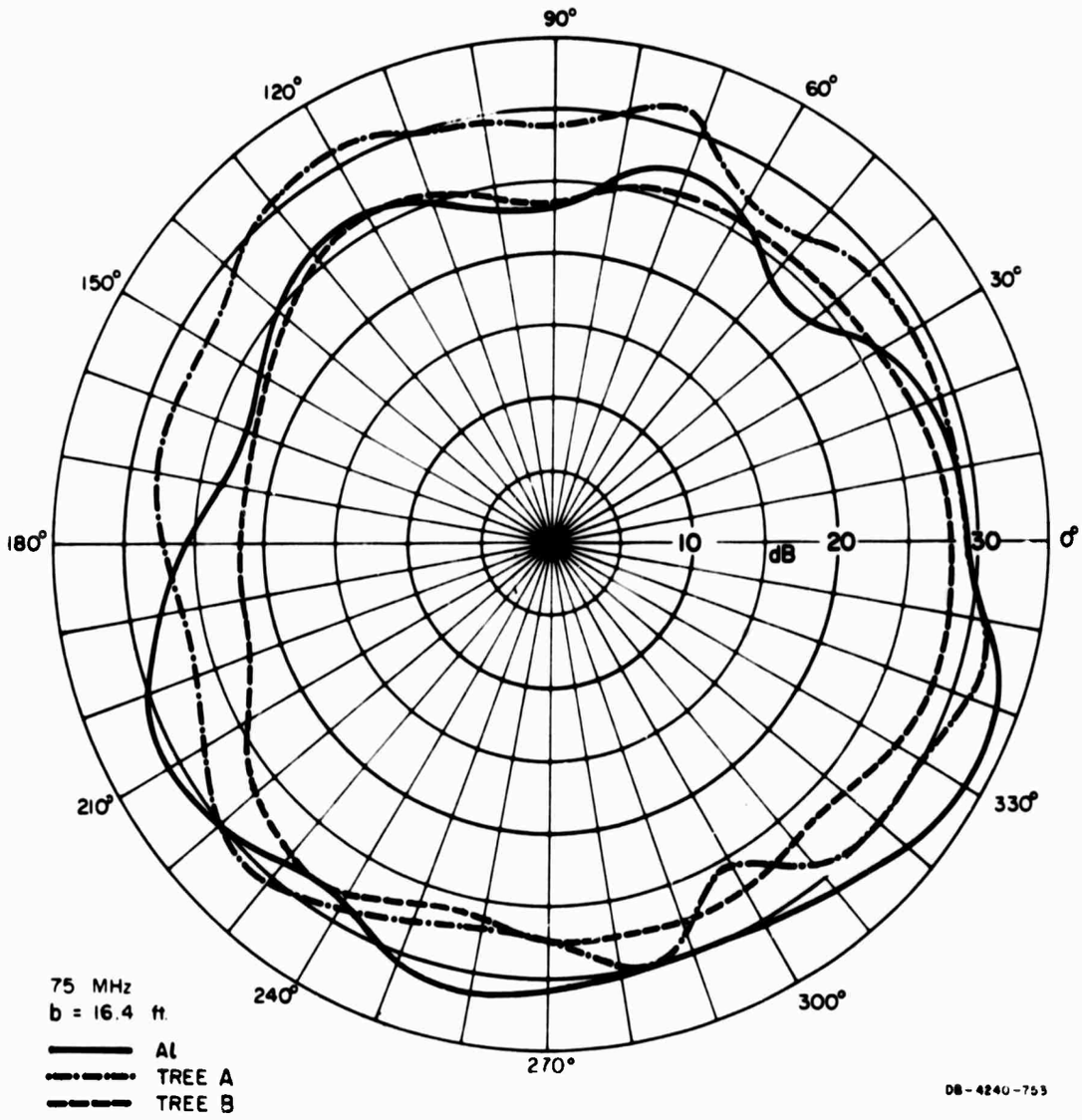

FIG. A-11 SCATTER PATTERNS OF RADIO WAVES AT 75.1 MHz WHEN THE XELEDOP TRANSMITTER IS 16.4 FEET AWAY FROM THE SCATTER

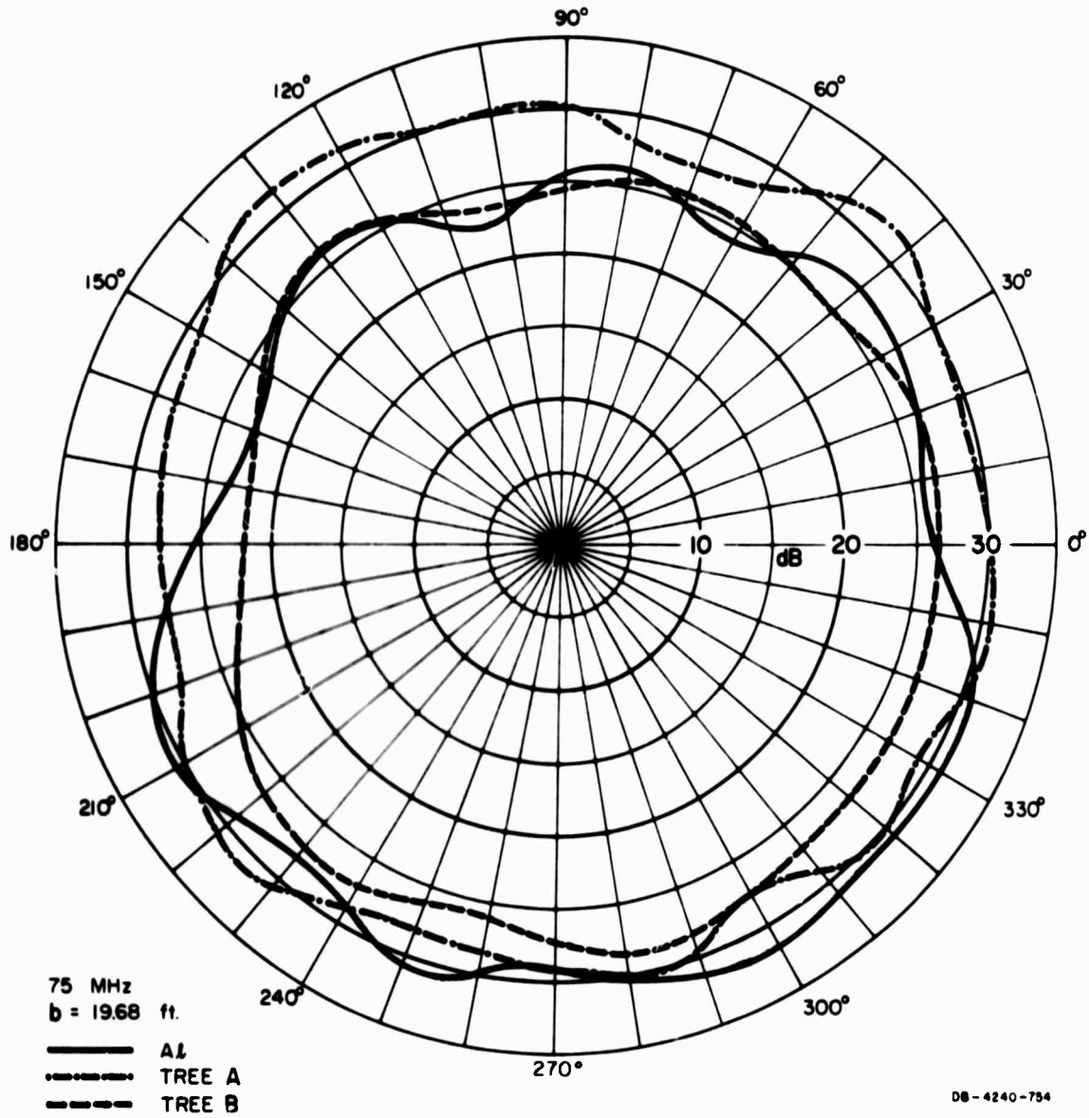

FIG. A-12 SCATTER PATTERNS OF RADIO WAVES AT 75.1 MHz WHEN THE XELEDOP TRANSMITTER IS 19.68 FEET AWAY FROM THE SCATTERER

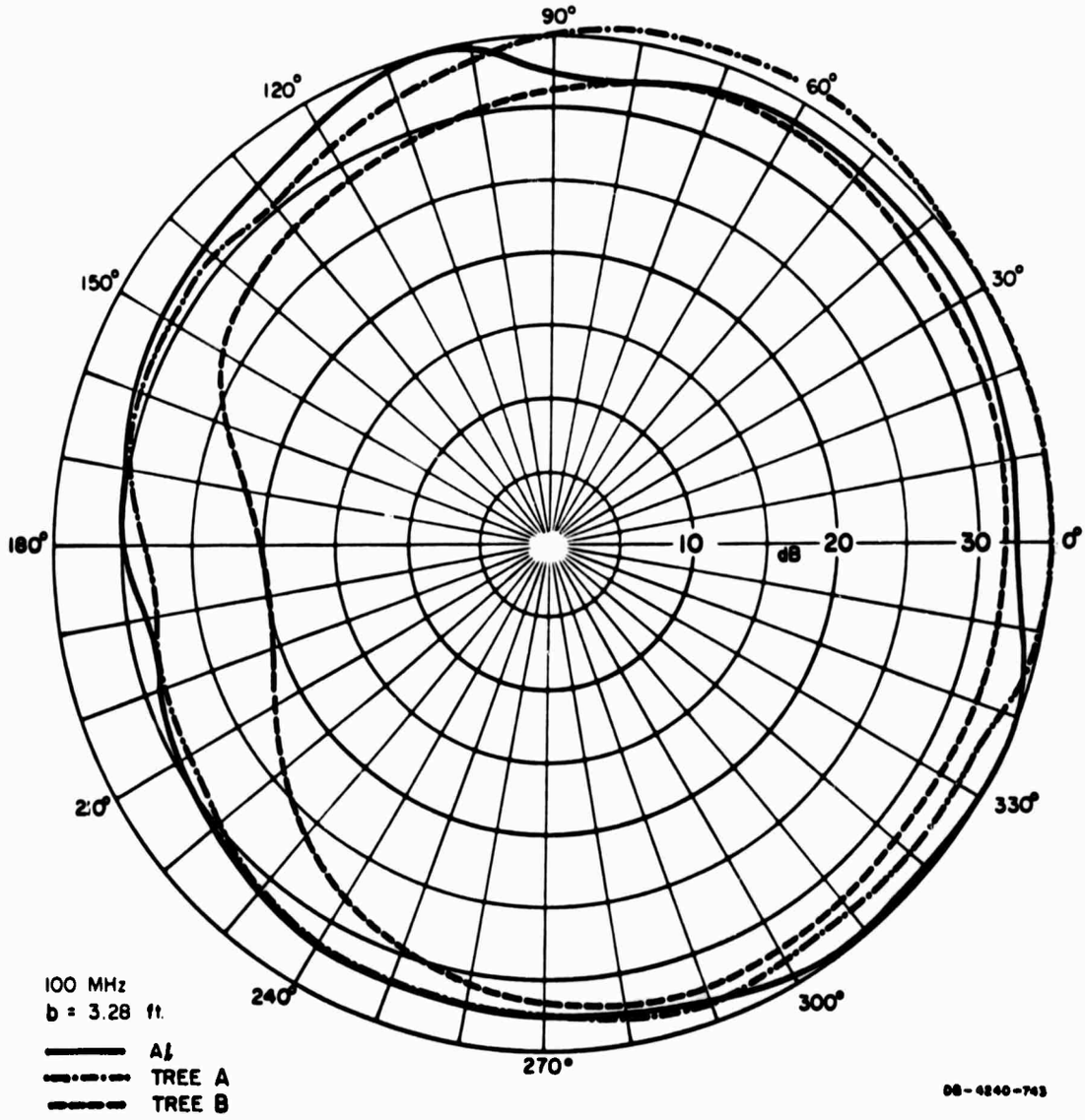

FIG A-13 SCATTER PATTERNS OF RADIO WAVES AT 100 MHz WHEN THE XELEDOP TRANSMITTER IS 3.28 FEET AWAY FROM THE SCATTERER

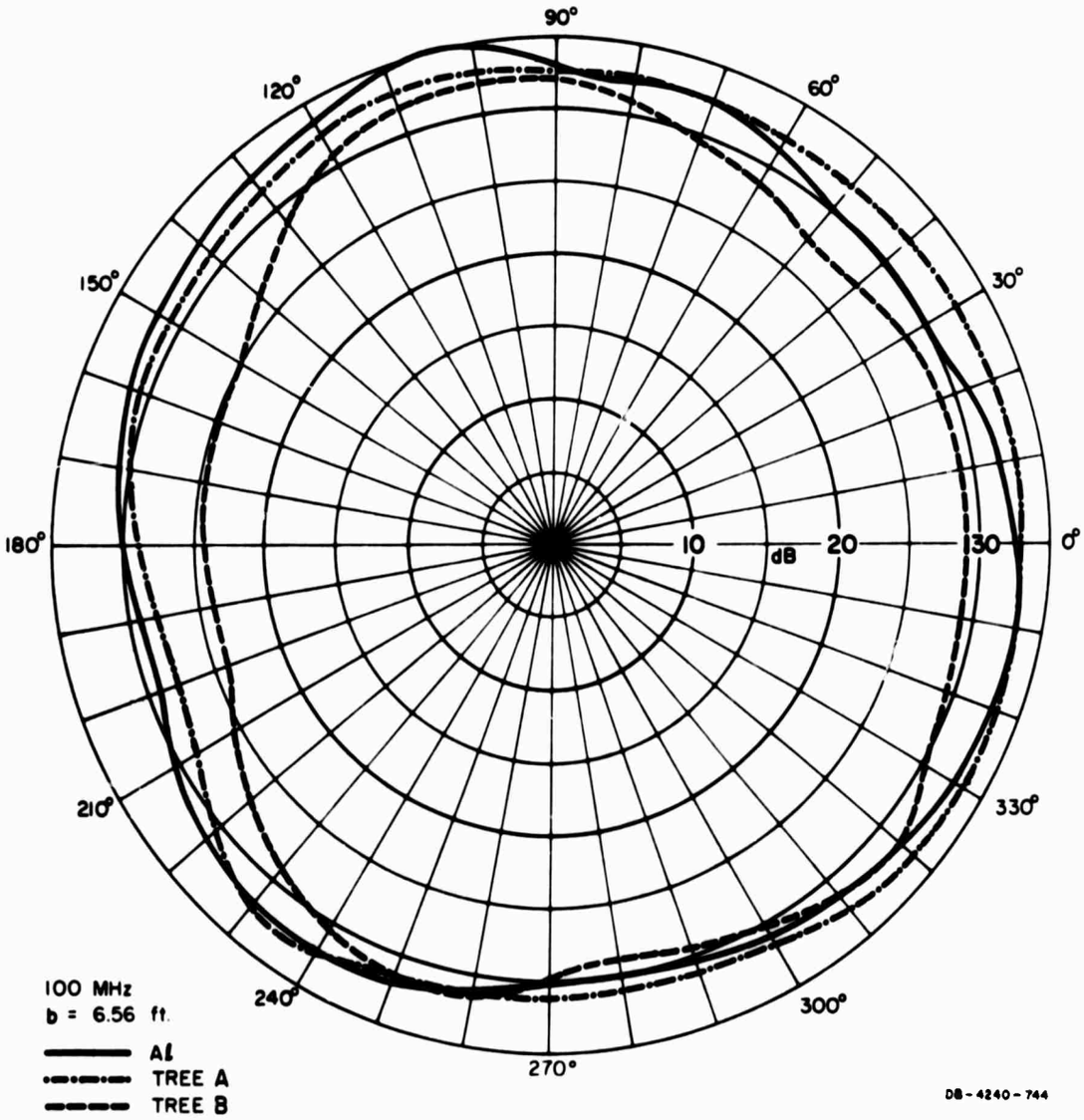

FIG. A-14 SCATTER PATTERNS OF RADIO WAVES AT 100 MHz WHEN THE XELEDOP TRANSMITTER IS 6.56 FEET AWAY FROM THE SCATTERER

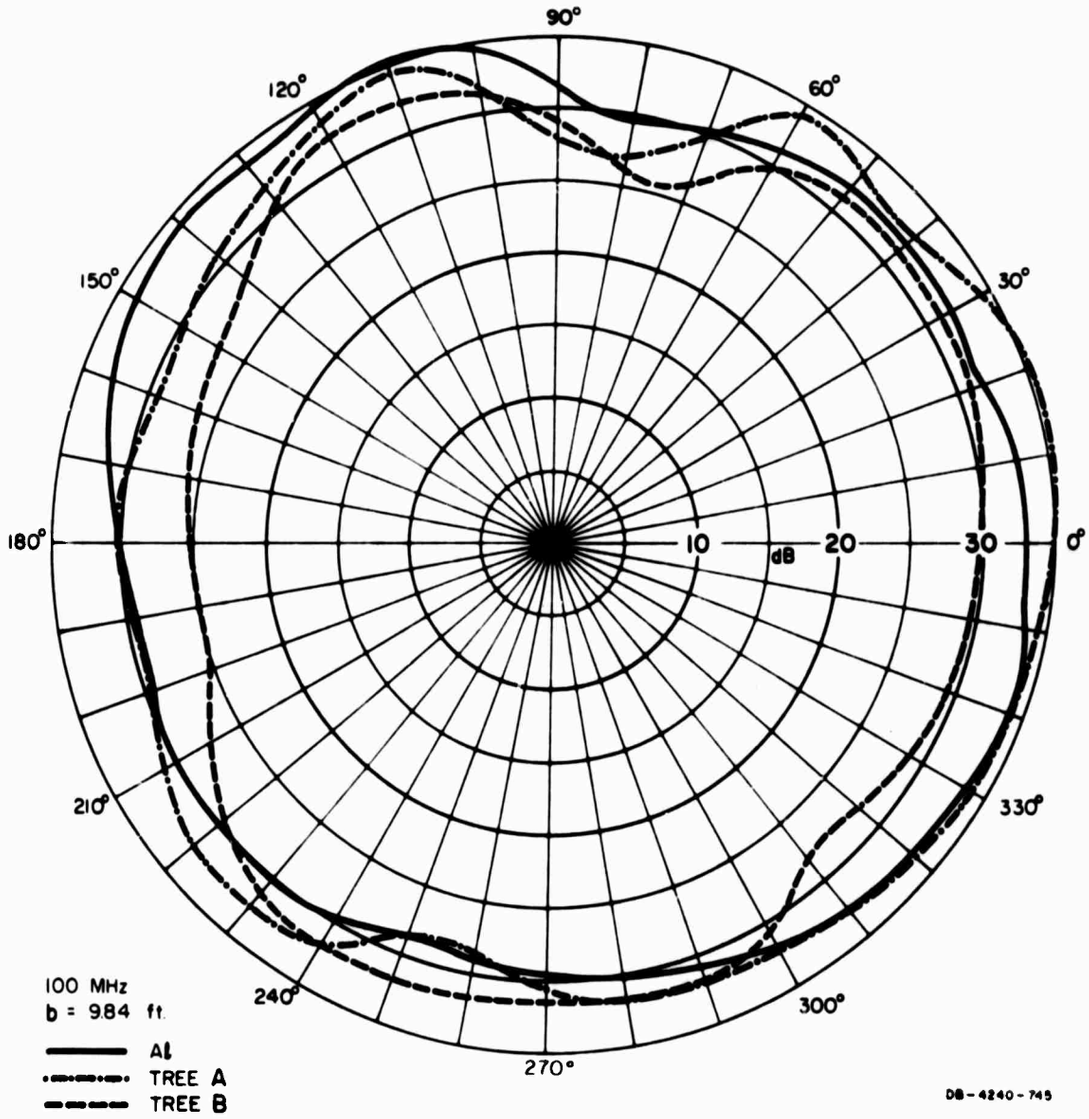

FIG. A-15 SCATTER PATTERNS OF RADIO WAVES AT 100 MHz WHEN THE XELEDOP TRANSMITTER IS 9.84 FEET AWAY FROM THE SCATTERER

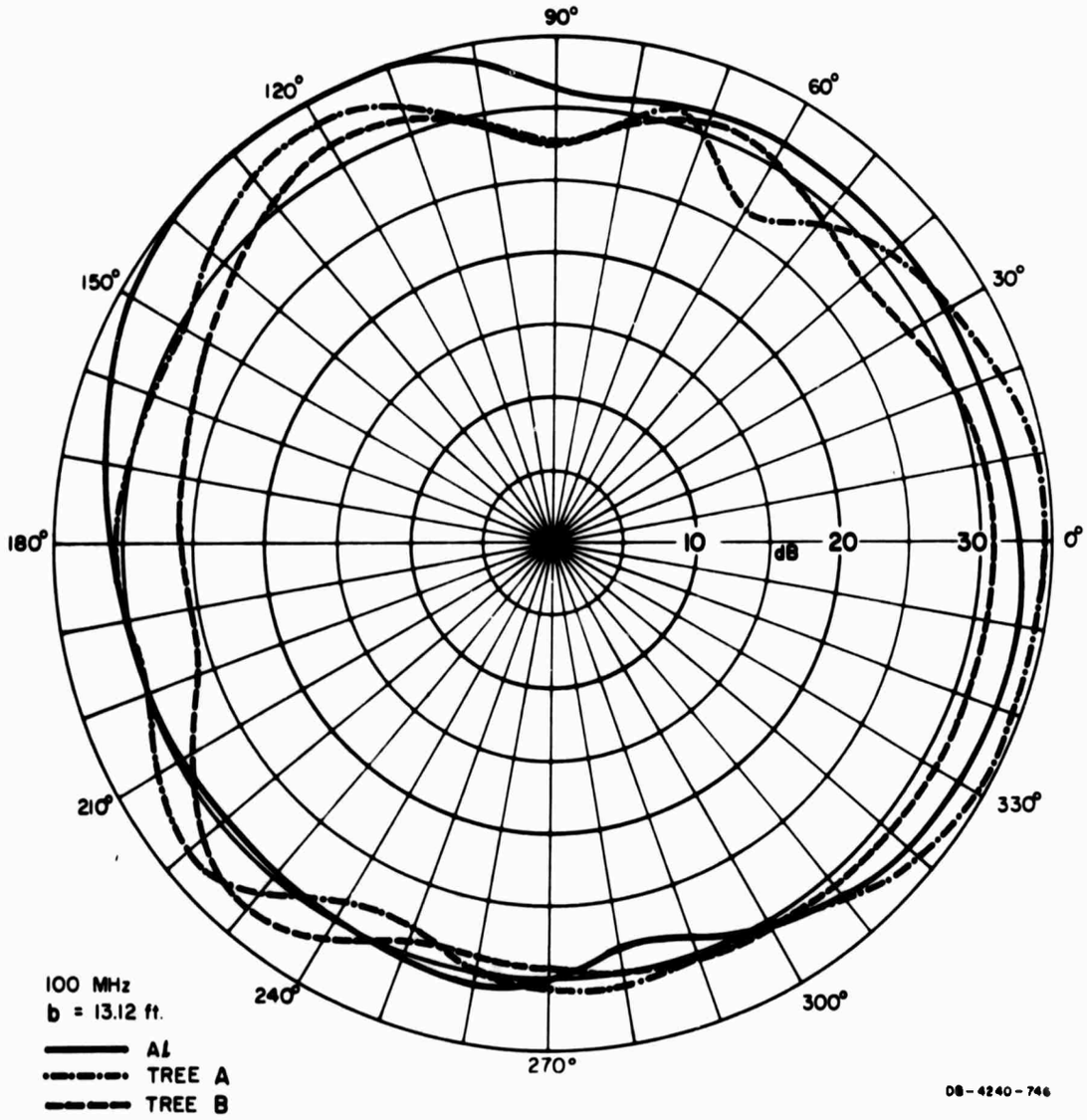

FIG. A-16 SCATTER PATTERNS OF RADIO WAVES AT 100 MHz WHEN THE XELEDOP TRANSMITTER IS 13.12 FEET AWAY FROM THE SCATTERER

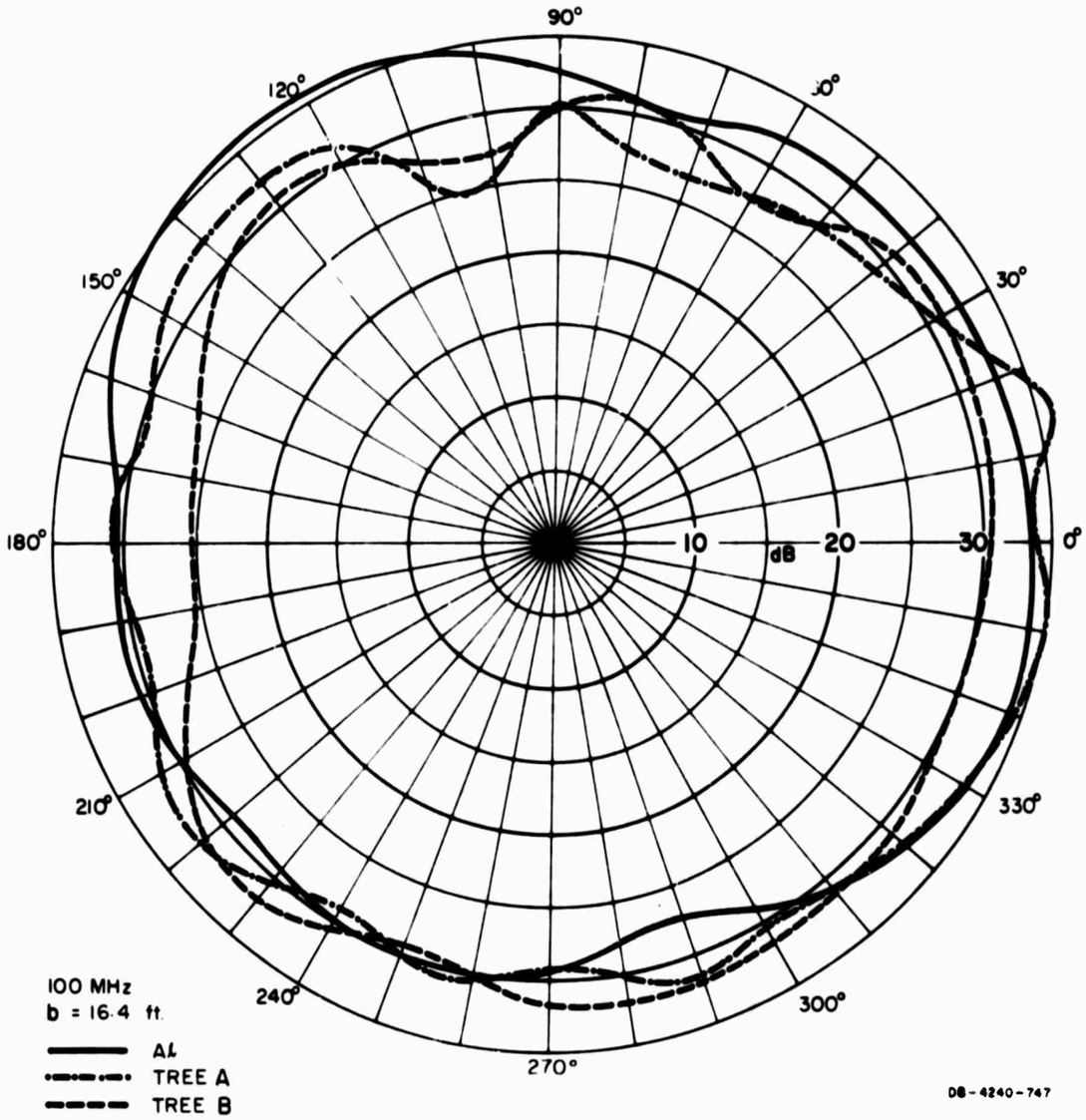

FIG. A-17 SCATTER PATTERNS OF RADIO WAVES AT 100 MHz WHEN THE XELEDOP TRANSMITTER IS 16.4 FEET AWAY FROM THE SCATTERER

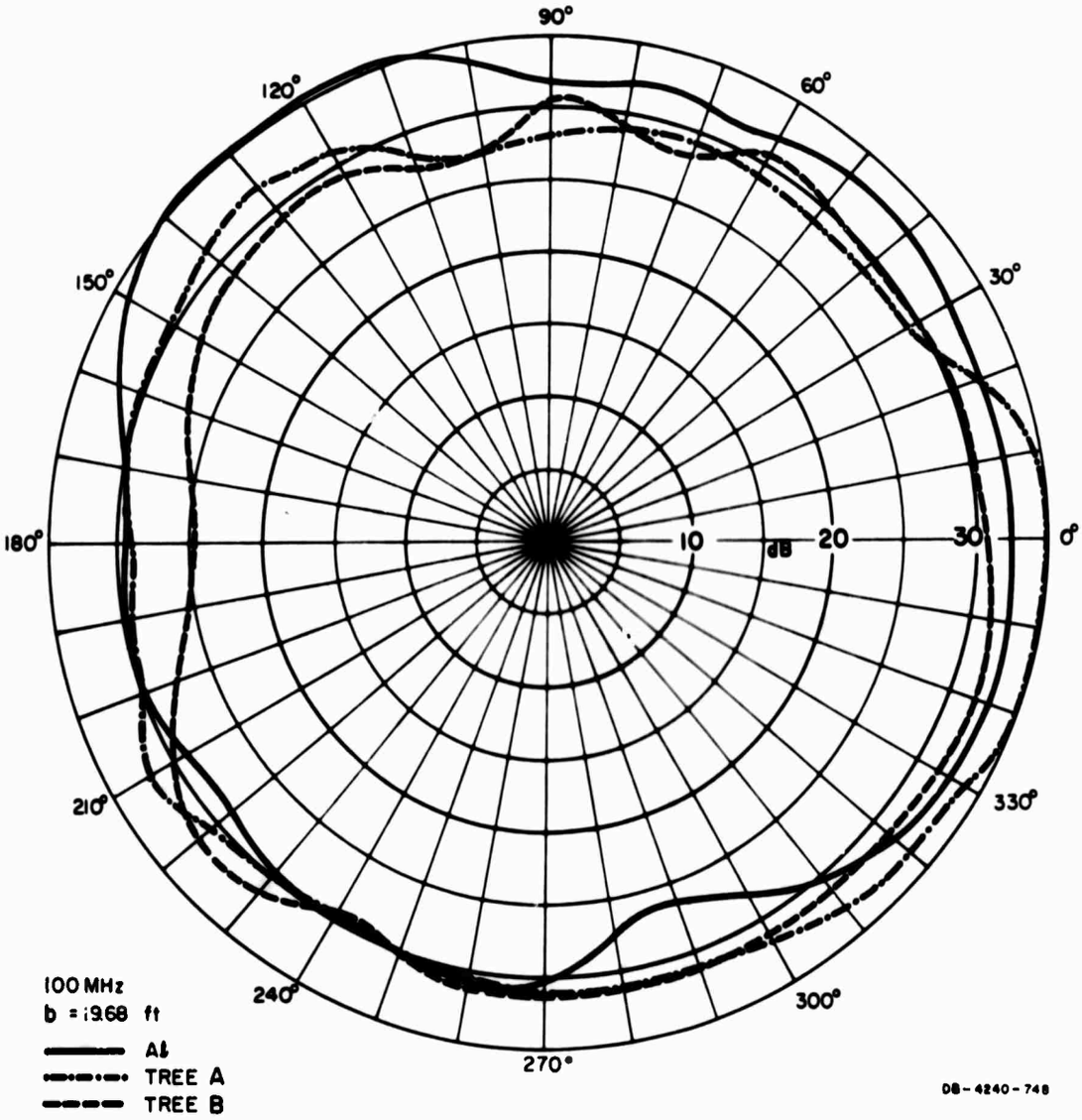

FIG. A-18 SCATTER PATTERNS OF RADIO WAVES AT 100 MHz WHEN THE XELEDOP TRANSMITTER IS 19.68 FEET AWAY FROM THE SCATTERER

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13. ABSTRACT

The objective of this report is to establish an electrical model to represent an isolated tree. Representation of an isolated tree by a perfectly conducting cylinder of smaller radius is shown to be feasible. This leads to the concept of using the equivalent radius of the tree to link the unknown electromagnetic theories of the tree to the well-developed theories of the perfectly conducting cylinder. Data from three kinds of experiments are analyzed to validate the electrical model:

(1) Patterns of radio waves scattered from an isolated tree and from an aluminum mast,

(2) Input impedance of a $\lambda/2$ vertical antenna in the vicinity of an isolated tree, and

(3) Patterns of an isolated tree as a shunt-fed, grounded radiator.

The frequencies used in the experiments were 50, 75.1, and 100 MHz; the polarization was vertical.

The variation of the input impedance of a $\lambda/2$ vertical antenna as it is moved close to a tree trunk that is similar to that of a $\lambda/2$ horizontal antenna as it approaches a lossy ground. The directivity of a tree as a shunt-fed, grounded radiator is demonstrated experimentally, and the front-to-back ratio is about 16 dB.

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Antenna impedance in vicinity of isolated tree						
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