Special Technical Report 29

AD 661058

ELECTRICAL GROUND CONSTANTS OF CENTRAL, EASTERN, AND NORTHEASTERN THAILAND

By: TERMPOON KOVATTANA

Prepared for:

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

CONTRACT DA 36-039 AMC-00040(E)
ORDER NO. 5384-PM-63-91

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Approved: W. R. VINCENT, MANAGER
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ARPA ORDER NO. 371
FOR THE
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SUPREME COMMAND HEADQUARTERS
BANGKOK, THAILAND

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ABSTRACT

In this report two methods suitable for measuring electrical ground constants in Thailand are described. The ground conductivity was measured at the broadcast frequencies of 820 kHz and 1455 kHz using the field-attenuation method. The ground dielectric constant was measured by the wave-tilt method at the high frequency of 27 MHz. Details are given for constructing the necessary equipment, and procedures for the collection and analysis of the data are outlined. The ground conductivity and ground dielectric constants in central, eastern, and northeastern Thailand were measured. The report also contains recommendations for improvements in equipment and measurement procedures.

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ACKNOWLEDGMENTS

The author would like to express thanks to Stanford Research Institute for providing two engineers, Mr. Kamthorn Vitvaskul and Mr. Withan Makarabhiromya, to assist in data collection and data analysis, and also to Mr. Uthai Mangtrisan and Mr. Pinyo Charusing, for constructing and operating the equipment.

The author is also indebted to the Advanced Research Projects Agency who kindly provided Mr. Chaya Jivacate to assist in constructing the RF receiver for the wave-tilt equipment and in data collection, and to Mr. G. H. Hagn and Mr. R. E. Leo for supplying technical material and for their most helpful suggestions.

I INTRODUCTION

The electrical properties of the ground have been measured from time to time in various parts of the world to establish the value of the ground conductivity and ground dielectric constant. This has been done because knowledge of the ground constant is very important in radio communications, physics, and electrical engineering. For radio communications, the electrical properties of the ground enter directly into the design of antenna systems for both transmitting and receiving stations, even in the case of a station employing an antenna array with no direct connection with the earth's surface. In the broadcast band, the ground conductivity is the dominating factor in determining the effective service area in which the communication is provided by the ground wave.

In general, the ground conductivity affects the ground wave of radio propagation, and therefore dominates lower-frequency propagation. The dielectric constant becomes more important for short-wave or higher frequencies. For short wave, when the propagation takes place via the ionosphere, only the ground in the vicinity of the transmitting and receiving antennas is of importance. The ground near the transmitter influences upward radiation and that near the receiver affects the downcoming wave.

In Thailand, knowledge of electrical ground constants and techniques for their measurement scarcely exists. It is the intention of this report to provide suitable procedures for (1) measuring electrical ground constants for Thailand, (2) carrying out some measurements to verify and improve the methods and equipment, and (3) establishing the ground-constant data for central and northeastern Thailand for the dry and rainy seasons.

The method selected for estimating ground conductivity is that of comparing measured field-intensity attenuation vs. distance, with calculated values, for various ground conductivities. Two frequencies in the broadcast band were chosen for this purpose.

After a literature search, it was decided that the wave-tilt method would be suitable for measuring the dielectric constant. The method is based upon measurement of the tilt angle of the vertically polarized ground wave. This tilt angle depends on the frequency, conductivity, and dielectric constant of the ground. The method meets the requirement for portability; the source for radiating the signal is already available in the laboratory or can be easily and inexpensively purchased. The 5-watt citizen's band transceiver was used as the radiating source, with a frequency around 27 MHz. The dielectric constant of the ground at this frequency may be used, with caution, to represent the value of the dielectric constant of the same ground at lower frequencies (see Ref. 1,* where it is shown that the dielectric constant of soil at frequencies of 1 MHz to 100 MHz does not change appreciably if soil moisture content is low enough). When soil moisture content becomes appreciable, the conductivity will dominate for ground-wave propagation in the broadcast band, and detailed knowledge of the dielectric constant becomes relatively unimportant.

The equipment for measuring dielectric constant was constructed, and measurements were carried out in the Bangkok area. It was found that the value of relative ground dielectric constant is around 20 to 30, which is reasonable for clay soil. The measurements were then carried out in other areas in the northeastern part of Thailand. The accuracy of the results has been increased by an improved method of analyzing the data (see Sec. IV-B). This new technique consists of incorporating the value of the ground conductivity measured by the field attenuation method into the analysis of the dielectric constant data.

The ground conductivity was measured by the field-attenuation measurement method, which is very widely used. The major limitation in using this method in Thailand is that there are very few roads; and therefore the electrical ground conductivity can only be evaluated in a limited area. In the field-attenuation measurement method, when used

*References are listed at the end of the report.

elsewhere, the field strength of the carrier frequency of the existing broadcast station is measured as a function of distance from a transmitting station. In the case of Thailand, however, existing stations cannot be used because the transmitted power of the broadcast stations fluctuates considerably, thus producing unreliable data. It is therefore necessary to have a portable transmitting station and to move it from place to place. The principle of this method is based upon a comparison between the computed field-intensity curve for different values of ground constants and the measured field-intensity data taken at various distances from the transmitter. Correlation of normalized measured data with values computed from a mathematical model then gave values for ground constants, as presented in Sec. IV-A. However, in many cases there was no correlation between computed and measured field intensity. Because the data were collected in the mountainous or undulating-type terrain, the measured field intensity did not decay smoothly as distance between transmitter and receiver was increased. Therefore the ground conductivity cannot be evaluated by this method. In such cases, values estimated from the soil map* are given instead.

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*Soil map in pocket, inside back cover.

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II ELECTRICAL GROUND CONSTANTS OF THE EARTH SURFACE

A. GENERAL

Electrical ground constants are the effective electrical properties of the earth, which may be expressed by three constants--i.e., the relative permeability (μ), the dielectric constant (ϵ), and the conductivity (σ). The relative permeability is normally regarded as unity in most cases concerning radio propagation work;* therefore the only important factors are the dielectric constant and the ground conductivity.

The ground conductivity and the dielectric constant of the earth surface vary from place to place depending upon the soil and many other factors. Typical values of the ground constants at MF (broadcast band) for various types of soils are given in Table I. The high value of the ground conductivity is normally associated with wet loam, while the poor conductivity and low dielectric constant are associated with dry, rocky, and sandy soil. It is found that the high value of the ground conductivity tends to relate with a large dielectric constant, and vice versa. The value of the ground conductivity can be expressed in CGS electromagnetic units. CGS electrostatic units, or MKS units (mho/m):

$$10^{-11} \text{ EMU} = 9 \times 10^{9} \text{ ESU} = 1 \text{ mho/m} \quad .$$

Dielectric constant is usually given in farads per meter, but in most radio propagation work the relative value of the dielectric constant is preferred--i.e., the ratio between the dielectric constant of the ground and the dielectric constant of free space.

---

*The magnetic permeability is the free-space value unless ferromagnetic material is present. Thus, the assumption that $\mu = 1$ may break down where there are iron deposits, and possibly for some lateritic soils. For radio purposes, however, the $\mu = 1$ assumption is quite a good one.

Table I

ELECTRICAL CHARACTERISTICS OF VARIOUS TYPES OF SOIL[2]

Type of Terrain	Relative Dielectric Constant	Conductivity (mmho/m)
Fresh water	80	1
Sea water, minimum attenuation	81	4640
Pastoral, low hills, rich soil typical of Dallas, Texas, Lincoln, Nebraska, areas	20	30
Pastoral, low hills, rich soil typical of Ohio and Illinois	14	10
Flat country, marshy, densely wooded, typical of Louisiana near Mississippi River	12	7.5
Pastoral, medium hills and forestation, typical of Maryland, Pennsylvania, New York, exclusive of mountainous territory and seacoasts	13	6
Pastoral, medium hills and forestation, heavy clay soil, typical of central Virginia	13	4
Rocky soil, steep hills, typical of New England	14	2
Sandy, dry, flat, typical of coastal country	10	2
City, industrial areas, average attenuation	5	1
City, industrial areas, maximum attenuation	3	0.5

In radio communication the electrical ground constant determines the effective ground-wave coverage for transmitters operating in the broadcast band and the lower part of the HF spectrum. In the case of good ground, as when the value of the ground conductivity is greater than 10 mmho/m, the ground conductivity becomes more significant than the dielectric constant for ground-wave propagation. In such cases the variation of the dielectric constant between 10 and 60 hardly affects the field strength of the propagated wave at all (Figs. 1 and 2).

The ground in many parts of Thailand is good for agriculture and may be classed as "good soil," so (one might think) the value of the ground conductivity would rarely fall below 10 mmho/m. In such cases the value of the dielectric constant will not contribute any significant effects to the ground-wave propagation in the low HF spectrum and even less in broadcast frequencies. Therefore it should not be necessary to collect the dielectric constant data in those places. However, at places where the ground has poor conductivity the dielectric constant becomes an important factor, especially in the HF spectrum (when propagation depends on skywaves), and the dielectric constant at the antenna site will require evaluation.

B. FACTORS DETERMINING THE EFFECTIVE GROUND CONSTANTS

The effective value of the electrical ground constants for use in radio propagation is determined by the factors discussed below.

1. Nature of the Soil

The ground constants vary with the nature of the soil--mainly its ability to absorb and retain moisture.[3] In general it is shown that the clay soils have a high conductivity (i.e., above 10 mmho/m) accompanied by a high dielectric constant, and the loam and chalk soils have an average value of about 10 mmho/m for conductivity and 20 for dielectric constant, while soil of a sandy or gritty nature gives much lower values of both conductivity and dielectric constant. The lowest values (of the order of 0.01 mmho/m) were obtained for the solid granite formations with slate subsoils.

2. Moisture Content

The moisture content of the ground seems to be the most important factor determining its electrical constants. J. Zenneck[4] studied the variation of conductivity with moisture content and found that for garden soil the value rose from 0.05 to 15 mmho/m as the moisture content was increased from 3 to 17 percent.

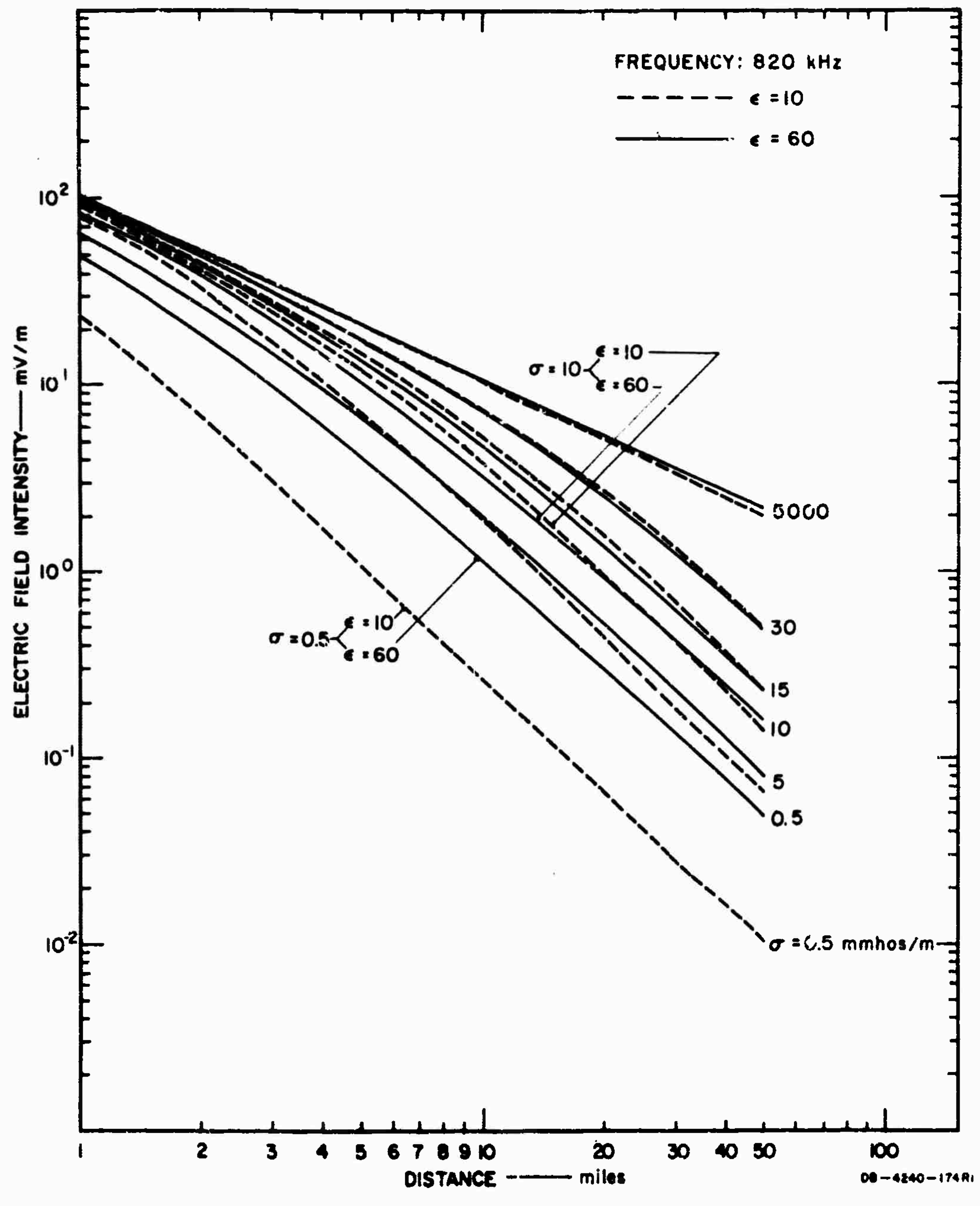

FIG. 1 COMPARISON BETWEEN CALCULATED GROUND-WAVE FIELD INTENSITIES FOR $\epsilon = 10$ AND $\epsilon = 60$ AND VARIOUS VALUES OF GROUND CONDUCTIVITY — 820 kHz

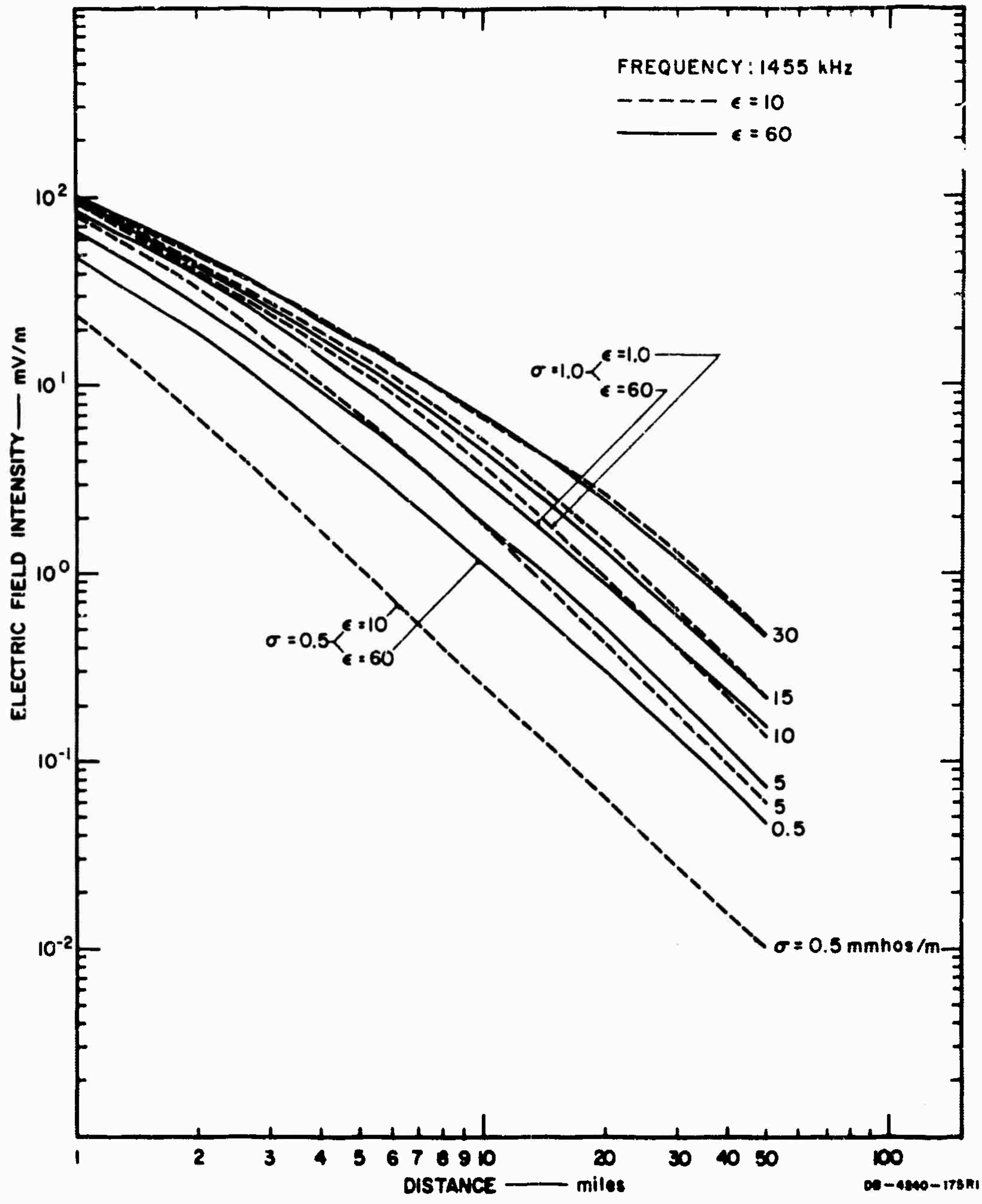

FIG. 2 COMPARISON BETWEEN CALCULATED GROUND-WAVE FIELD INTENSITIES FOR $\epsilon = 10$ AND $\epsilon = 60$ AND VARIOUS VALUES OF GROUND CONDUCTIVITY — 1455 kHz

3. Temperature

It has been found that the normal temperature change of the ground causes very little effect on the value of the ground constant. Except when temperature changes abnormally (i.e., under laboratory control), the mean temperature coefficient of conductivity of different types of soil lies within the range of 2 to 2.5 percent per degree centigrade, while that of the dielectric constant is negligible; at the freezing point there is a large, rapid change in both constants. In Thailand the temperature differences are very small throughout the year; therefore, it is not likely that these differences will affect the value of the ground constants.

4. Frequency

The variation of the electrical properties with frequency was found to depend upon the moisture content, as described below.[1]

As the moisture content is increased, the variation of conductivity with frequency reduces considerably, although it is still perceptible for moist soil at the higher frequencies. The dielectric constant behaves in a different manner. At low moisture contents there is practically no variation of its value with frequency, while at a normal moisture content of about 26 percent the dielectric constant decreases from about 90 at 100 kHz per second to 25 at 10 MHz per second.

Such apparently abnormal values of the dielectric constant have been previously experienced in the study of solid dielectrics, more particularly with electrolytes, and the effects have been interpreted as being caused by the formation of a polarization film of molecular thickness over the surface of the electrodes.

The frequency of the radio wave affects the determination of the ground-constant value in two ways:

(1) At low frequencies the radio wave penetrates deeper into the ground than at high frequencies, and the constants are determined from the average value of the different types of soil beneath the ground.

(2) At low frequencies, the ground behaves more like a conductor, whereas it is more like a dielectric at high frequencies.

5. <u>Surface Objects and Foliage</u>

Surface objects and foliage have no direct influence on the constants of the ground itself, but they cause attenuation (and scattering) in the ground wave and can cause appreciable error in determining the value of the ground constant by both field attenuation and wave-tilt methods.

C. APPLICATION OF THE GROUND CONSTANTS TO GROUND-WAVE PROPAGATION

In broadcast band and at the low end of the HF band, the electrical ground constants directly affect the ground-wave propagation. To determine the required radiated power for a given coverage area, the ground conductivity is the prime factor used in the calculation. The ground dielectric constant is also used, but does not contribute any significant effect, as mentioned in Sec. II-A. At the fringe of the coverage area, the field strengths required to provide satisfactory reception are given in Table II.* The required field strength is estimated from the interference level and absorption of the big buildings or surroundings.

In a city like Bangkok, the noise power increases considerably, and like capital cities elsewhere it is crowded with big buildings. To provide a satisfactory signal, the required field strength is much greater than in the rural area where man-made noise is negligible.

From the desired coverage area and the required field strength at the fringe area as given in Table II, the transmitted power may be calculated from the following equation:[2]

---

*These values of required field strength were estimated by the author from field measurements made in Thailand using a field-strength meter and a communications receiver. Field-strength values supplied by the FCC were used as guidelines.

Table II

FIELD STRENGTHS REQUIRED FOR GROUND-WAVE COVERAGE

Coverage Area	Required Field Strength (mV/m)
City with tall buildings or built-up area as in Bangkok	10-50
Dense residential area close to city, as in a suburb of Bangkok or large up-country town	2-10
Small up-country town	0.5-2
Rural area, rice paddy field or agriculture area	0.1-0.5

$$E_r = \frac{2EoA}{d} \text{ mV/m} \quad (1)$$

where

E_r = Required field strength at fringe area in millivolts per meter

2Eo = Free-space field produced at a distance of 1 mile from transmitting antenna

A = Attenuation factor due to effect of the ground at a given frequency

d = Distance in miles from transmitting antenna to fringe area.

The value of E_r is selected from the Table II. The coverage area determines the distance d. The attenuation factor A is obtained from the curve shown in Fig. 3 where p, "the numerical distance," is computed from the following equations:

$$p \cong \frac{\pi}{x} \frac{d}{\lambda} \cos b \quad (2)$$

$$b \cong \tan^{-1} \frac{(\epsilon + 1)}{x} \quad (3)$$

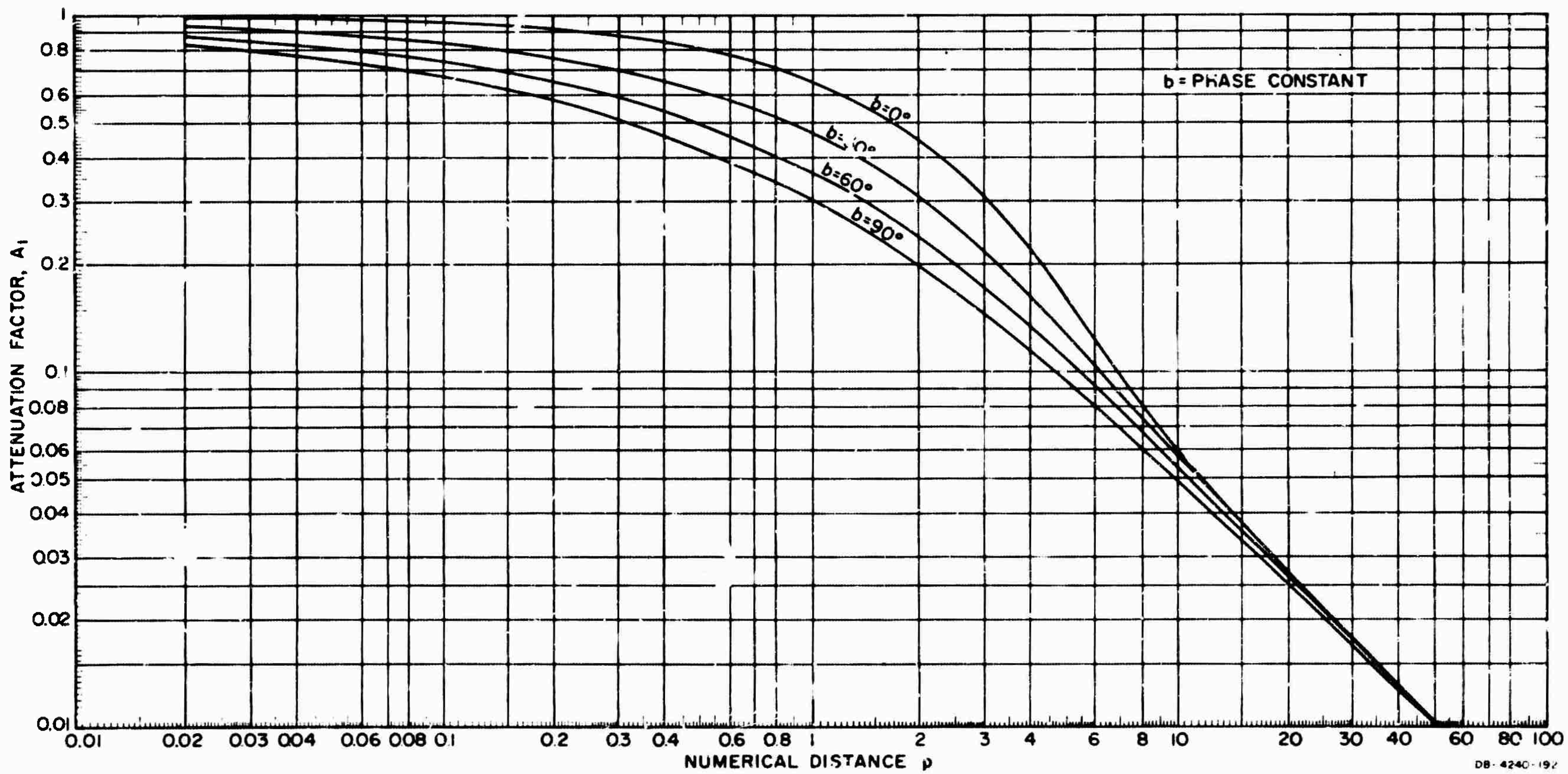

FIG. 3 GROUND-WAVE ATTENUATION FACTOR AS A FUNCTION OF THE PARAMETERS p AND b

where

$$x = \frac{18 \times \sigma}{f}$$

f = Frequency in MHz

σ = Ground conductivity in mmho/m

ε = Relative dielectric constant

λ = Wavelength in miles

b = Phase constant in degrees.

Then the field at one mile from transmitter is

$$2Eo = \frac{Er \times d}{A} \text{ mV/m} \quad . \qquad (4)$$

The radiated power P_α inkkilowatts for short vertical antenna is given by[3]

$$P_\alpha = \left(\frac{2Eo}{186.4}\right)^2 \text{ kilowatts} \quad . \qquad (5)$$

Supposing one wants to know the radiating power required for a transmitting station located in suburb area of Bangkok; the broadcast frequency is 820 kHz and the desired coverage area includes Ayutthaya, 50 miles north of Bangkok. The ground conductivity is approximately 40 mmho/m (see Table III, p. 44), and the dielectric constant is approximately 16 (see Table IV, p. 50). Ayutthaya is an up-country town of reasonable size, so the required field strength will be between 2 and 10 mV/m (see Table II). The suburbs of Ayutthaya are mostly rice paddy fields, and the population is spread out. Then to be on the safe side, a required field strength of about 5 mV/m will be sufficient.

Using Eqs. (2) and (3) and Fig. 3, the attenuation factor A can be obtained as follows:

σ = 40 mmho/m

f = 0.82 MHz

λ = 0.22866 miles

d = 50 miles

$$x = \frac{18 \times 40}{0.82} = 879.$$

From Eq. (3),

$$b \cong \tan^{-1} \frac{16 + 1}{659} \approx 2^{\circ} 1' \qquad \cos b = 0.9998 \quad .$$

From Eq. (2),

$$p \cong \frac{\pi}{879} \times \frac{50}{0.22866} \times 0.9998 = 0.778$$

A ≅ 0.72, which corresponds to "p" equal to 0.778 from Fig. 3.

Then from Eq. (4),

$$2Eo = \frac{5 \times 50}{0.72} \text{ mV/m} = 347 \text{ mV/m}$$

and from Eq. (5),

$$P_{\alpha} = \frac{347}{190.4}^{2} \text{ kilowatts} = 3.46 \text{ kilowatts} \quad .$$

This gives a required radiated power from the Bangkok transmitter site of approximately 3.5 to 4 kilowatts. In the suburban area close to Bangkok--i.e., the residential area of Bangkok within a radius of 10 miles--the field strength is about 25 mV/m, which is more than satisfactory for good reception. This can also be computed from the above equation, where 2Eo is equal to 347 mV/m.

If the value of the ground conductivity for the example case above decreases to 20 mmho/m, the required radiated power will increase to 8.5 kilowatts. This shows that it is important to know the minimum limit of the ground conductivity in the coverage area. The change in the minimum limit of the ground conductivity can require 100 percent increase of the radiated power for the same coverage area.

The above example demonstrates that knowledge of the electrical ground constants can assist in designing the radio system transmitter. To obtain the output power to meet the required radiated power, factors such as antenna efficiency, loss in transmission line between the antenna and the transmitter outlet, and matching network must be considered in the calculation. These factors can easily be obtained when the type of transmitting antenna and the distance between the transmitter and antenna feed point is known. The efficiency of e transmitting antenna can also be increased if wire ground plane is used at the antenna site, since this increases the value of the ground conductivity in the immediate vicinity of the antenna.

The electrical ground constants also affect radio communication in the HF band. The value of the ground constants at the antenna site will affect both antenna pattern and antenna impedance. Therefore it is important to know the electrical ground constants at the antenna site and their variation, and to include them in the design of antenna system.

III ELECTRICAL-GROUND-CONSTANT MEASUREMENT METHOD AND EQUIPMENT

A. CONDUCTIVITY

The field-attenuation method was selected for measuring the ground conductivity. The method involves measuring the field strength of a carrier wave as a function of distance from a transmitting station, and comparing the results with a set of computed field-intensity curves for different values of ground constants. The normalized measured data are correlated with the computed data, and the best curve fit then is the estimate of the value for ground conductivity.

The electric field for the measurement is normally provided by the local broadcasting radio station transmitting an unmodulated carrier frequency at a constant output power. But unfortunately, when the radio stations in Bangkok and the provinces assisted in the measurement they could not maintain constant output power. It was then necessary to have our own transmitters for providing the electric field.

Two frequencies, 820 kHz and 1455 kHz, were selected for the transmitters, both of them being free from interference from other radio stations during the daytime. The interferences were carefully checked by monitoring these two frequencies and adjacent frequencies in Bangkok and the provinces. After the frequencies were chosen, the Norton curves were computed for these frequencies using an IBM 1620 computer. This involved 3000 calculations and resulted in 20 pages of curves containing 200 graphs.

The sites for the transmitters to cover central and northeastern Thailand were carefully selected. The roads were one of the main factors, since the shortage of roads in Thailand limited the coverage area for the measurement. The sites were selected where there were at least three roads going in different directions, and sites with more than three exit roads in different directions were considered to be very good.

After the transmitters were built, they were checked out and tested with a vertical antenna for matching and adjustment. A 100-foot bamboo antenna tower was constructed but unfortunately it was blown down by the monsoon. It was replaced by a portable vertical steel antenna, which reduced the height considerably and also reduced antenna efficiency.

The measurements were taken from seven transmitter sites covering central and northeastern Thailand in both dry and rainy seasons.

1. Computing Field-Intensity Curves

The curves of field strength versus distance were computed from one mile up to 50 miles, at one-mile intervals up to ten miles, and at ten-mile intervals up to 50 miles. The values of the ground conductivity are 0.5, 1, 1.5, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 30, 40, and 5000 mmho/m. The values of the dielectric constants are 10, 20, 30, 40, 50, 60.

The curves were plotted on a log-log graph paper for field strength in millivolts per meter, vers s distances in miles on one sheet of graph paper for all values of ground conductivity at one value of dielectric constant as shown in Figs. 4 and 5.

The parameter p, "the numerical distance," and parameter b were computed from the following equations:

$$p \approx \frac{\pi}{x} \frac{d}{\lambda} \cos b \qquad (6)$$

$$b \approx \tan^{-1} \frac{(\epsilon + 1)}{x} \quad . \qquad (7)$$

The computer program was written for both equations and the values of p, d, b, ϵ, and σ were tabulated for both frequencies, 820 kHz and 1455 kHz.

The field strength at distance d miles from the transmitting antenna was computed from the equation

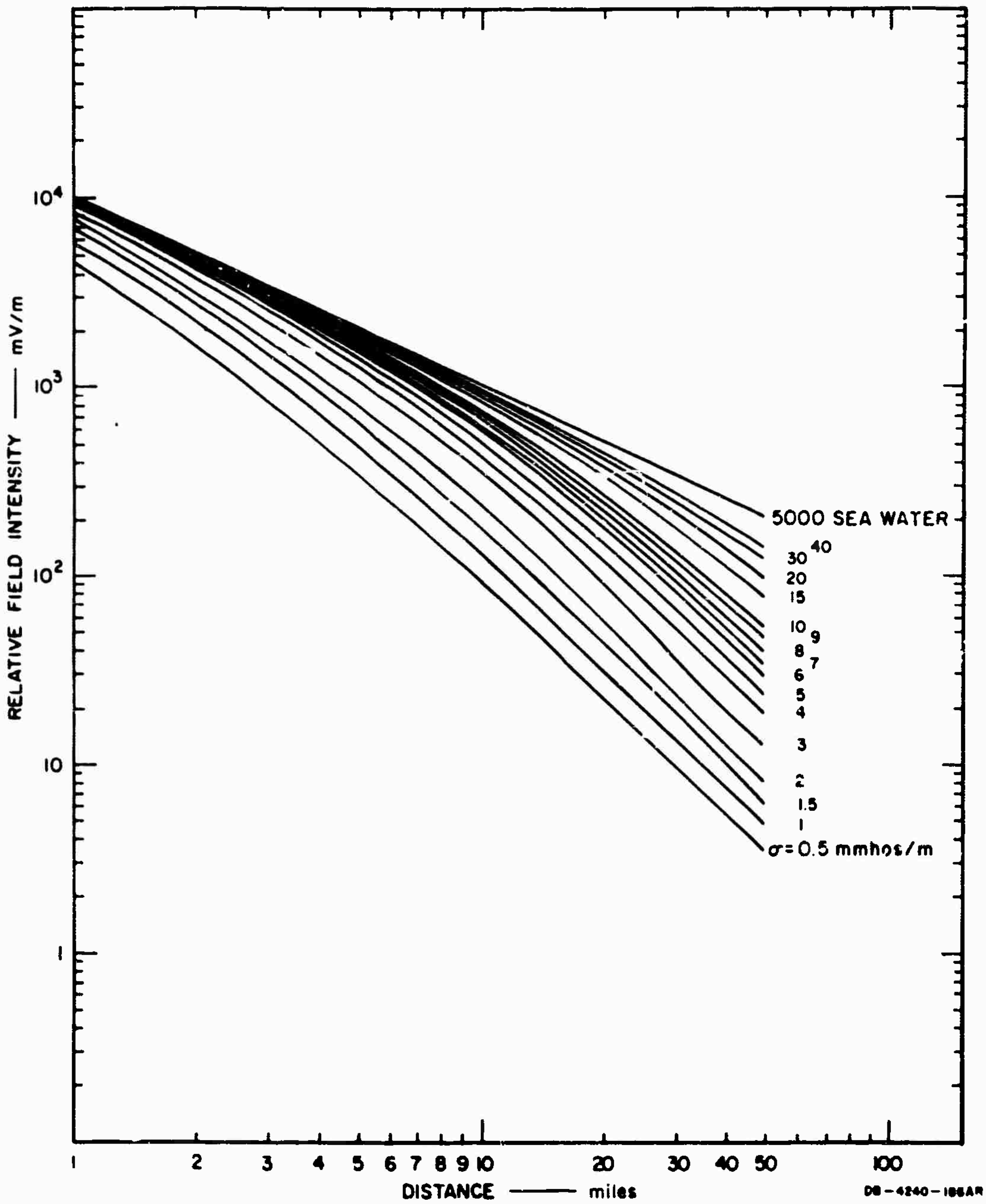

FIG. 4 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 820 kHz, $\epsilon = 20$

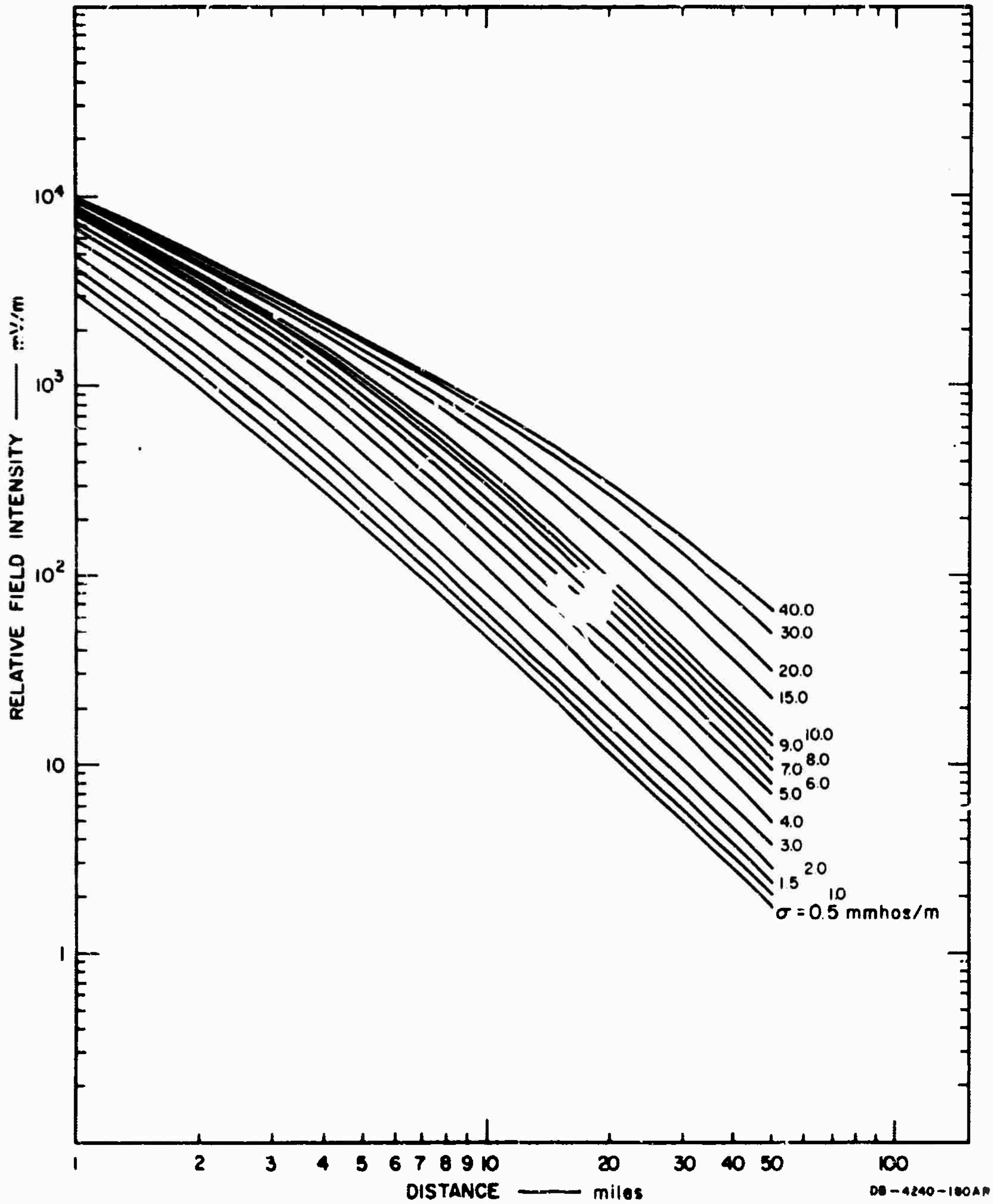

FIG. 5 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 1455 kHz, ϵ = 20

$$E_d = \frac{2Eo\ A}{d} \text{ millivolts per meter}$$

where

E_d = Field intensity of ground wave at distance d miles, in millivolts per meter

d = Distance in miles from the antenna

Eo = Free-space field at one mile from the transmitting antenna in free space with the same antenna currents as are actually present when the antenna is instead near the earth.

A = Attenuation factor.

The value of 2Eo in millivolts per meter is equal to $186.4\sqrt{P}$ at one mile, where P is the radiated power in kilowatts. For the calculations, P was chosen to yield 100 millivolts per meter for 2Eo. The attenuation factors "A" were obtained from Fig. 3 for the corresponding values of p, d, b, ϵ, and σ. The complete set of calculated curves for both frequencies is given in Appendix A.

2. Transmitters, Matching Network, and Antenna

The transmitters were designed and built in the MRDC Electronic Laboratory, Bangkok, Thailand. They comprise two stages, the first is an oscillator circuit deriving its frequency from a crystal. The output of the oscillator is directly fed into the last stage which is a push-pull power amplifier. The 100-watt output was obtained from a pair of 6146 power tubes. The schematic diagrams of both transmitters are given in Figs. 6 and 7.

The power supply for the transmitters was also designed and built in the MRDC Electronic Laboratory. The schematic diagrams of the power supply is given in Fig. 8. It converts 115V ac into 650V @ 300 mA dc for supplying current to the output tubes and 375V @ 100 mA dc for the oscillator circuit.

The 820 kHz and 1455 kHz were transmitted alternately from the same antenna. The two transmitters were connected to the matching

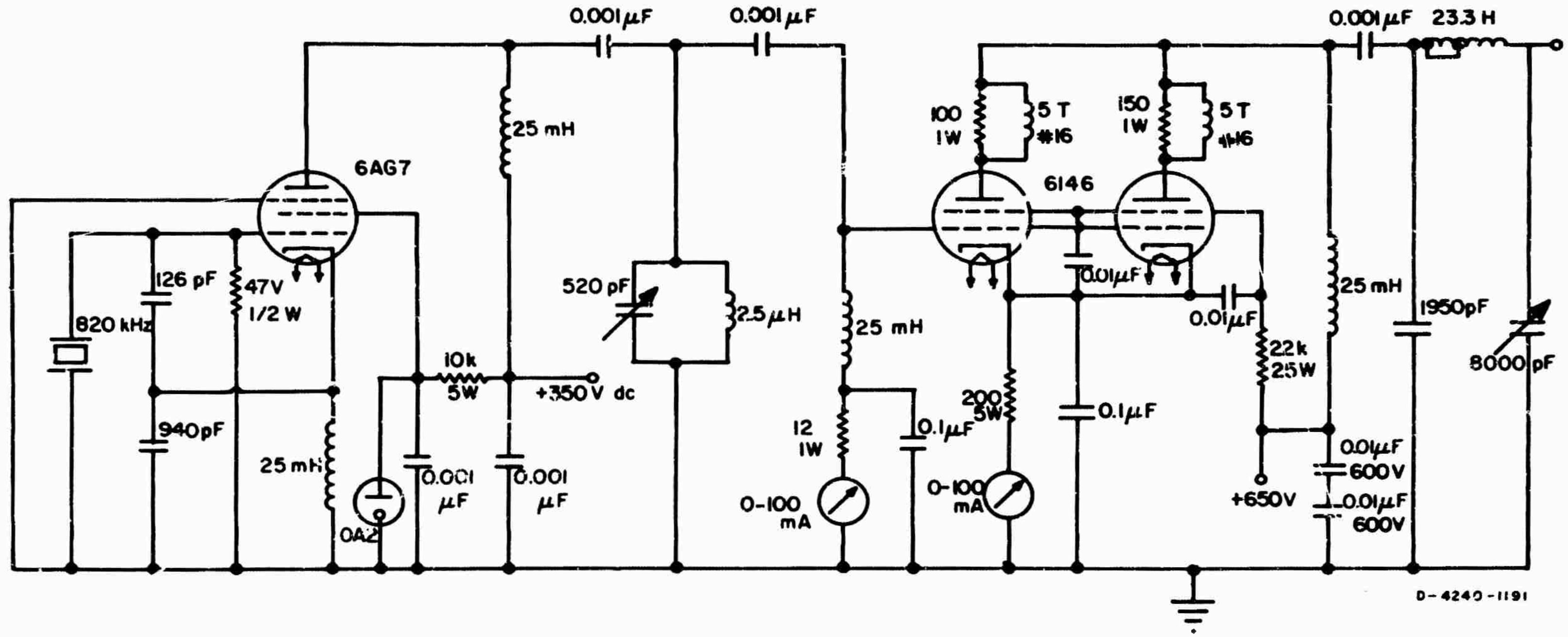

FIG. 6 820-kHz-TRANSMITTER SCHEMATIC DIAGRAM

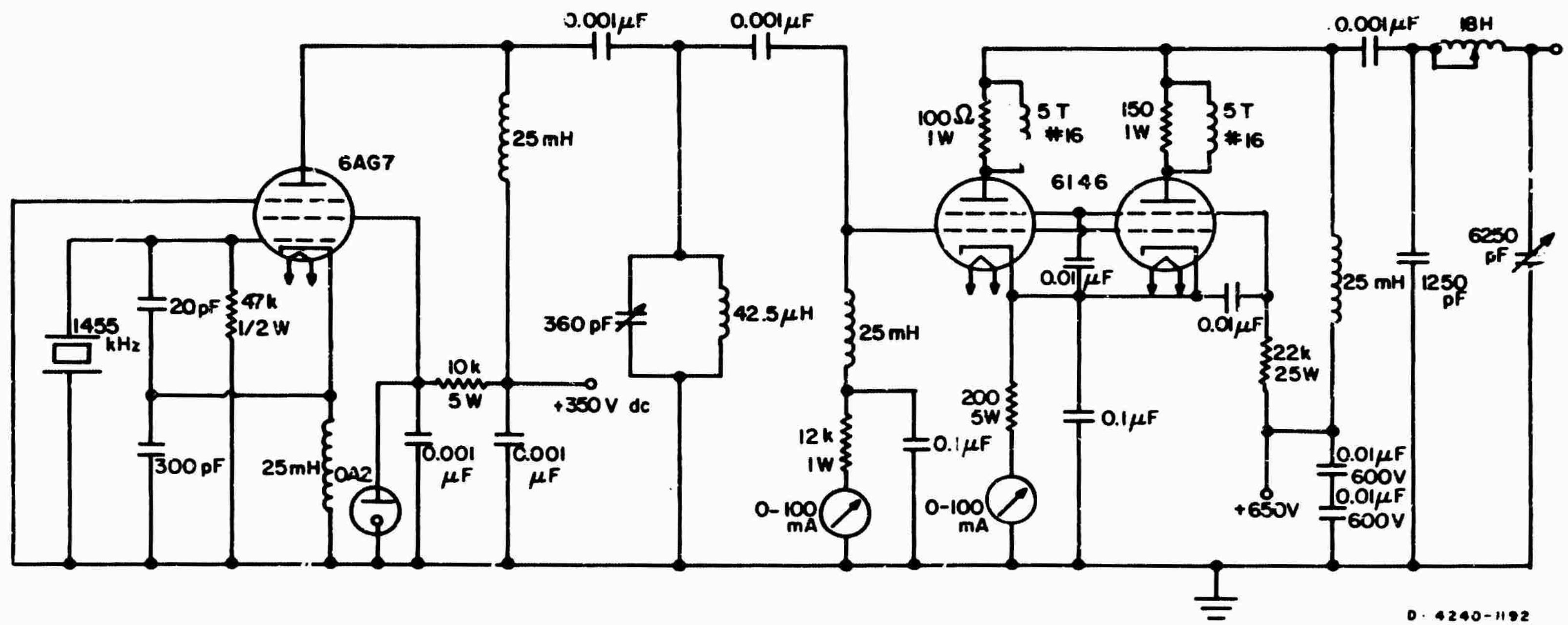

FIG. 7 1455-kHz-TRANSMITTER SCHEMATIC DIAGRAM

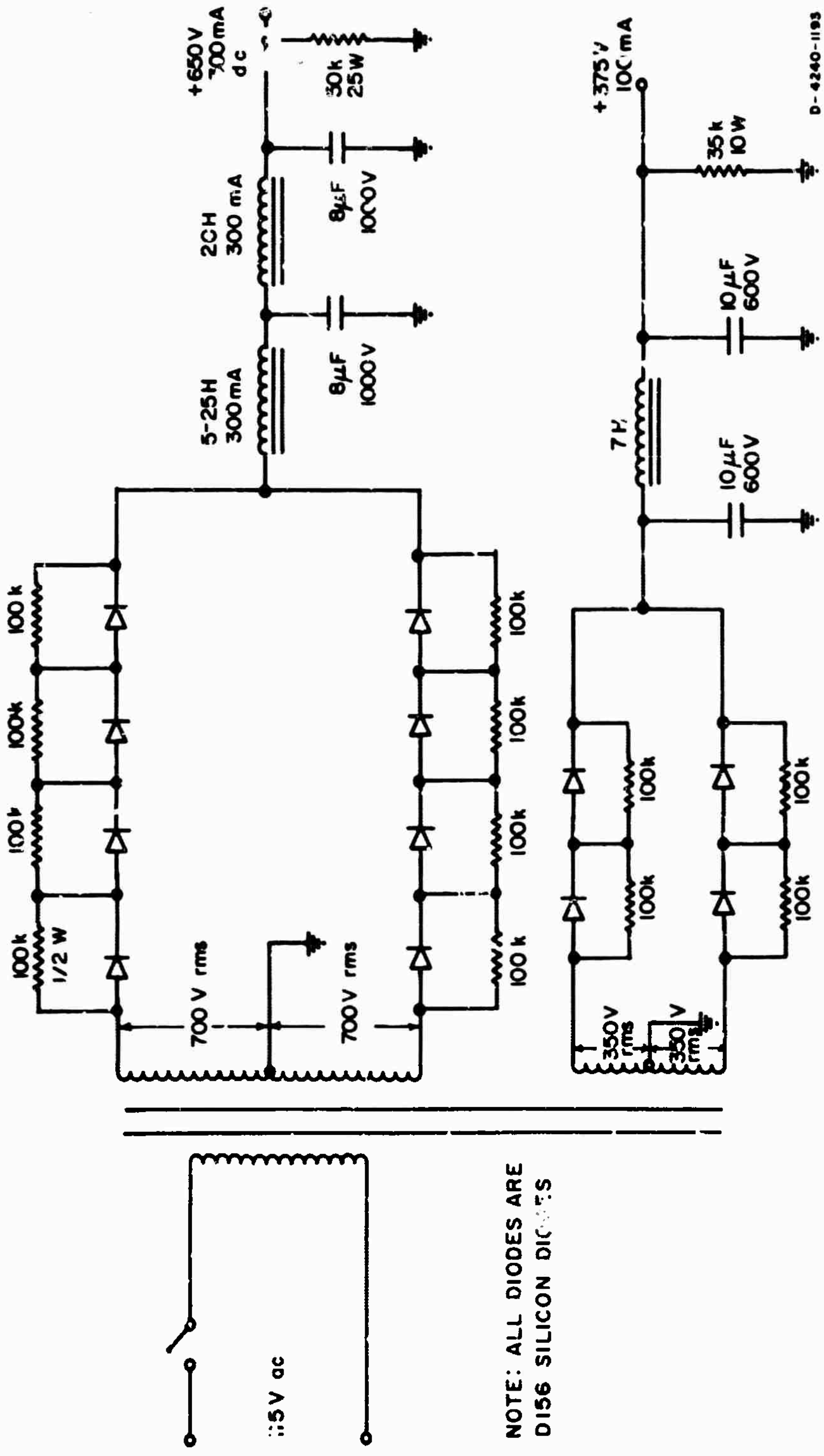

FIG. 8 POWER-SUPPLY SCHEMATIC DIAGRAM

network and antenna via an automatic coaxial switch. The switching time was controlled by a time-switch synchronous motor.

The schematic diagram for the matching network for both 820 kHz and 1455 kHz is given in Fig. 9. Figure 10 shows the connection of the equipment via a synchronous motor time switch and coaxial switches.

The transmitting antenna is a steel vertical antenna 70 feet high with a 10-foot extension rod at the end. The antenna is a telescoping metal tower made by Rohn, easily erected and removed. To increase the efficiency of the transmitting antenna system, a 12-radial ground screen was provided at each transmitting site.

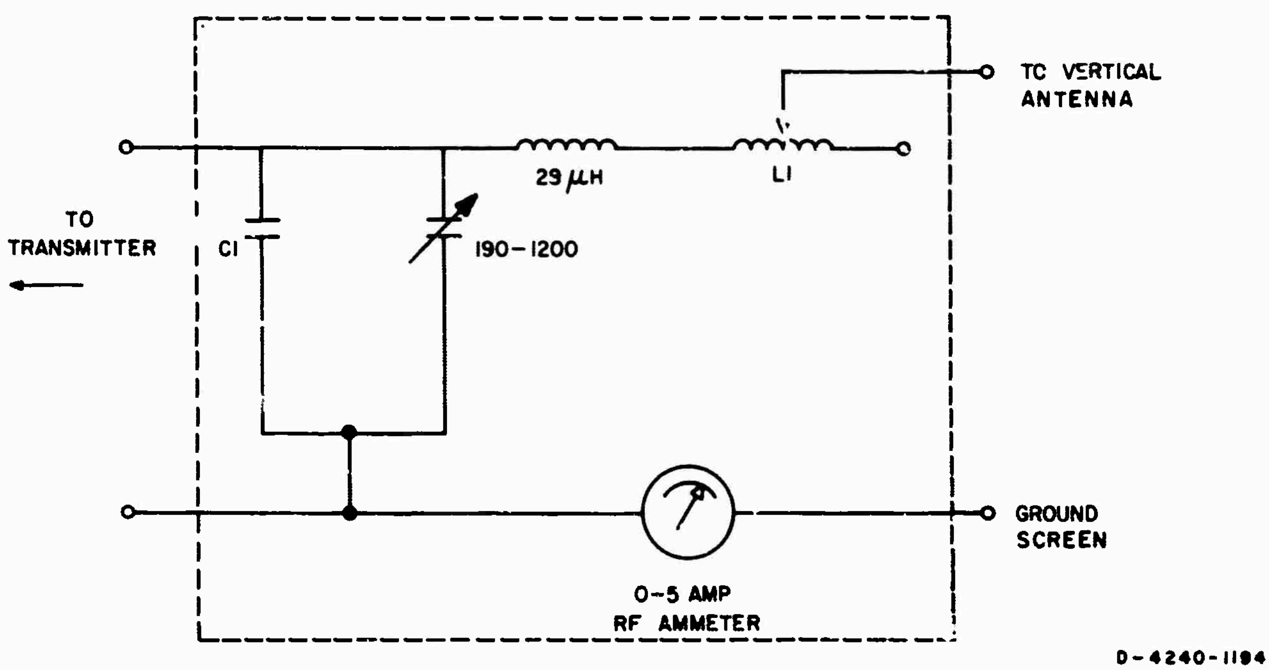

FIG. 9 MATCHING-NETWORK SCHEMATIC DIAGRAM

3. Data Collection

Prior to the measurements, a crew was sent out to the preselected site to put up the antenna. To provide low-resistivity ground in the vicinity of the antenna, 12-gauge copper wire, approximately 90 meters in length, was buried radially from the antenna base, one foot

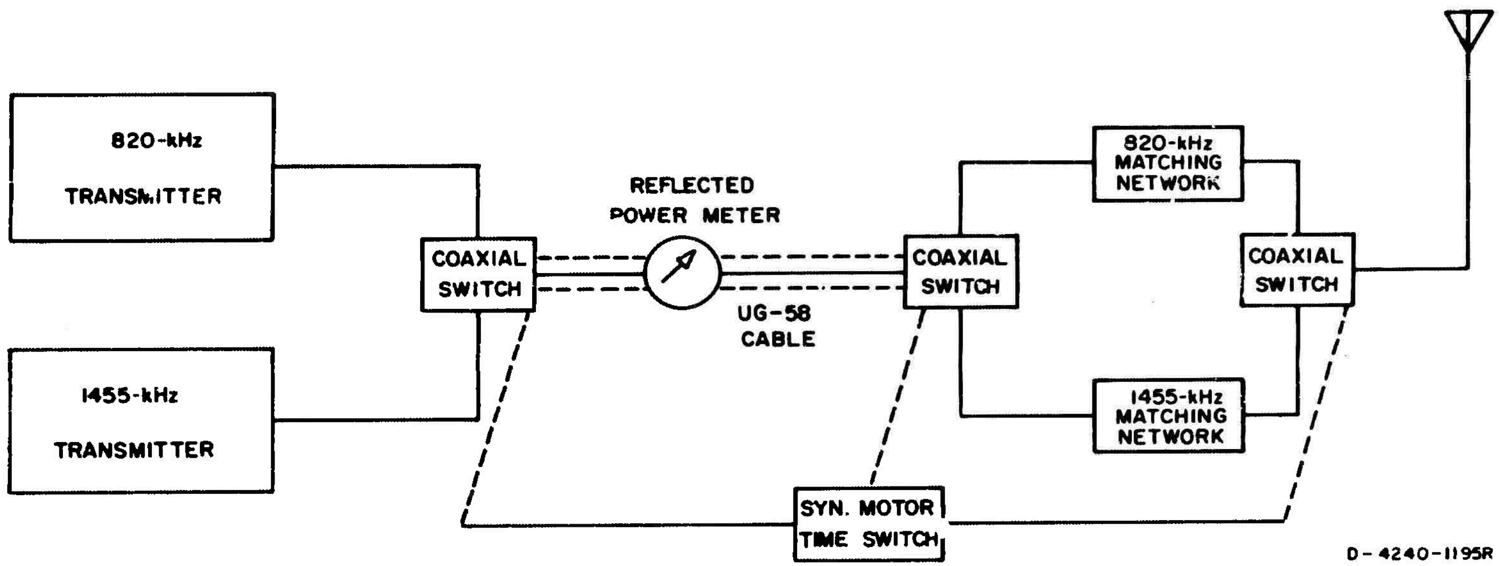

FIG. 10 EQUIPMENT SET-UP FOR TRANSMITTING

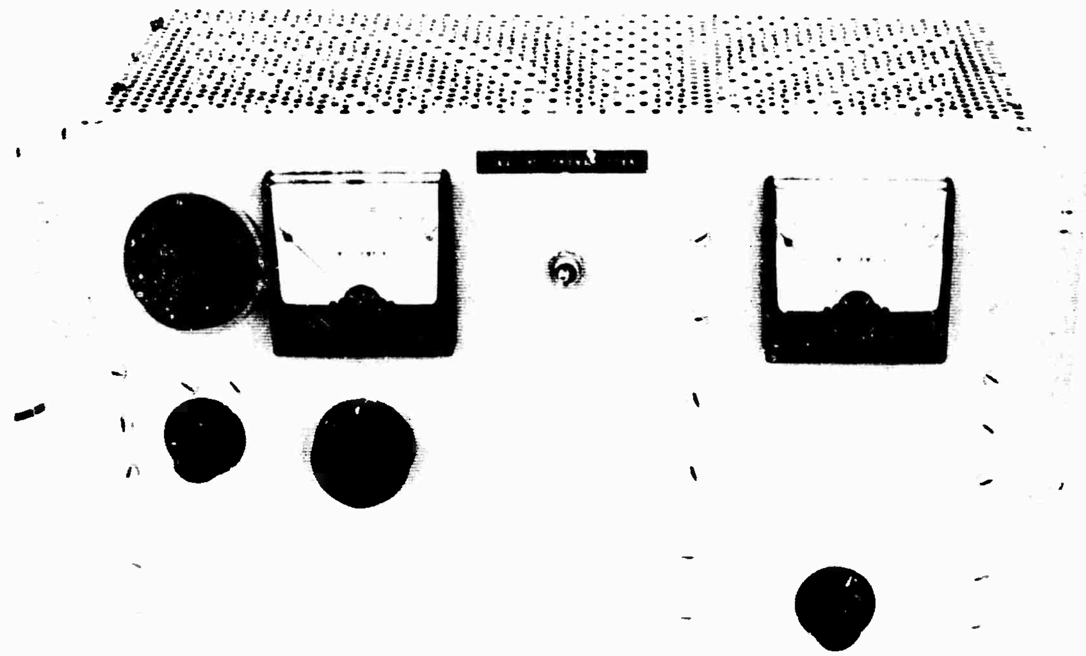

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FIG. 11 FRONT VIEW OF TRANSMITTER

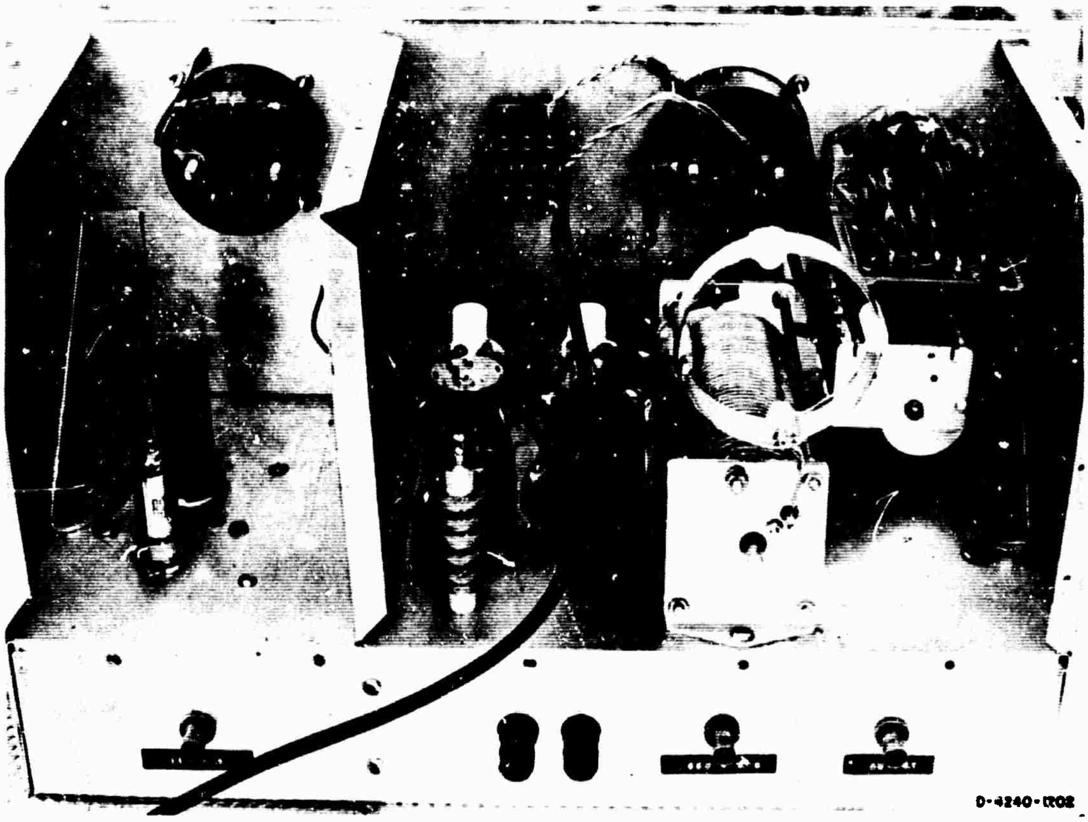

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FIG. 12 BACK VIEW OF TRANSMITTER

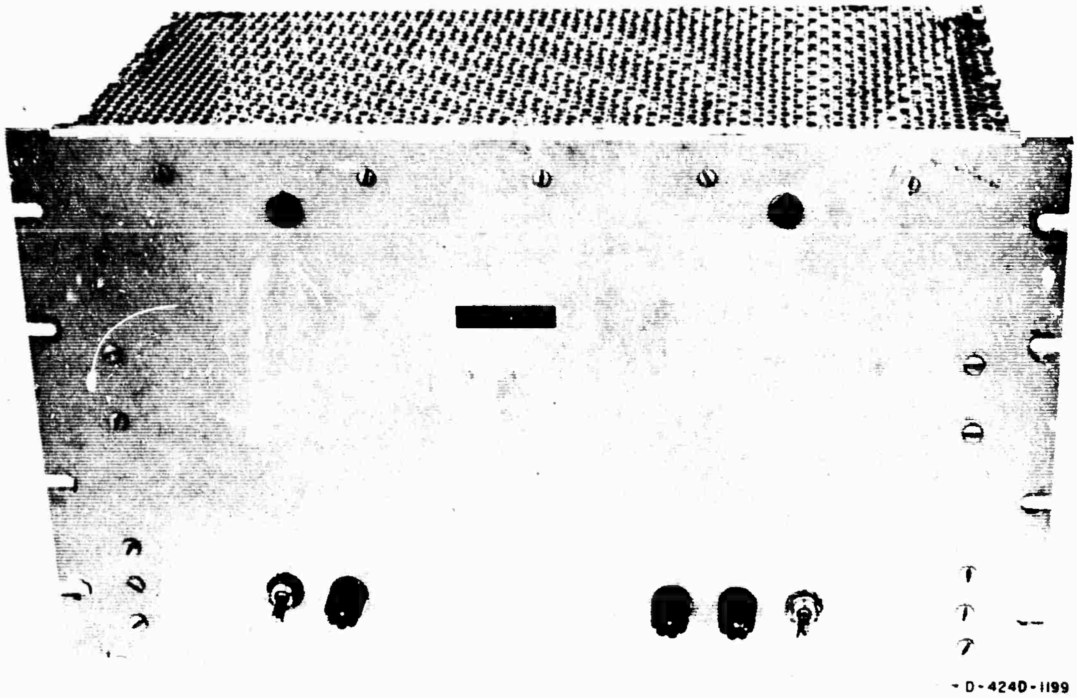

FIG. 13 POWER-SUPPLY UNIT

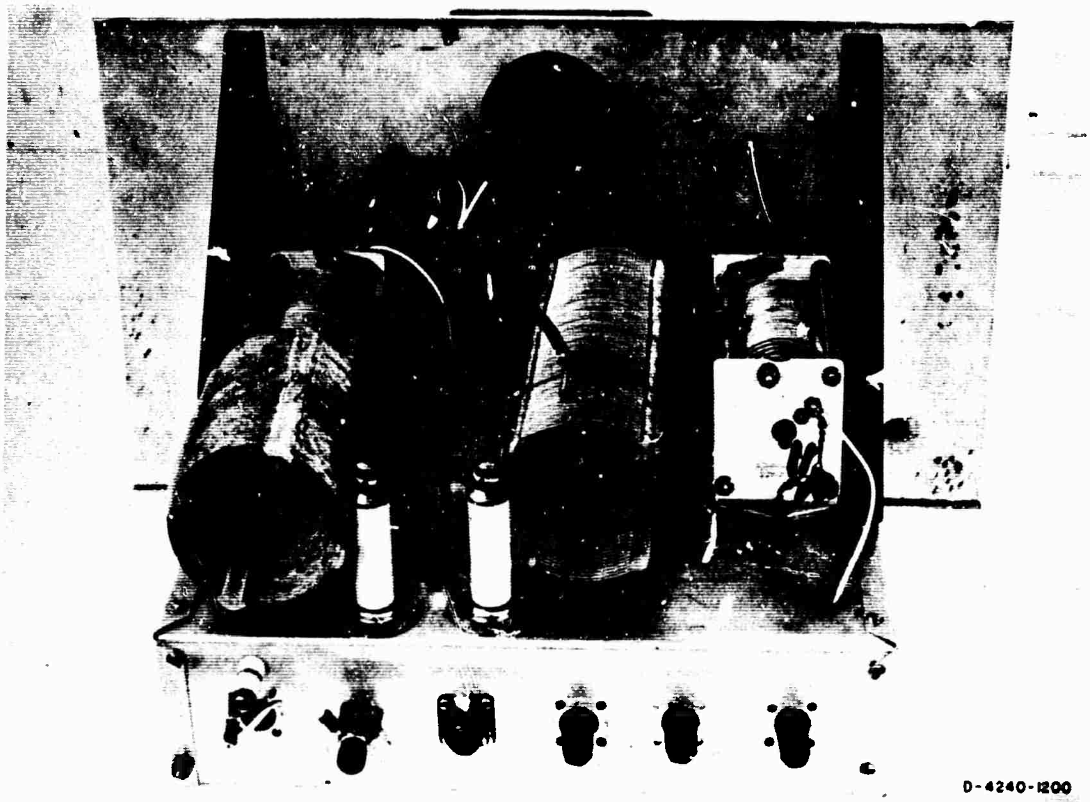

FIG. 14 MATCHING NETWORK

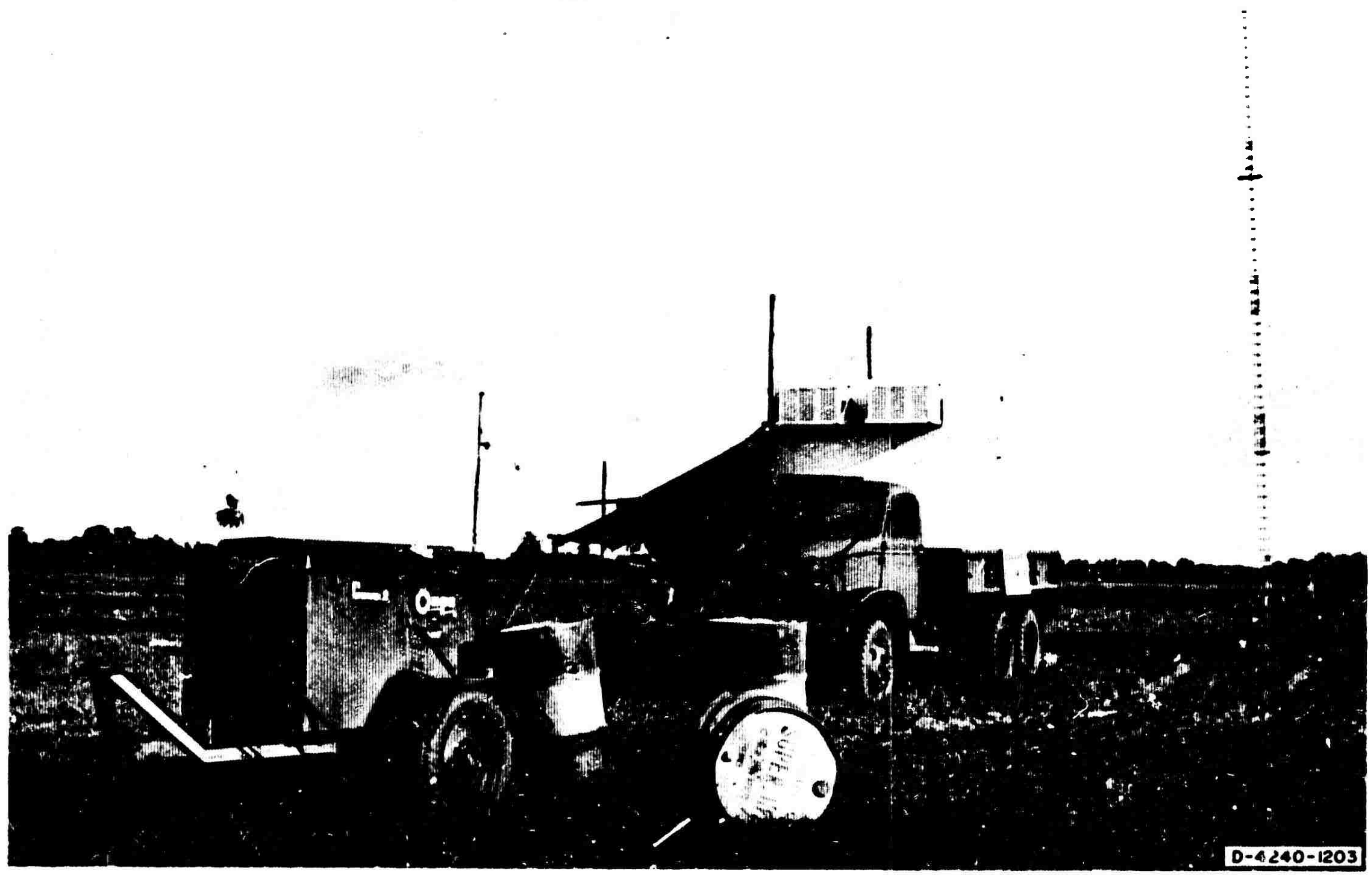

FIG. 15 EQUIPMENT VAN AND THE TRANSMITTING ANTENNA

deep in the ground. After the antenna was erected, the measuring team were sent out to the site with an equipment van containing the two transmitters, power supplies, impedance matching networks, coaxial switches, and test and repair instruments. The value of the electrical ground constant at each site differs considerably, and in order to protect the transmitter from overloading due to impedance mismatch between the antenna impedance and transmitter output impedance, prior to connection of the antenna with the transmitter the antenna impedance was measured by an impedance bridge. When the antenna impedance was obtained, the values of the capacitor and the inductor of the impedance-matching network were calculated, and these components were adjusted before the transmitter was connected and switched on. After the connection was made, the system was tuned to give maximum output power for both transmitters. A 161-162A Jones Micromatch Reflected Power Meter was used between the transmitter and matching unit in final tuning to observe the reflected power during the tuning process. Each transmitter was arranged to transmit alternately for two and a half minutes at a time. A synchronous-motor time switch was employed to apply the power from each transmitter to the antenna, on this schedule. The output current was monitored by an RF ammeter. The value of the current was recorded at half-hour intervals during the time the field-strength measurements were being carried out.

To permit calculation of the value of free-space field 2Eo as accurately as possible, the field strength at 400 meters and one mile from the antenna was measured at many points around the antenna as accurately as possible. The distances were measured with a tape. To assist the measurement, stakes were driven into the ground every 100 meters in a straight line.

The field strength was measured by an RCA Field Strength Meter Type WX-2E at the preselected points. The selection was made from a map. At each preselected point, field-strength measurements were made for both frequencies. Data were taken during both the dry and rainy seasons; however, more data were collected during the rainy season. The field-strength meter was placed on a tripod in a clearing away from trees and buildings.

During the field-strength measurement, the antenna crew moved to the new preselected site and prepared the ground, erecting the other set of antennas. The whole operation took about three months for each season. The data were analyzed at the end of each part of the field-measurement program.

B. DIELECTRIC CONSTANT

The wave-tilt method was selected to measure the dielectric constant. It was intended to employ the results of the dielectric constant measured by this method to assist in the data reduction of the ground conductivity. Although the effect of dielectric constant on computed field attenuation-vs.-distance curves is slight (especially for high conductivity and low frequency), some increase in the accuracy of the ground-conductivity measurements can be obtained by considering the effect (see Sec. IV-A).

It was also realized that the ground dielectric constant does not considerably change its value between the frequency of 1 MHz and 30 MHz.[1]* The measurement of the dielectric constant at the frequency of 30 MHz can then be cautiously used to represent the value of the dielectric constant at 1 MHz without appreciable error. This assumption is likely to have a high degree of error only if the value of the ground constant of the soil at the surface of the e[illegible]ly differs from that immediately below and down to a depth of 3 meters or when the moisture content of the soil is too great.

The dielectric constant does not greatly affect the transmission loss of the broadcast frequency propagation and the low end of the HF band and only affects the antenna efficiency. Therefore it is more important to develop a convenient method to measure the dielectric constant at higher frequencies for covering a small area. Using the

*This statement applies when the moisture content of the soil is not too great.

wave-tilt method at the frequencies between 30 to 100 MHz, the measuring equipment can be made very portable and can be carried around in a 1/4-ton vehicle.

The wave-tilt method is based on the behavior of the propagated radio wave over the imperfectly conducting ground. The electric field of the radio wave transmitted from a vertical antenna tilts forward slightly from the vertical axis. The angle θ, at which the electric field tilts, depends on the frequency, conductivity, and dielectric constant of the ground. At a sufficiently high frequency and low value of ground conductivity, the tilt angle depends largely on the dielectric constant of the ground.

To measure the tilt angle, a dipole is placed in the electric field and oriented until it receives minimum signal--i.e., when it is perpendicular to the electric field. The angle of the dipole can then be measured. The accuracy of the result depends on the measurement of the tilt angle and the requirement in measurement accuracy increases as the tilt angle becomes smaller. In an experimental period, a signal generator and power amplifiers were used as a signal source, and the output from the power amplifier was then fed into the vertical antenna. The tilt angle was measured by a rotating dipole antenna and a receiver. It was found that at the low frequencies, the interference from broadcast band and HF band caused great difficulty in determining the tilt angle. (There are many radio stations around the Bangkok area and the majority of these were overmodulated, radiating on harmonic frequencies and therefore it is not practical in Thailand to use this method for measuring ground constants in the broadcast band and adjacent higher bands.)[1] It was also found that the measured result was affected by the feed line between the dipole and the receiver, causing inaccuracy in determining the tilt angle. This problem is solved by using a transistorized receiver small enough to be attached to the middle part of the dipole antenna, thus omitting the feed line.

Equipment for measuring the tilt angle of a vertically polarized radio wave was built and tested in the MRDC Electronic Laboratory.

It consists of a remote-control rotating dipole antenna with built-in transistorized RF receiver and signal-strength indicator. The dipole antenna is balanced. A remote control is necessary because of the capacitance effect between the experimenter and the dipole antenna. Vertically polarized radio waves are launched by a battery-operated 27-MHz transmitter and portable vertical antenna.

1. Basic Theory

Over an imperfectly conducting ground, the electric field of the ground-wave propagation, transmitted from a vertically polarized antenna, tilts forward slightly from the vertical axis as shown in Fig. 16. This phenomenon is caused by the presence of the small horizontal

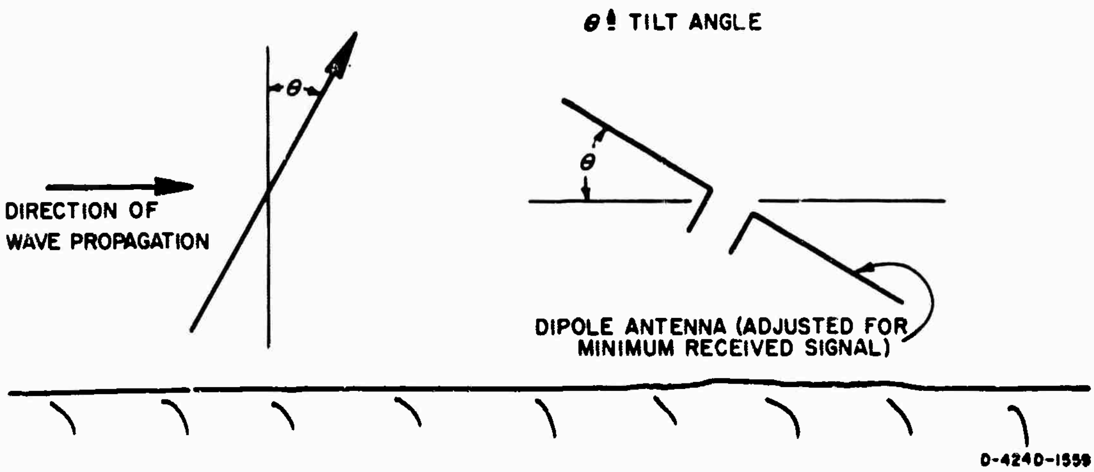

FIG. 16 WAVE TILT OF THE GROUND WAVE

component of electric force in the direction of propagation when the ground is not a perfect conductor. Furthermore, this horizontal component is normally out of phase with the vertical component; therefore the resultant electric field vector is elliptically polarized, having its main axis tilting forward from the vertical axis along the radial from the transmitting antenna. The tilt angle θ, the ground conductivity σ, the dielectric constant ϵ, and the frequency f are related by the equation:[5]

$$\tan^2\theta \approx \frac{\epsilon + \sqrt{\left[\epsilon^2 + \frac{(18\sigma)^2}{f}\right]}}{2\left[\epsilon^2 + \frac{(18\sigma)^2}{f}\right]}$$

where

ϵ = Relative dielectric constant

σ = Ground conductivity in mmho/m

f = Frequency in MHz.

At high frequency and low value of ground conductivity the term $(18\sigma)^2/f$ becomes small when compared with ϵ^2; then

$$\tan^2\theta \approx \frac{1}{\epsilon} \quad .$$

This shows that at high frequency, the value of the relative dielectric constant is inversely proportional to the square of the tangent of the tilt angle (see also Sec. IV-B). The tilt angle θ can be measured by the aid of a rotating dipole antenna, rotating about the horizontal axis. The axis of the antenna is in the direction of the propagated wave--i.e., one end of the dipole is pointing toward the vertical transmitting antenna. The measurement is made by turning the dipole about the horizontal axis until the signal strength is minimum. This occurs when the dipole is tilted slightly from the horizontal as shown in Fig. 16, with the angle θ corresponding to the tilt angle θ. When the signal received by the dipole is at its minimum value, the dipole is perpendicular to the electric field of the wave front.

2. Description of Equipment

The source for generating the ground wave is a commercially built transceiver, giving an output power of approximately 5 watts. The transceiver microphone input was modified so that when the transceiver is switched on, the microphone terminal is short-circuited, and the set transmits only the carrier wave. The output of the transmitter is connected to a 1/4-wave vertical monopole antenna. The antenna system is composed of a 12-gauge copper wire cut to 1/4 of the wavelength of the transmitter frequency. One end is fixed to the top of a bamboo tripod via an eyelet insulator. To ensure that the antenna is vertically erected from the ground, the other end of the antenna wire is connected to a heavy lead weight via an insulator. When the antenna is erected, the weight is connected to the copper ground stake. This end of the wire is also the feed point, and the output of the transmitter is connected to the antenna by a coaxial transmission line. The central core of the feed line is connected to the antenna wire and the outer core to the weight via a coaxial connector. A 12-volt, 57-amp-hour automobile-type storage battery is used to power the transmitter. The detecting end consists of a rotating dipole antenna, a crystal-tuned, transistorized receiver (see Fig. 17), and a microammeter.

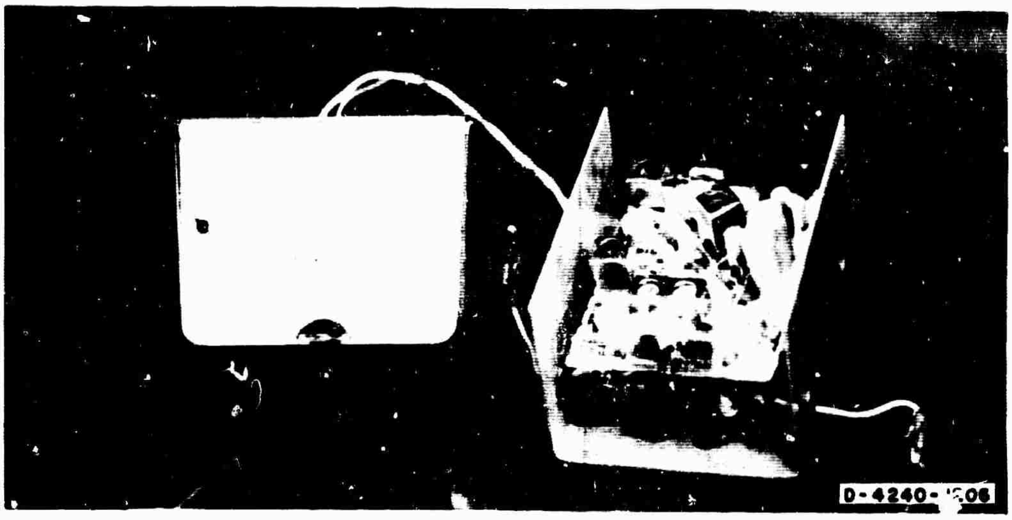

FIG. 17 PHOTOGRAPH OF THE TRANSISTORIZED RECEIVER

The receiver is a superheterodyne type. To minimize the frequency drift of the receiver, the local oscillator is controlled by a crystal (see Fig. 18). Three intermediate-frequency amplifiers follow the mixer stage, and the last stage is the detector. The microammeter is provided at the emitter circuit of the detector for indicating the received signal strength. Since only the relative value of the received

NOTE: ALL CAPACITORS IN $\mu\mu F$ UNLESS OTHERWISE STATED

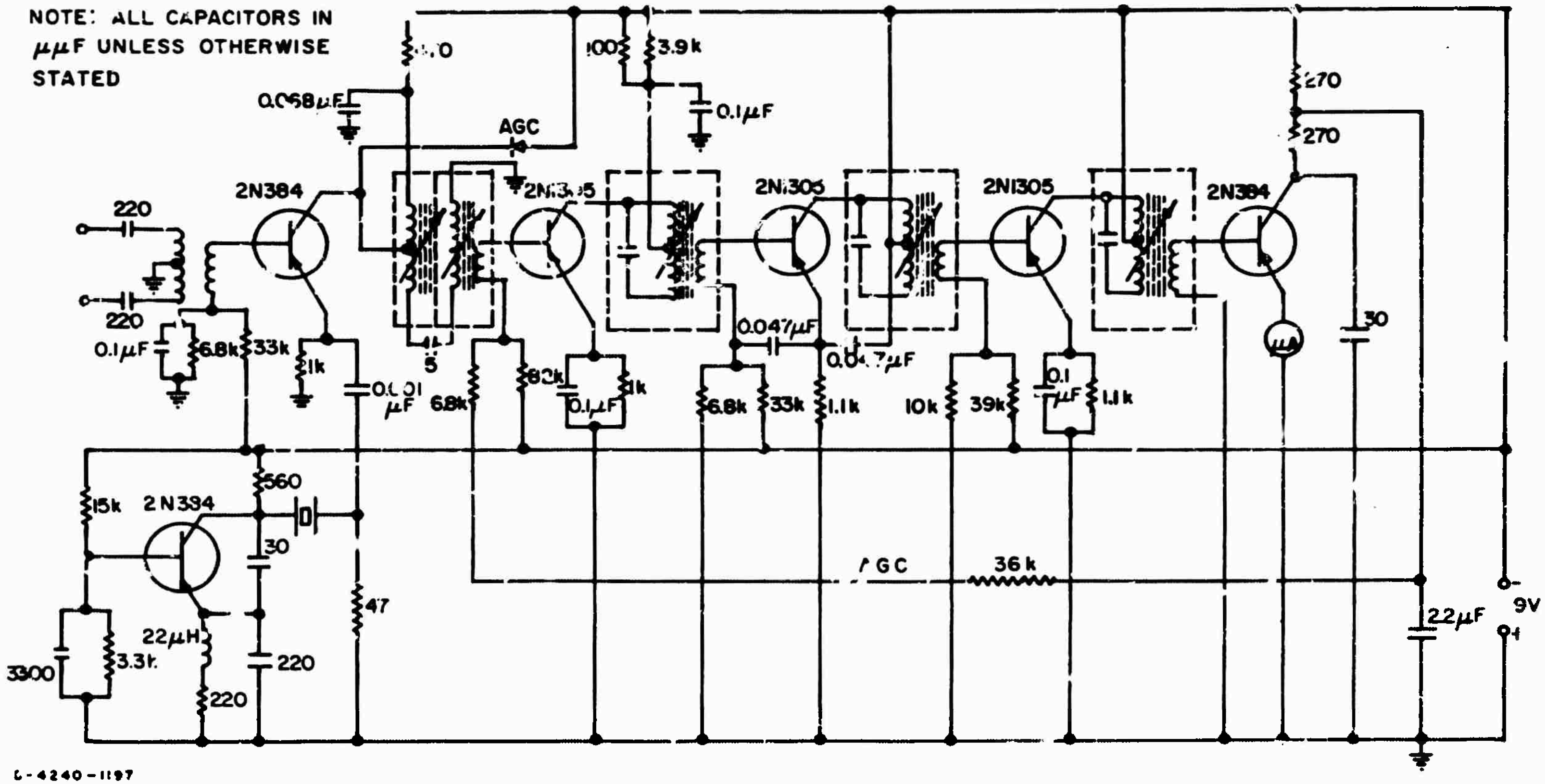

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FIG. 18 WAVE-TILT-RECEIVER SCHEMATIC DIAGRAM signal is required, it is not necessary to calibrate the receiver output current. To ensure proper balancing of the dipole antenna, the primary end of the receiver input transformer is balanced and grounded at the center tap of the primary wiring. The receiver is shielded to prevent the signal being picked up by the receiver wiring without passing through the antenna system. Each arm of the dipole antenna is connected directly to the receiver, and the microammeter is provided outside the receiver and mounted directly below.

Two telescopic-type automobile antennas are used to form the arms of the dipole. The length of the antenna can be adjusted to suit the signal strength but they must be adjusted so that arm lengths are equal.

The antennas and receiver are mounted on a long insulator. The receiver is at the center of the insulator which also serves as the fulcrum for the rotating dipole. Another piece of long insulator is provided immediately below the dipole to serve as a reference line. The microammeter is mounted on it. The rotating dipole, mounted on the insulator directly above the reference insulator, is shown on Figs. 19 and 20. The reference insulator is always set parallel to the ground.

The long insulators serve as a set of instruments for measuring the tilt angle. The tilt angle is calculated from the displacement of the end of the rotating insulator and the distance from the fulcrum point and a fixed point on the reference insulator. AB is the displacement, and BC is the fixed distance. The angle θ is equal to $\tan^{-1}$ (AB/BC).

To enable the displacement (AB) to be measured quickly, a ruler is fixed vertically from the reference insulator, one meter from the fulcrum point--i.e., BC = 1 meter One end of the ruler (see Fig. 21) is at the same level as the fulcrum point, projecting from the reference insulator. The scale on the ruler is in centimeters.

To prevent capacitance effect between the experimenter and the antenna, the displacement of the antenna is remotely controlled. A string is attached to the downward end of the insulator and passed

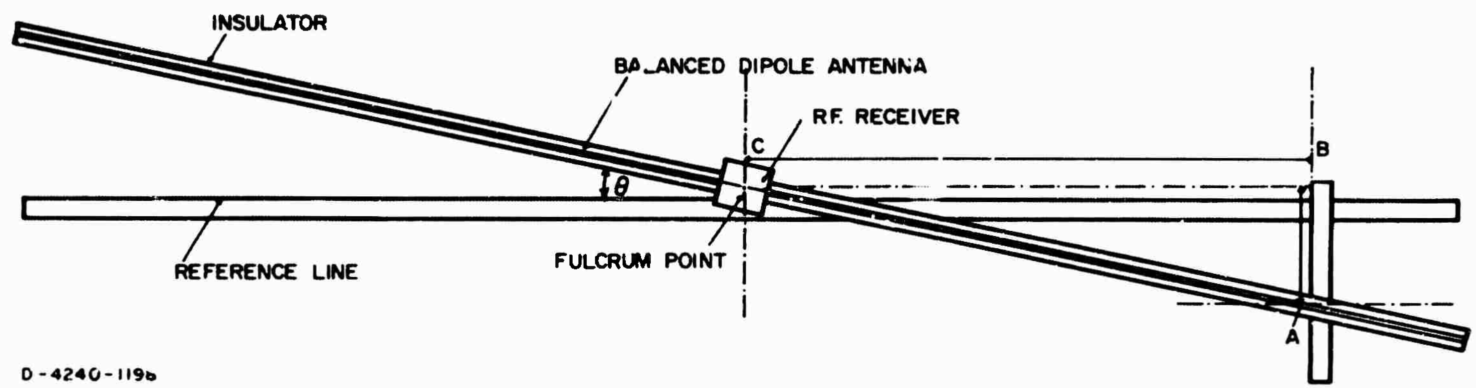

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FIG. 19 DIAGRAM OF THE ROTATING DIPOLE ANTENNA

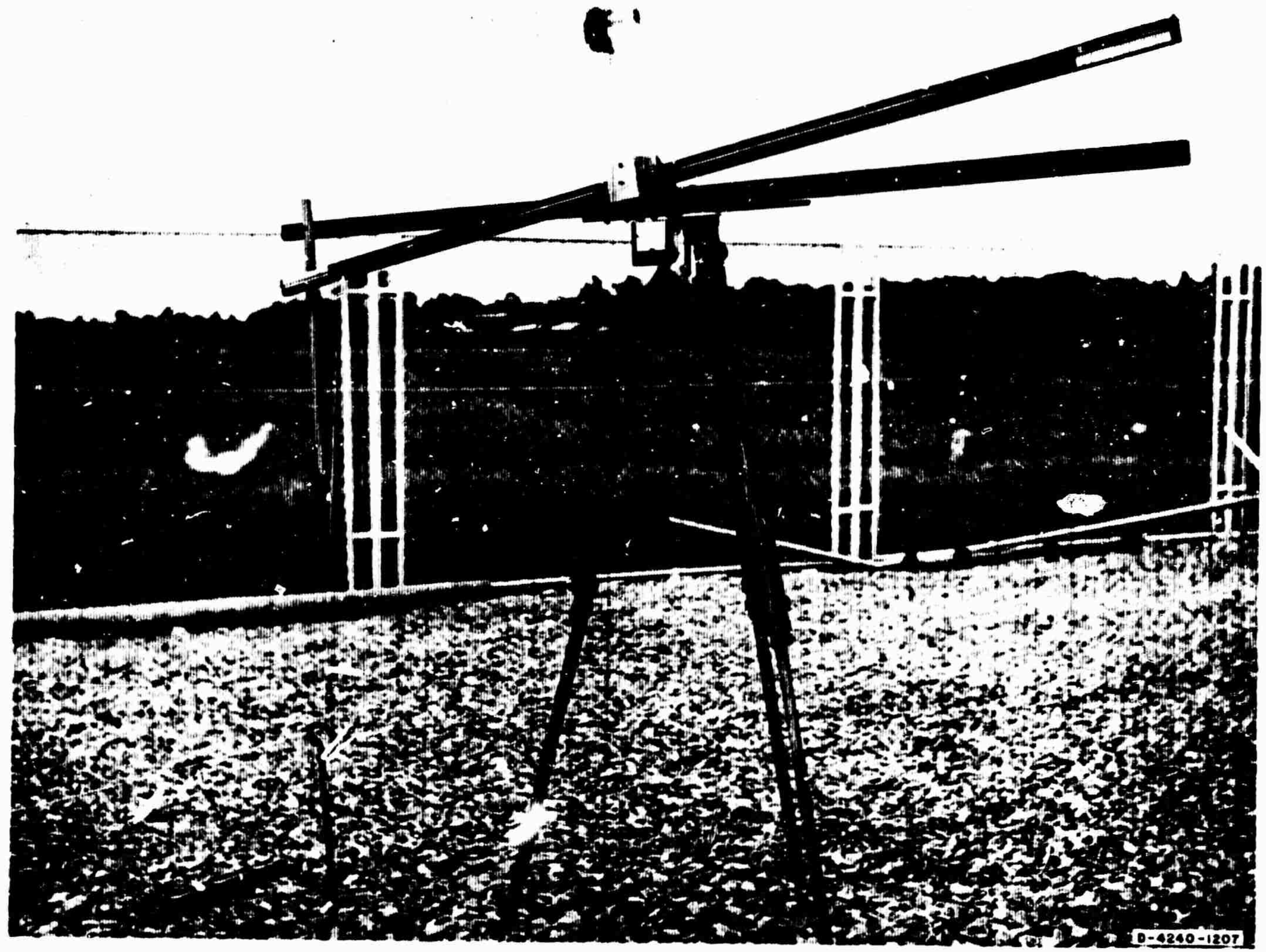

FIG. 20 PHOTOGRAPH OF THE ROTATING DIPOLE ANTENNA

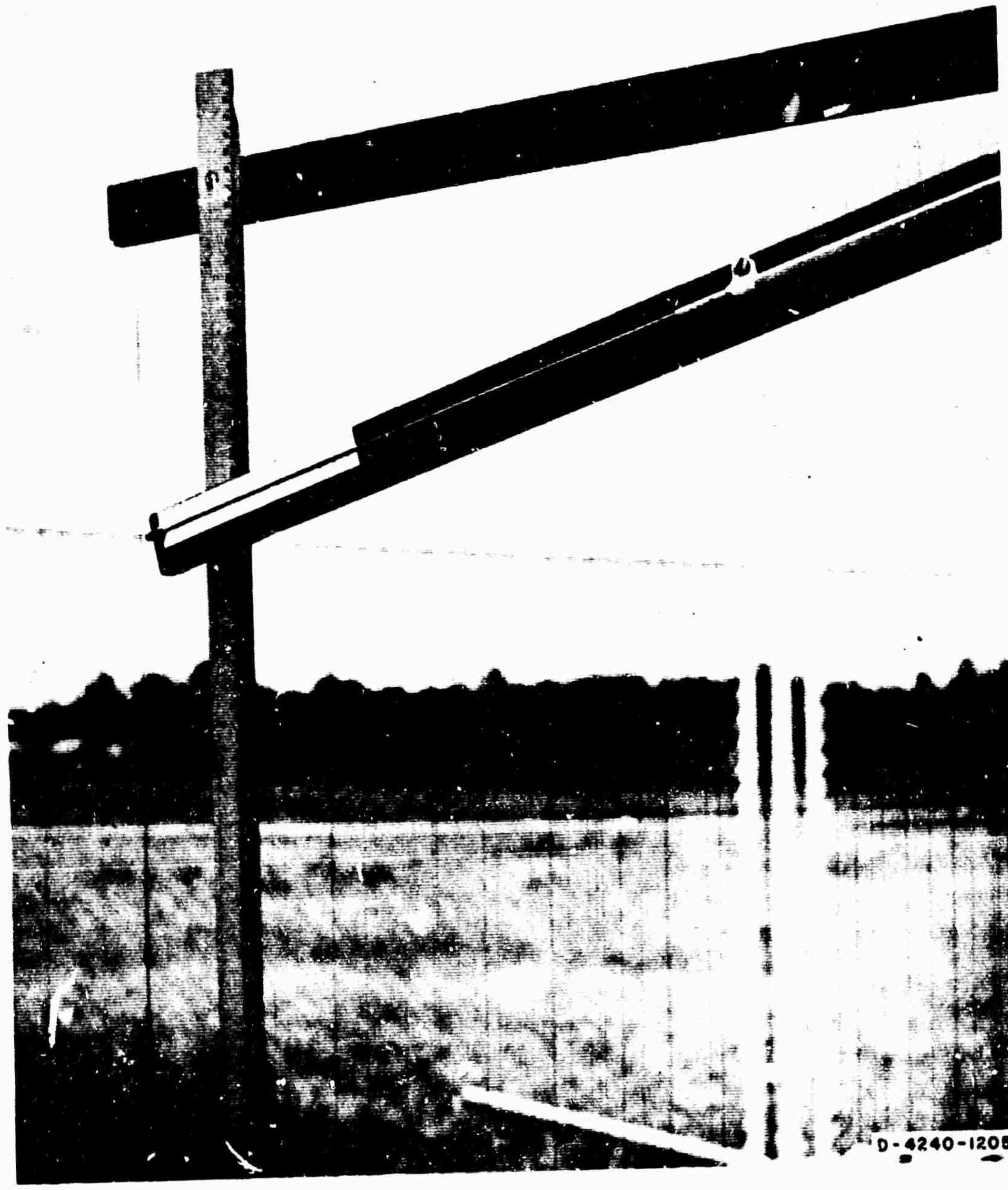

FIG. 21 SCALE ON THE DIPOLE ANTENNA

through the loop at the end of a stake close to the ground directly below the end of the insulator. The movement is effected by pulling the end of the string from a position a few meters away from the antenna. A piece of rubber is attached to the end of the insulator and the support to provide restoring torque for the insulator arm. The value of the current registered on the microammeter is read through a telescope mounted on a tripod.

3. Data Collection

Measurement were made at 42 sites covering the central and northeastern parts of Thailand. The sites were selected so that they were in the same propagation path as the field-attenuation measurement. The sites must be open areas, or at least there must be no obstacle between the transmitter and the receiver. The ground between the transmitter and the receiver must be level, since slight inclination of the ground will affect the tilt angle. At the selected site the transmitting antenna was erected by putting up the bamboo tripod. The legs of the tripod were adjusted until the lead weight nearly touched the ground. A copper ground stake was driven into the ground directly below the lead weight and connected to the weight to provide the earth point for the antenna feed line. The transmitter was then connected to the antenna via a coaxial lead. After the power supply was connected to the transmitter, a test transmission was made to ensure that the equipment was functioning properly.

At the receiver end, the rotating antenna was erected about 200 meters from the transmitter. A tripod about 1.2 meters high was used as a support for the whole antenna system. When the rotating antenna was mounted on the tripod, the legs of the tripod were adjusted until the reference insulator was parallel to the ground. A spirit level was used for this adjustment. The antenna was then oriented until both ends of the arms were in line with the transmitting antenna. A steel stake with a loop at one end was driven into the ground directly below the arm of the antenna to provide a loop for the remote-control string. A telescope was mounted on another tripod a few meters from the rotating antenna directly opposite the microammeter. As the measurement sequence began, the receiving antenna was rotated to find the approximate position of the tilt angle--i.e., the minimum reading of the microammeter. Then the values of the current around the minimum reading were read together with the corresponding displacement of the antenna arm in the vertical direction. To determine the tilt angle, the antenna displacements were plotted on a graph paper together with the corresponding value of the current; then a smooth curve was drawn to obtain the minimum value of the current and the corresponding value of the displacement of the antenna arm. The tilt angle was calculated from this displacement value. At each site, measurements were made at many points around the transmitting antenna to find the average value of the dielectric constant. The type of soil and terrain, and other observations also were recorded. The complete measurement for each site takes about two hours.

The wave tilt was found to be very sensitive to the water content on the surface of the ground. Therefore it is not advisable to take the measurements after the rain or early in the morning before the dew has dried out, if values representative of the soil during the day (or somewhat beneath the surface layer) are desired.

IV RESULTS

A. CONDUCTIVITY

The values of ground conductivity obtained by analysis of the data are given in Table III. The measurements were taken from seven transmitter sites, two sites in the central part of Thailand and the other five in the northeastern and eastern parts. The measurements were carried out first in the rainy season for all seven sites; the dry season was measured later. In the dry season, only three transmitting sites were used. This is because the results of the first few sampling measurements show that for both seasons there was little variation in the results. In Table III, the first column shows the names of the places where the transmitters were located. The second column shows the direction from the transmitting site for which the measurements were taken. The third column gives the observational bounds on the ground conductivity in rainy and dry seasons. The unit for ground conductivity is mmho/m.

The results shown in Table III were obtained by comparing the slopes of measured-field-intensity-vs.-distance curves with the slopes of the curves computed using Norton's method.[6] The computed Norton's curves for various values of ground conductivity were plotted on the same graph paper. The dielectric constant for each set of curves remains the same value as shown in Fig. 4. For each frequency, six sets of computed curves were plotted, each set having a different value of dielectric constant, ranging from ten to sixty. The measured curves were plotted on transparent paper for each direction for both frequencies and both seasons, and then compared with the set of Norton's curves computed for the same frequency. This was done by placing the measured curve on top of one set of Norton's curves, normally starting off with the set with the lowest value of dielectric constant. The measured curve is slid along the vertical axis of the computed curve until a computed curve of approximately the same slope as the measured curve is found. Thus the measured curve will have the same value of ground

Table III

GROUND CONDUCTIVITY OF CENTRAL, EASTERN, AND NORTHEASTERN THAILAND

Station	Direction	Ground Conductivity (mmho/m)	
		Rainy Season $\leq \sigma \leq$	Dry Season $\leq \sigma \leq$
Bang Pa In	Ban Hin Kong-Prachinburi		40-5000
	Saraburi-Lopburi		40-5000
	Ban Hin Kong-Nakhon Ratchasima	40-5000	40-5000
	Minburi-Chachoensao	40-5000	40-5000
Ban Pong	Kanchanaburi-Suphan Buri	3-15	
	Bangkok	30-5000	
	Petchaburi	15-30	
Nakhon-Ratchasima (Ban Choho)	Saraburi	8-20	4-15
	Chaiyaphum	10-20	7-20
	Khon Kaen	6-30	6-30
	Ban Nong Pling, Ban Wang Mi		6-15
Udon	Sakhon	3-10	
	Nong Khai	4-10	
	Khon Kaen	10-15	
	Nong Bua Lam Phui	3-10	
Sakhon	Udon	1.5-4	
	Nakhon Phanom	2-10	
	Tard Phanom	3-7	
	Kalasin		
Roi Et	Suwannaphum-Surin		4-10
	Chaturapak Phiman-Kaset Wisai	1.5-10	
	Maha Sarakham-Ban Phai	4-10	4-10
	Yasothon-Ubon	2-10	2-10
	Yasothon-Phahom Phrai	2-6	2-6
Ubon	Phibun Mangsahan	1.5-5	
	Amnat Charoen	2-4	
	Yasothon-Roi Et	1-3	
	Det Udom	1.5-3	

conductivity as the computed one. However the measured curves are not always smooth and therefore will not have a slope identical to that of the computed one. Thus two boundary values of ground conductivity are given. This gives a close estimation of the ground conductivity for that particular measured curve--e.g., between 8 and 20 mmho/m (see Fig. 24). To assist the comparison of the curves, a ground glass table, illuminated from underneath by a fluorescent light is used. This made the comparison much easier because both graphs are clearly shown, one on top of the other. The map in Fig. 22 shows the transmitter sites, the routes where the measurements were carried out, and the values of the ground conductivity along the routes.

The map in Fig. 23 gives estimated values of the ground conductivity over a larger area than in Fig. 22. The estimations were made after considering the soil map (see pocket in back cover) and terrain map,[8] and from the value of ground conductivity given in Table III. The values of the ground conductivity found in the central part of Thailand are mostly above 40 mmho/m. In the northeastern part they are between 3 and 10 mmho/m, and in the eastern part between 1 and 5 mmho/m.

The graphs in Appendix C (an example is given in Fig. 24) show the attenuation curves as measured from each site for the direction shown on the map in Fig. 22. The curves were plotted on the log × log graph paper. The distance is plotted along the horizontal axis, in miles, from one to fifty miles. The vertical axis shows the relative field intensity, with units in millivolts per meter, which is the same as the computed Norton's curve. Since only the slope of the curve is required, it is not necessary to plot the exact value of the field strength in millivolts per meter. By using the relative values of the field intensity, it is then possible to show four curves on the same graph for both frequencies and both seasons, which simplifies the comparison between each season.

B. DIELECTRIC CONSTANT

The measurement of the dielectric constant was carried out at approximately 42 sites in the central, eastern, and northeastern parts

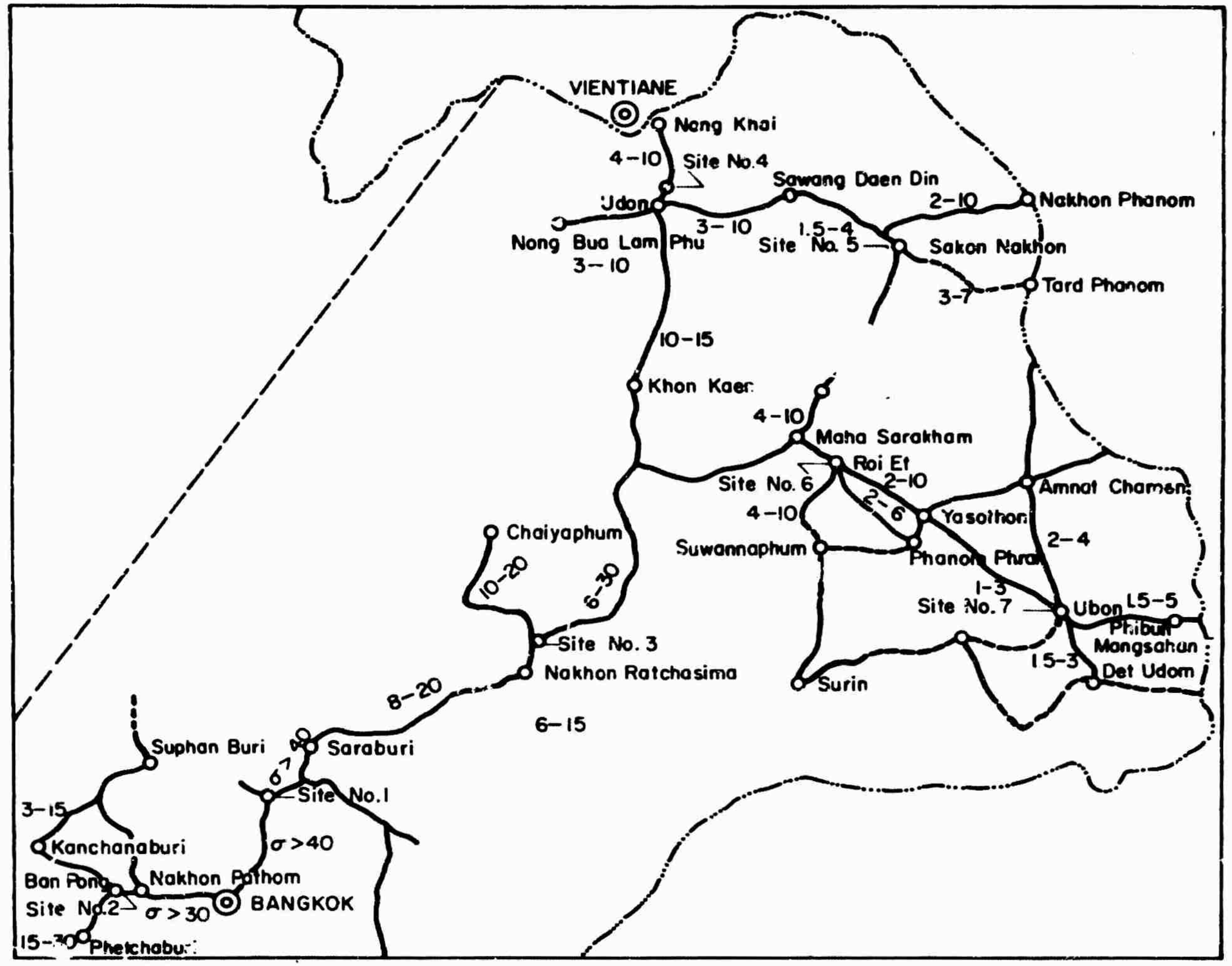

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FIG. 22 MAP OF AVERAGE GROUND CONDUCTIVITY ALONG THE MEASURED ROUTES IN CENTRAL, EASTERN, AND NORTHEASTERN THAILAND

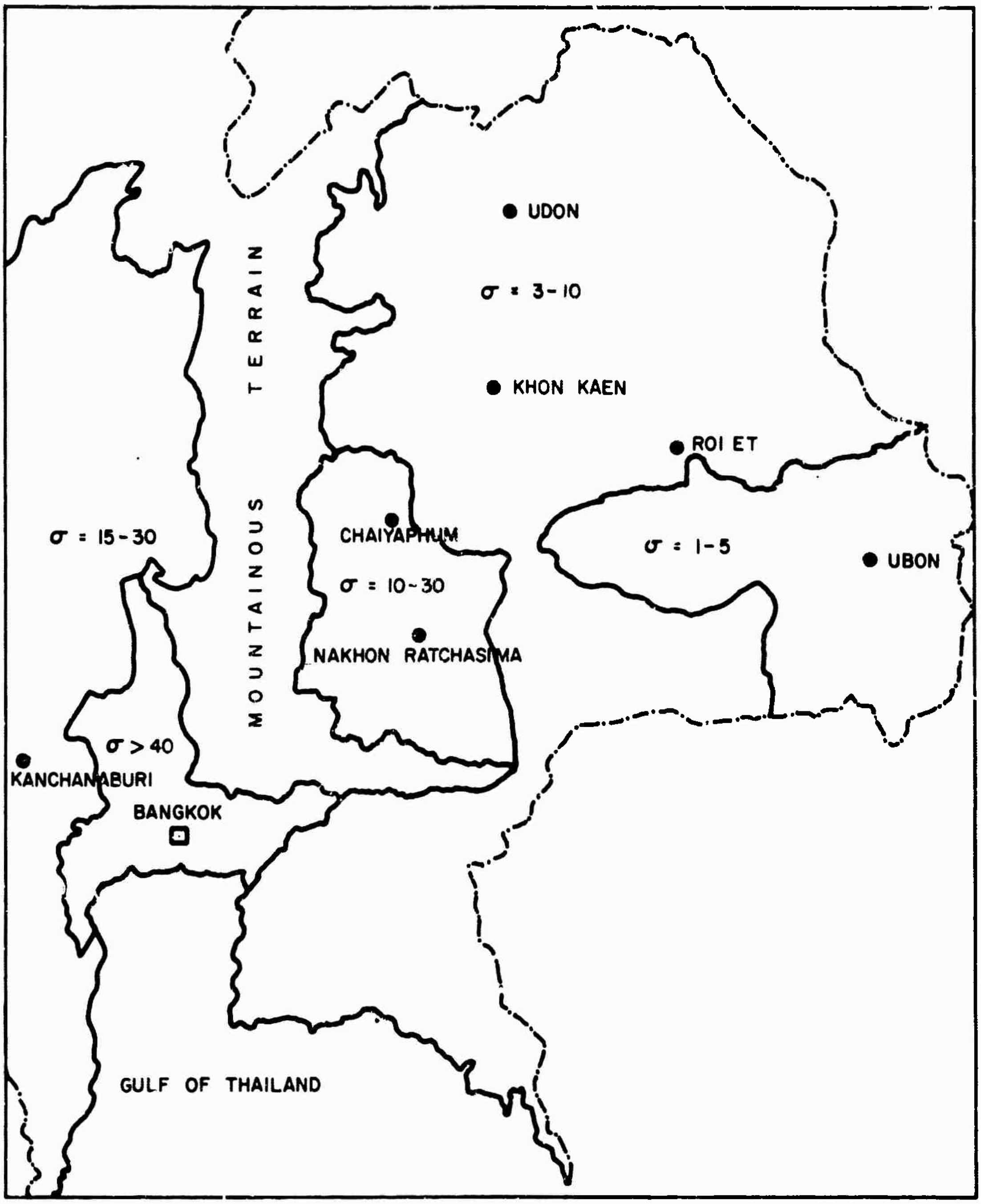

FIG. 23 MAP OF GROUND CONDUCTIVITY IN CENTRAL, EASTERN, AND NORTHEASTERN THAILAND (units in mmho/m)

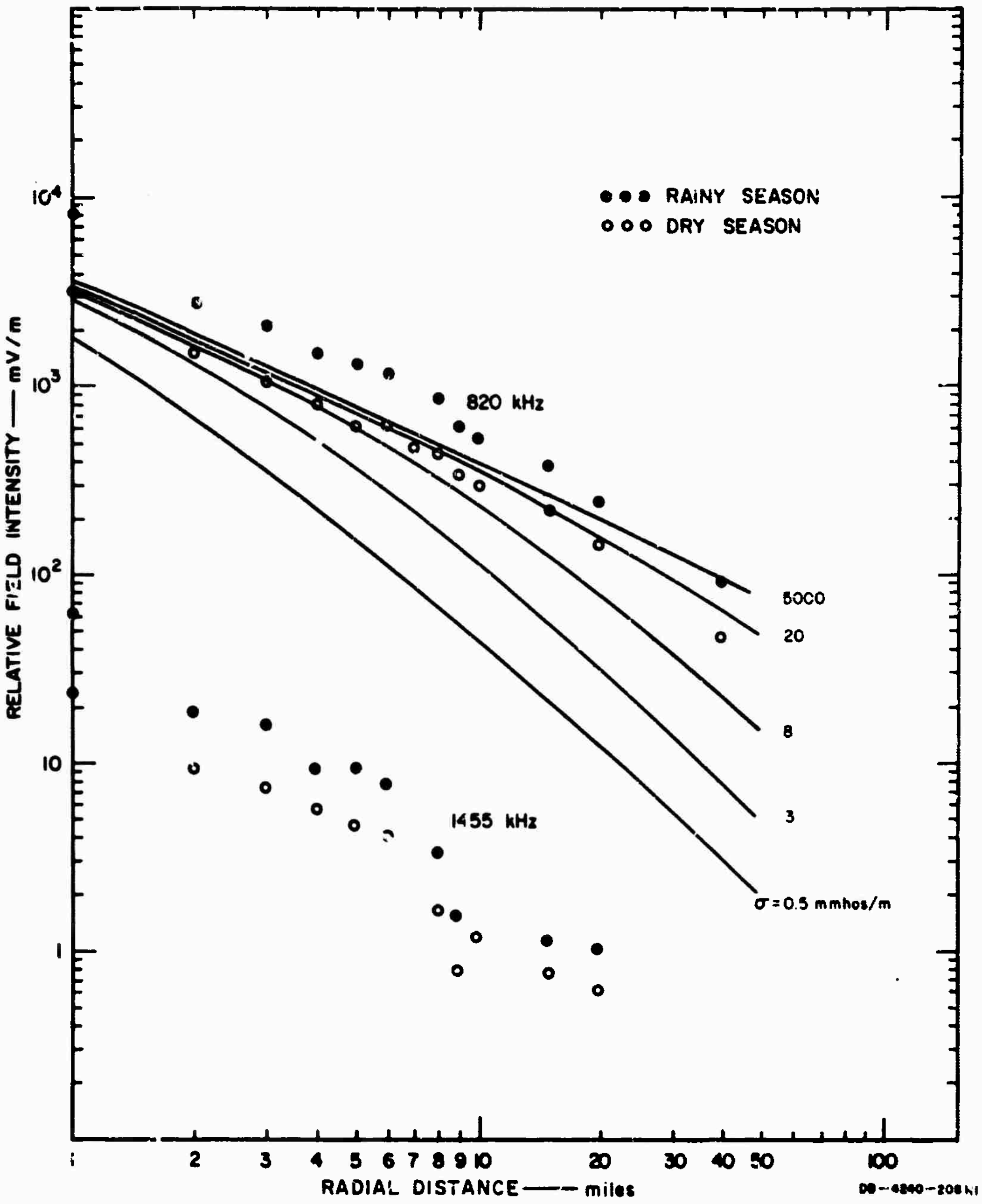

FIG. 24 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE

of Thailand. The data were taken during the dry season, but on many occasions there were a few rain showers. Table IV shows the value of the dielectric constant analyzed from the measurement value of the tilt angle. The first column gives the name or location of the site where the measurements were taken. The second column gives the description of soil and terrain and the third column gives the value of the tilt angle of the wave front. The last column shows the value of the dielectric constant. The two numbers in the last column show that the dielectric constant can vary between these numbers.

The relationship between the tilt angle, the dielectric constant, the ground conductivity, and the frequency is given by:[5]

$$\tan^2\theta \approx \frac{\epsilon + \sqrt{\left[\epsilon^2 + \left(\frac{18\sigma}{f}\right)^2\right]}}{2\left[\epsilon^2 + \left(\frac{18\sigma}{f}\right)^2\right]} \qquad (8)$$

where

θ = Tilt angle

ϵ = Relative dielectric constant

σ = Ground conductivity in mmho/m

f = Frequency in MHz.

The relative dielectric constant of the ground is the ratio of the dielectric constant of the ground and the dielectric constant of free space--i.e.,

$$\epsilon = \frac{\epsilon g}{\epsilon_{fs}}$$

where ϵg is the value of the dielectric constant of the ground and ϵ_{fs} is (by definition) the value of the dielectric constant of free space.

To obtain the value of the dielectric constant from the tilt angle, a series of curves calculated from Eq. (8) were plotted as shown in Fig. 25. Each curve shows a relationship between the tilt angle θ and

Table IV

TILT ANGLE AND DIELECTRIC CONSTANT IN CENTRAL, EASTERN, AND NORTHEASTERN THAILAND

Place	Soil Description	θ (Tilt Angle)	≤ ε ≤
1. Near Pra-In lock off Paholyotin Highway	Dry Rice Field	10.13	20-24
2. Off Friendship Highway 108 km from Bangkok	Dry and Sandy	13.1	14-18
3. Off Korat-Choho Highway 390 km from Bangkok	Dry and Sandy	12.5	18-20
4. Off Korat-Pimai Highway 7 km from the entrance to Choho	Black Soil	9.1	29-32
5. Nong Talak	Gray with water underneath	8.2	35-43
6. Ban Kokejig	Red with water underneath	10	18-24
7. Khon Kaen Town Hall	Covered with dried grass	20.3	5-7
8. Khon Kaen Nursery of Plants	Sandy, newly-ploughed	20	5-7
9. Off Khon Kaen-Chum Phae Highway, 5 km from Khon Kaen	Dry sandy, newly-ploughed	20.2	5-7
10. Site for Khon Kaen University	Flooded		3-3.5
11. At intersection to Nam Phong Dam	Damp and crumbly	12.5	16-20
12. 3-4 km from Nam Phong Dam	Red, stony rough surface after rain	9.4	24-28
13. Near Sukran Reservoir	Covered with green grass	12.5	8-16
14. Hard Kam Village	Damp Soil	7.5-8	42-48
15. Near Nong Song Hong Reservoir	Sandy-damp	9-10	20-37
16. Ban Pol Sa, Tha Bo District	Sandy dry surface water underneath	9.3	28-32
17. Wat Pra Tat School	Dry, crumbly	12.7-13.5	16-18
18. Nong Khai Airfield	Dry	13.8	14-16
19. Nong Khai Airfield	Damp	9.9-10.3	18-24
20. Off Udorn-Nong Khai Highway	Red stony few days after rain	11.3	20-24
21. Sri Muang Field Udorn	Sandy, crumbly	14.1-15.4	14-16
22. Paddy Field Near Udorn	Crumbly, salty with water underneath		4-4.5
23. Cheign Pheng	Crumbly	12.1	20-22
24. Close to Swang-daendin District Office	Sandy, hilly	13.4	16-18
25. Off Udorn-Sakon Nakhon Highway	Dry black	16.2	8-11
26. Donkuang Village	Paddy field, crumbly	12.1-13.9	13-18
27. Off Udorn-Sakon Nakhon Highway, 121 km from Udorn	Hilly, sandy	19.5	5-8
28. Near Nong Han	--	7.5-9.4	42-48
29. Near Nong Han	--	13-16.5	5-14
30. Sakon Nakhon Animals Breeding Station	Sandy, big tree	12.8	16-19
31. Sakon Nakhon Airport	Red, sandy	17.6-19	7-9
32. Off Sakon Nakhon-Kalasin Highway, 22 km from Sakon Nakhon	Rough laterite	13.5	15-17
33. Ban Don Soong	After rain crumbly	15.7	9-13
34. Nong Yeng Village	Sandy soil	16.2-16.9	10-12
35. Near Nong Saeng Village	Sandy, dry dusty	13.4	17-19
36. Off Yasothon-Roi Et Highway 126 km from Yasothon	Paddy field, sandy soil	15.3-18	7-12
37. Between Yasothon-Roi Et	Sandy Soil	17.5	8-10
38. Off Roi Et-Suwannaphum Highway, 6 km from Roi Et	Paddy field, dry	19	4-8
39. 85 km from Roi Et to Maha Sarakham	Paddy field after rain	10.5	18-26
40. Kanglingchan Reservoir	Big swamp, trees and short stumps	9.8	25-31
41. Off Sarakham-Ban Phai Highway, 55 km from Sarakham	Black, crumbly, sandy	13.5-14.8	14-19
42. Off Sarakham-Ban Phai Highway, 17 km from Sarakham	Hilly, Sandy	22	4-6

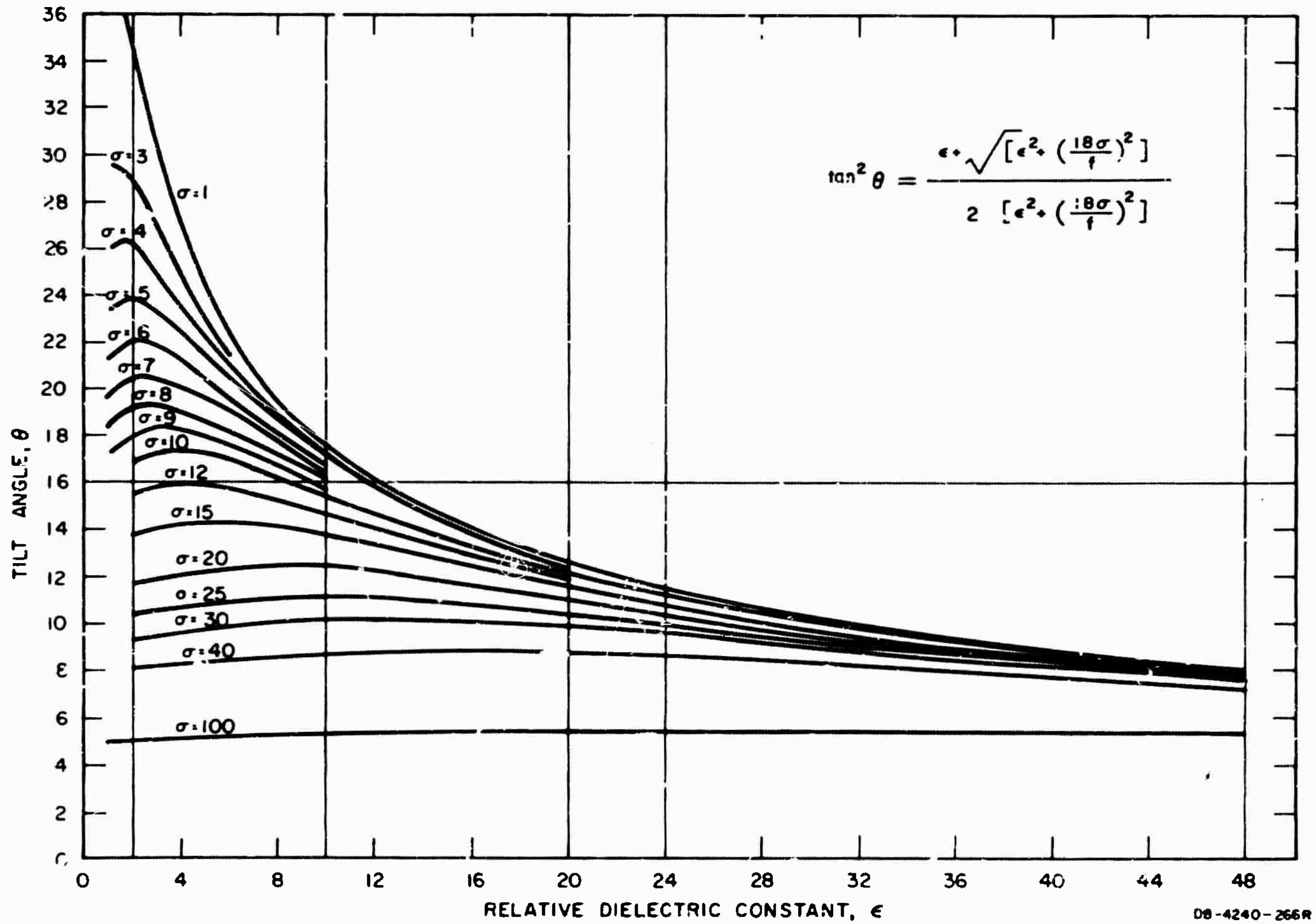

FIG. 25 THE RELATIONSHIP BETWEEN TILT ANGLE θ AND THE DIELECTRIC CONSTANT FOR VARIOUS VALUES OF GROUND CONDUCTIVITY

the relative dielectric constant ϵ for each value of the ground conductivity. The values of the ground conductivity are 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 20, 25, 30, and 40 mmho/m. The frequency used in all calculations is 27 MHz. The value of ϵ is determined from these curves. For each site, the value of the ground conductivity was estimated from the type of soil and the measured value from the field-intensity method. Then these values are used together with the tilt angle to obtain the value of the dielectric constant from the curve. Two values of the dielectric constant are given, showing the range in which the values of the dielectric constant of that site can vary (i.e., giving the maximum and the minimum value).

The map in Fig. 26 shows the values of the relative dielectric constant on the map of eastern and northeastern Thailand.

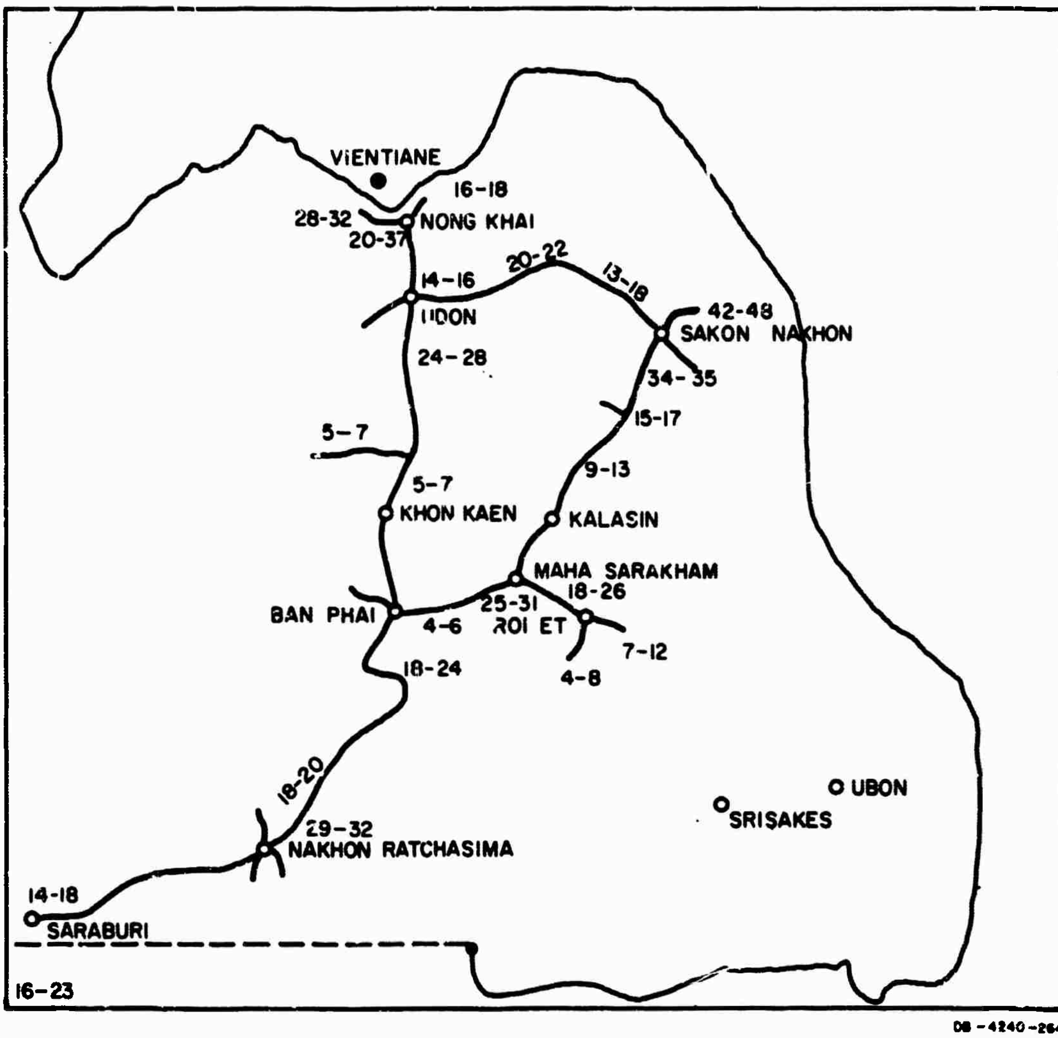

FIG. 26 MAP OF DIELECTRIC CONSTANTS IN EASTERN AND NORTHEASTERN THAILAND

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V DISCUSSION OF RESULTS

The major findings of this project can be divided into two categories: the evaluation of the effectiveness of the methods and equipment used for measuring the ground constants, and the values of the ground constants obtained by analysis of the data. These results will be discussed separately, the effectiveness of methodology and techniques being dealt with first.

The field-intensity method is a very straightforward means of obtaining the values of ground conductivity and can give excellent results when the terrain is flat and free of vegetation as in central Thailand. The measured field-intensity curve is almost identical with the calculated curve, except that there are some points on the measured curve where the value of field intensity bears no relationship with the overall curve. This may be due to various factors that were overlooked, such as the change in the power of the transmitter (due to unknown causes) when that particular point was measured, or the misuse of the field-intensity meter at that point. This problem can easily be solved by using a paper-chart recorder, recording the field intensity at a fixed distance from the transmitter when the measurement is taking place. Any variation in transmitting power will show on the paper chart and can be used to correct the data. The field-intensity-vs.-distance curve should be plotted immediately after the measurement is completed. The point that bears no relation to the rest of the curve can be remeasured, and if the value remains the same, measurement may be repeated at several locations close to that point. The uncorrelated value may be due to local terrain which does not represent the overall ground conductivity. In many cases local man-made noise increases the field intensity, and in such cases a non-transmitting interval should be incorporated in the switching circuit of the transmitter to permit the local noise to be measured. This will enable the data to be corrected prior to the processing.

In general, the exact values are not required for the application of the ground conductivity and in most cases the ground conductivity of the soil changes from place to place and cannot be expected to remain the same over a large area. Therefore the measured-field-intensity curve will never be identical with the computed one and cannot result in a single value of ground conductivity. Thus it is more practical to show the range of variation of the ground constant over that particular area--i.e., the maximum and the minimum values.

The equipment for measuring the tilt angle of the vertical propagated wave was designed and constructed at the MRDC Electronic Laboratory and many modifications were made to simplify its operation. The final result was a very simple piece of equipment, highly accurate and easy to handle. The equipment is capable of measuring the dielectric constant locally with very accurate results if the ground conductivity in the vicinity of the measurement is known, and even if the value of the ground conductivity is unknown, results will be reasonably accurate.

An improvement was made in the method of analyzing the data for the wave tilt. Previous authors normally approximated

$$\tan^2\theta \approx \frac{\epsilon + \sqrt{\left[\epsilon^2 + \left(\frac{18\sigma}{f}\right)^2\right]}}{2\left[\epsilon^2 + \left(\frac{18\sigma}{f}\right)^2\right]}$$

by

$$\tan^2\theta \approx \frac{1}{\epsilon} \quad .$$

They assumed that the term $(18\sigma/f)^2$ is very much smaller than the term ϵ^2, and therefore can be neglected. However, this assumption is only valid if the value of the ground conductivity is very small or the frequency relatively very large. If the ground conductivity is larger, even when the frequency is high, the term $(18\sigma/f)^2$ is still not small compared with the term ϵ^2. Consider the relationship $\tan^2\theta = 1/\epsilon$ or tan $\theta = 1/\sqrt{\epsilon}$. At $\theta = 14^\circ$ the simple approximation will give a dielectric constant of 16, but if the value of σ is equal to 15 mmho/m, then at 14° the dielectric constant is 9. In Thailand the ground conductivity is rather high, especially around the central part, and therefore using the approximation tan $\theta = 1/\sqrt{\epsilon}$ may lead to an error as high as 100 percent.

The use of the value of the ground conductivity in obtaining the value of the dielectric constant from Eq. (8) helps to minimize the error. This method is essential when the ground conductivity is larger than 10 mmho/m, for otherwise it will result in greater error than expected.

The wave-tilt method appears to give reasonably good results. The equipment is easily constructed and the method of analyzing the data is simple. The limitation of this method in Thailand is that it cannot be used at low frequencies because of the interference from crowded broadcasting stations, and therefore it cannot be used for measuring ground conductivity. At the frequency used, the tilt angle seems to be very sensitive to the moisture on the surface of the ground and it gives a very small tilt angle when the grass is slightly wet--for instance in the morning when there is dew. This is because the tilt angle is caused mainly by the electric component in the vicinity of the earth's surface.

The measurements of ground conductivity obtained from central Thailand are high--in many cases over 40 mmho/m. This is to be expected since the land was originally sea and was filled up by mud, which later dried out. At present its height is about the same as sea level. In the rainy season the water level rises about one foot above the ground, and in the dry season it dries up, making the water level at this time very close to the surface of the earth. The values of the ground conductivity measured between these two seasons are very close together, because when the surface of the ground has dried out, the current of the propagated wave penetrates deeper into the wetter part. The soil is homogeneous for several meters in depth as is usual with land reclaimed from the ocean.

In the western part of Thailand the ground can also be classified as good ground, but not as good as that in the central part. This is because there are several mountain ranges in the western area, making the ground much higher than sea level.

In eastern and northeastern Thailand, the ground is classified as fine sandy loam and in some parts the flat grassy plains are unable to retain water. The values of the ground conductivity obtained from these parts are low, especially in the east. The northeastern and eastern parts are full of mountain ranges and high hills that cause the field-intensity to fluctuate, thus preventing reasonably smooth field-intensity curves from being obtained. These curves cannot compare with Norton's curve in giving the value of the ground conductivity, for in such cases only the portion of the curve that is relatively smooth can be used in the analysis of the results.

At first, it was thought that the free-space field 2Eo would be an important factor in analyzing the value of the ground conductivity. However, when the curve-matching process was being carried out it was realized that the free-space field can be determined by the overall slope of the curve of the measured field intensity, and therefore it is not so important to have prior knowledge of the value of the free-space field. However, it is an advantage if it can be accurately measured.

In obtaining the transmission path loss,* the free-space field becomes an important factor, as it can contribute a large error to the calculation when it deviates slightly from its true value.

The path loss plotted from the measured field intensity shows that the curves for both frequencies have generally the same characteristics rising and falling at the same points. However, in some cases variations occur that may be due to measurement error, to changes in the transmitting power, or to a high noise level at one of the frequencies.

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*The basic transmission loss data for 820 and 1455 kHz are presented in Appendix B.

The value of the dielectric constant measured by the wave-tilt method is a spot measurement. The sites were chosen so that the soil at each site is representative of the ground in that area. The result shows that the average value of the dielectric constant in central, northeastern, and eastern Thailand varies between 10 and 30. Therefore the dielectric constant will not be an important factor dominating the service area of the broadcast stations, except in certain places in the east where the ground conductivity has a very low value.

It is recommended that the values of the ground constant obtained by both methods over these parts of Thailand be compared with those obtained by other methods, such as the two-wire-transmission line[7] for the same frequencies and location. The measurements should be extended to cover the north and the south of Thailand. Since northern Thailand is very mountainous, the field-intensity method may fail to give satisfactory results. It may therefore be necessary to employ other methods involving on the spot measurement of soil samples at several points over a wide area. In this case a number of measurements would be necessary to obtain the average value of the ground conductivity.

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Appendix A

CALCULATED GROUND-WAVE FIELD INTENSITY VS. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY

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Appendix A

CALCULATED GROUND-WAVE FIELD INTENSITY VS. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY

The Norton's curves shown in Figs. A-1 through A-12 were computed from the following equation:[7]

$$E_d = \frac{2E_o A}{d} \text{ millivolt per meter}$$

where

E_d = Field intensity of ground wave at distance d miles in millivolts per meter

d = Distance in miles from the transmitting antenna

Eo = Free-space field at one mile from the transmitting antenna in free space with the same antenna currents as are actually present when the antenna is instead near the earth

A = Attenuation factor

p = The numerical distance.

The attenuation factor "A" was obtained from Fig. 3 in the main text, for the corresponding value of p, d, b, ϵ, and σ, where

$$p \cong \frac{\pi}{x}\frac{d}{\lambda}\cos b$$

$$b \cong \tan^{-1}\frac{(\epsilon + 1)}{x}$$

$$x = \frac{18 \times \sigma}{f}$$

f = Frequency in MHz

σ = Ground conductivity in mmho/m

ϵ = Relative dielectric constant

λ = Wavelength in miles.

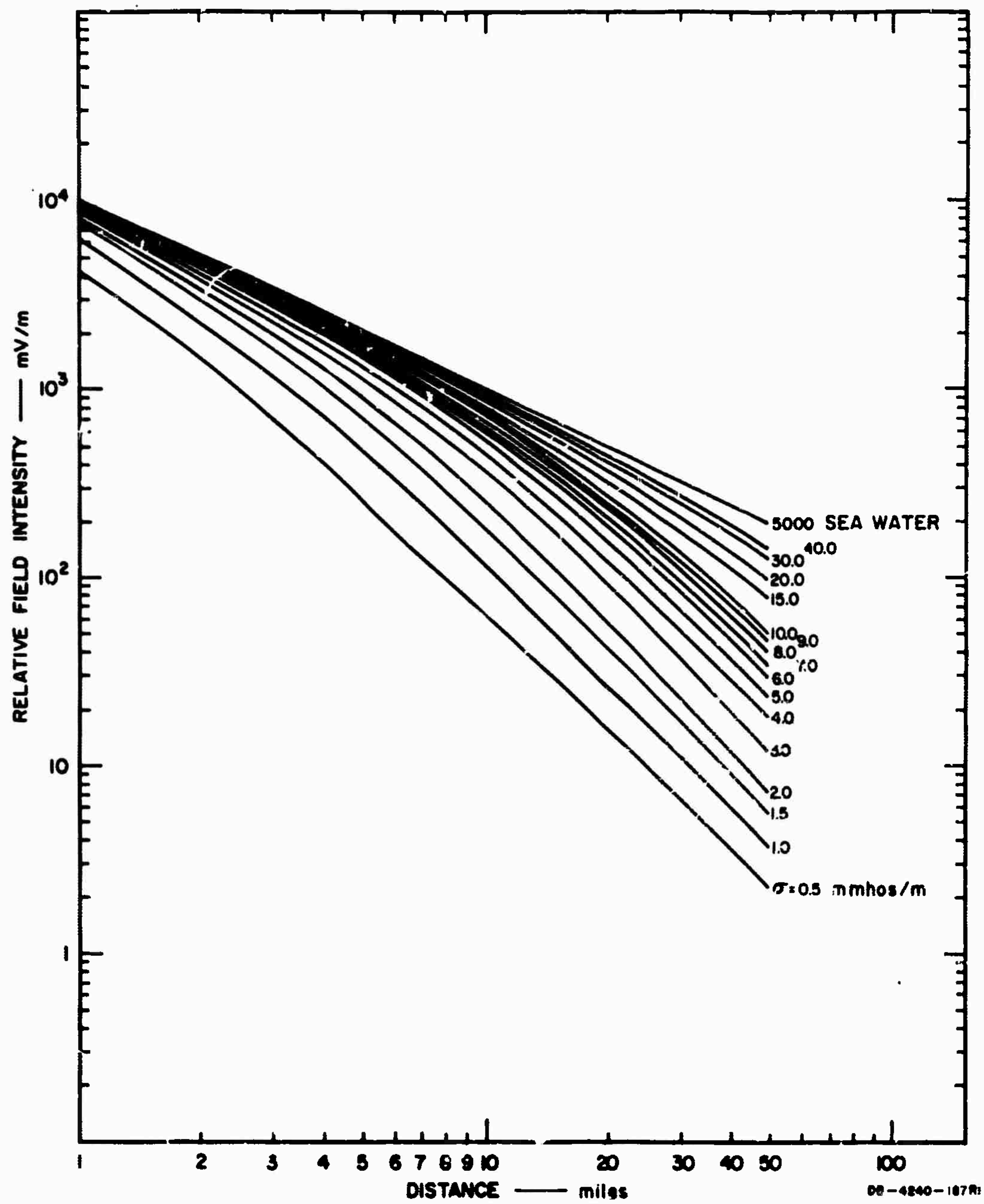

FIG. A-1 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 820 kHz, $\epsilon = 10$

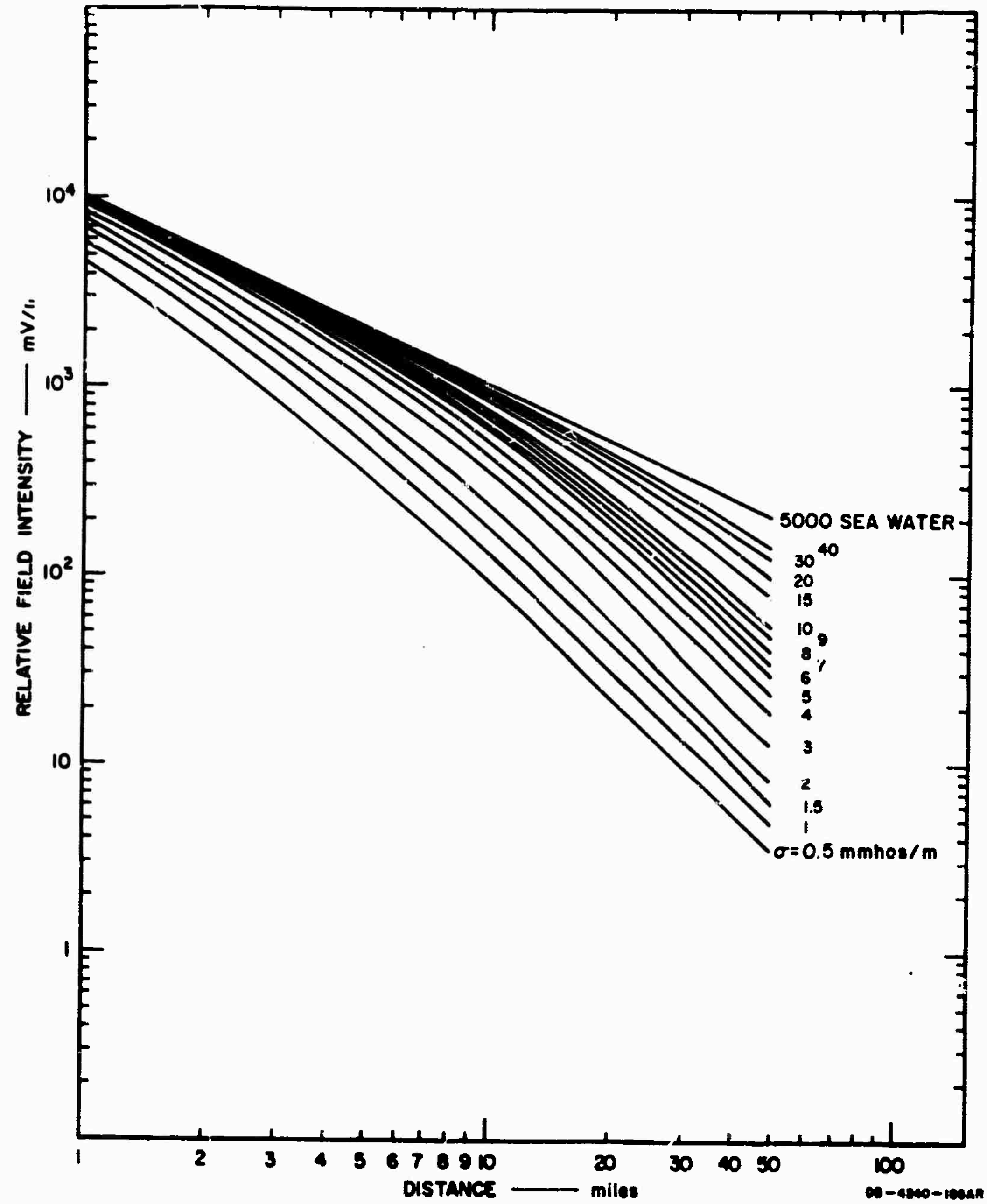

FIG. A-2 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 820 kHz, $\epsilon = 20$

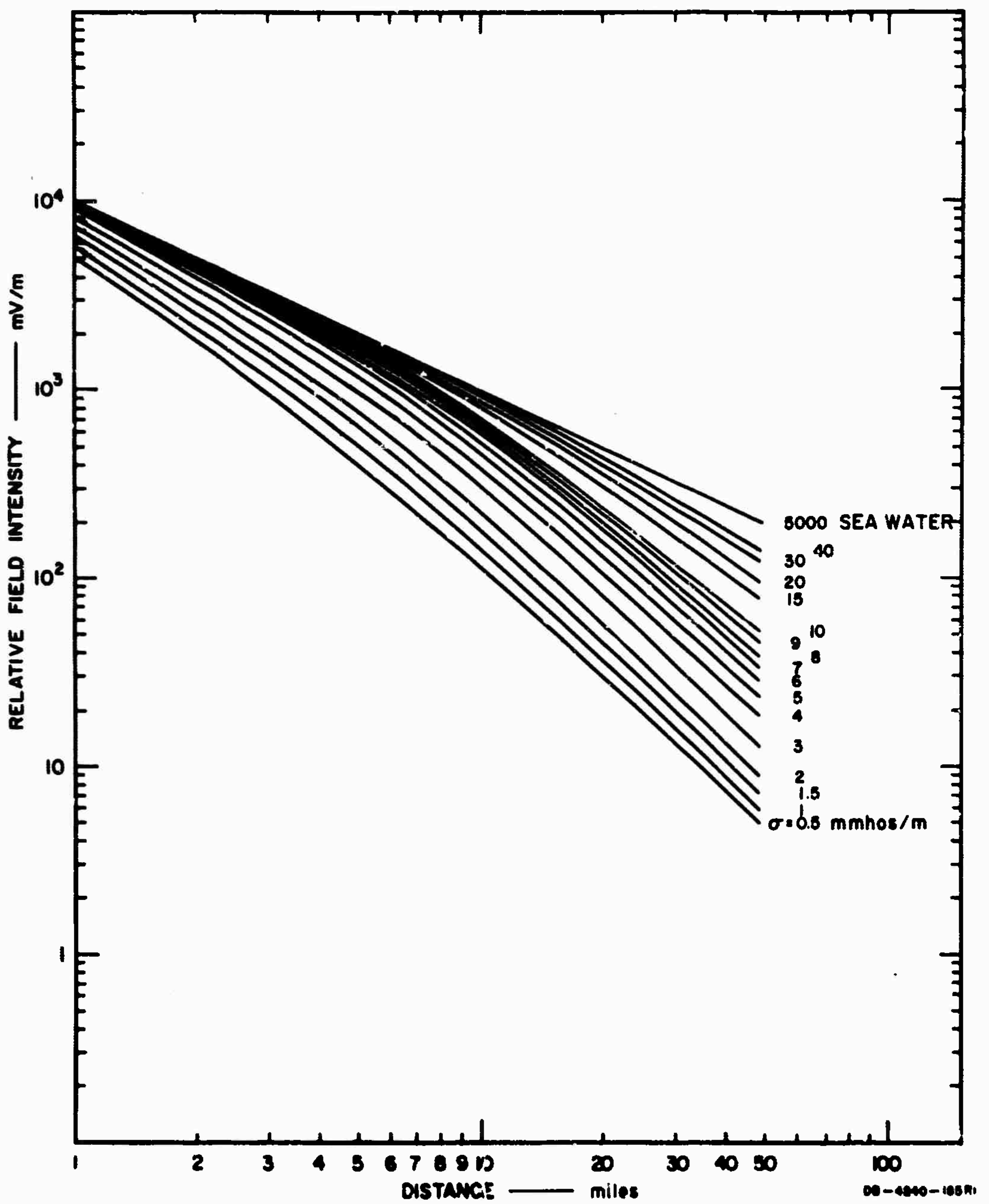

FIG. A-3 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 820 kHz, $\epsilon = 30$

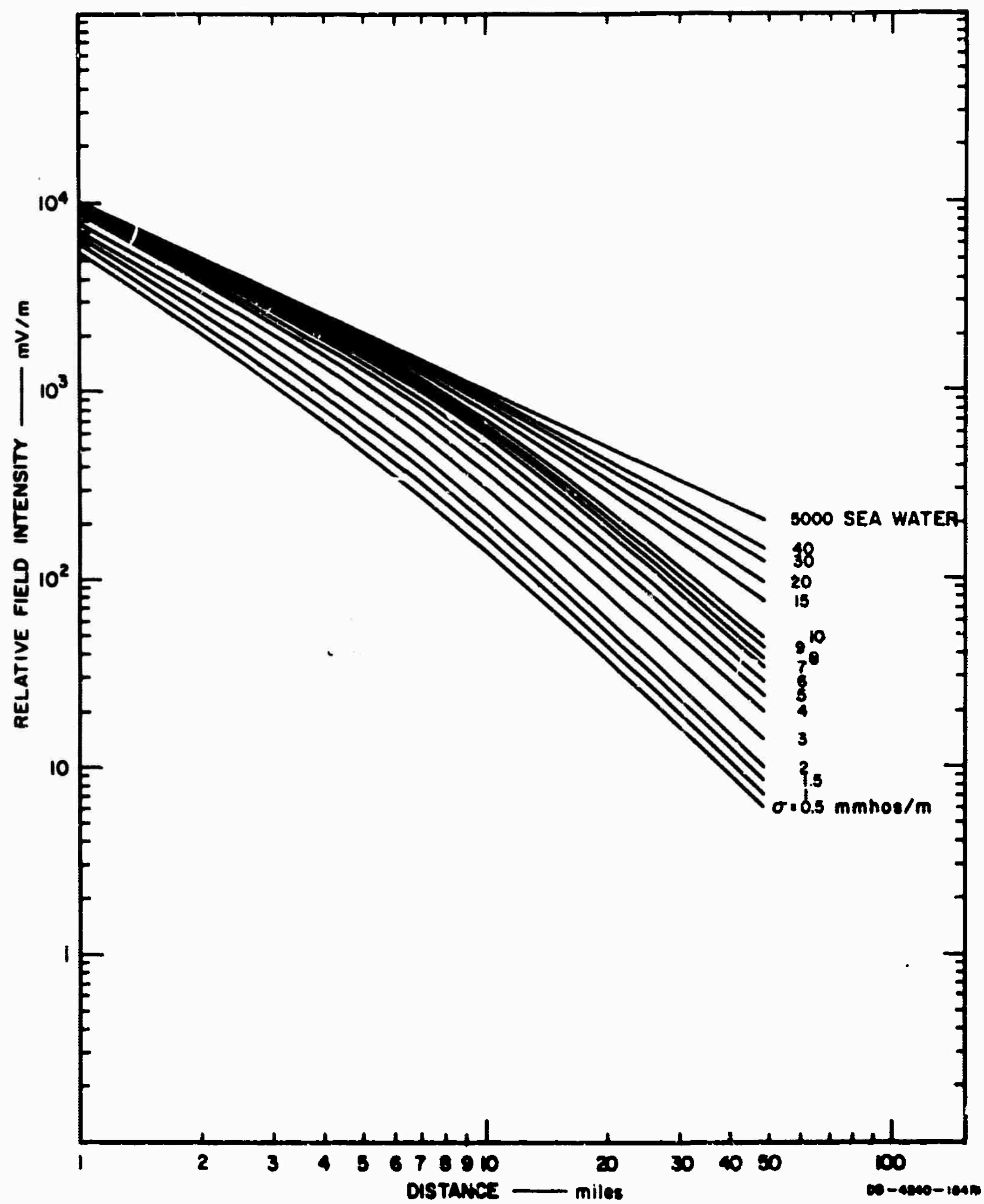

FIG. A-4 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 820 kHz, ϵ = 40

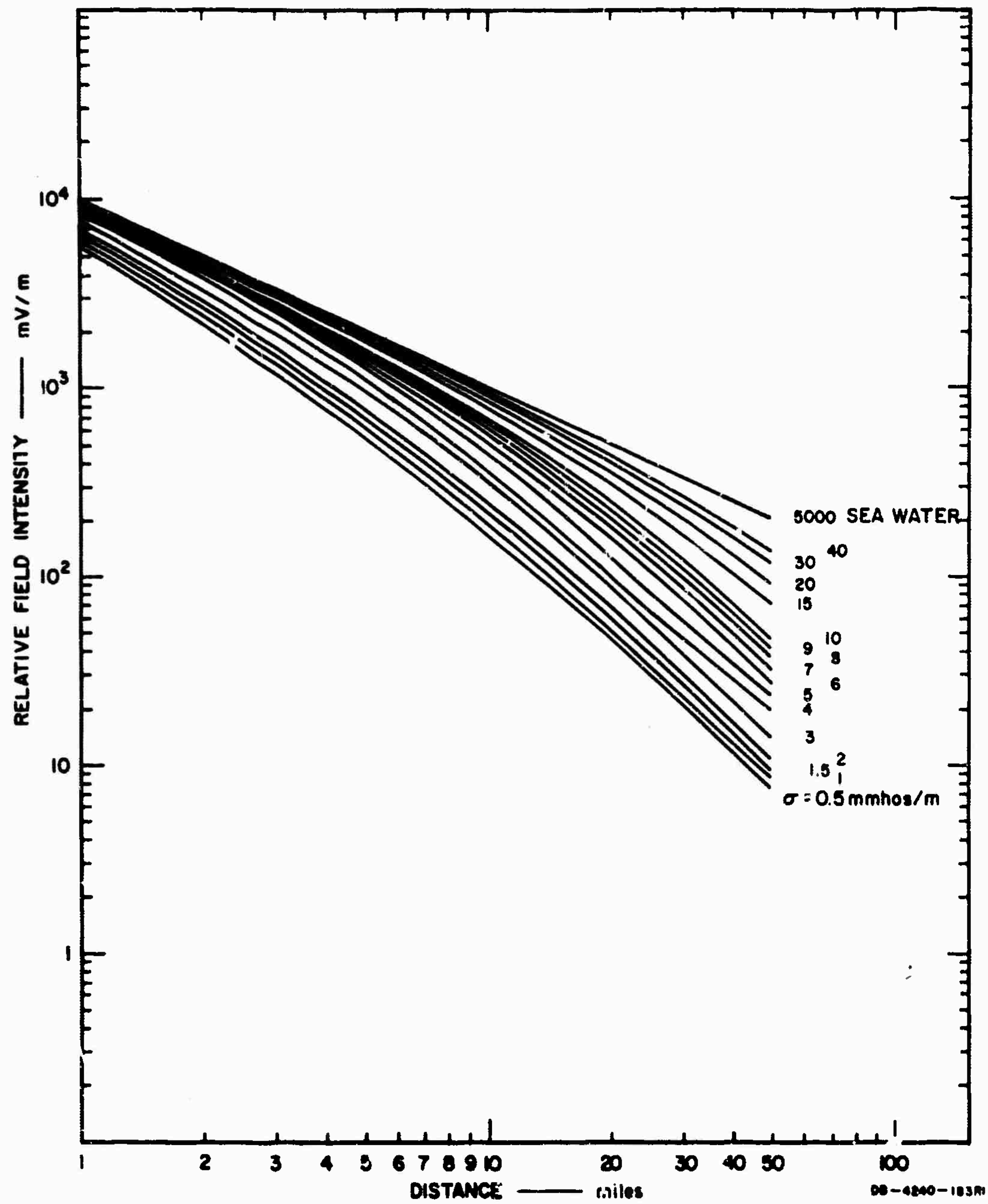

FIG. A-5 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 820 kHz, $\epsilon = 50$

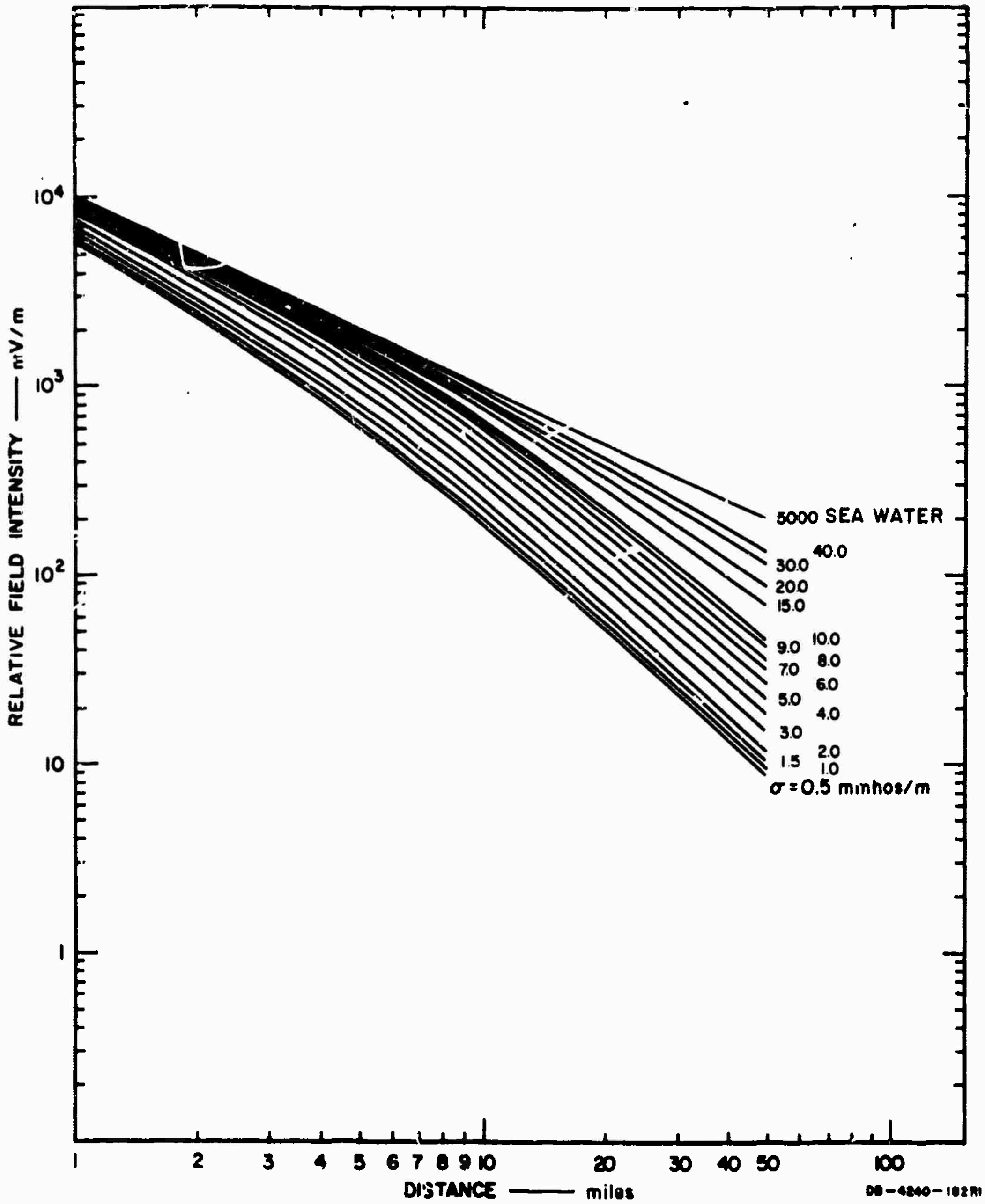

FIG. A-6 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 820 kHz, $\epsilon = 60$

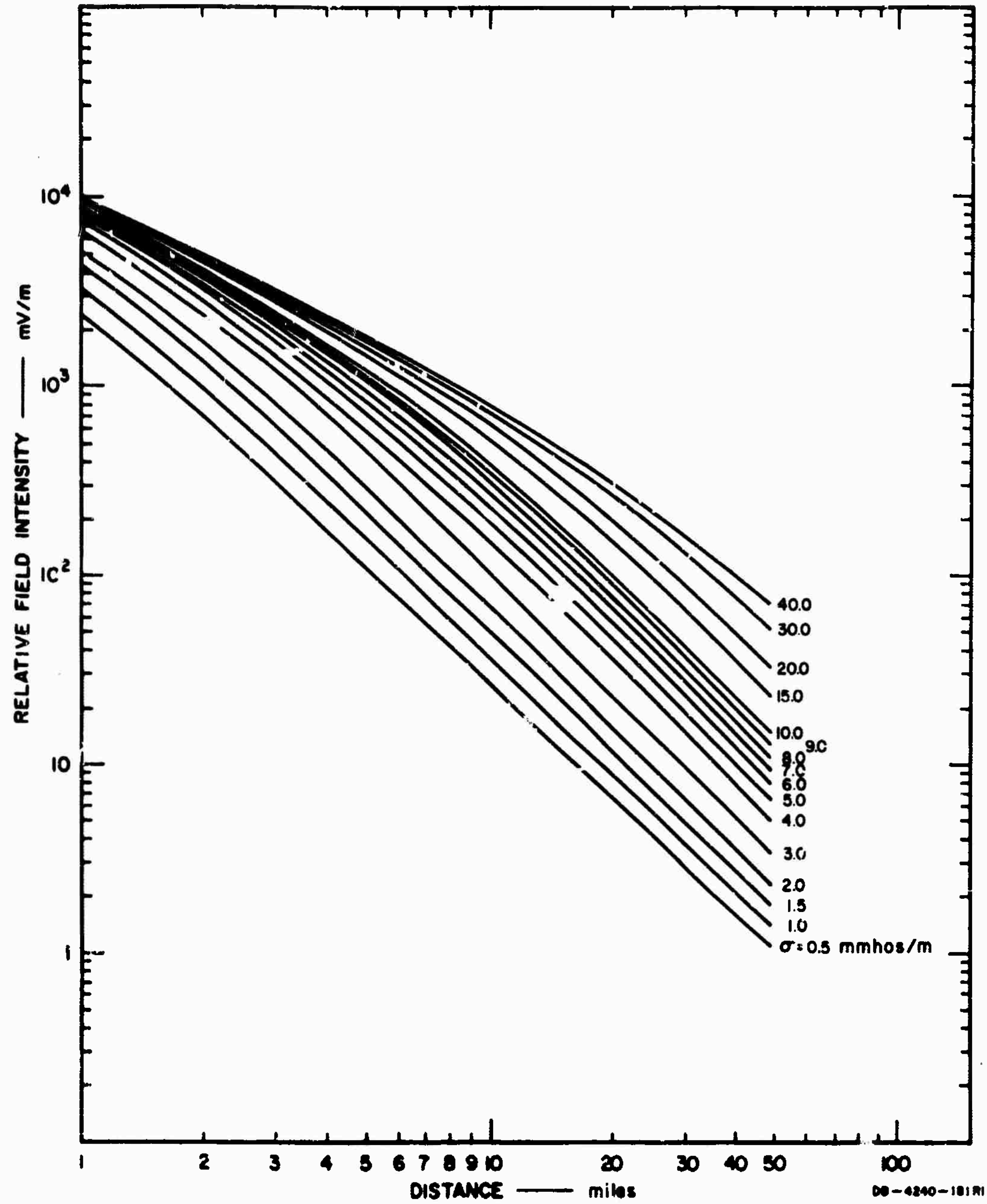

FIG. A-7 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 1455 kHz, $\epsilon = 10$

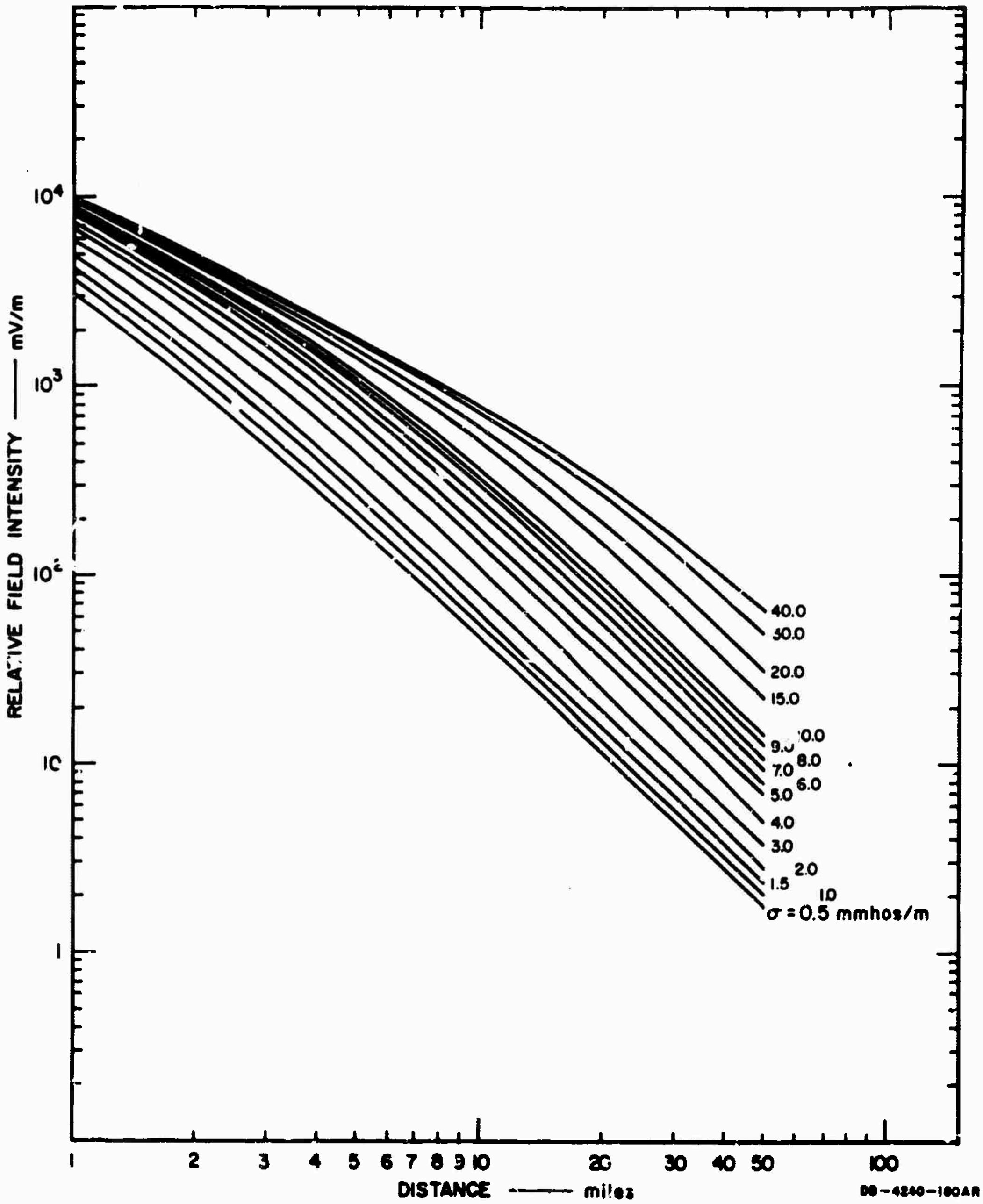

FIG. A-8 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 1455 kHz, ϵ = 20

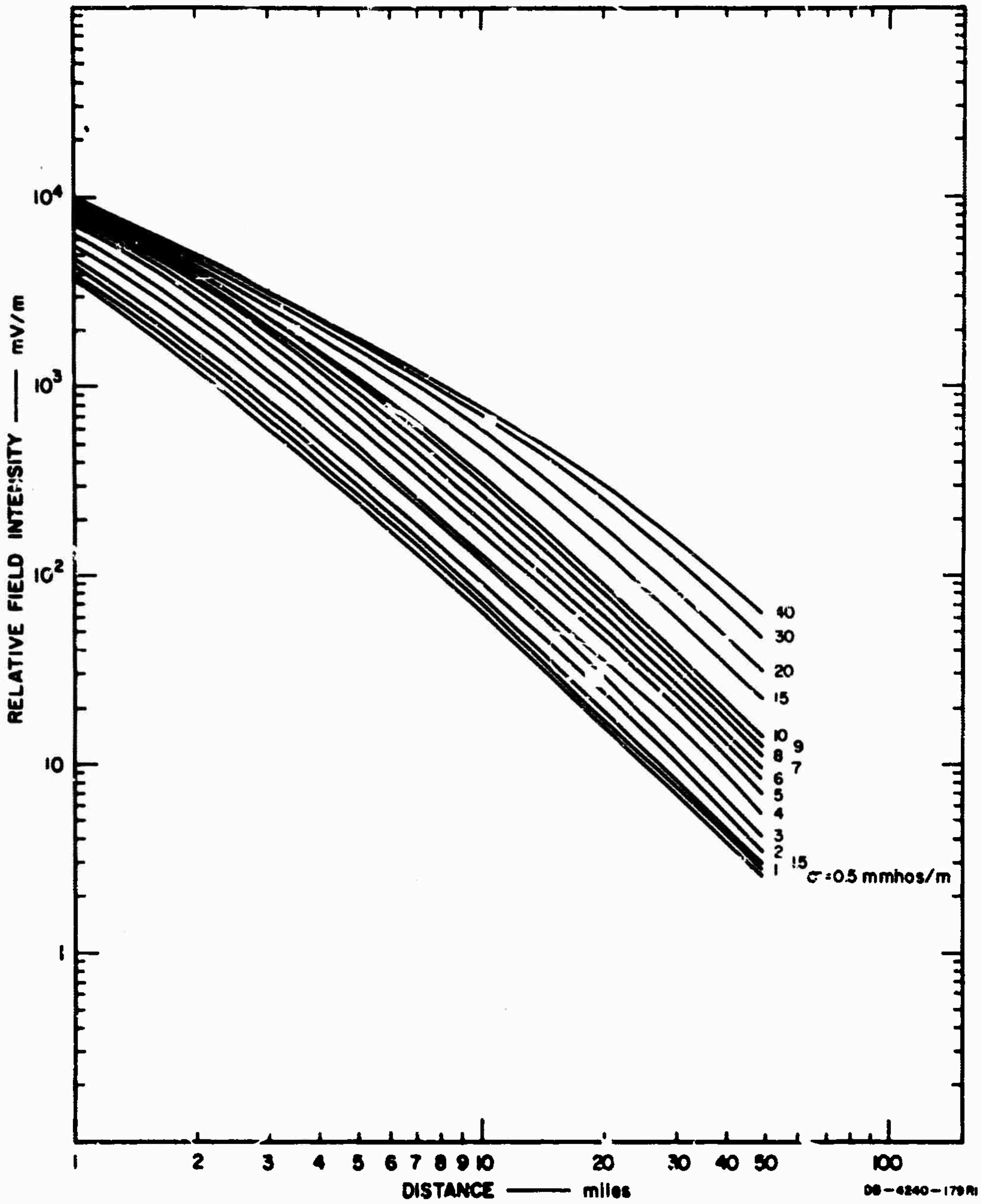

FIG. A-9 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 1455 kHz, = 30

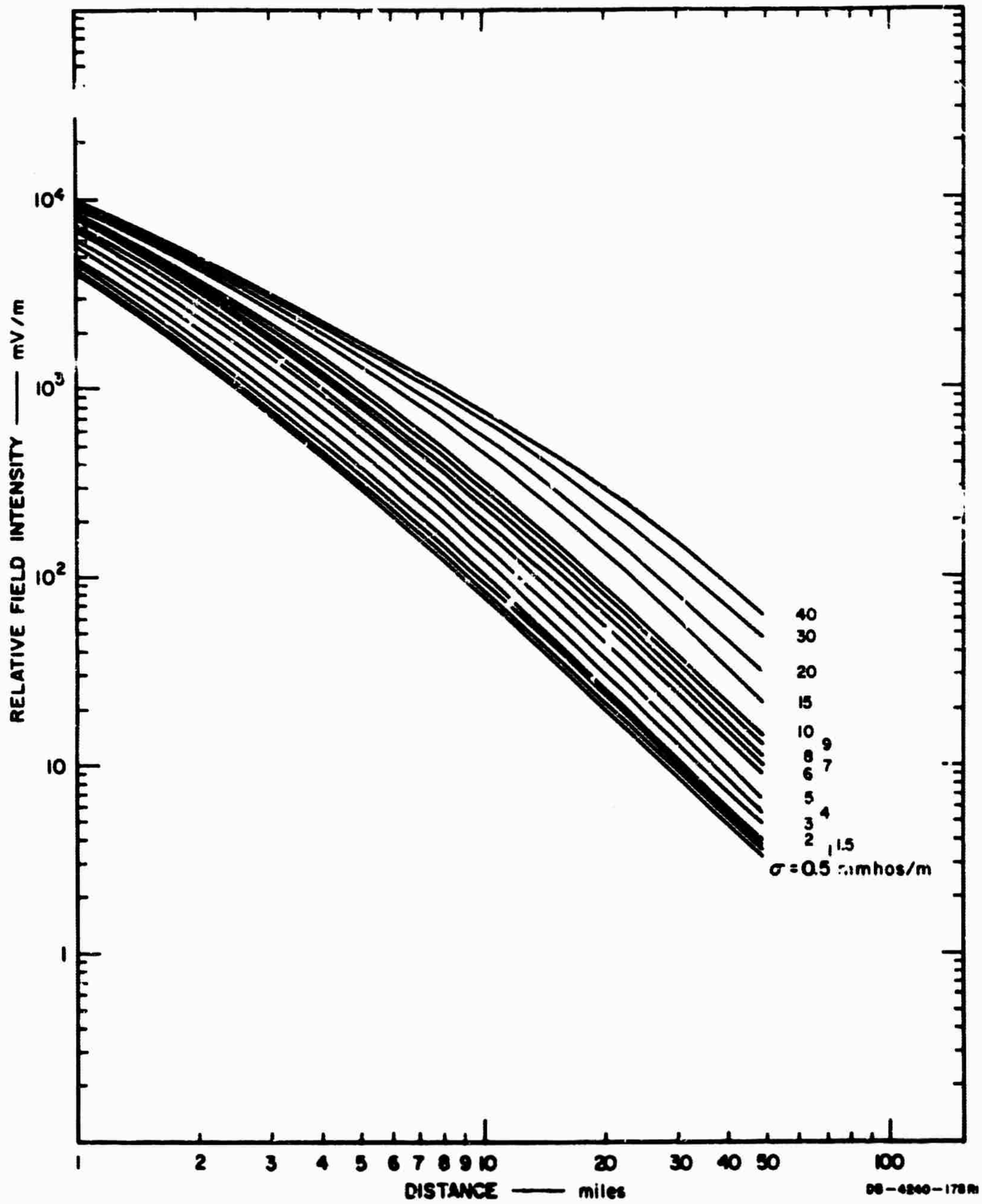

FIG. A-10 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 1455 kHz, = 40

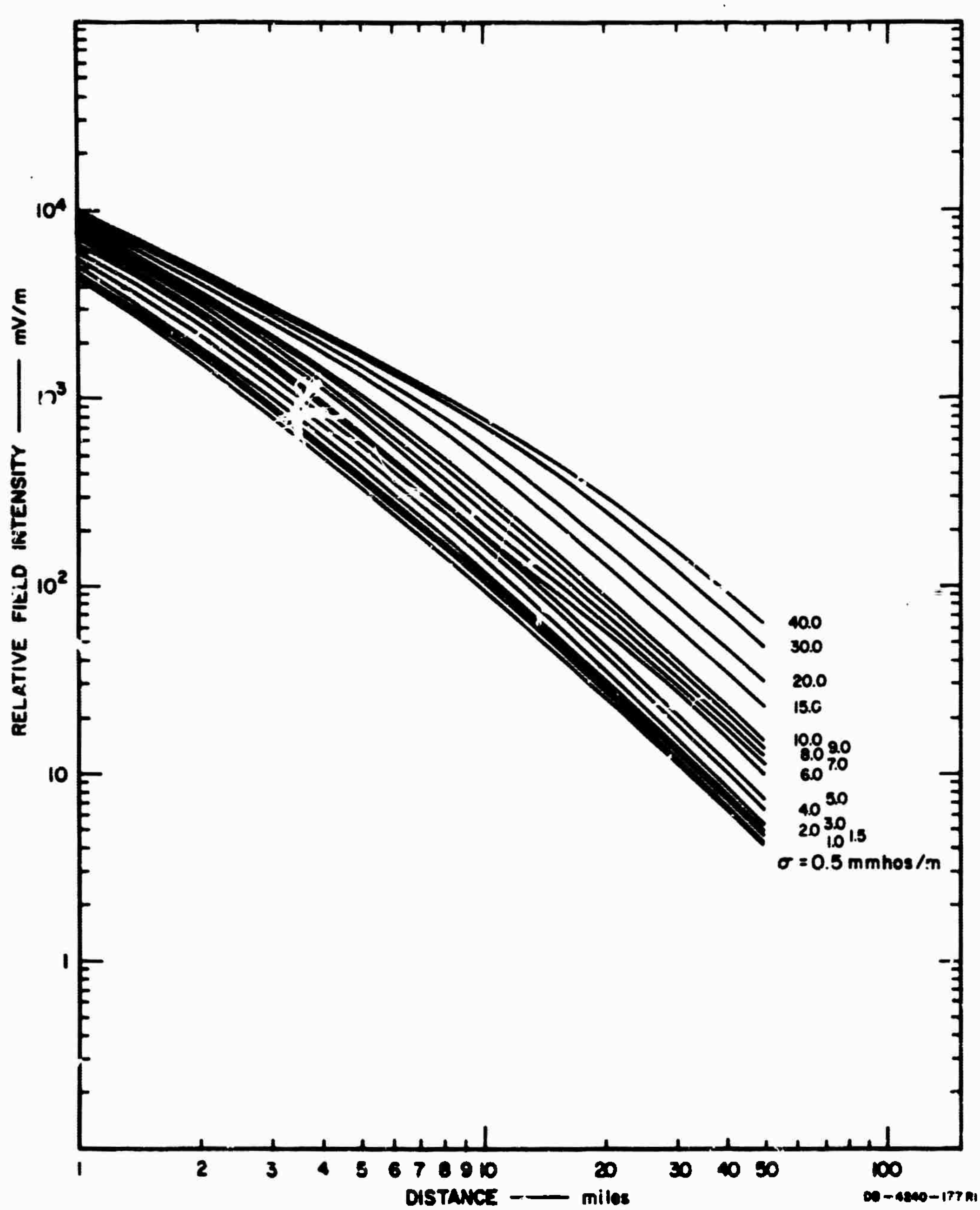

FIG. 4-11 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY – 1455 kHz, = 50

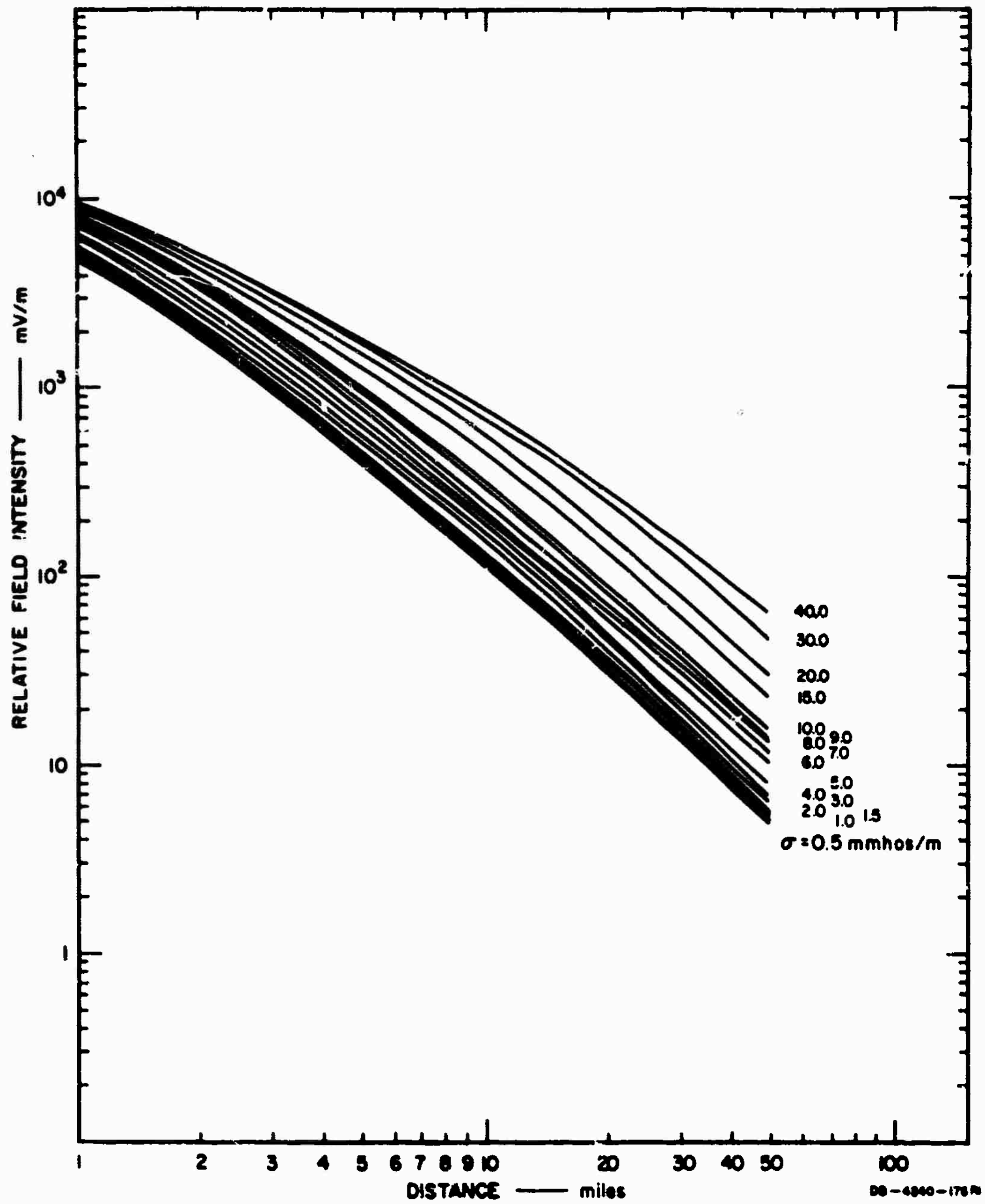

FIG. A-12 CALCULATED GROUND-WAVE FIELD INTENSITIES vs. DISTANCE, FOR VARIOUS VALUES OF GROUND CONDUCTIVITY — 1455 kHz, = 60

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Appendix B

BASIC-TRANSMISSION-LOSS MEASUREMENTS AT 820 AND 1455 kHz

Appendix B

BASIC-TRANSMISSION-LOSS MEASUREMENTS AT 820 AND 1455 kHz

1. General

Figures B-1 through B-28 show the basic transmission loss L_b along each direction from the transmitter sites computed from the measured values. The basic transmission loss L_b is the transmission loss between the isotropic transmitting and receiving antenna or the sum of the measured transmission loss L and the path antenna gain G_p of the actual transmitting and receiving antenna:

$$L_b = L + G_p \tag{B-1}$$

where

L_b = Basic transmission loss in decibels

L = Measured transmission loss in decibels

G_p = Path antenna gain

$$L = 10 \log_{10} \frac{P_r}{P_a} \tag{B-2}$$

and

$$G_p = G_t + G_r \tag{B-3}$$

P_r = Power radiated from a transmitting antenna in watts

P_a = Power available from the receiving antenna in watts

G_t = Free-space gain over an isotropic radiator of the transmitting antenna, in decibels

G_r = Free-space gain over an isotropic radiator of the receiving antenna, in decibels.

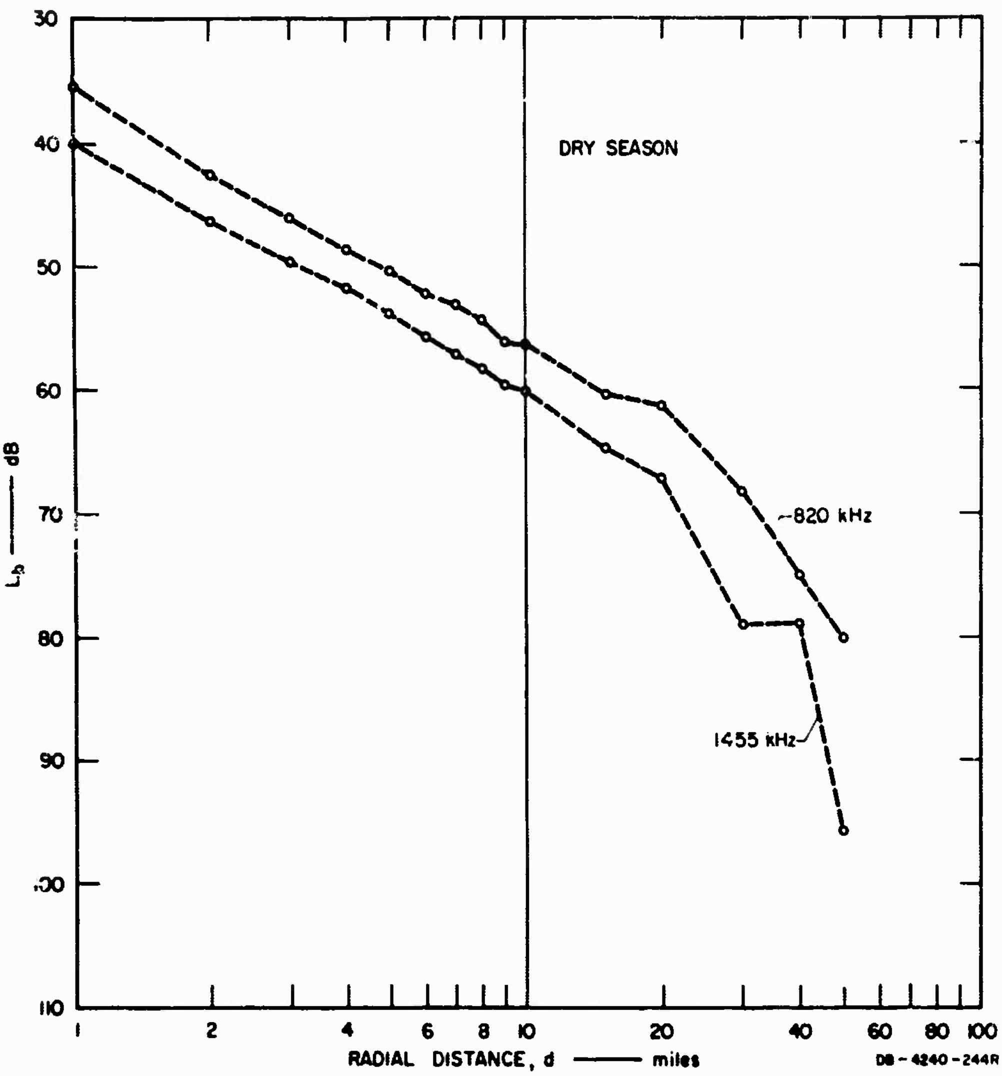

FIG. B-1 BASIC-TRANSMISSION-LOSS MEASUREMENTS — BANG PA IN TO BAN HIN KONG AND PRACHINBURI

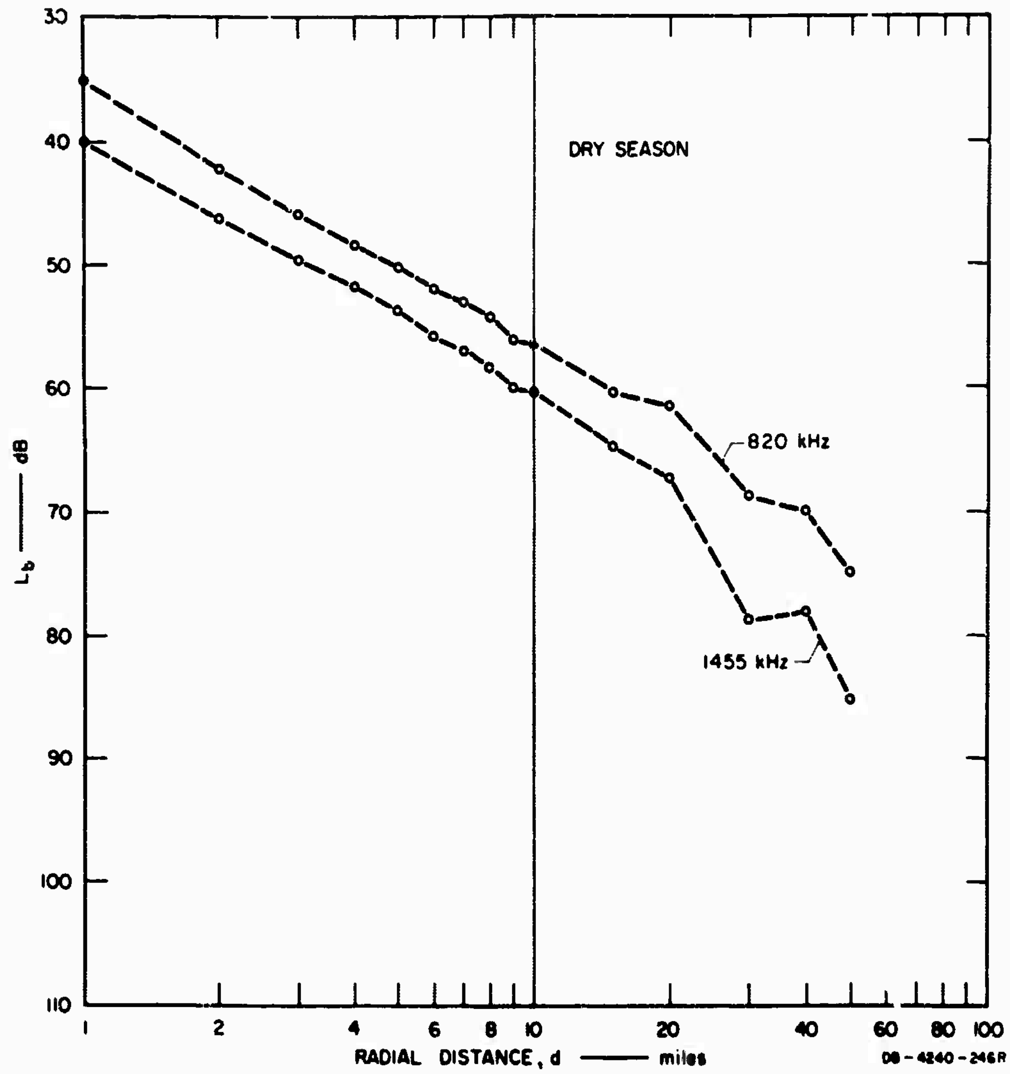

FIG. B-2 BASIC-TRANSMISSION-LOSS MEASUREMENTS — BANG PA IN TO SARABURI AND LOPBURI

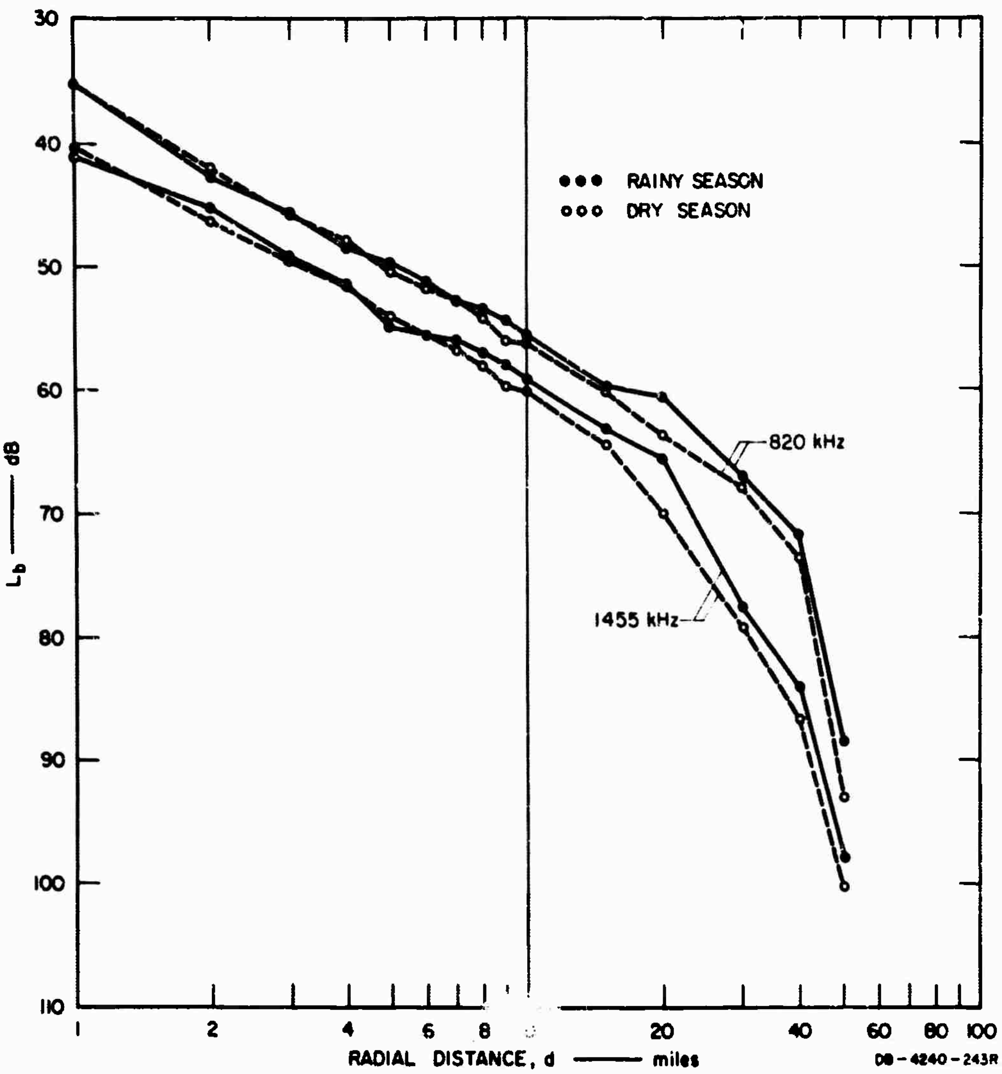

FIG. B-3 BASIC-TRANSMISSION-LOSS MEASUREMENTS — BANG PA IN TO BAN HIN KONG AND NAKHON RATCHASIMA

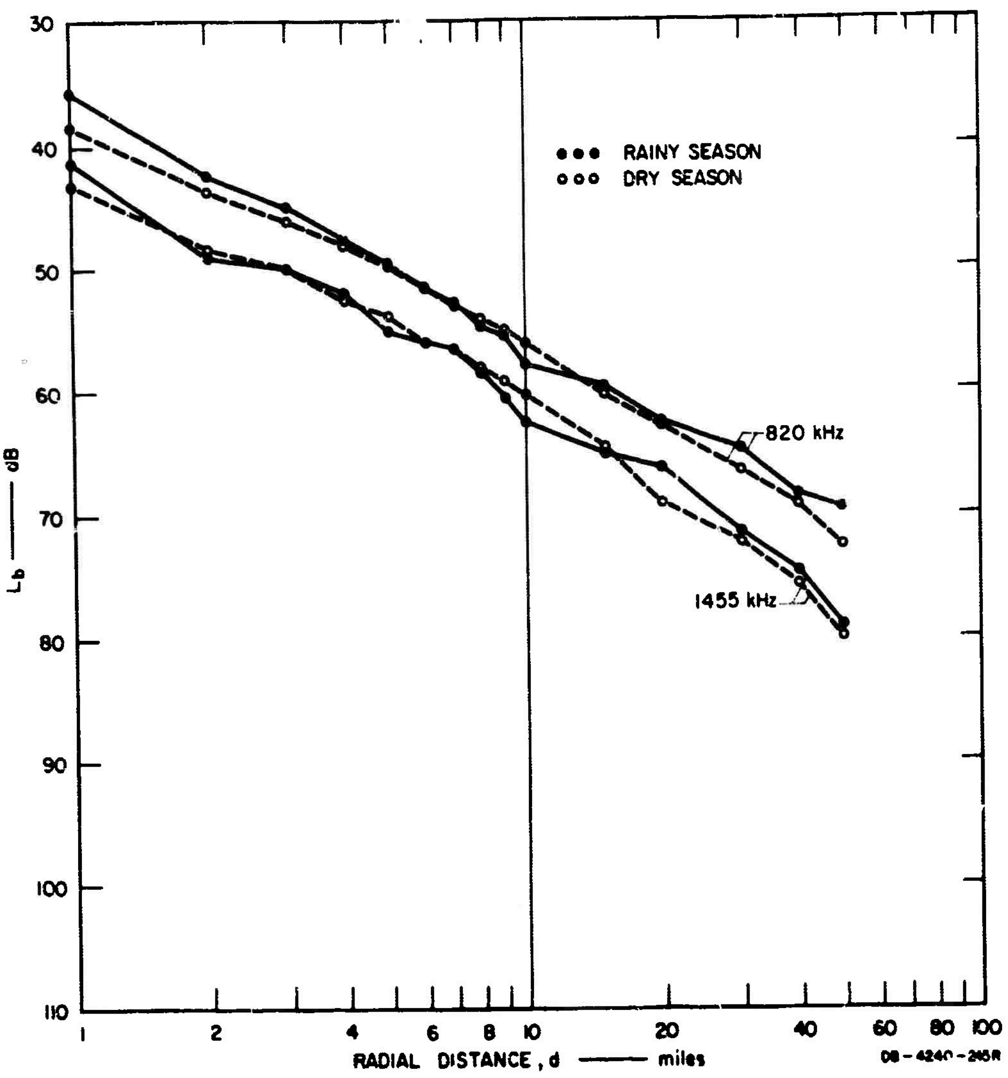

FIG. B-4 BASIC-TRANSMISSION-LOSS MEASUREMENTS — BANG PA IN TO MINBURI AND CHACHOENSAO

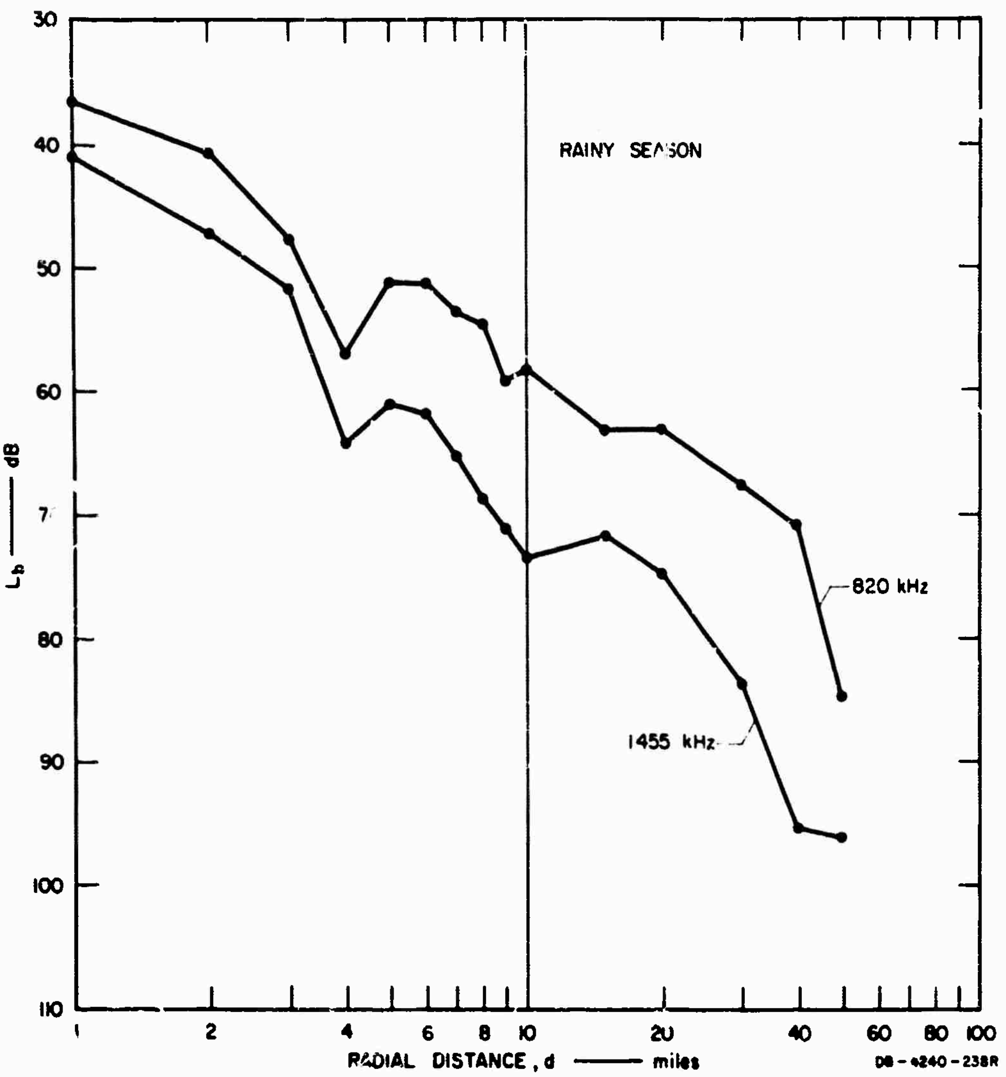

FIG. B-5 BASIC-TRANSMISSION-LOSS MEASUREMENTS — BAN PONG TO PETCHABURI

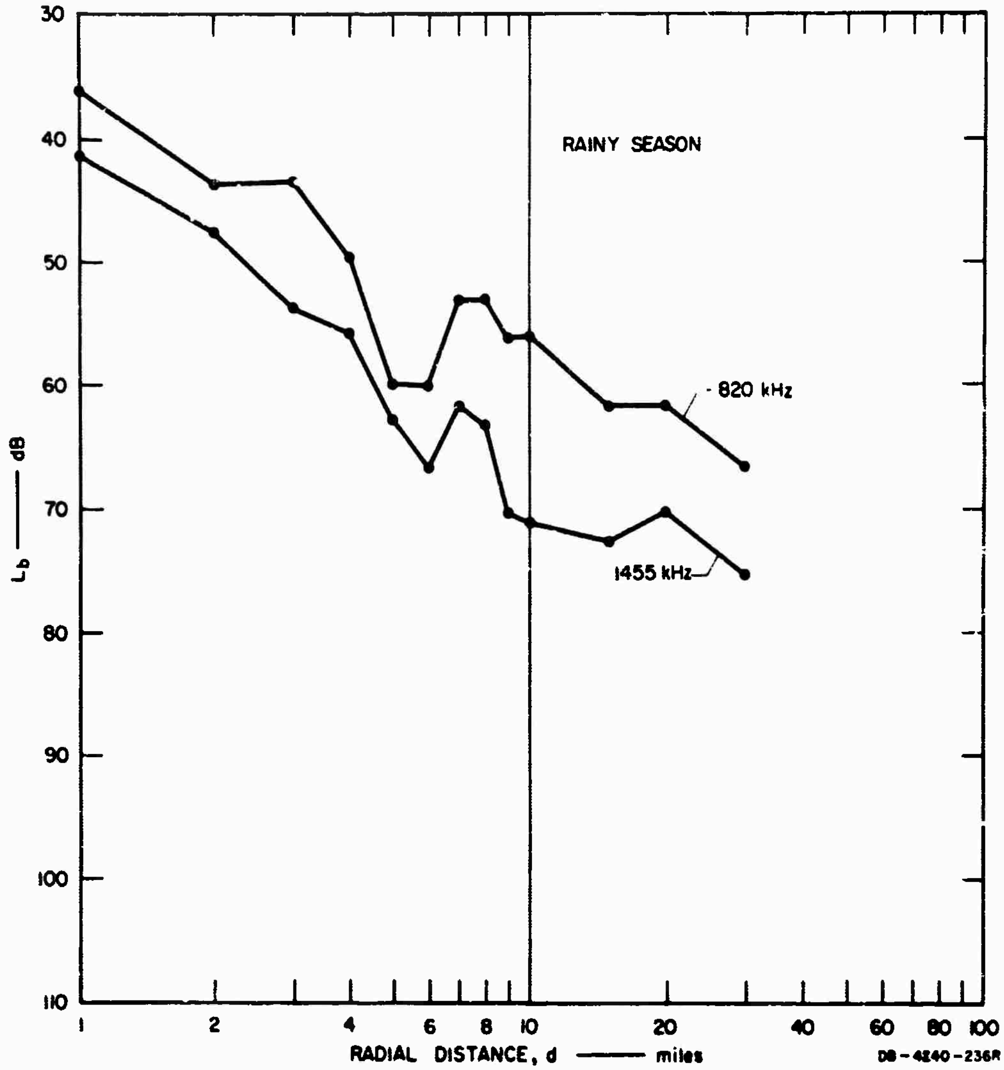

FIG. B-6 BASIC-TRANSMISSION-LOSS MEASUREMENTS — BAN PONG TO BANGKOK

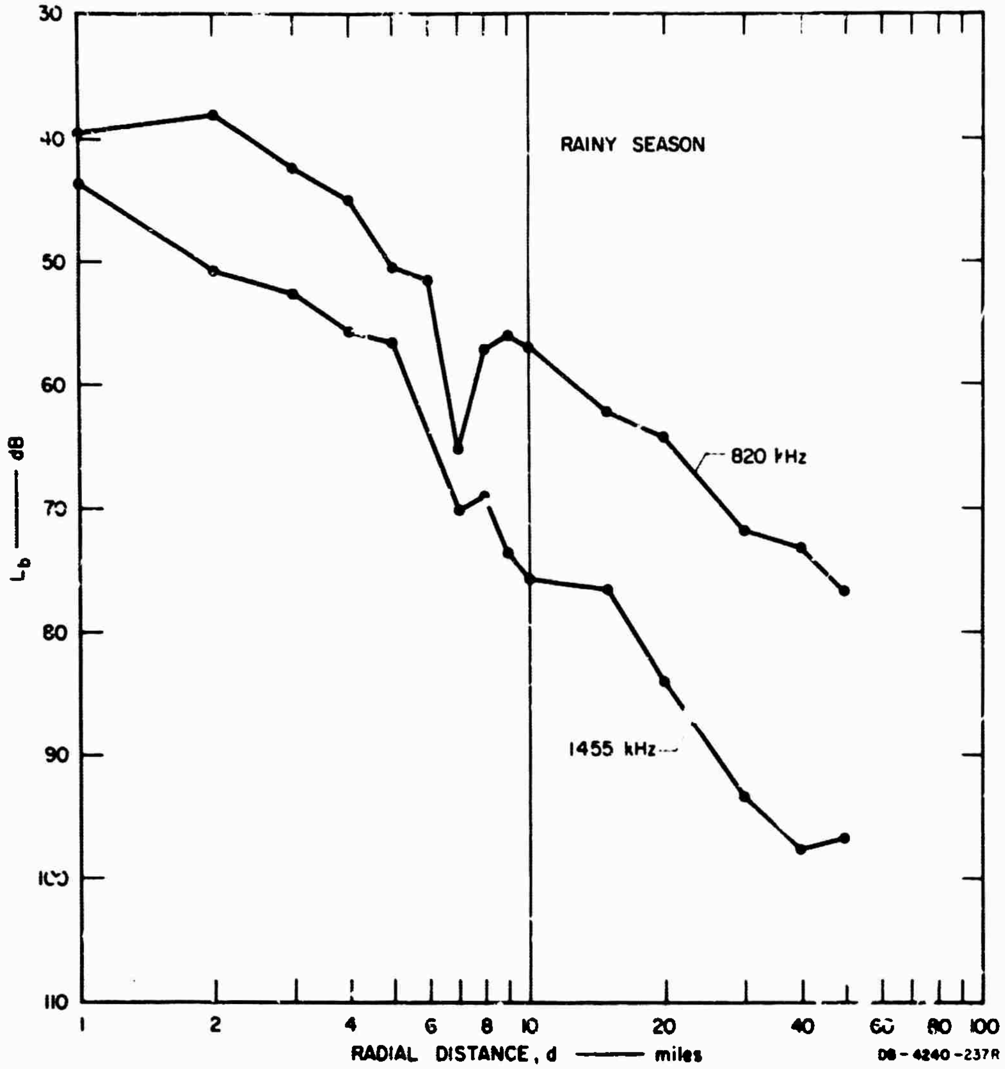

FIG. B-7 BASIC-TRANSMISSION-LOSS MEASUREMENTS — BAN PONG TO KANCHANABURI AND SUPHAN BURI

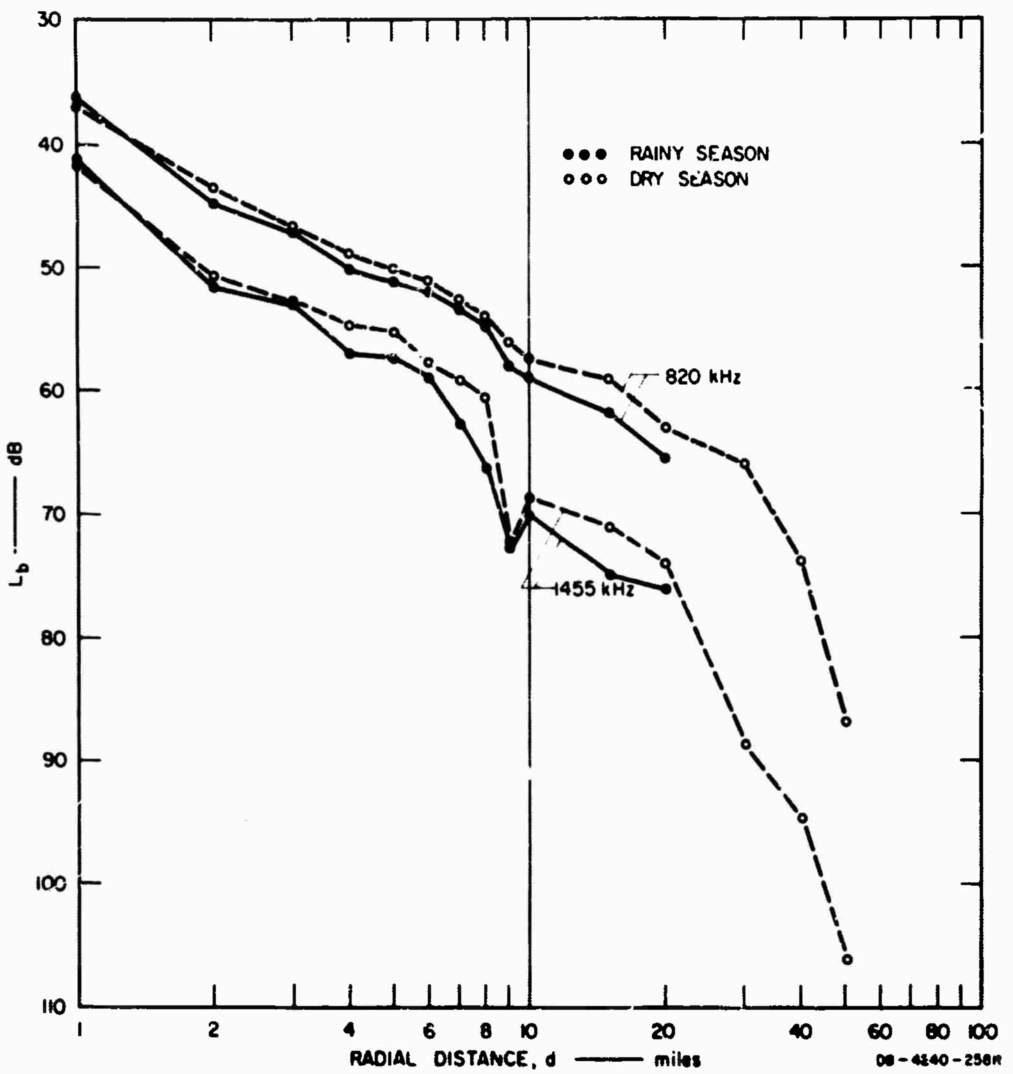

FIG. B-8 BASIC-TRANSMISSION-LOSS MEASUREMENTS — NAKHON RATCHASIMA TO SARAB 'RI

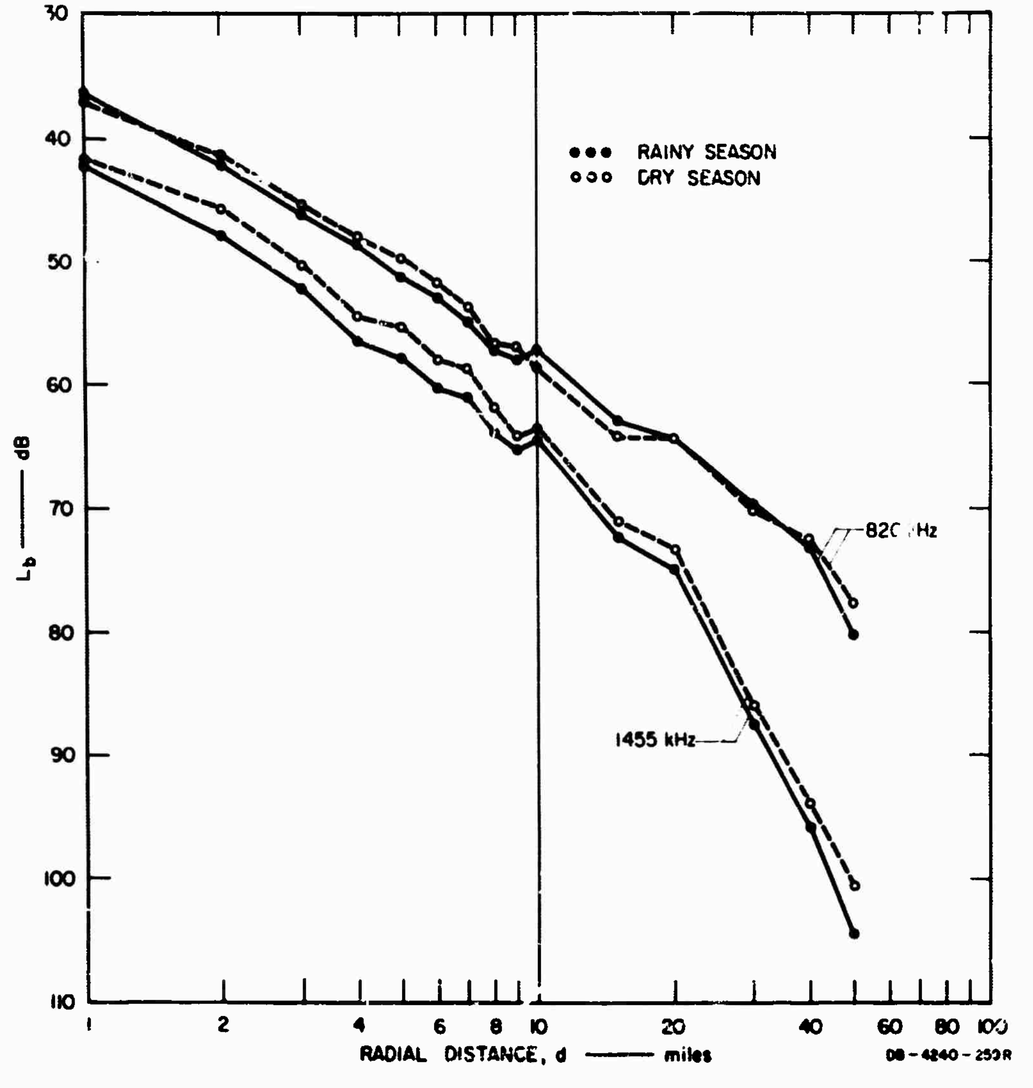

FIG. B-9 BASIC-TRANSMISSION-LOSS MEASUREMENTS — NAKHON RATCHASIMA TO CHAIYAPHUM

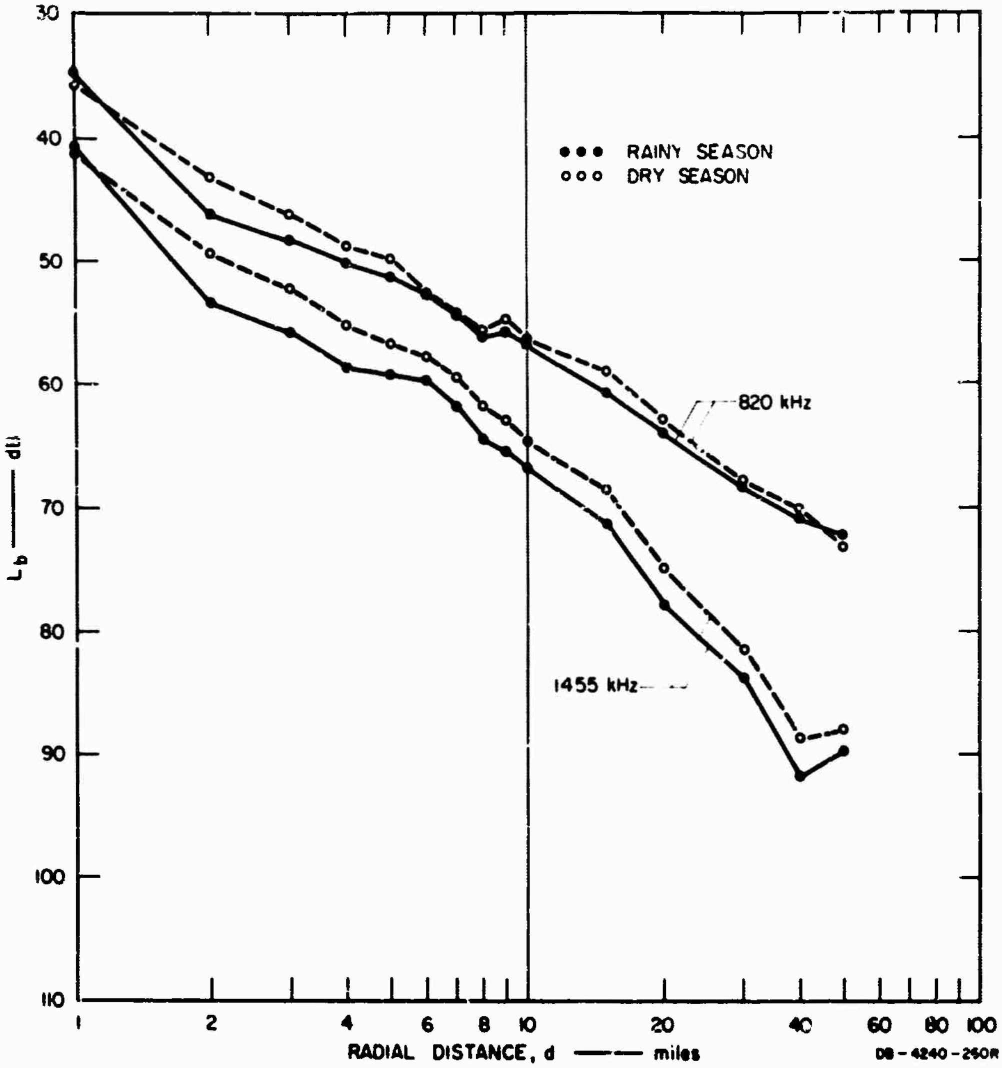

FIG. B-10 BASIC-TRANSMISSION-LOSS MEASUREMENTS — NAKHON RATCHASIMA TO KHON KAEN

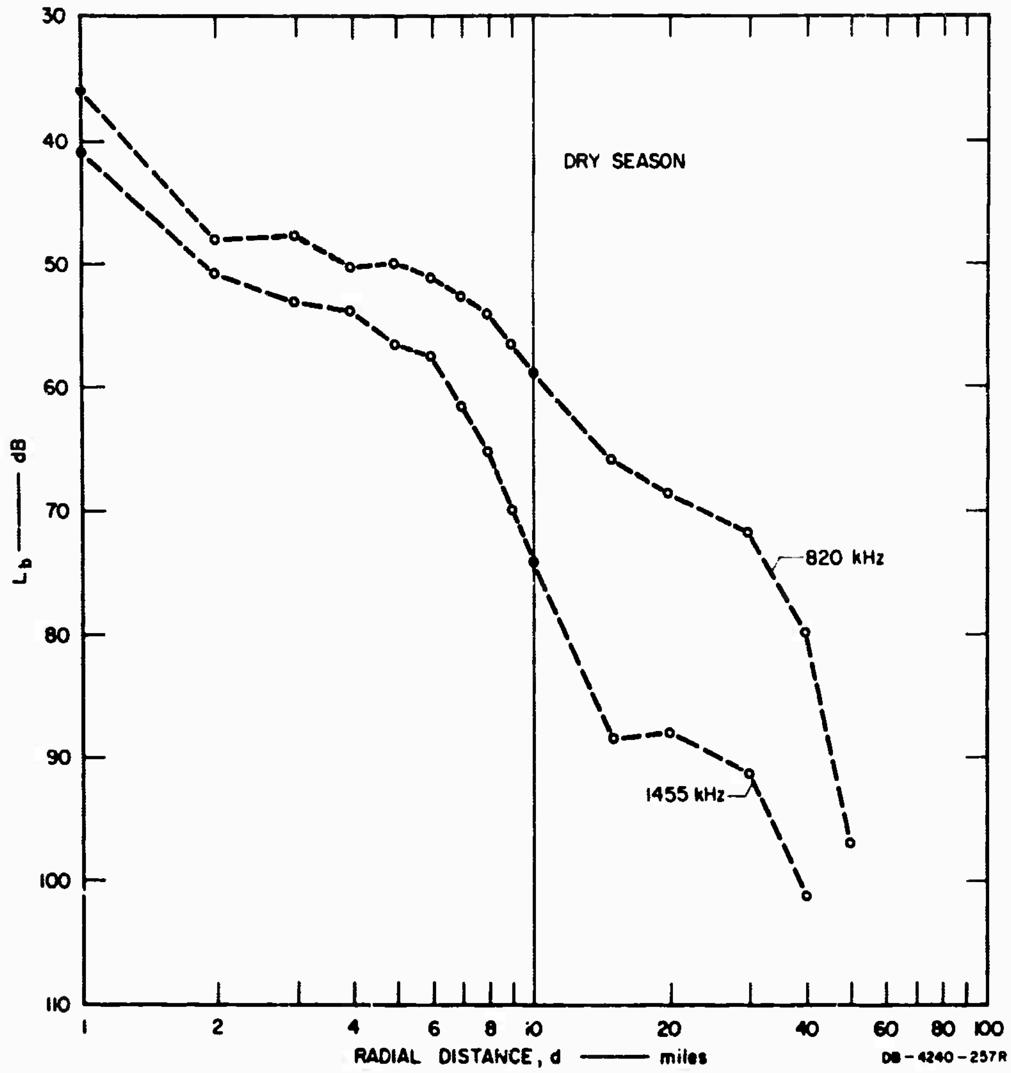

FIG. B-11 BASIC-TRANSMISSION-LOSS MEASUREMENTS — NAKHON RATCHASIMA TO BAN NONG PLING AND BAN WANG MI

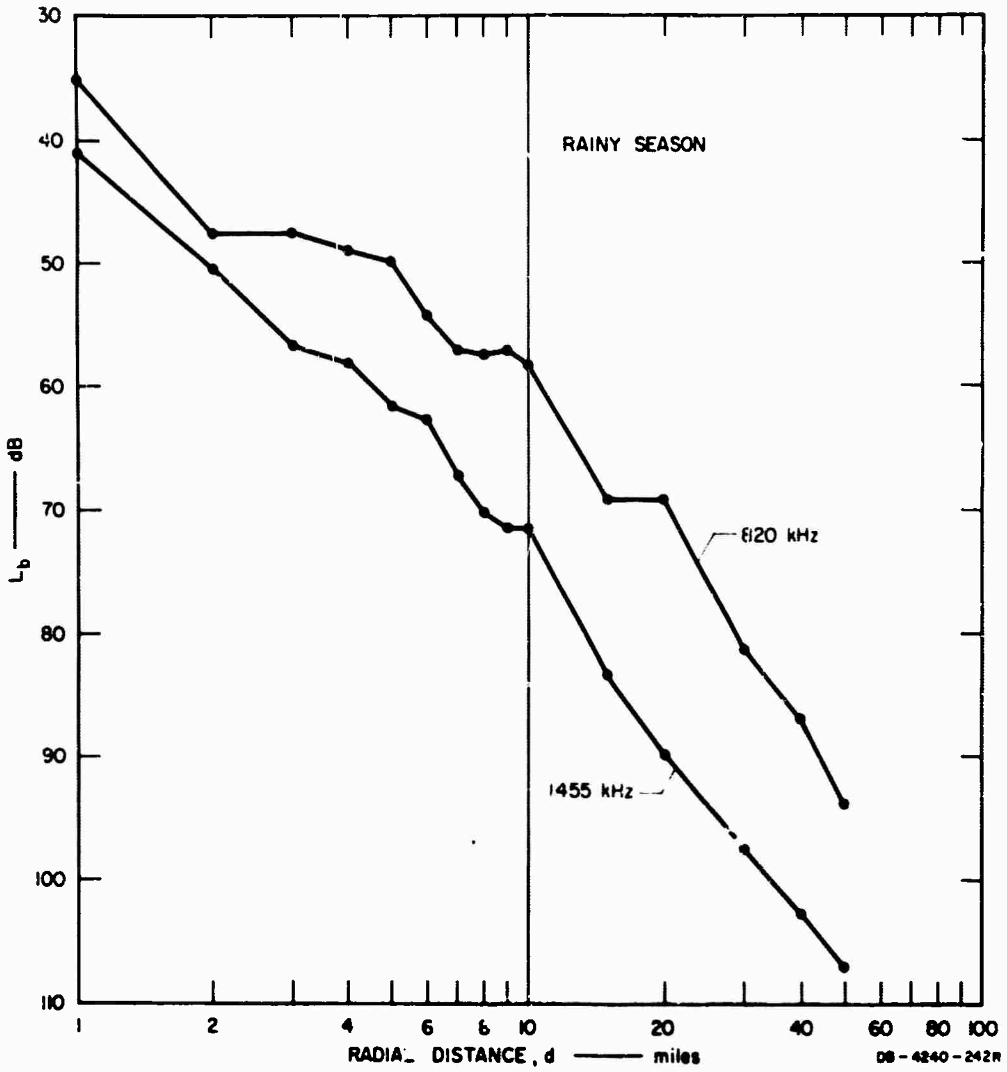

FIG. B-12 BASIC-TRANSMISSION-LOSS MEASUREMENTS — UDON TO SAKHON

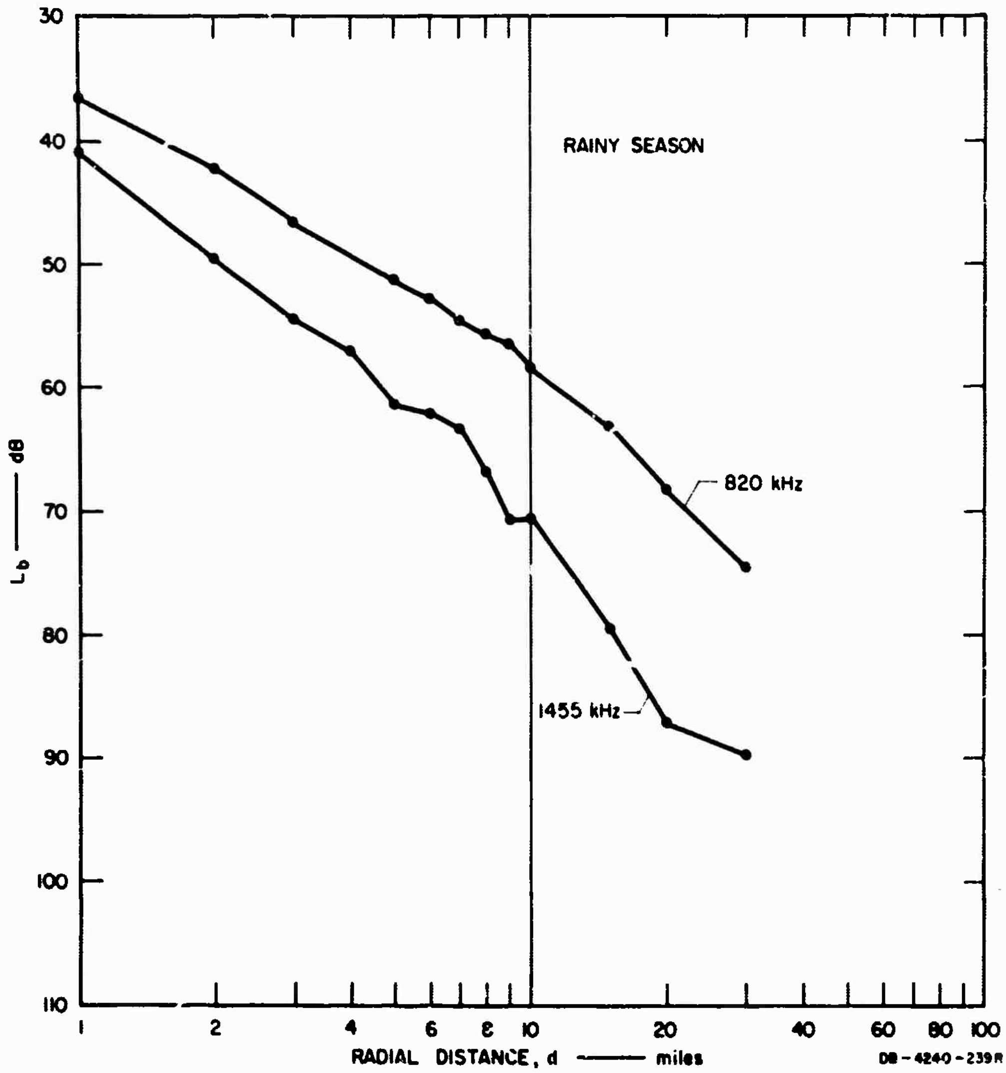

FIG. B-13 BASIC-TRANSMISSION-LOSS MEASUREMENTS — UDON TO NONG KHAI

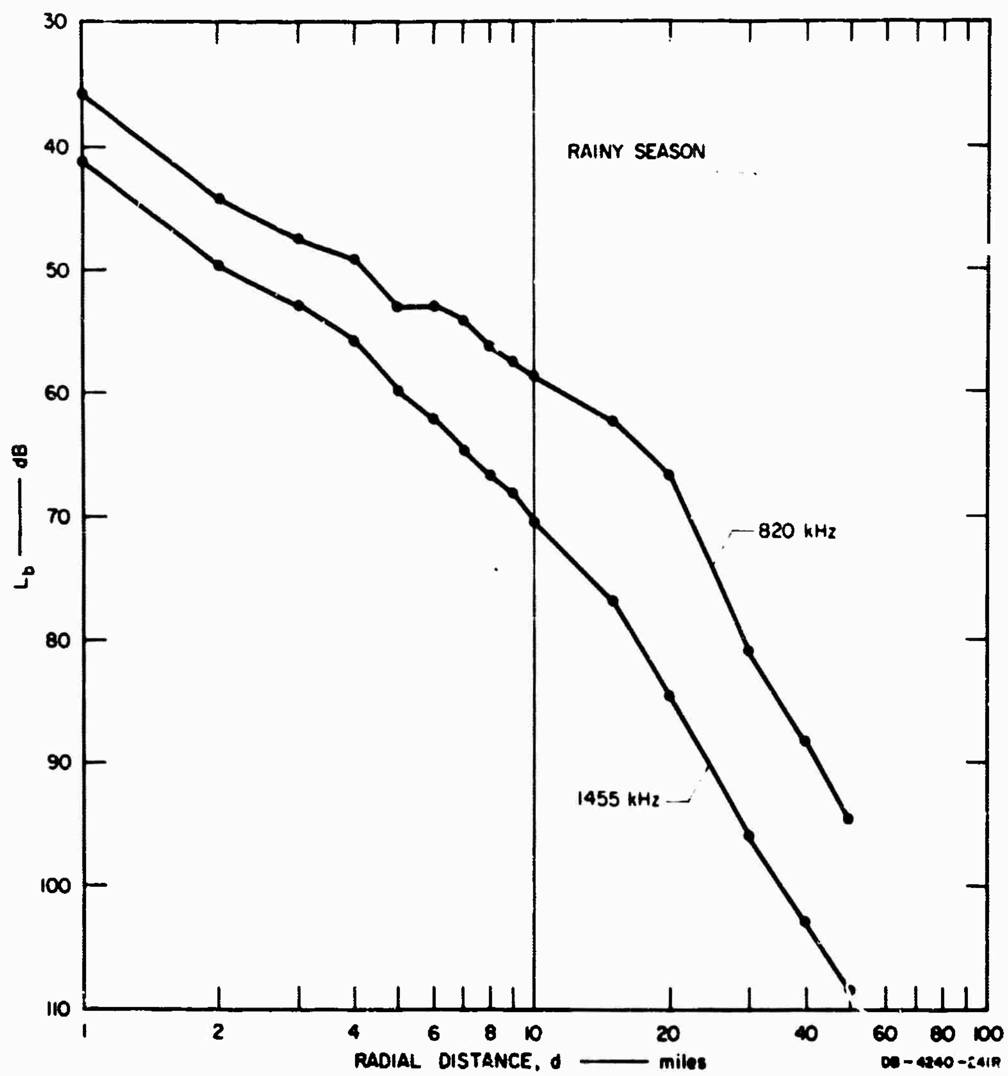

FIG. B-14 BASIC-TRANSMISSION-LOSS MEASUREMENTS — UDON TO KHON KAEN

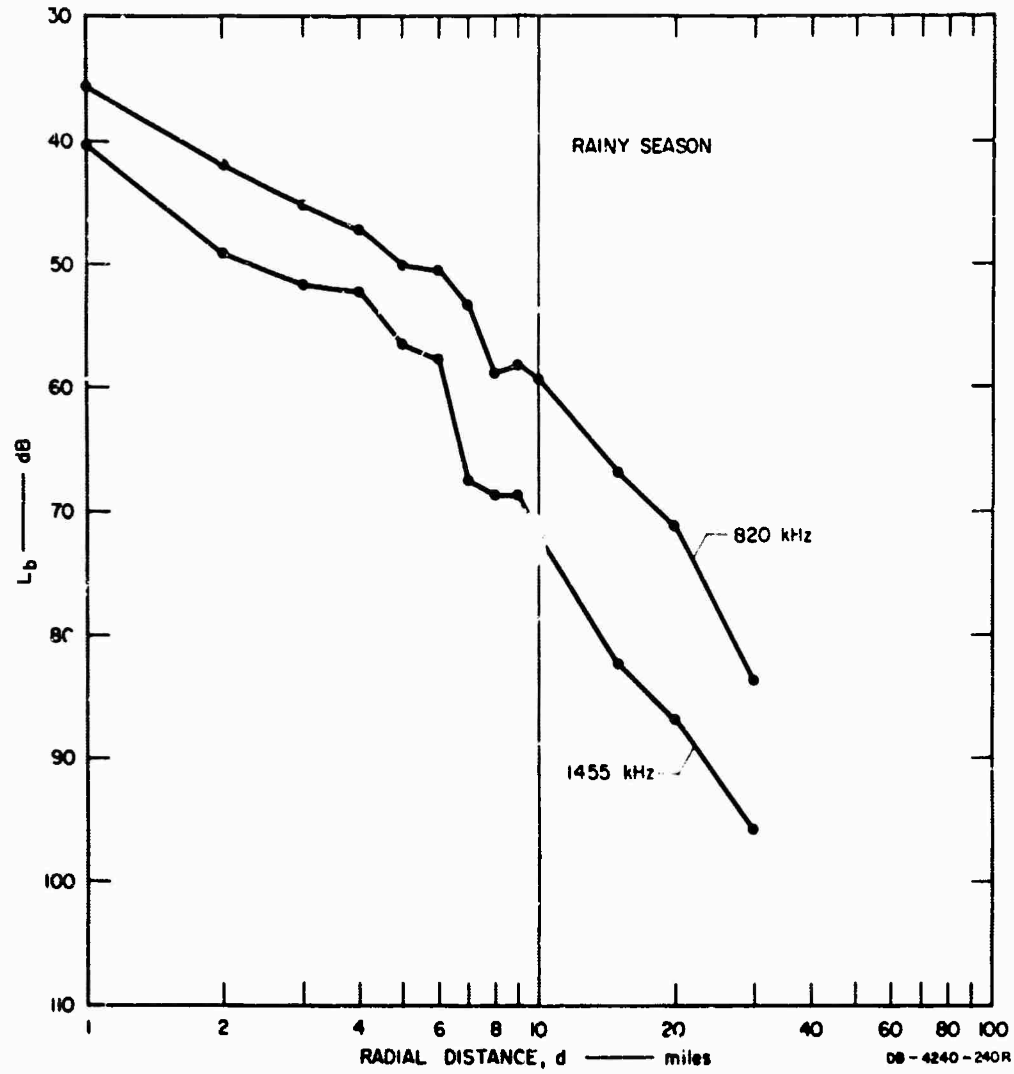

FIG. B-15 BASIC-TRANSMISSION-LOSS MEASUREMENTS — UDON TO NONG BUA LAM PHU

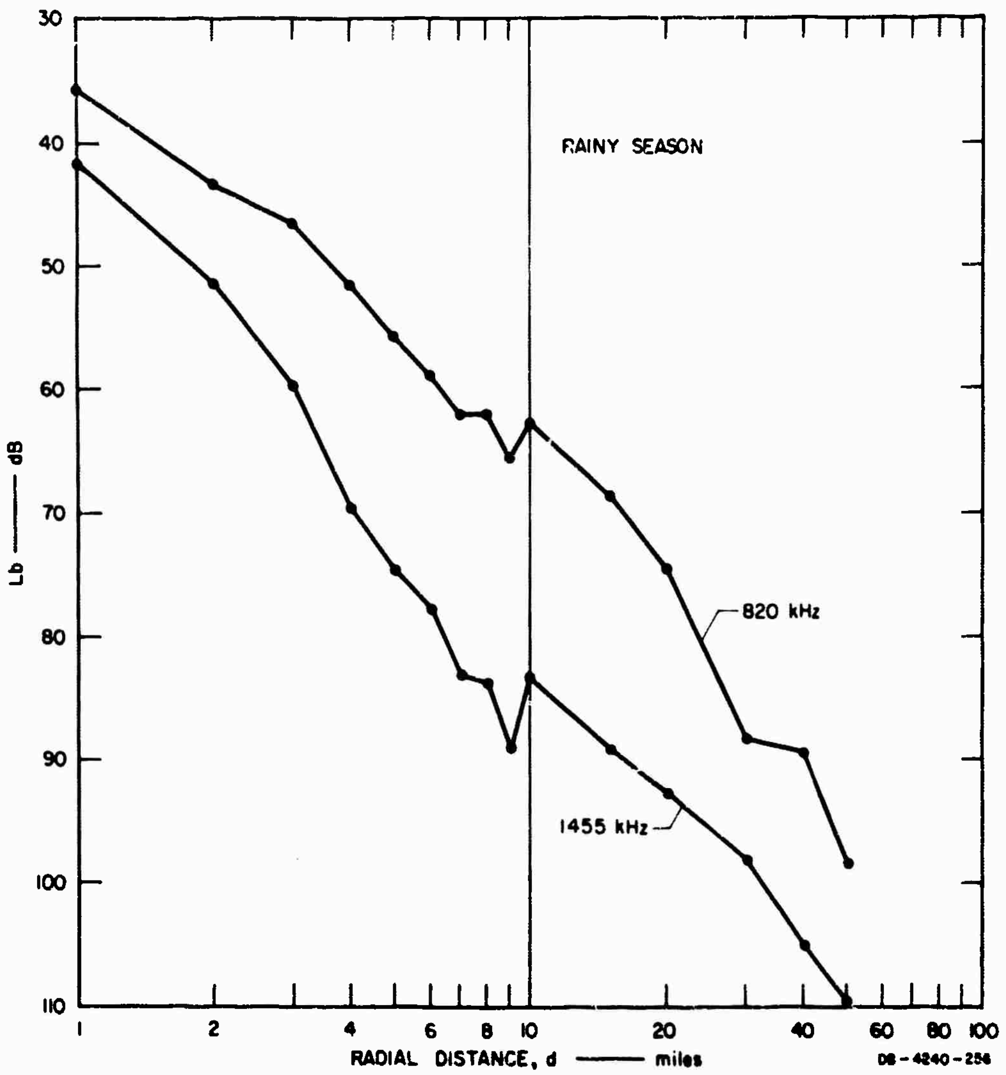

FIG. B-16 BASIC-TRANSMISSION-LOSS MEASUREMENTS — SAKHON TO UDON

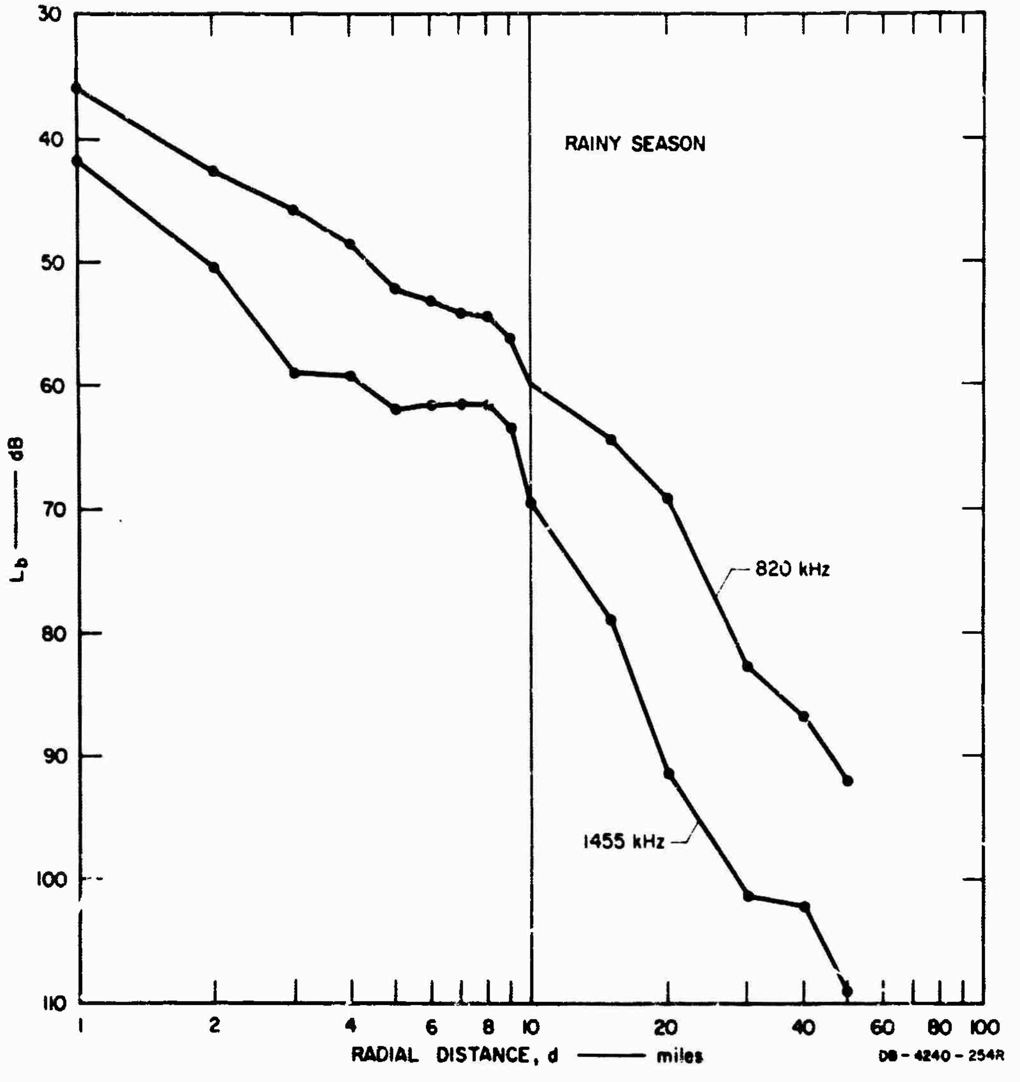

FIG. B-17 BASIC-TRANSMISSION-LOSS MEASUREMENTS — SAKHON TO NAKHON PHANOM

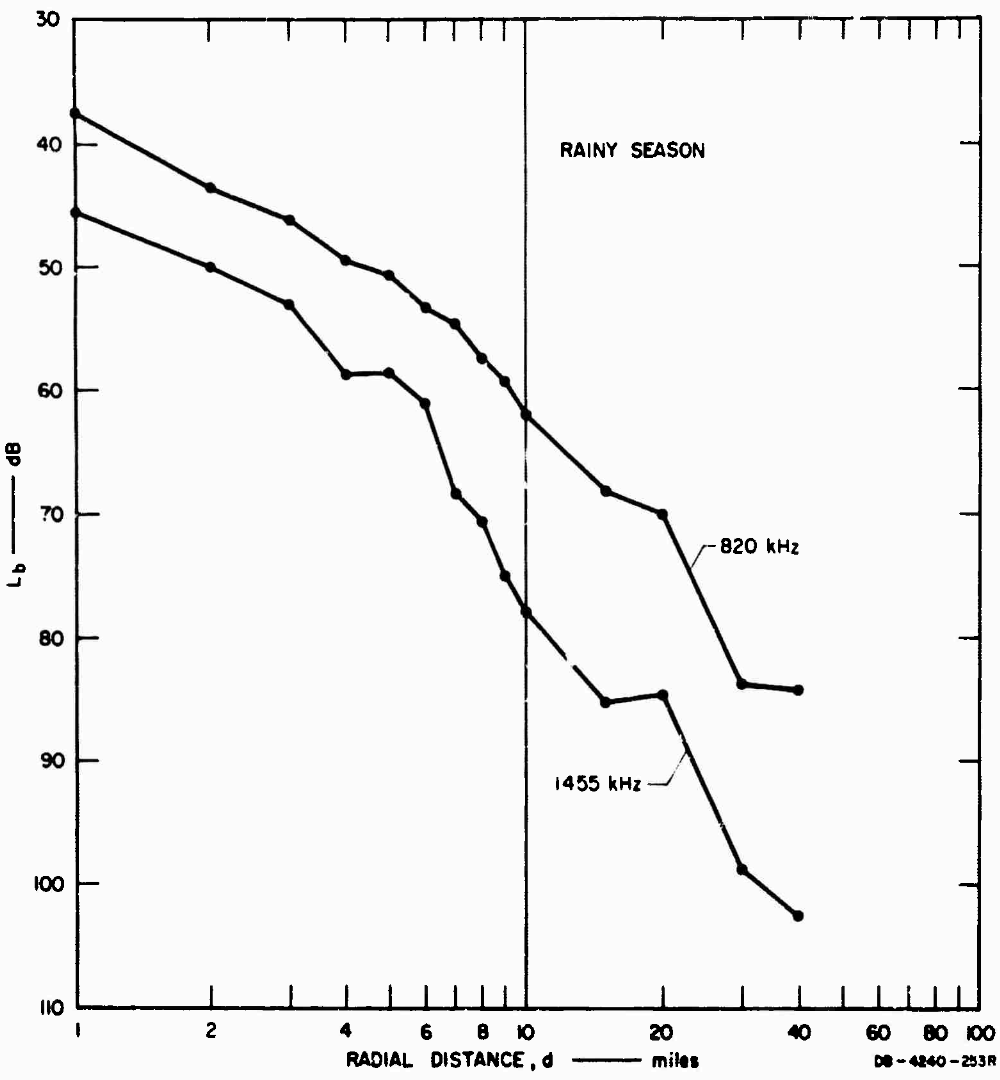

FIG. B-18 BASIC-TRANSMISSION-LOSS MEASUREMENTS — SAKHON TO TARD PHANOM

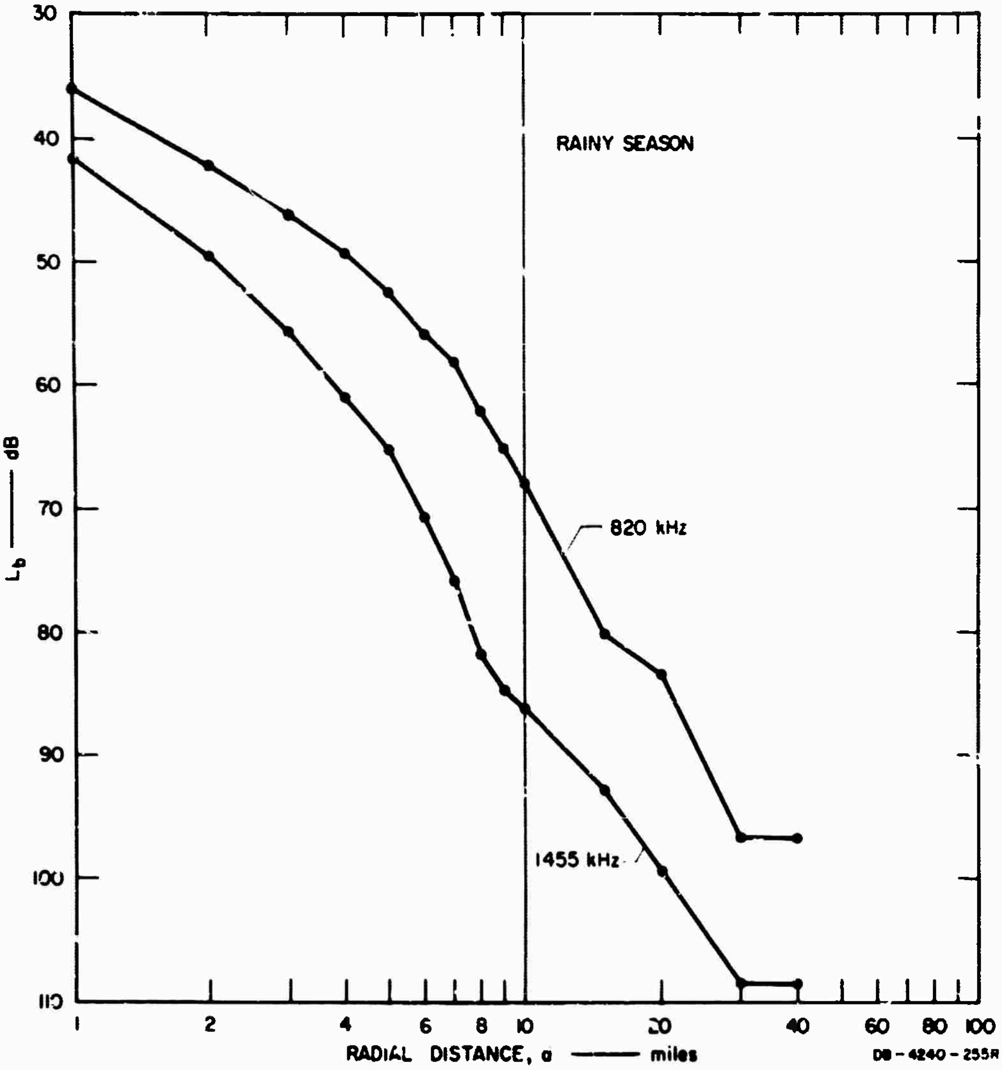

FIG. B-19 BASIC-TRANSMISSION-LOSS MEASUREMENTS — SAKHON TO KALASIN

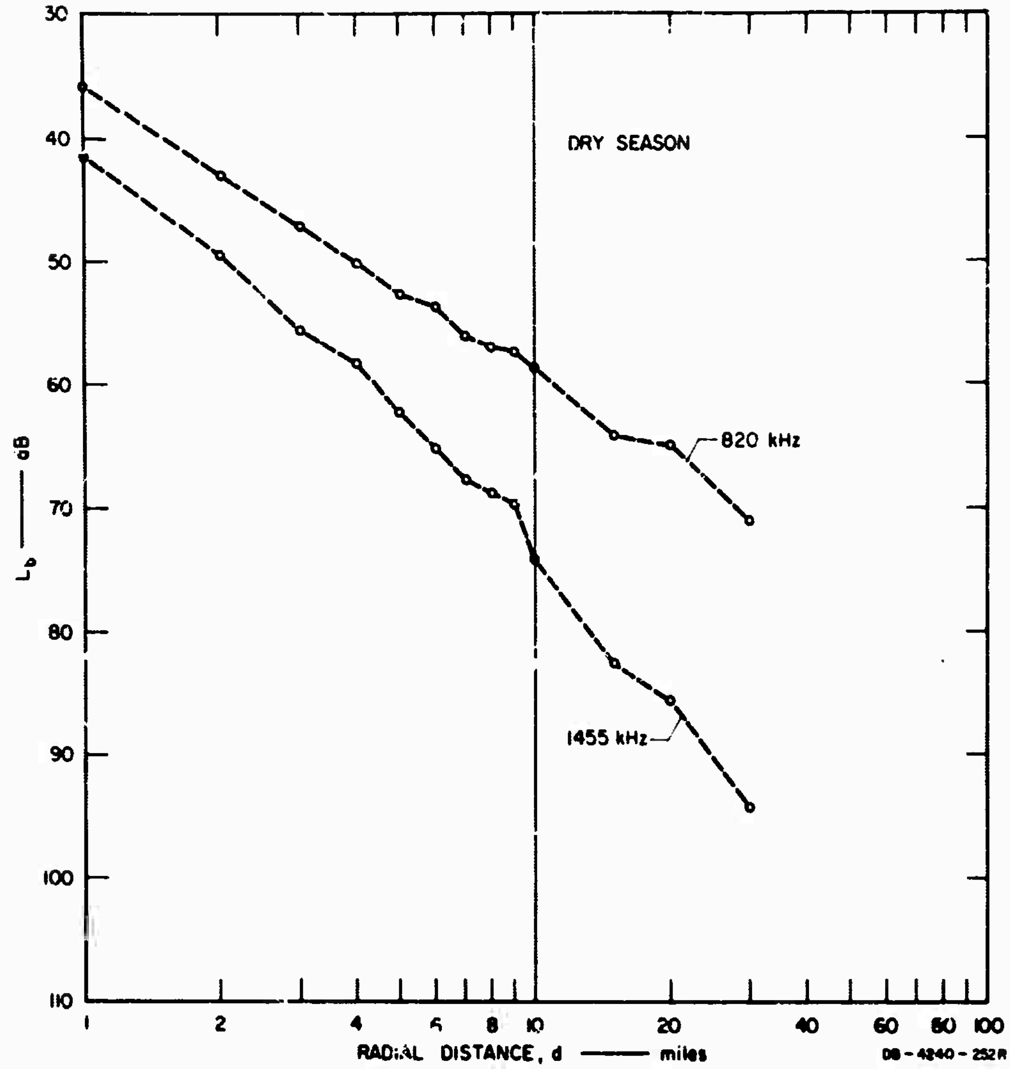

FIG. B-20 BASIC-TRANSMISSION-LOSS MEASUREMENTS — ROI ET TO SUWANNAPHUM AND SURIN

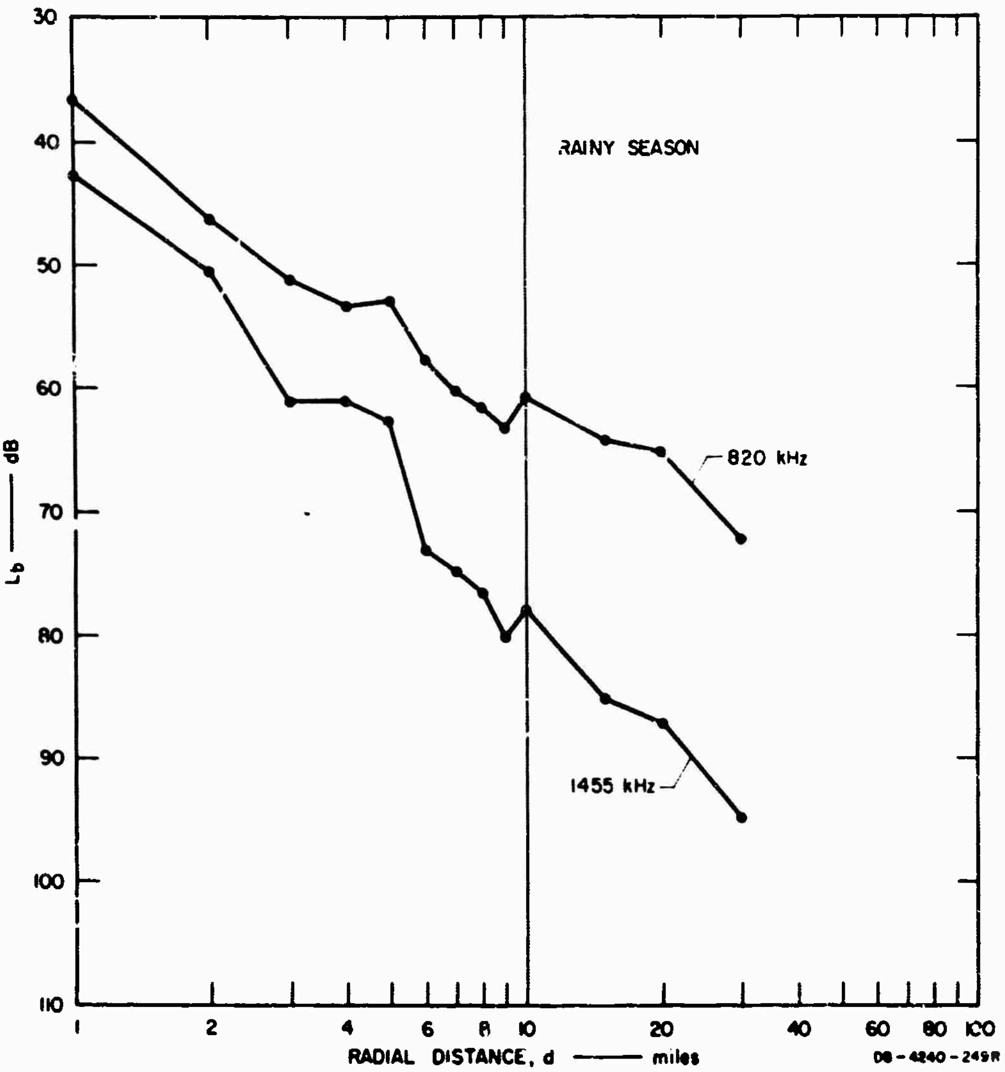

FIG. B-21 BASIC-TRANSMISSION-LOSS MEASUREMENTS — ROI ET TO CHATURAPHAK PHIMAN AND KASET WISAI

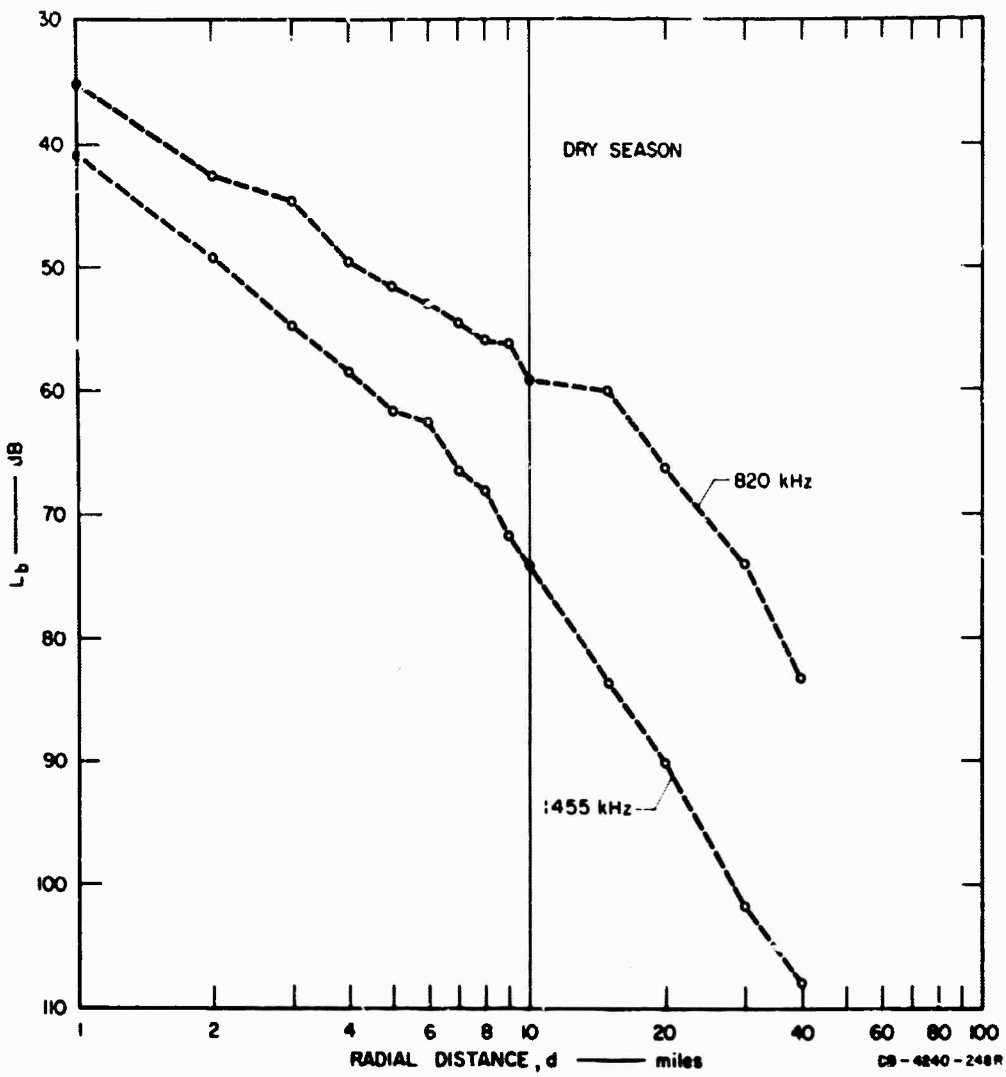

FIG. B-22 BASIC-TRANSMISSION-LOSS MEASUREMENTS — ROI ET TO MAHA SARAKHAM AND BAN PHAI

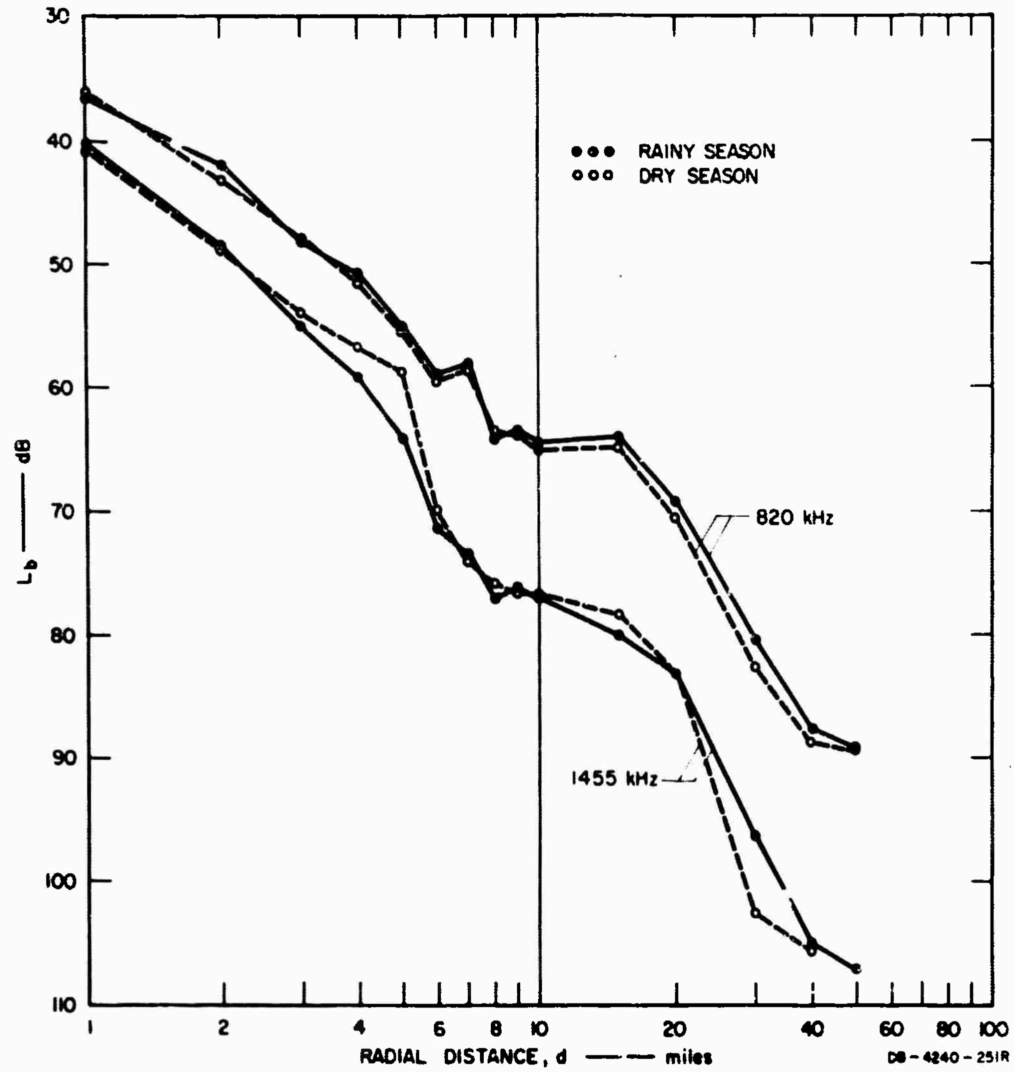

FIG. B-23 BASIC-TRANSMISSION-LOSS MEASUREMENTS — ROI ET TO YASOTHON AND UBON

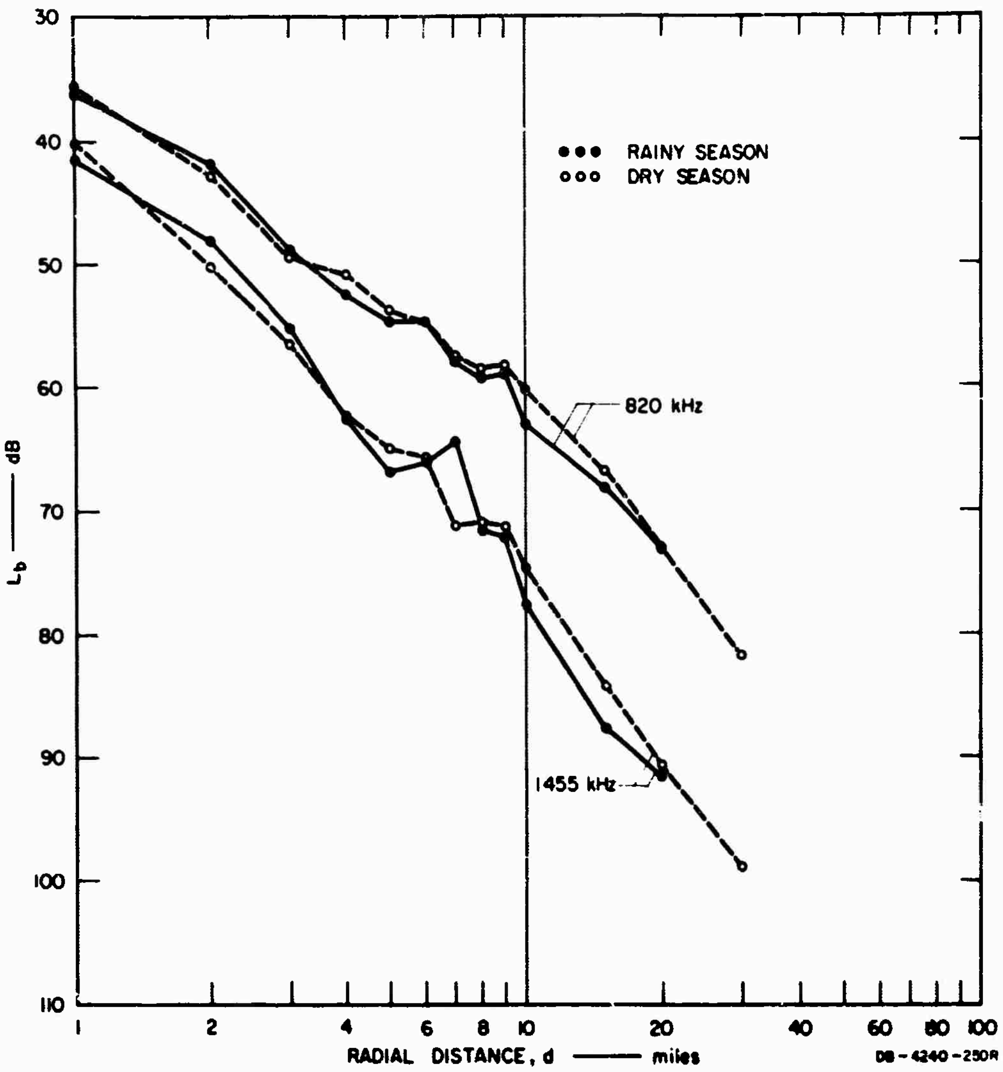

FIG. B-24 BASIC-TRANSMISSION-LOSS MEASUREMENTS — ROI ET TO YASOTHON AND PHAHOM PHRAI

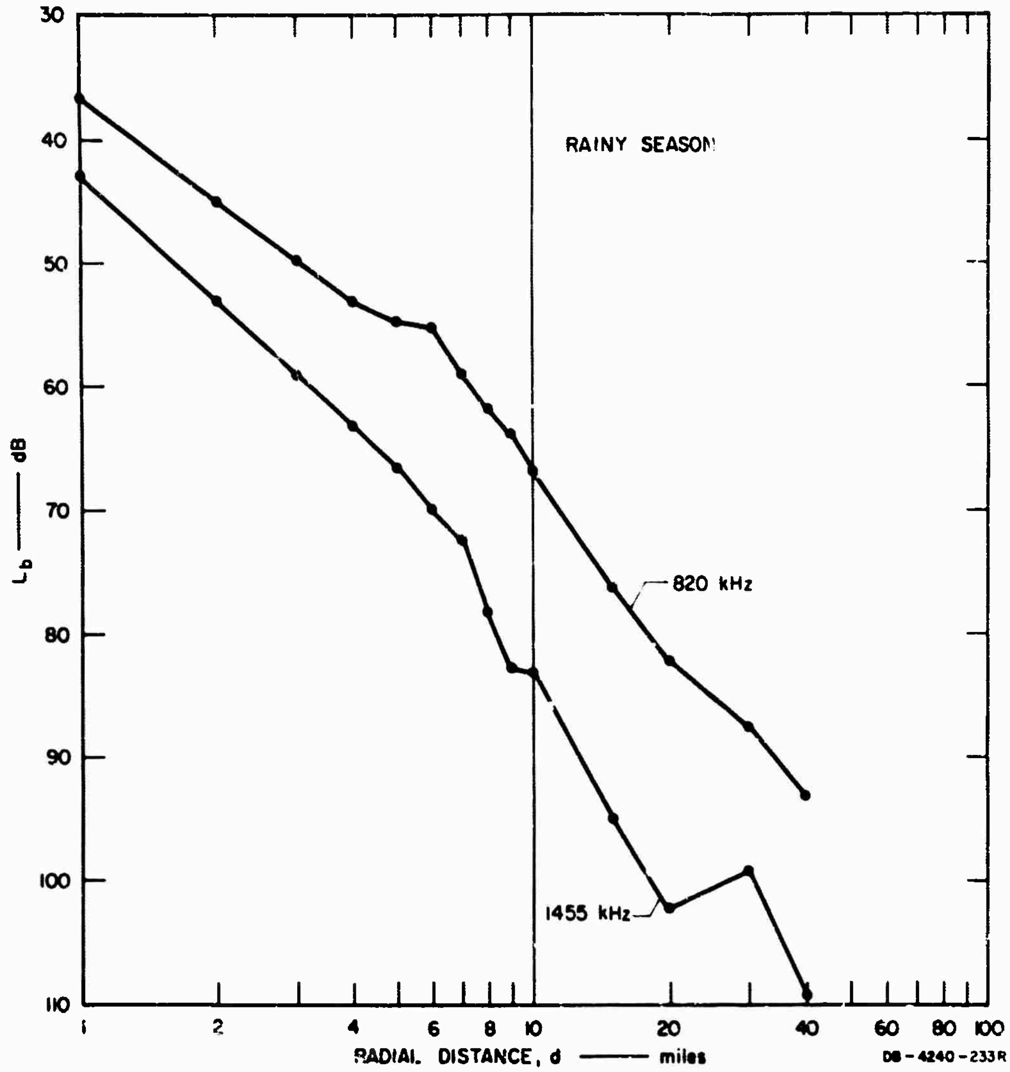

FIG. B-25 BASIC-TRANSMISSION-LOSS MEASUREMENTS — UBON TO PHIBUN MANGSAHAN

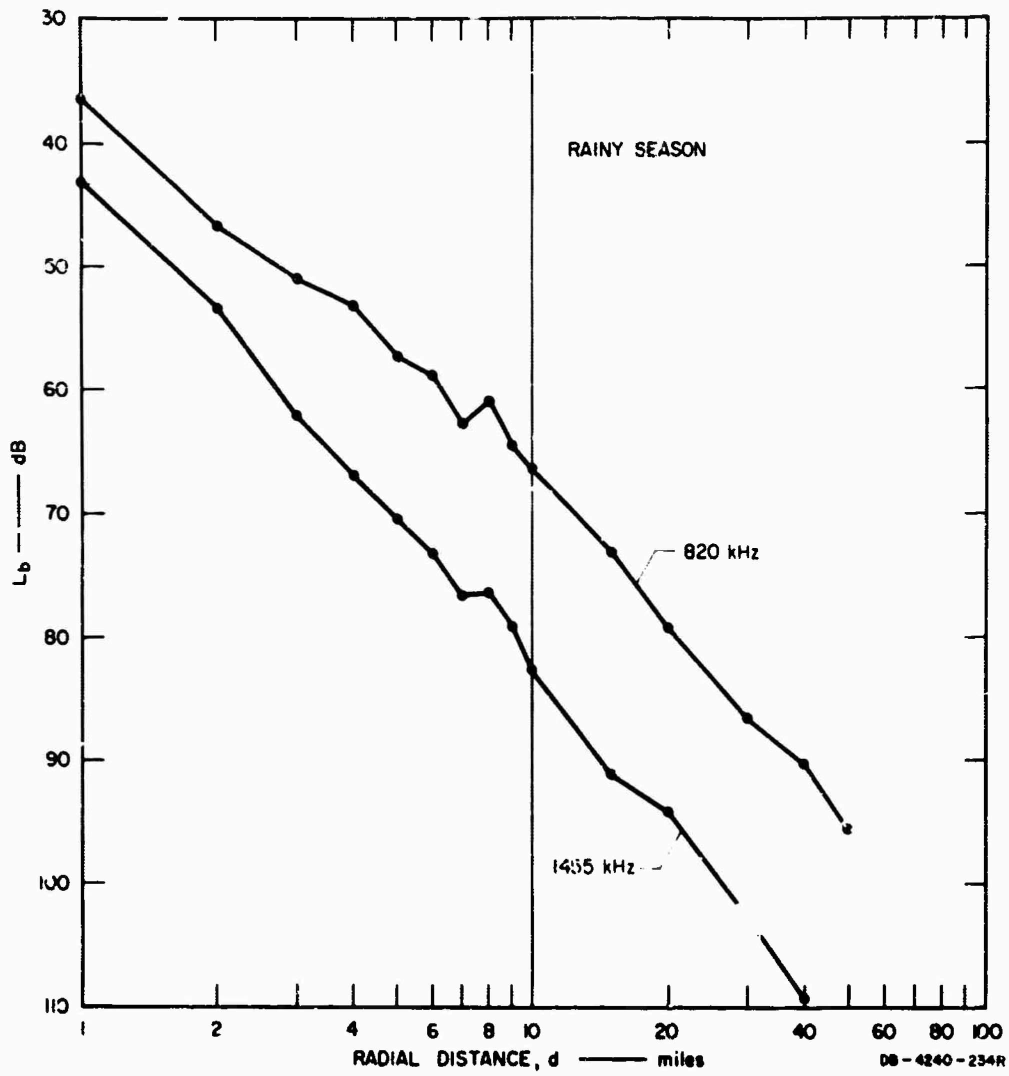

FIG. B-26 BASIC-TRANSMISSION-LOSS MEASUREMENTS — UBON TO AMNAT CHAROEN

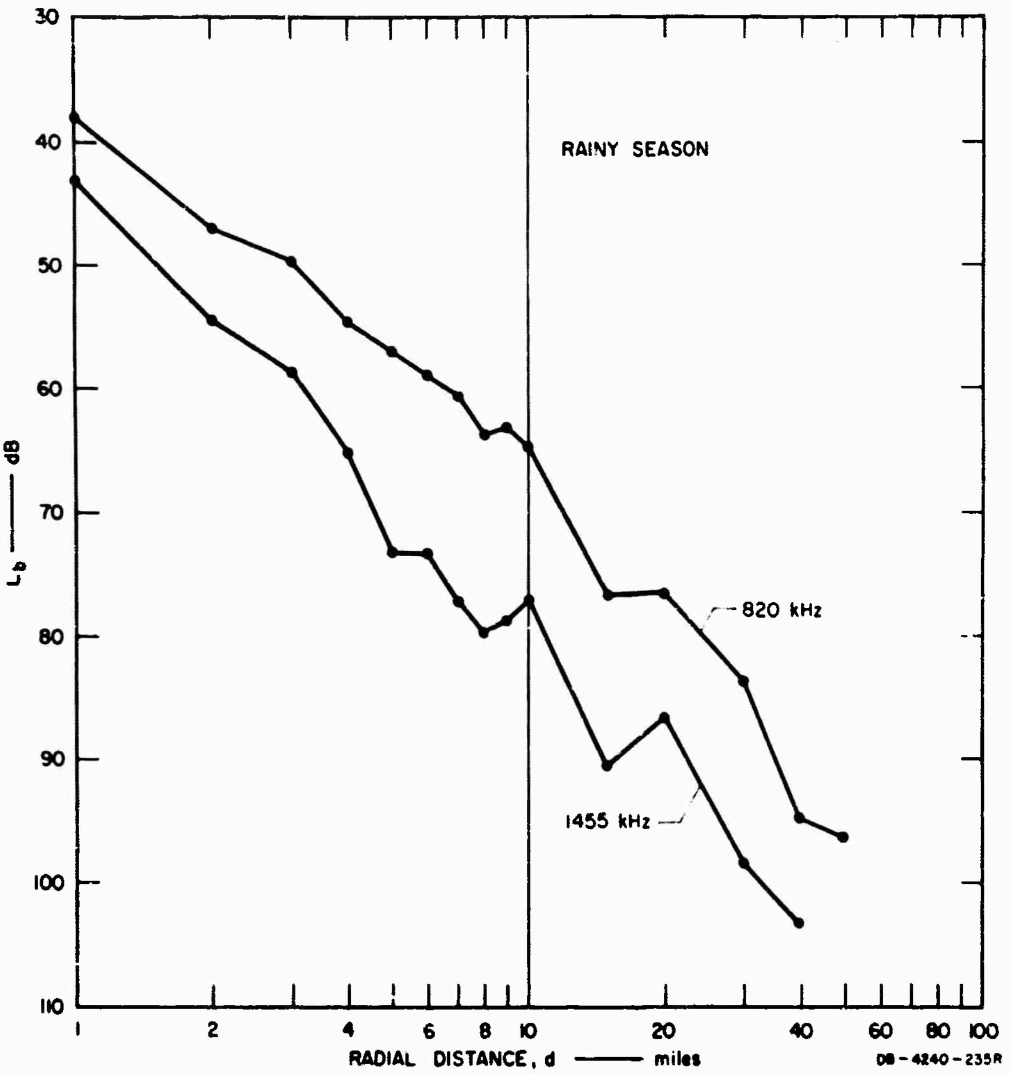

FIG B-27 BASIC-TRANSMISSION-LOSS MEASUREMENTS — UBON TO YASOTHON AND ROI ET

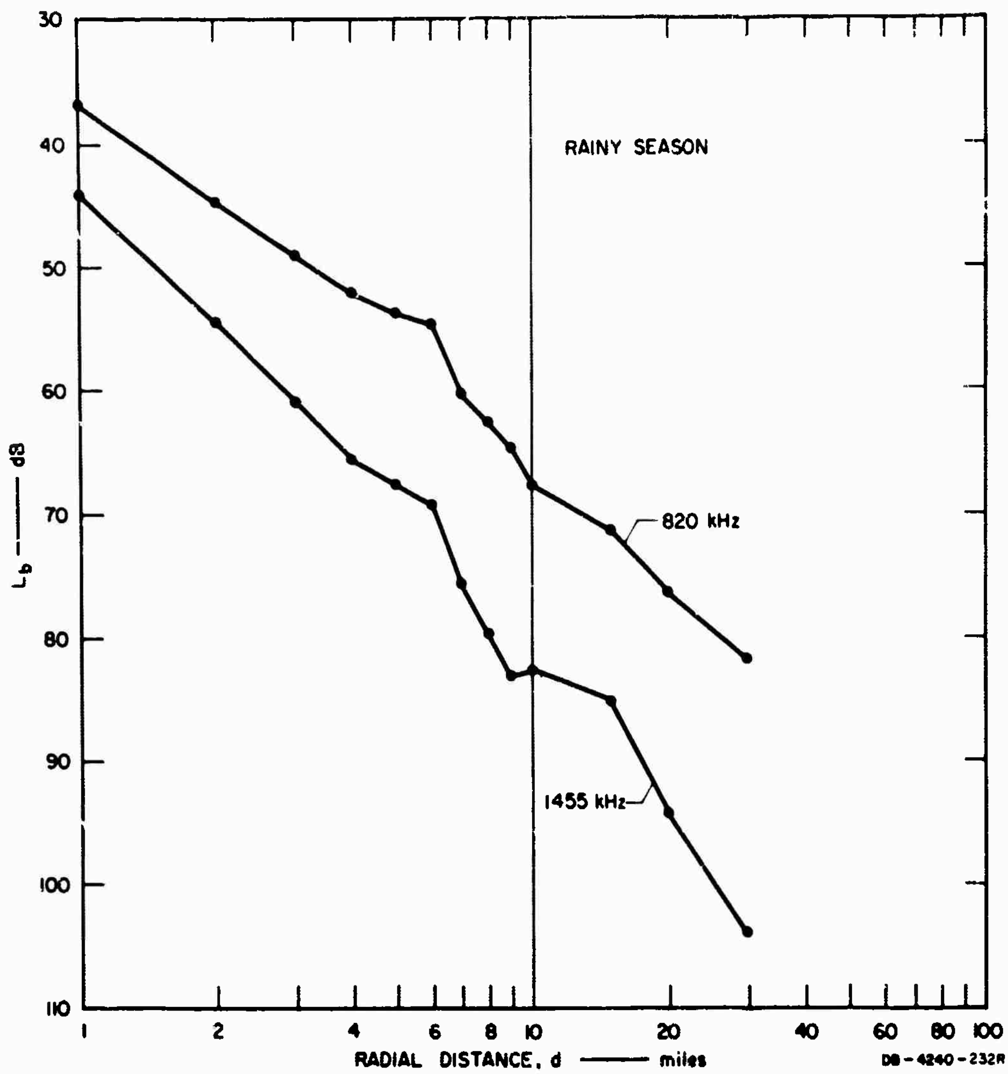

FIG. B-28 BASIC-TRANSMISSION-LOSS MEASUREMENTS — UBON TO DET UDOM

The power P_r radiated from a transmitting antenna in free space may be determined for the case of interest (i.e., along the ground) from the following relation:

$$P_r = \frac{4\pi(1609)^2(2Eo \times 10^{-6})^2}{g_t \eta_o} \qquad (B\text{-}4)$$

where

Eo = Free-space field in microvolts per meter at 1 mile from transmitting antenna

η_o = Impedance of free space

g_t = Gain of the transmitting antenna above an isotropic antenna.

The power P_a available from a receiving antenna in free space is given by:

$$P_a = \frac{e^2 \lambda^2 g_r \times 10^{-12}}{4\pi \eta_o} \qquad (B\text{-}5)$$

where

e = Field strength at the receiver in microvolts per meter

g_r = Gain of the receiving antenna above an isotrope

λ = Free-space wavelength in meters.

Then, substituting for the above,

$$L_b = 36.57 + 20 \log f_{MHz} + 20 \log 2Eo - 20 \log e \qquad (B\text{-}6)$$

where

F_{MHz} = frequency in MHz.

2. Evaluation of Free-Space Field

The free-space field 2Eo produced at a distance of one mile from the transmitting antenna is one of the factors used in calculating the basic transmission loss. To obtain an estimate of the free-space field, the actual field intensity at 400 meters and one mile at various points was measured instead. These measurements were carried out as accurately as possible. The free-space field was then calculated from these results and the results from the other field-intensity measurements at sites from 1 to 50 miles from the transmitter.

3. <u>Calculation of Free-Space Field</u>

The field strength E at the distance d from the antenna is given as

$$E = \frac{2EoA}{d} \text{ mV/m} \qquad \text{(B-7)}$$

where A is an attenuation factor and 2Eo is the free-space field at a distance of one mile from the transmitting antenna [see Eq. (1), Sec. III-C].

Using the value of the ground constant determined by field-attenuation measurement and wave-tilt method, E can be calculated. Let E_c denote the calculated value of the field intensity at the distance "d" miles and give the free-space field 2Eo equal to 100 mV/m. Then,

$$E_c = \frac{100A}{d} \text{ mV/m} \quad . \qquad \text{(B-8)}$$

Assuming that the measured field intensity E_m will obey Eq. (B-7), then

$$E_m = \frac{2EomA}{d} \text{ mV/m} \qquad \text{(B-9)}$$

where 2Eom is the free-space field for the actual transmitting power when E_m was measured. Along the same direction from the transmitting antenna, the attenuation, A, at the same distance, d, for both calculated and measured values must be the same. Then, from Eq. (B-9) it is easily seen that

$$2E_{om} = \frac{\text{measured field intensity}}{\text{calculated field intensity}} \times 100 \text{ mV/m} \quad . \qquad \text{(B-10)}$$

The value of 2Eom was calculated at all points in each direction and the required free-space field for each site is obtained from the mean value of the 2Eom.

Appendix C

MEASURED RELATIVE FIELD INTENSITY VS. RADIAL DISTANCE*

*See Fig. 23 for site locations.

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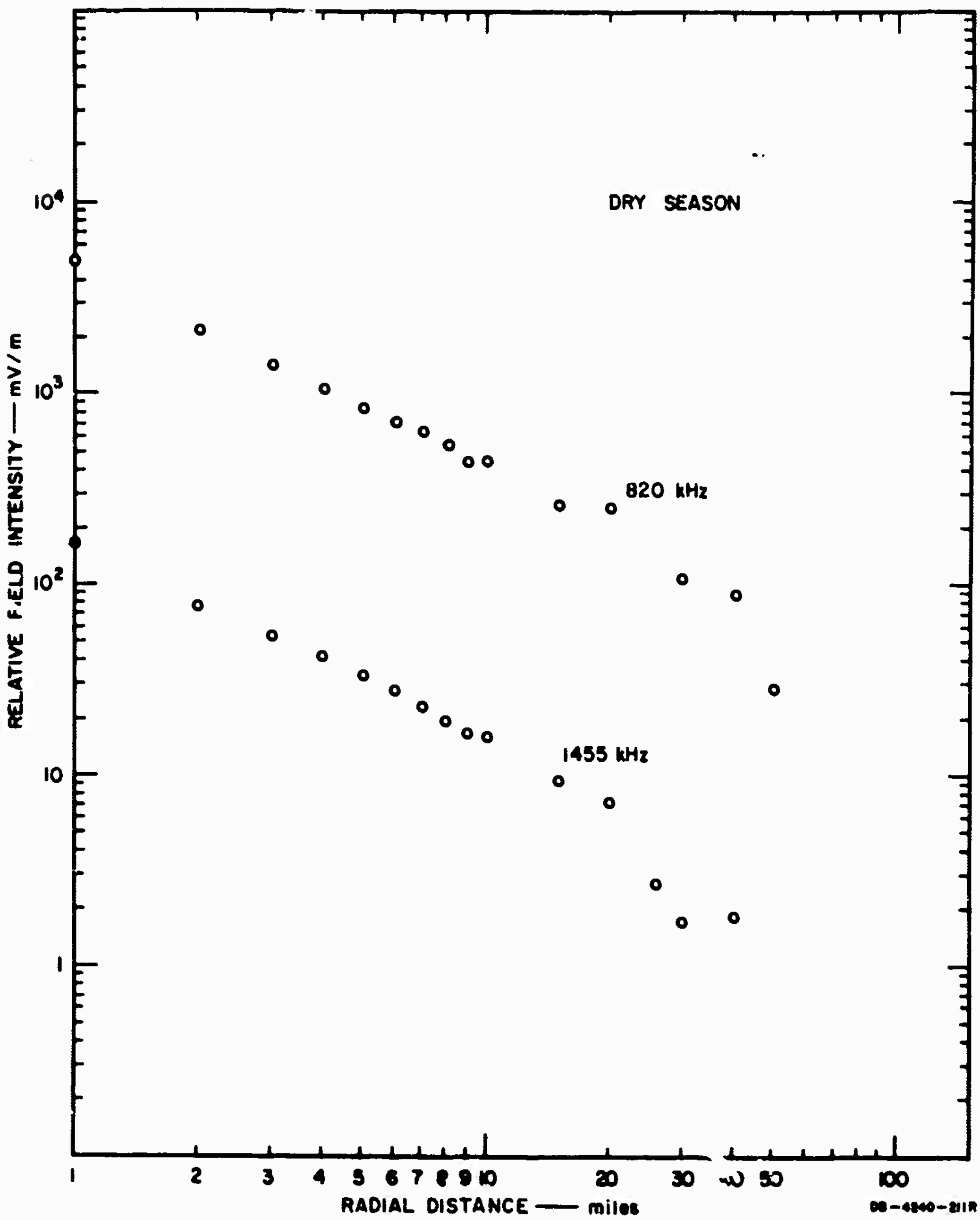

FIG. C-1 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — BANG PA IN TO BAN HIN KONG AND PRACHINBURI

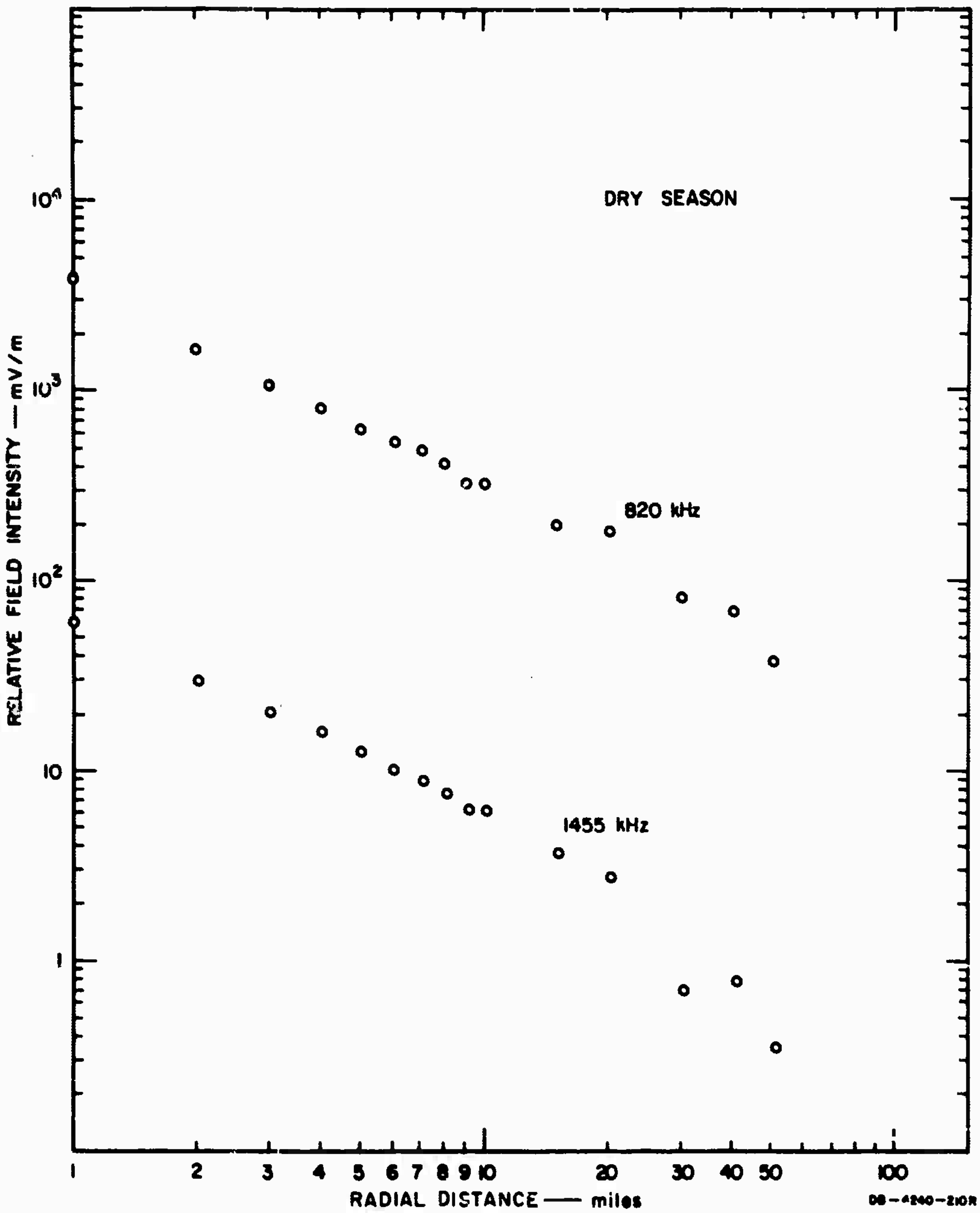

FIG. C-2 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE —
BANG PA IN TO SARABURI AND LOPBURI

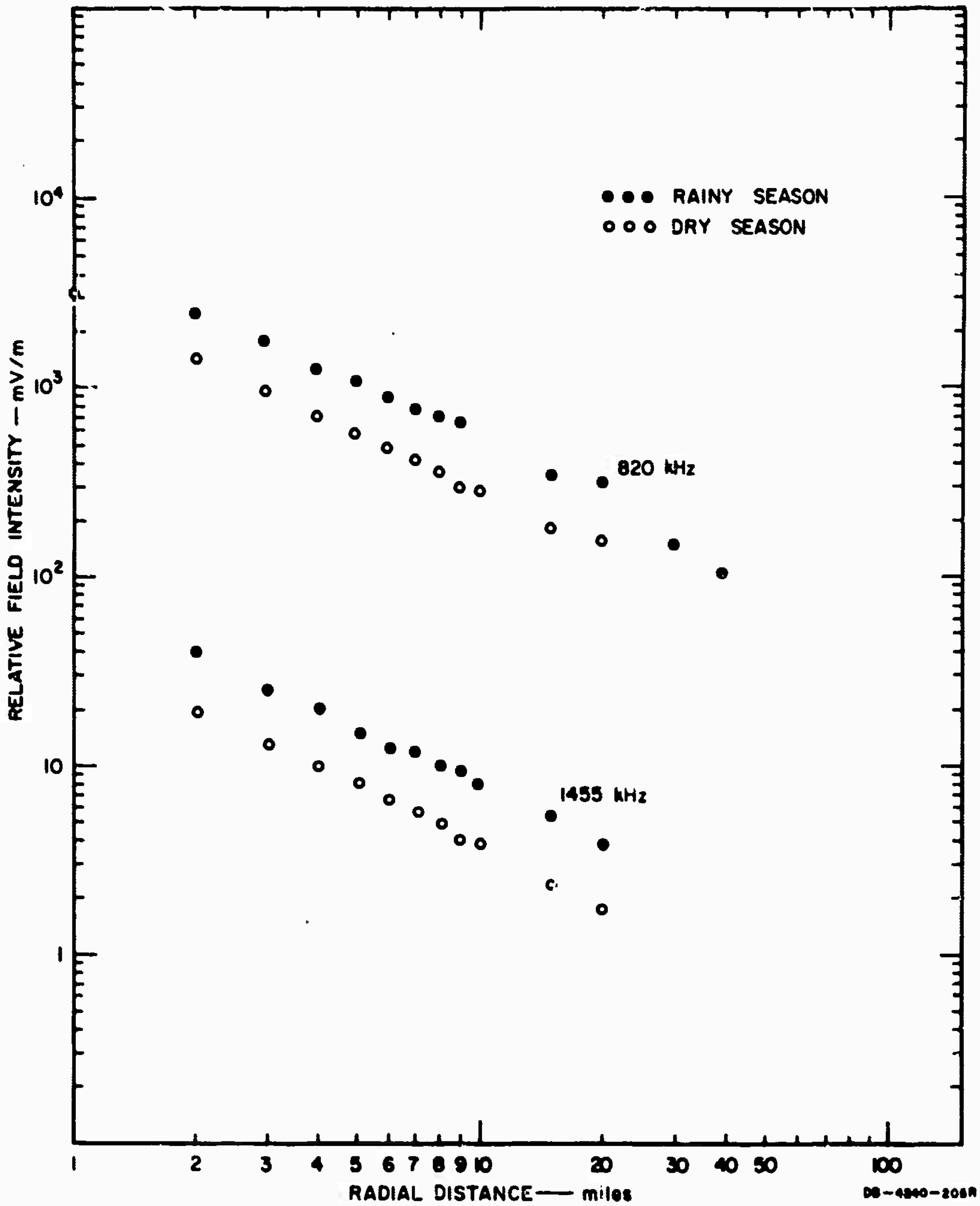

FIG. C-3 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — BANG PA IN TO BAN HIN KONG AND NAKHON RATCHASIMA

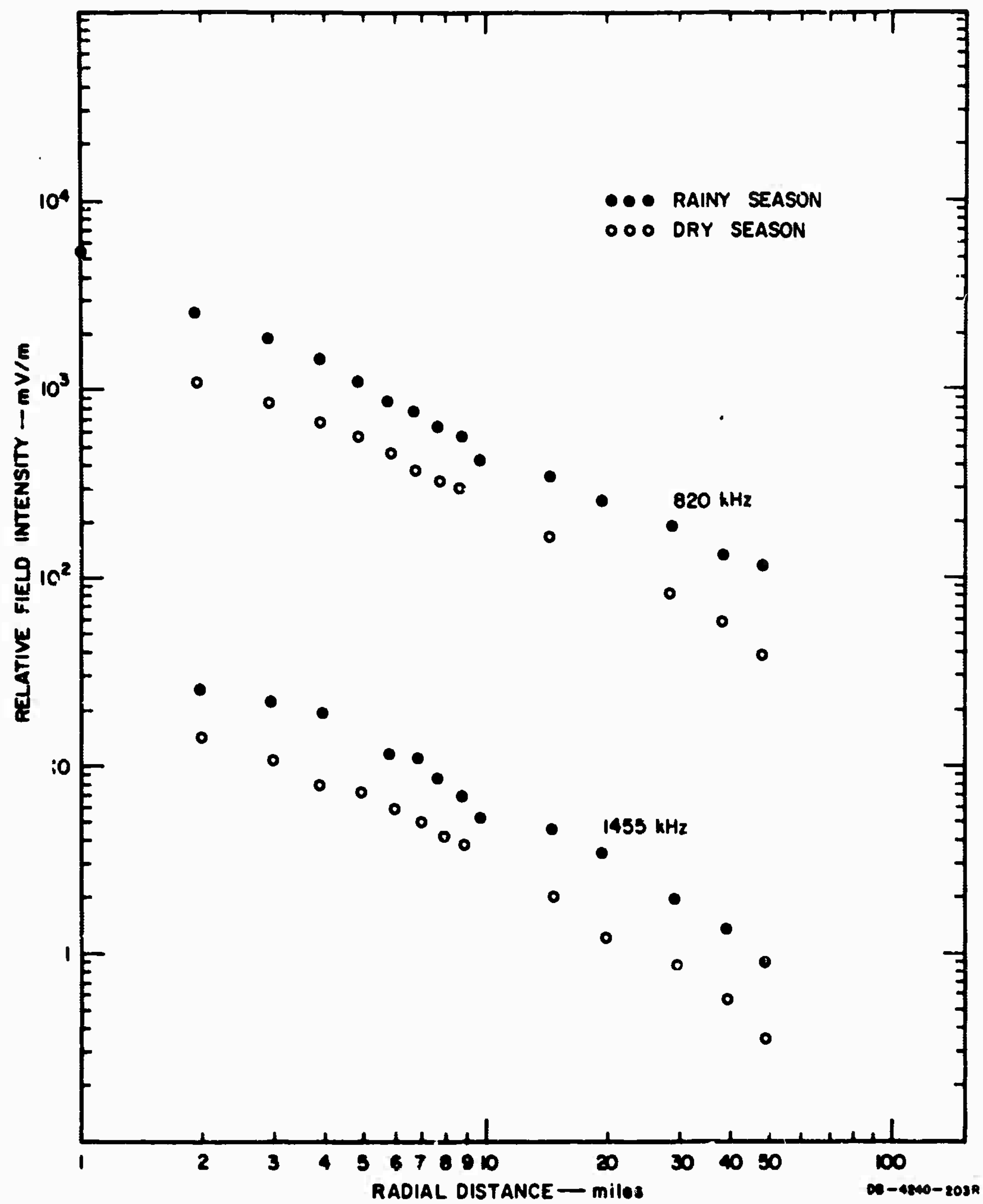

FIG. C-4 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — BANG PA IN TO MINBURI AND CHACHOENSAO

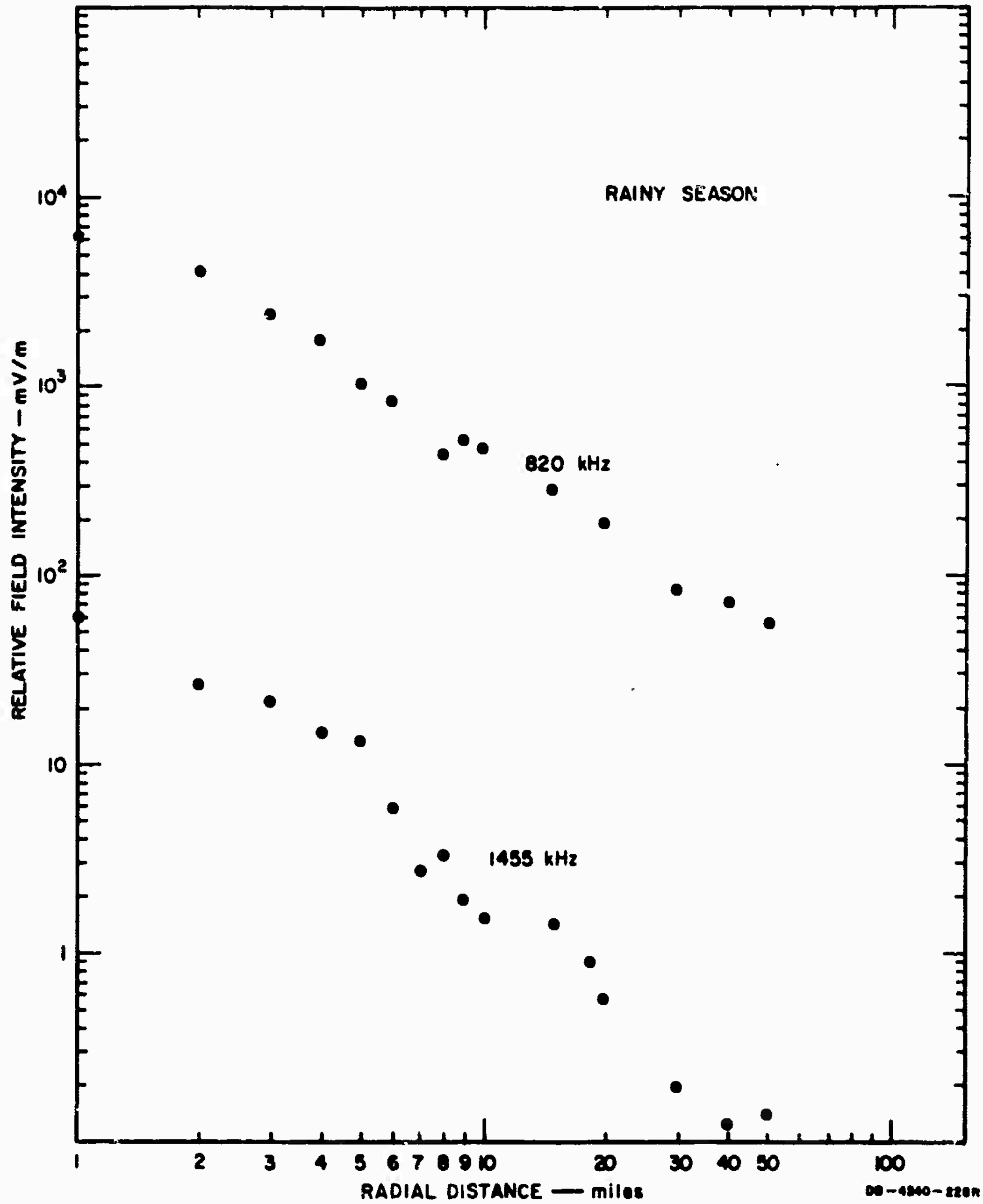

FIG. C-5 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — BAN PONG TO KANCHANABURI AND SUPHAN BURI

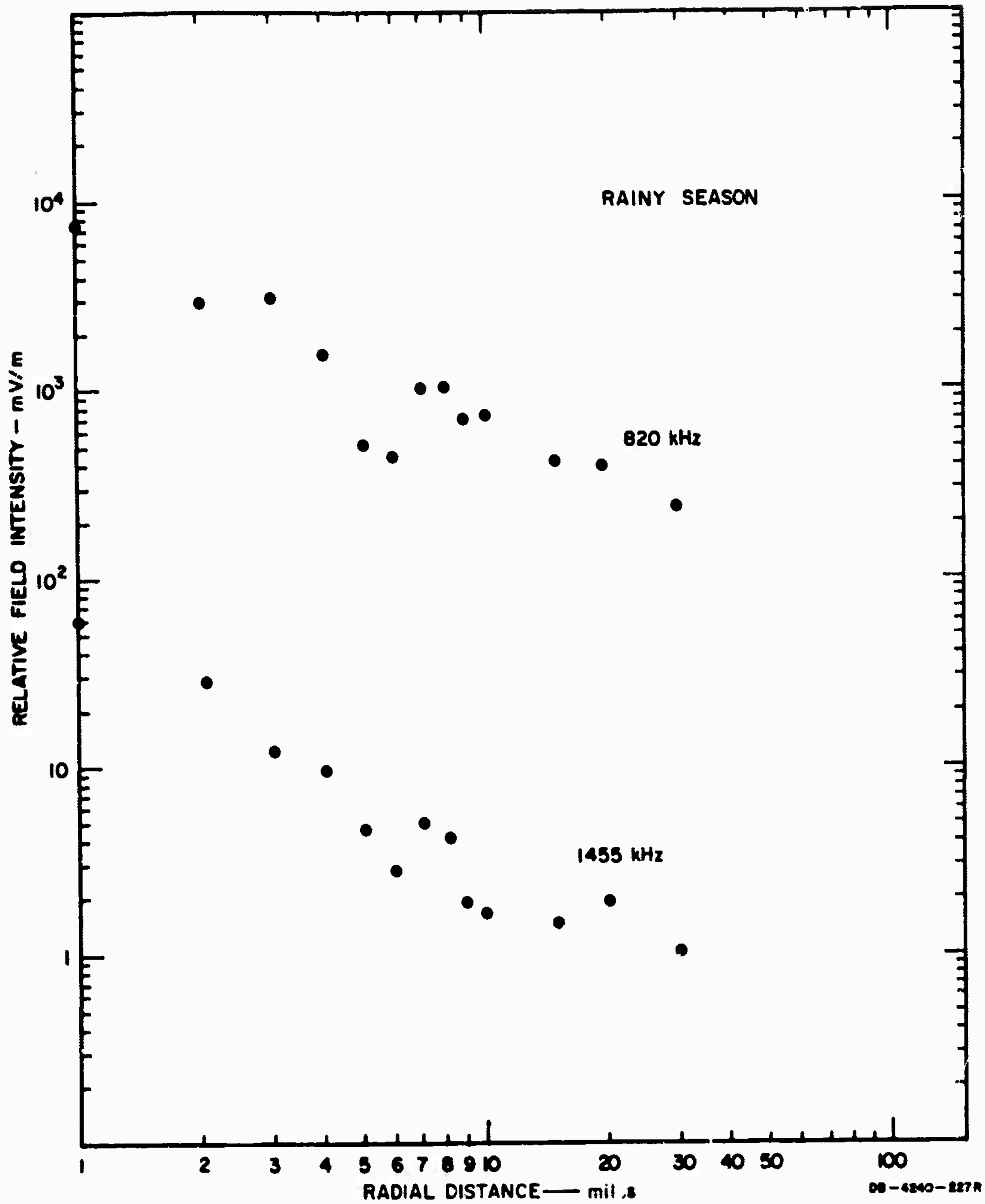

FIG. C-6 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — BAN PONG TO BANGKOK

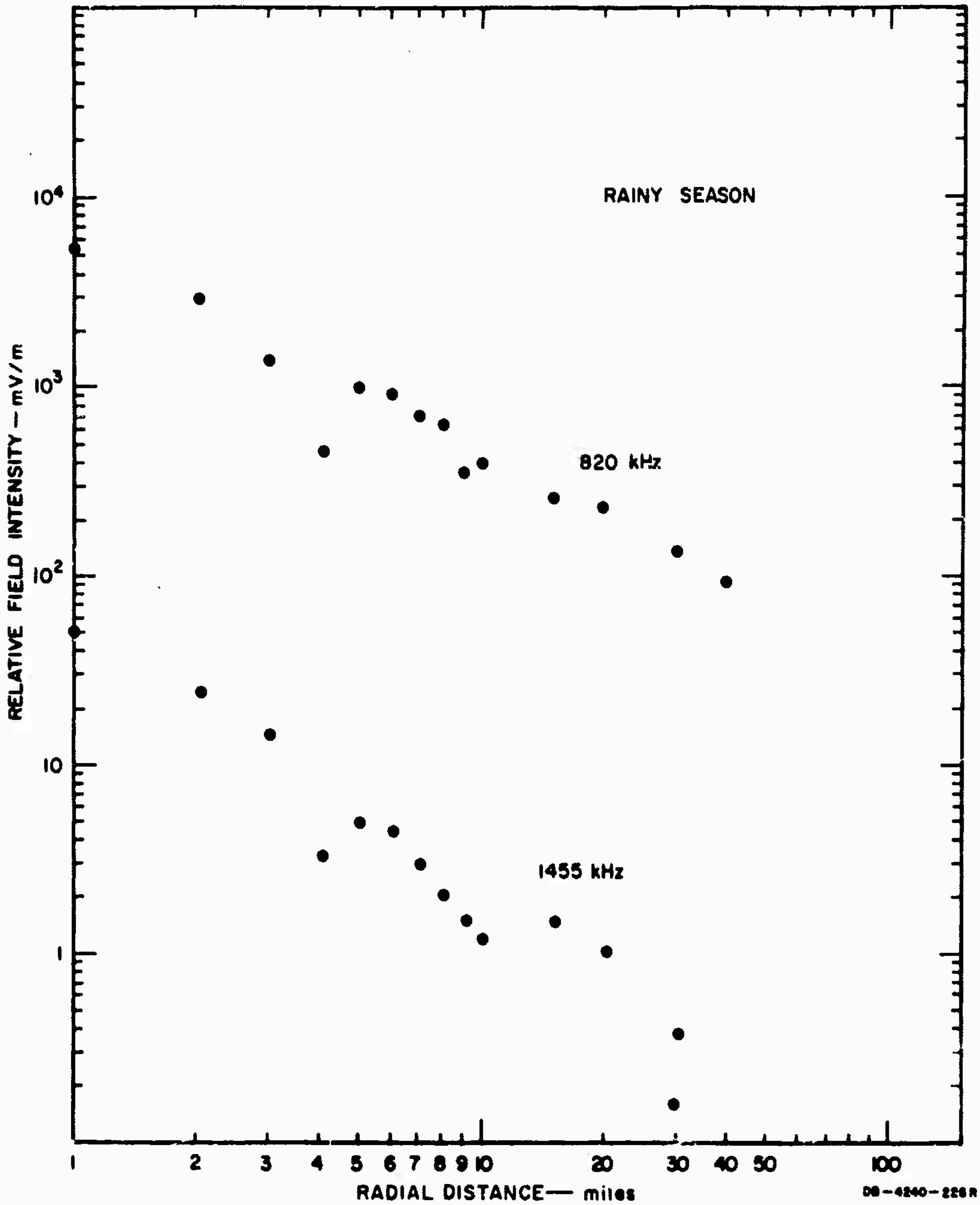

FIG. C-7 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — BAN PONG TO PETCHABURI

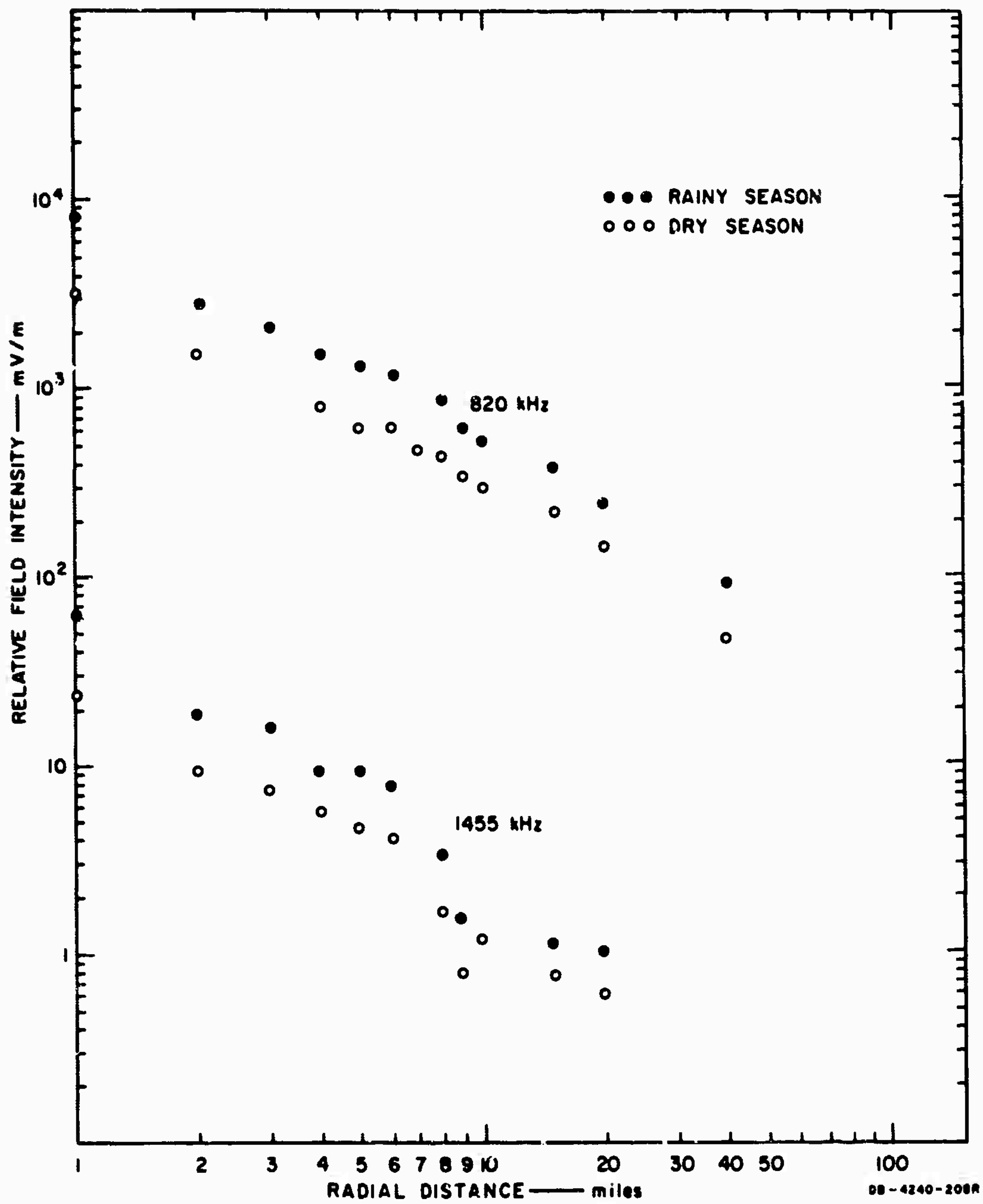

FIG. C-8 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — NAKHON RATCHASIMA TO SARABURI

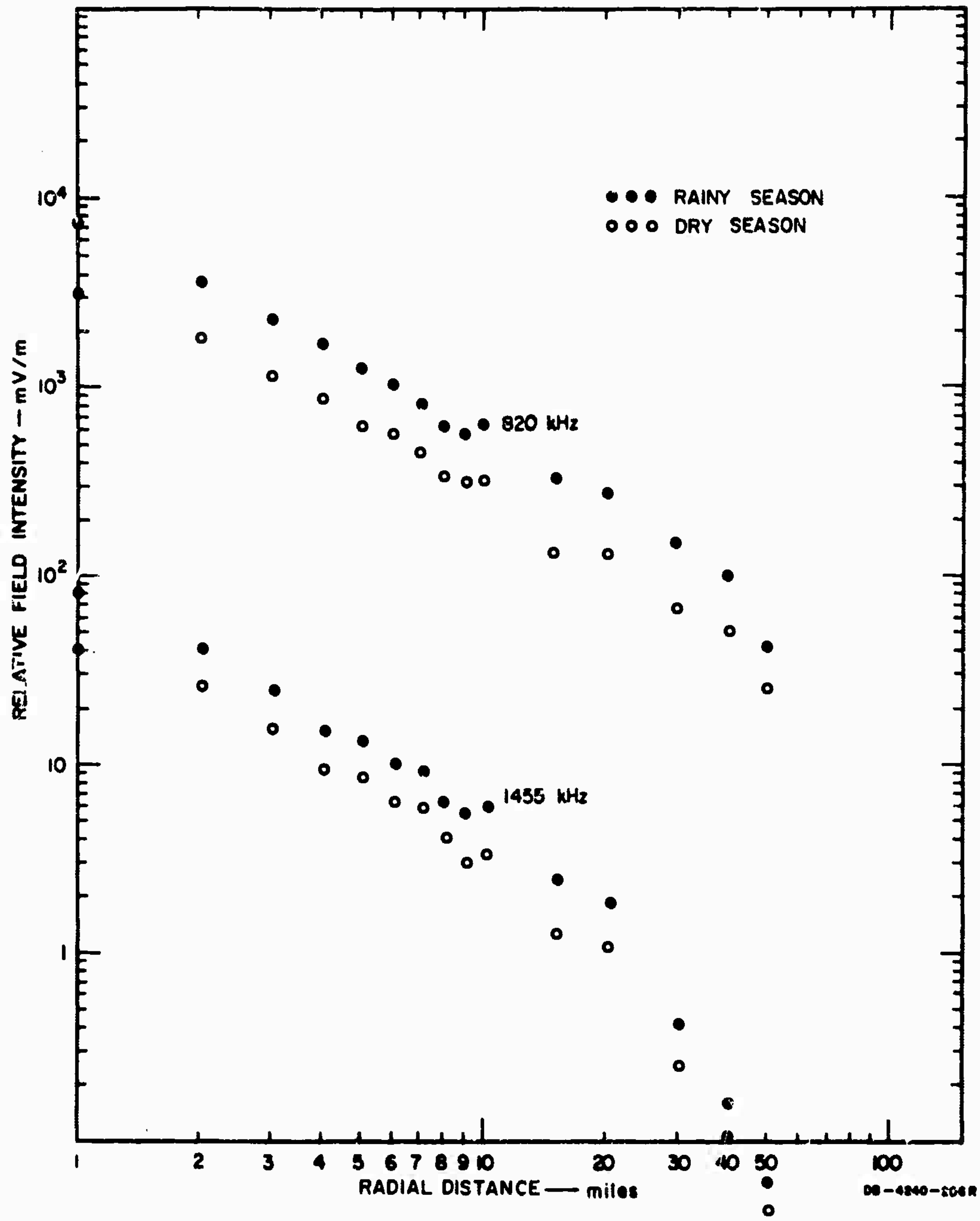

FIG. C-9 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — NAKHON RATCHASIMA TO CHAIYAPHUM

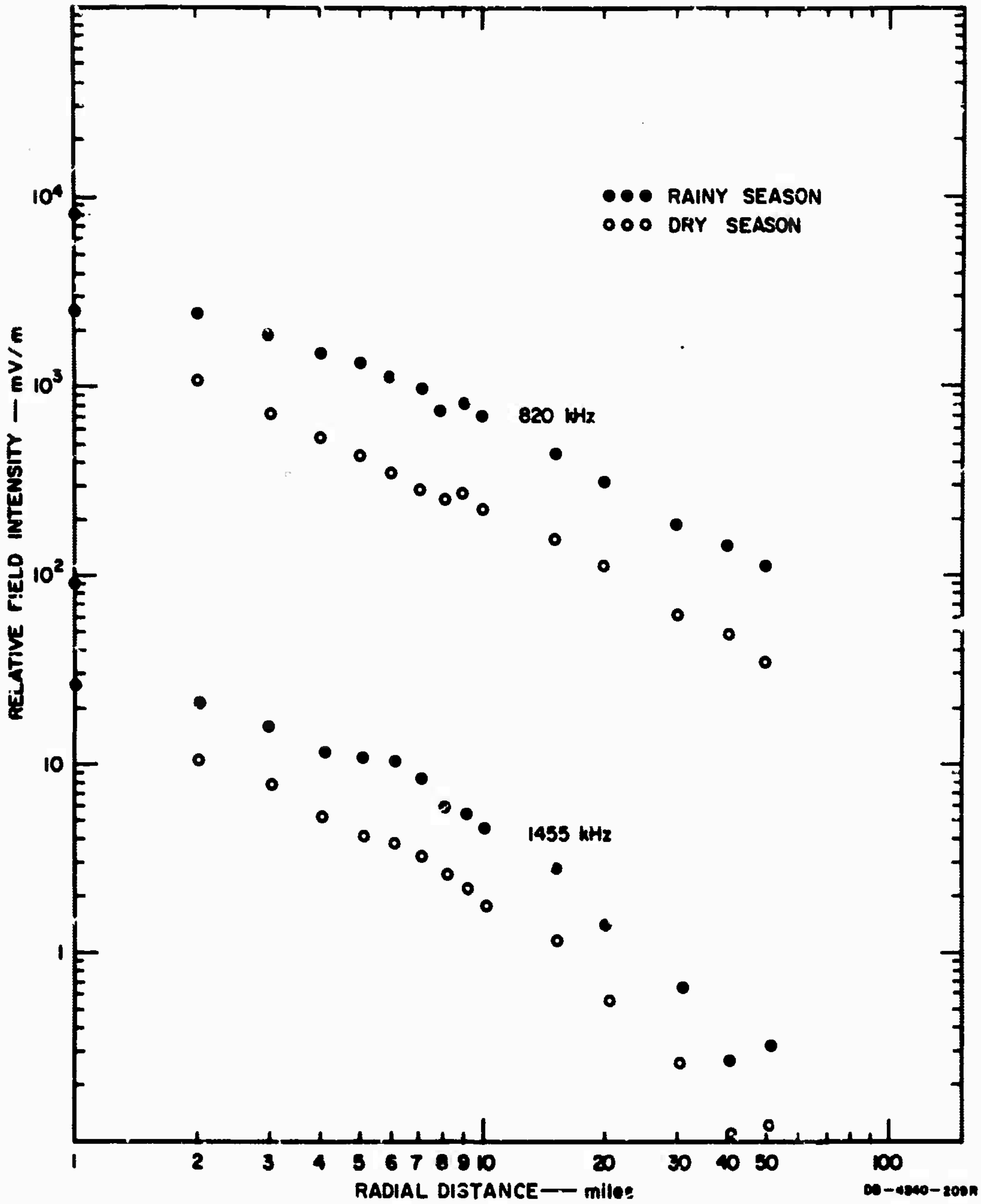

FIG. C-10 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — NAKHON RATCHASIMA TO KHON KAEN

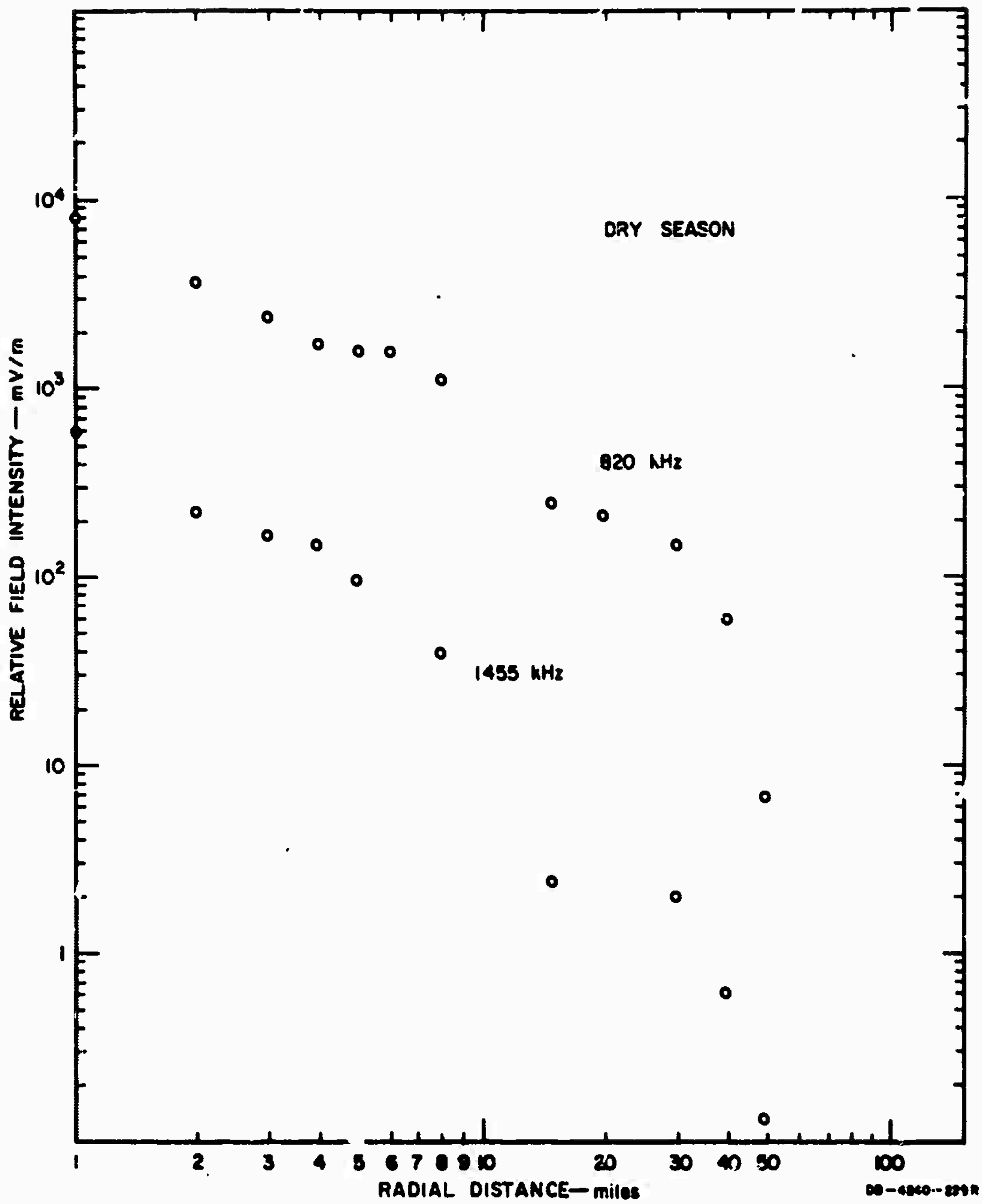

FIG. C-11 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — NAKHON RATCHASIMA TO BAN NONG PLING AND BAN WANG MI

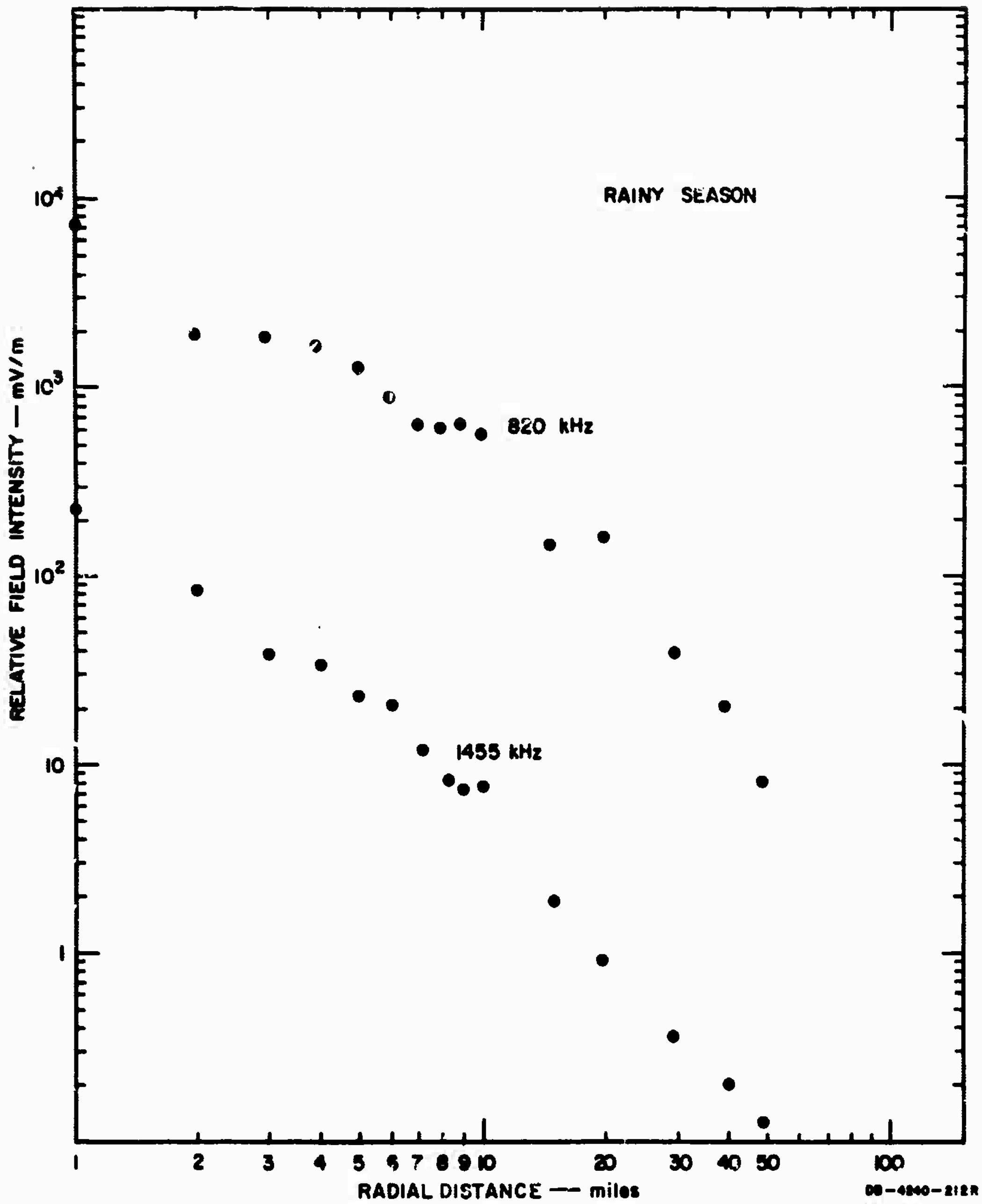

FIG. C-12 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — UDON TO SAKHON

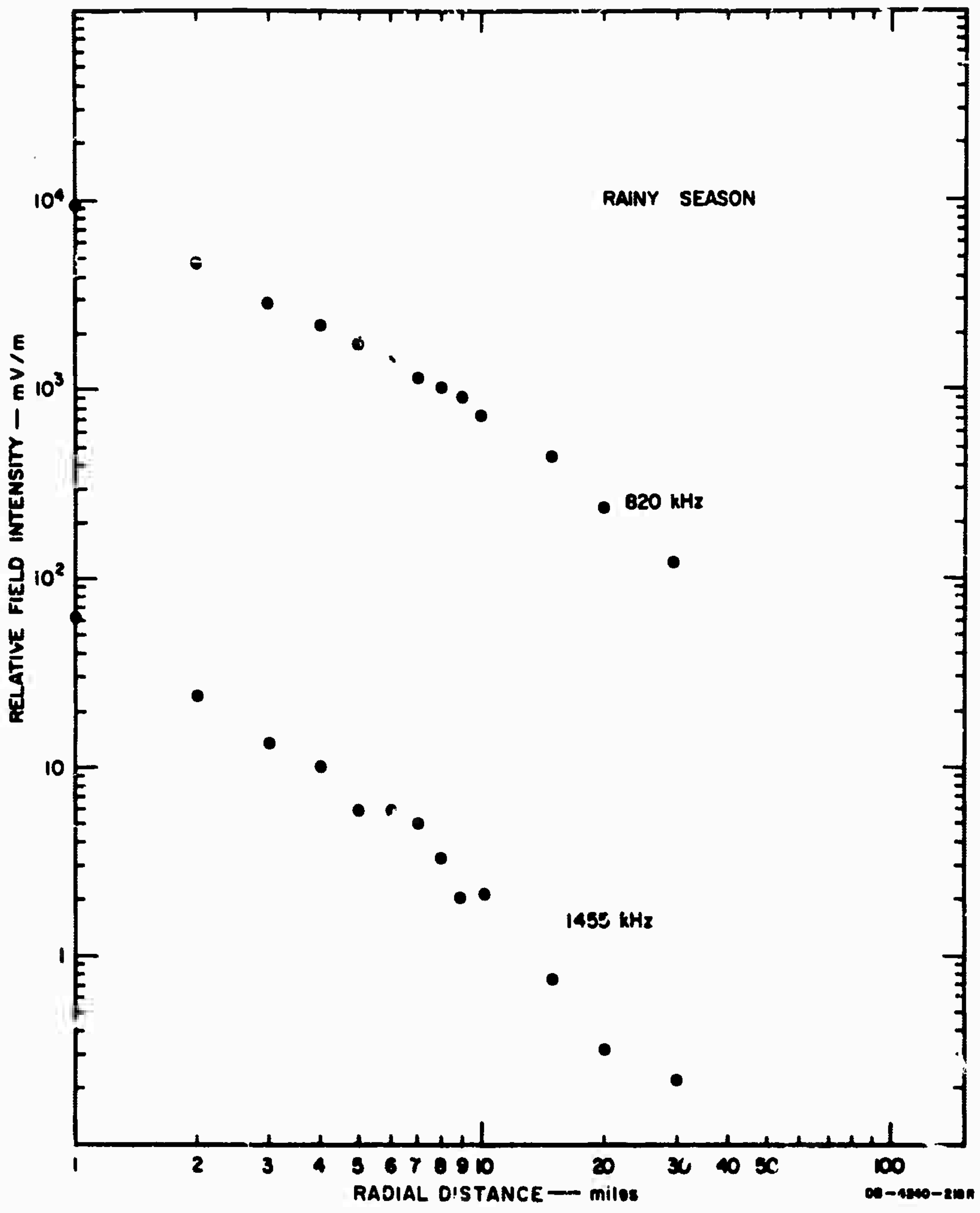

FIG. C-13 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — UDON TO NONG KHAI

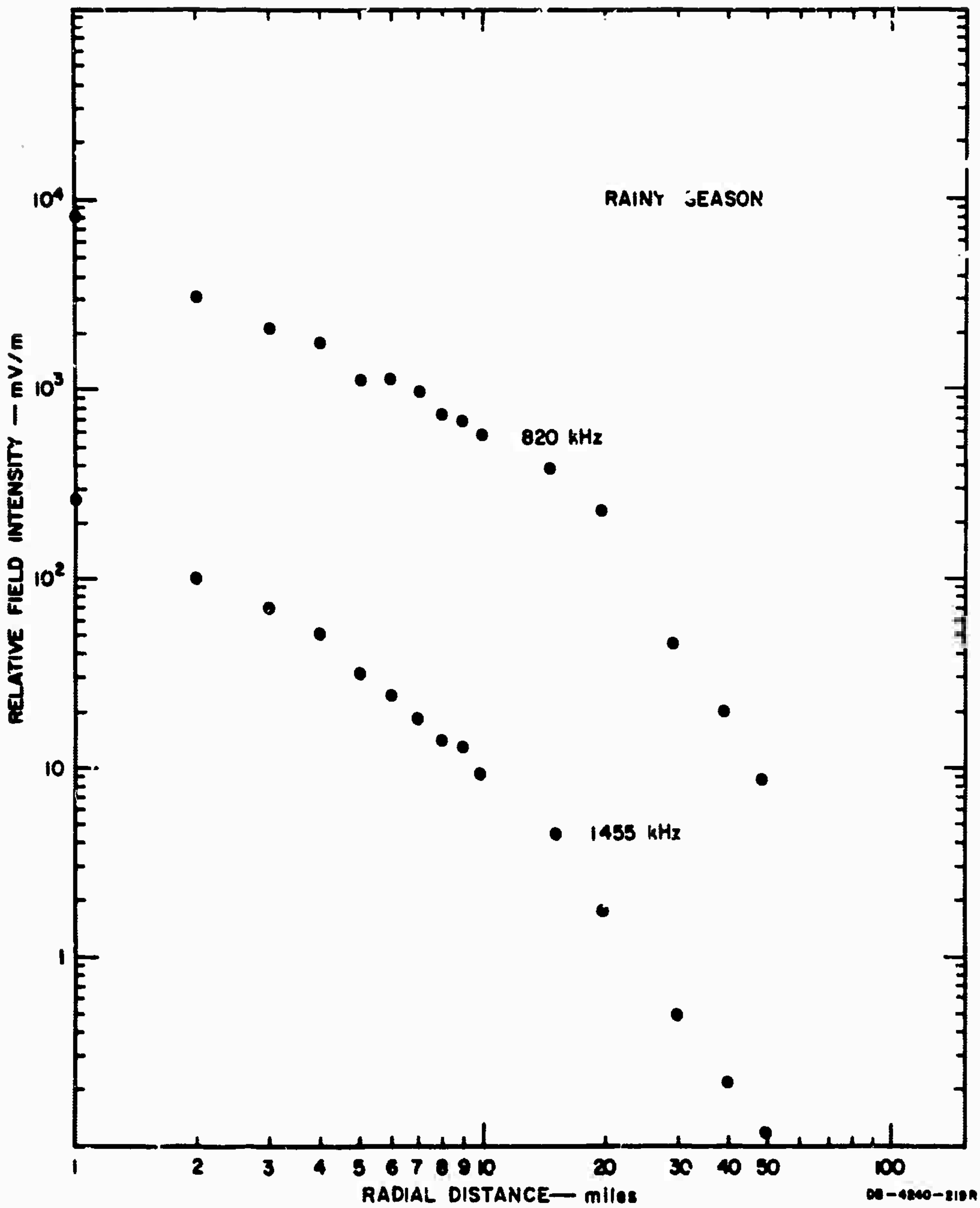

FIG. C-14 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — UDON TO KHON KAEN

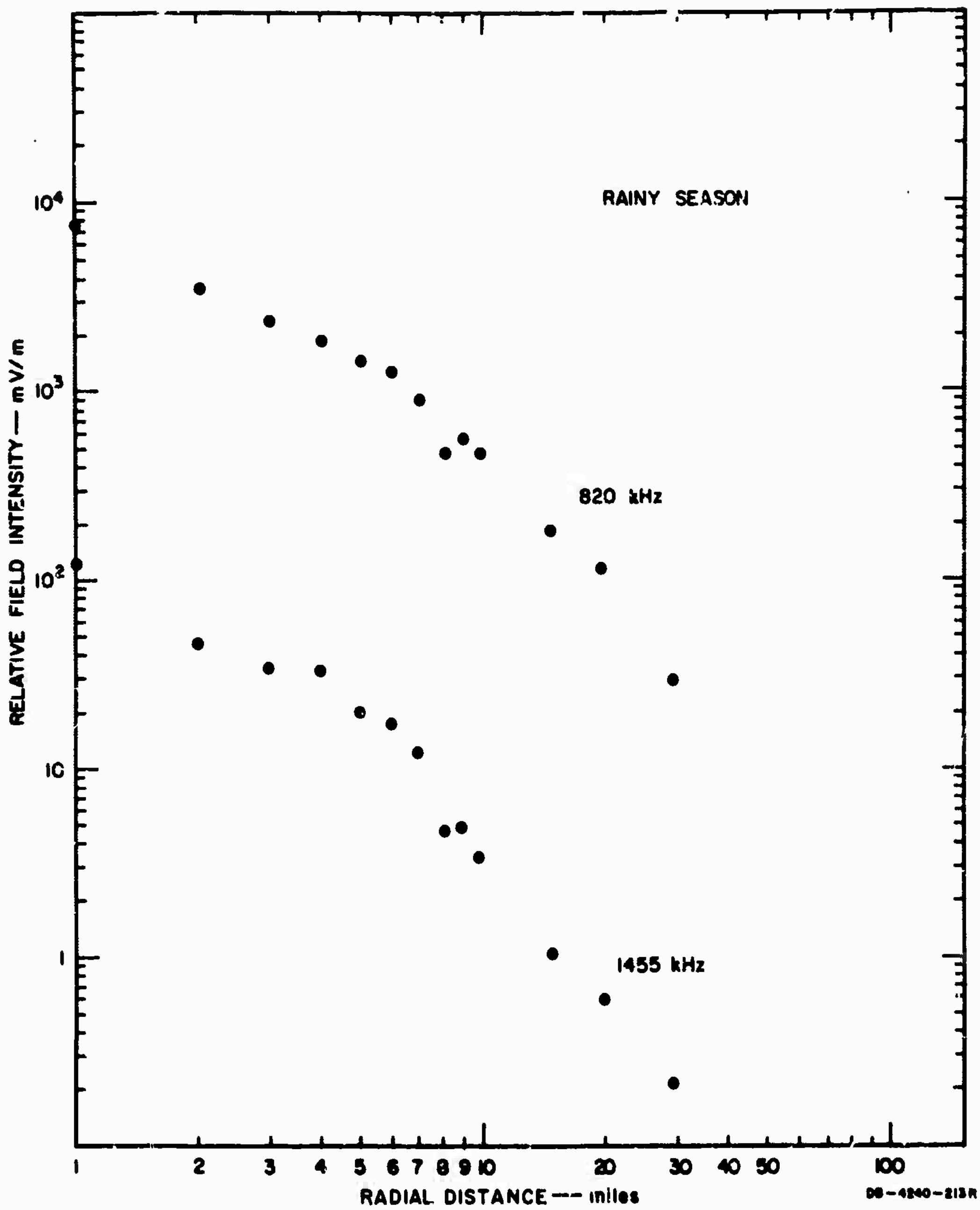

FIG. C-15 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — UDON TO NONG BUA LAM PHUI

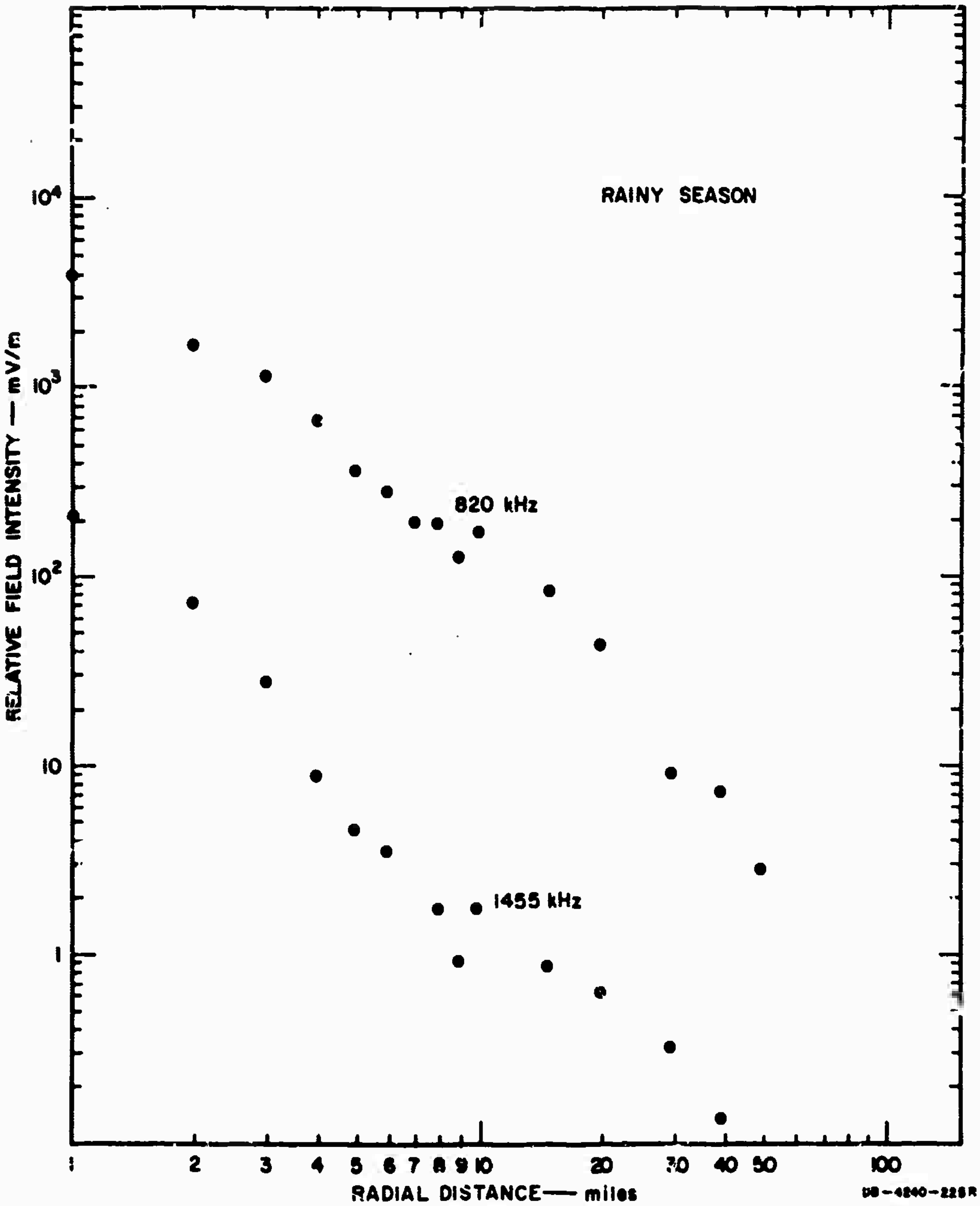

FIG. C-16. MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — SAKHON TO UDON

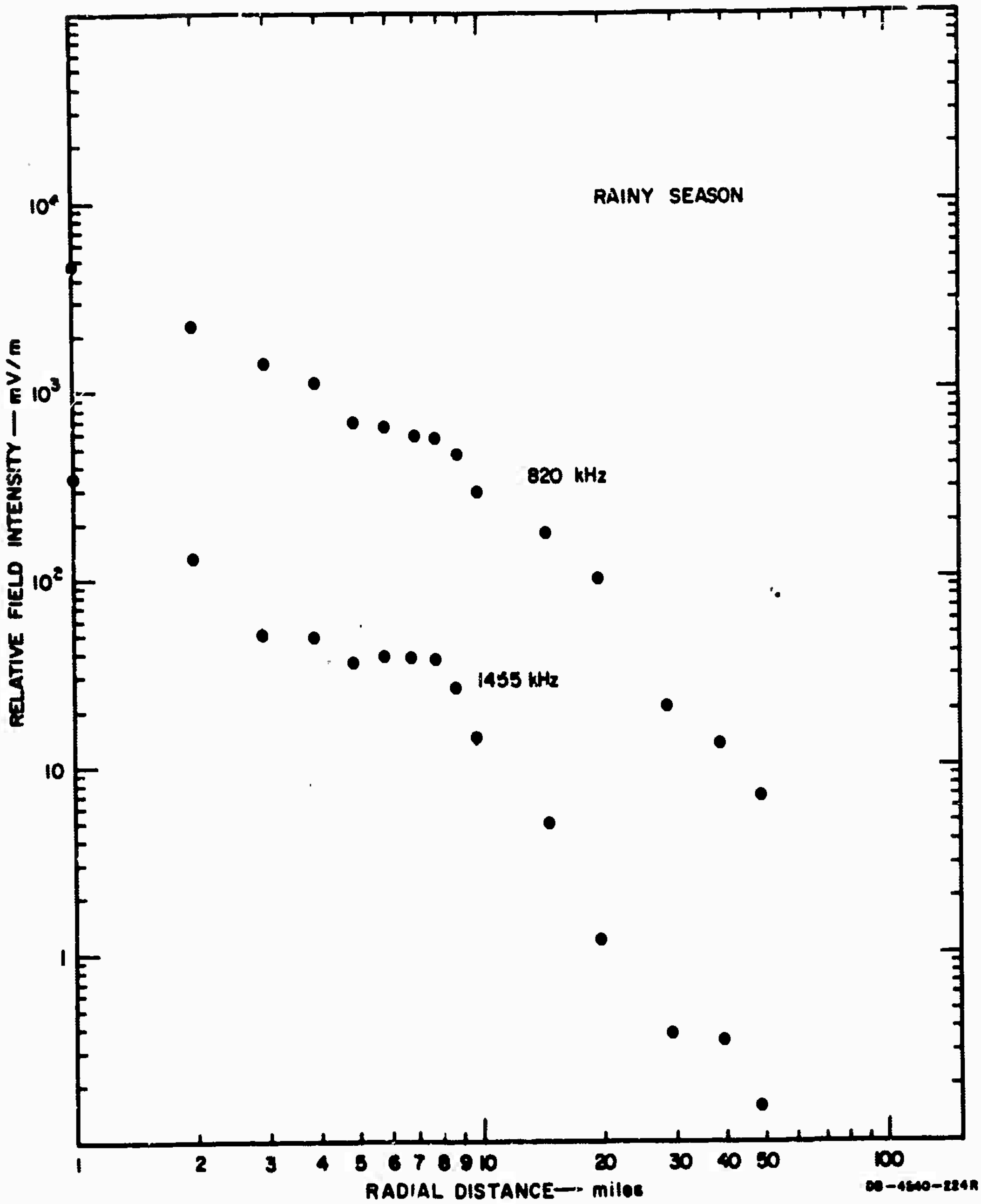

FIG. C-17 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — SAKHON TO NAKHON PHANOM

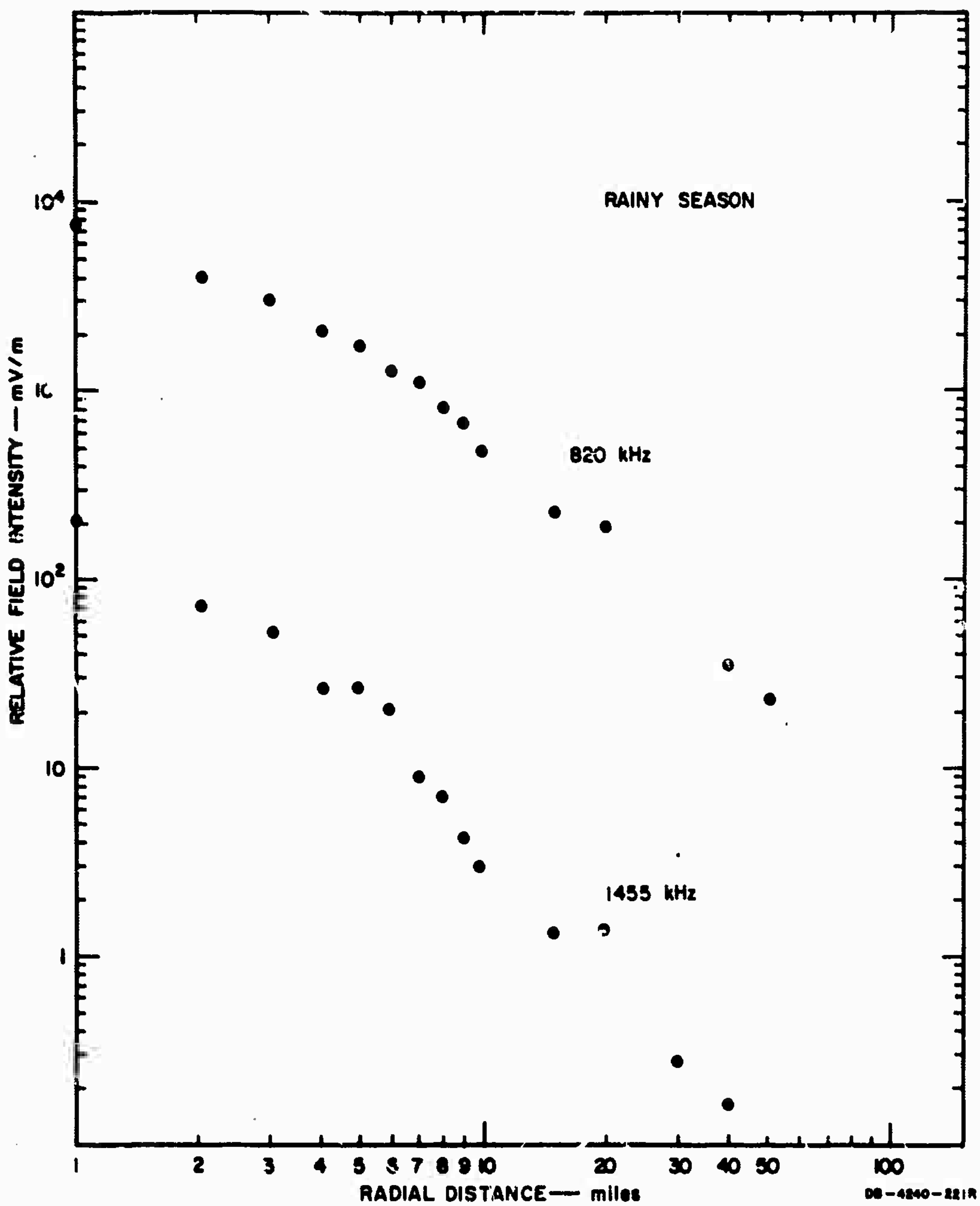

FIG. C-18 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — SAKHON TO TARD PHANOM

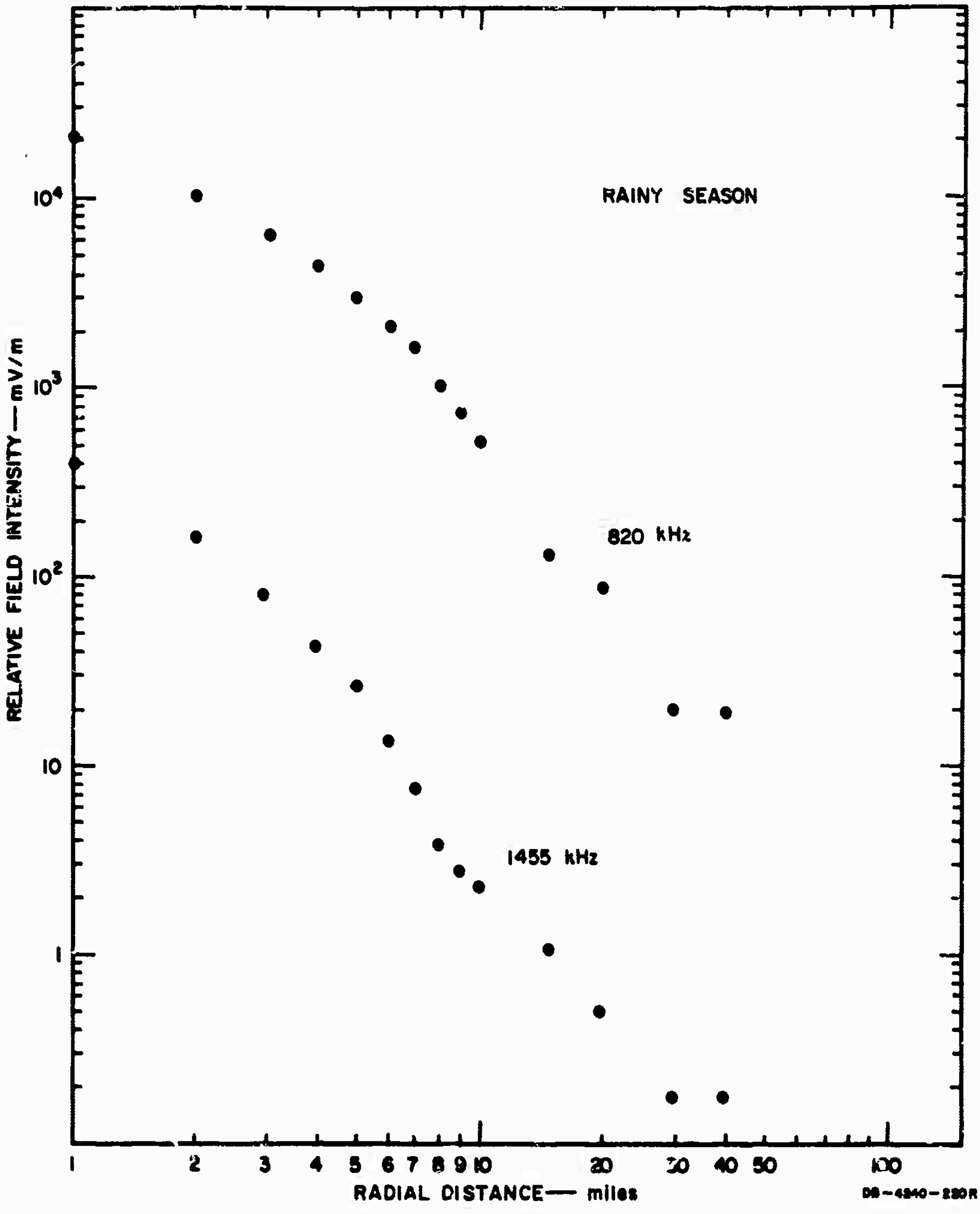

FIG. C-19 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — SAKHON TO KALASIN

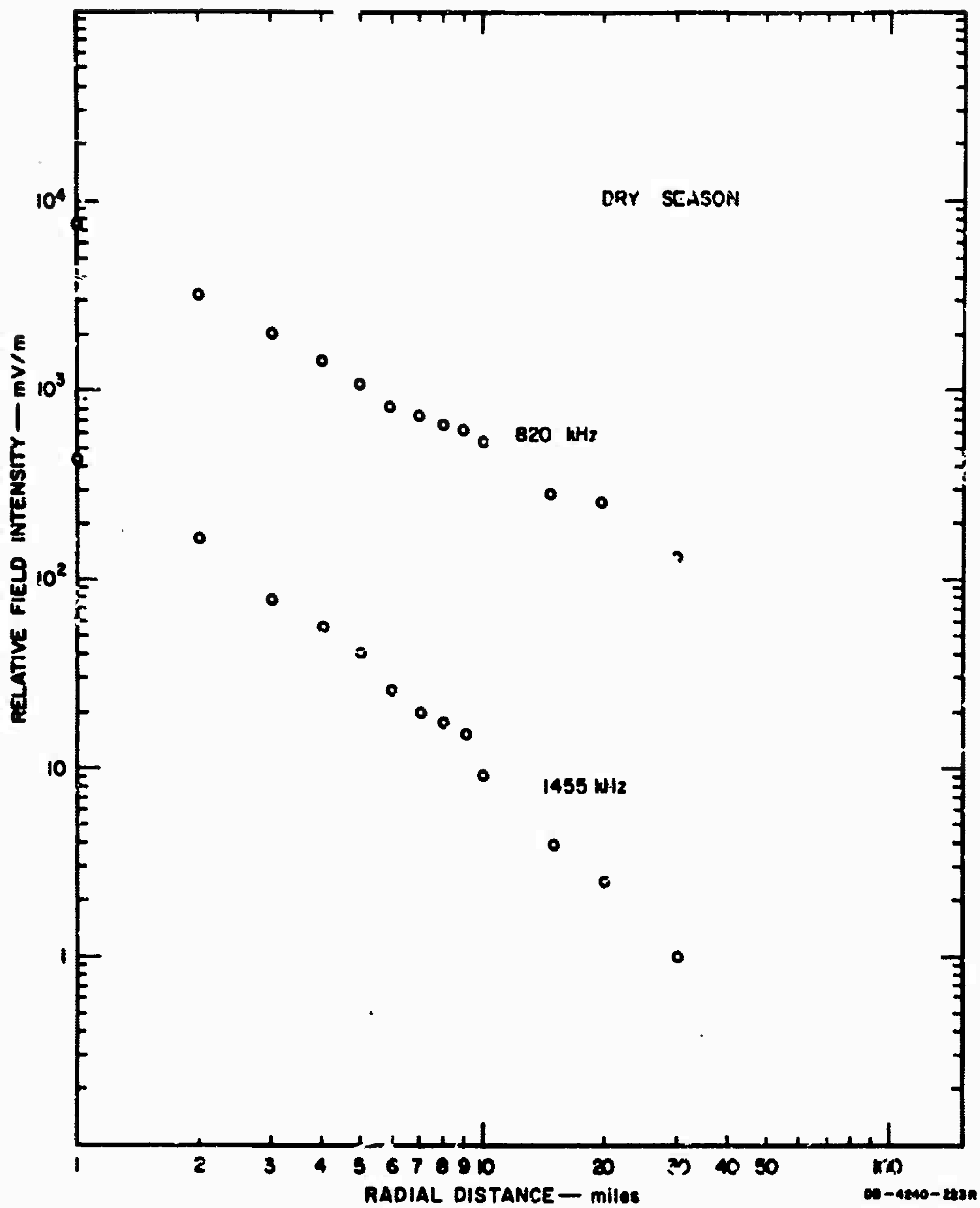

FIG. C-20 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — ROI ET TO SUWANNAPHUM AND SURIN

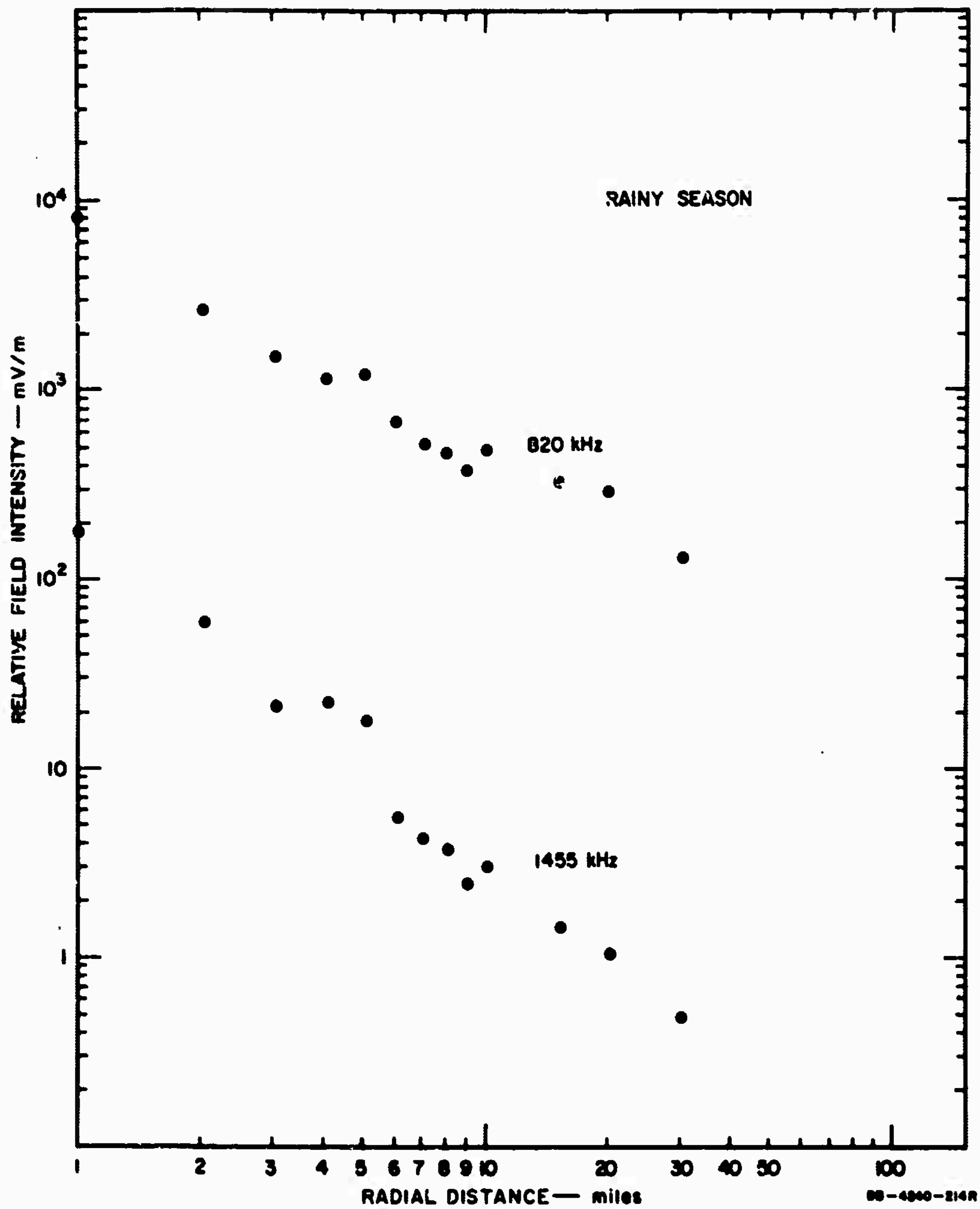

FIG. C-21 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — RO! ET TO CHATURAPHAK PHIMAN AND KASET WISAI

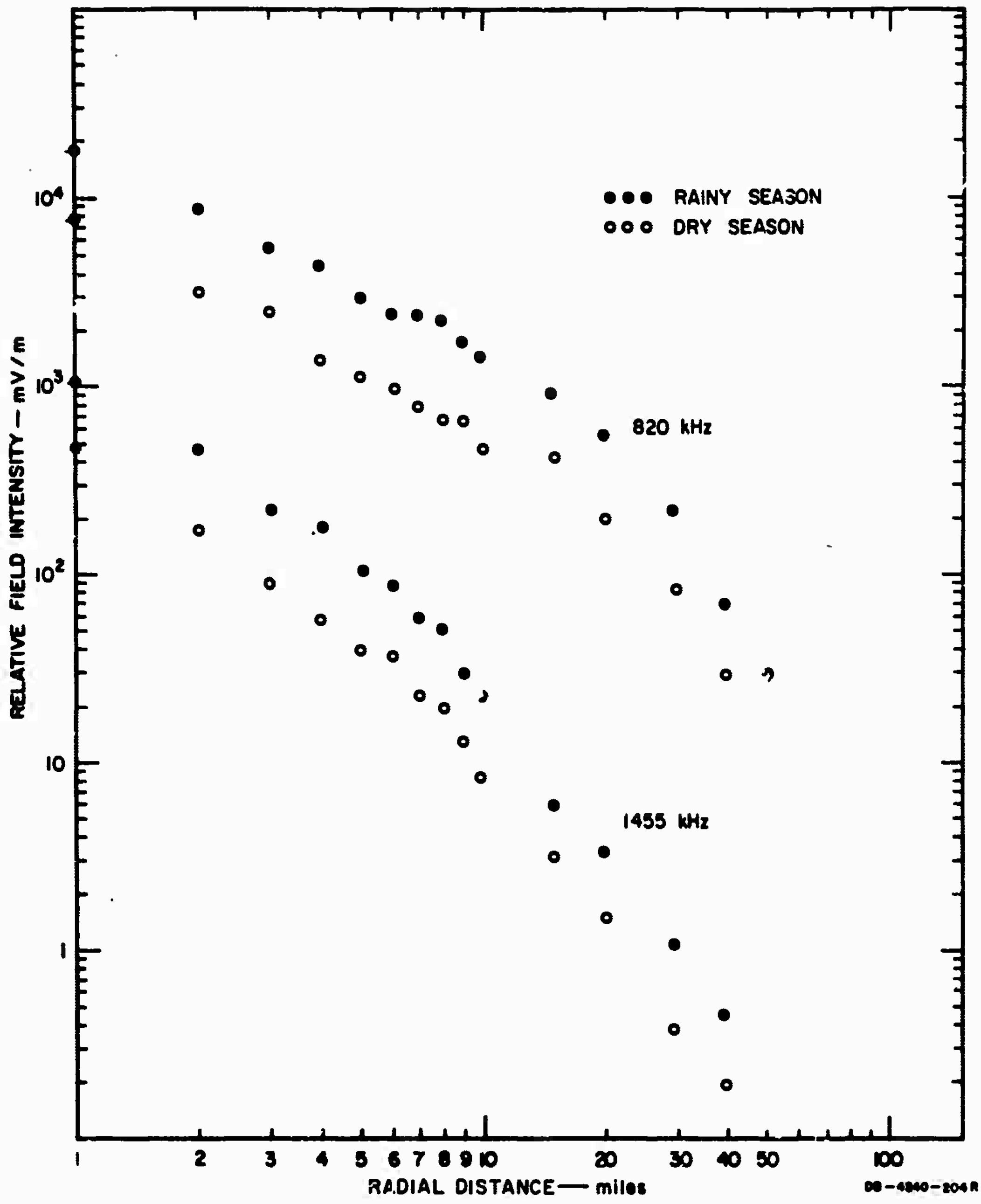

FIG. C-22 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — ROI ET TO MAHA SARAKHAM AND BAN PHAI

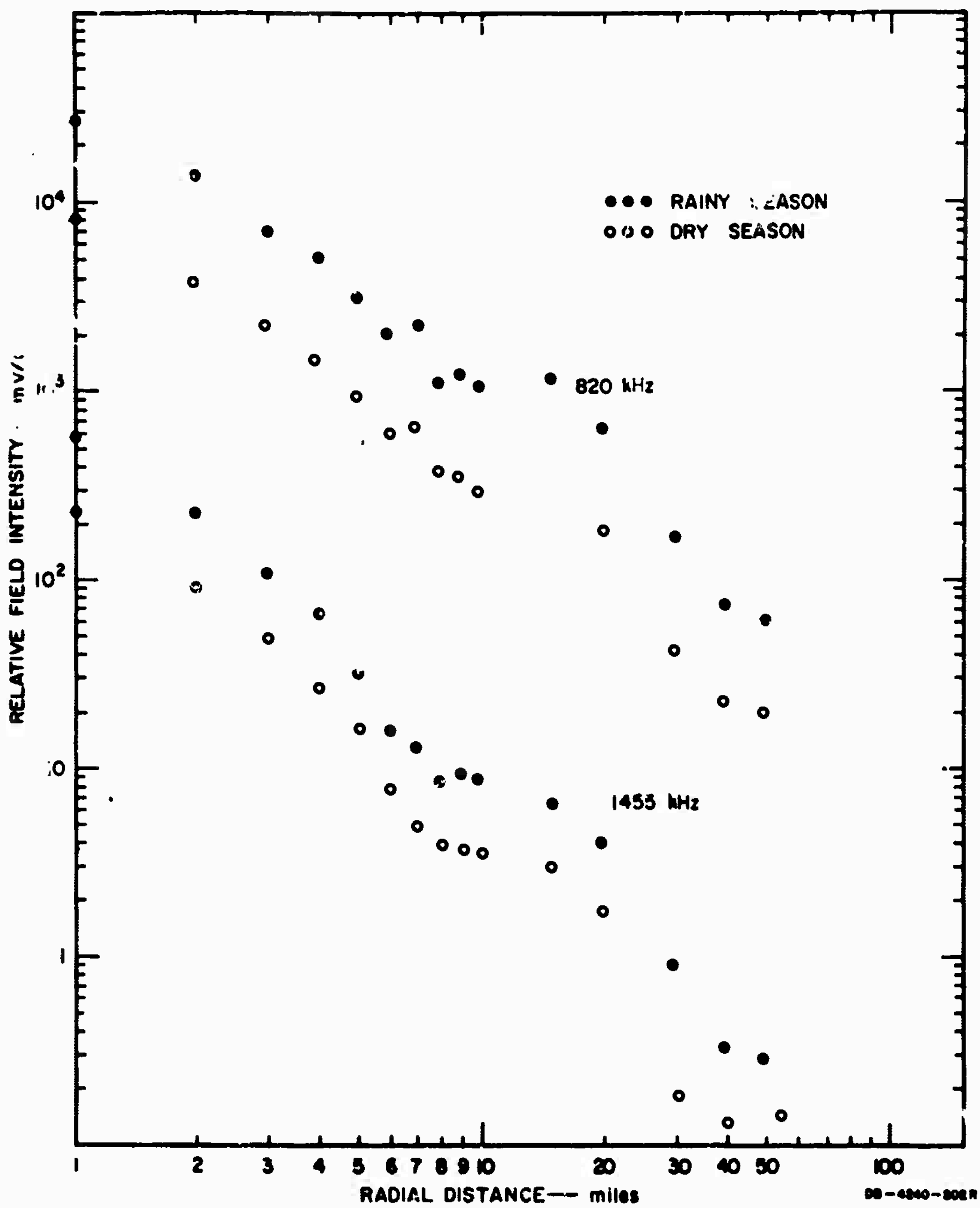

FIG. C-23 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — ROI ET TO YASOTHON AND UBON

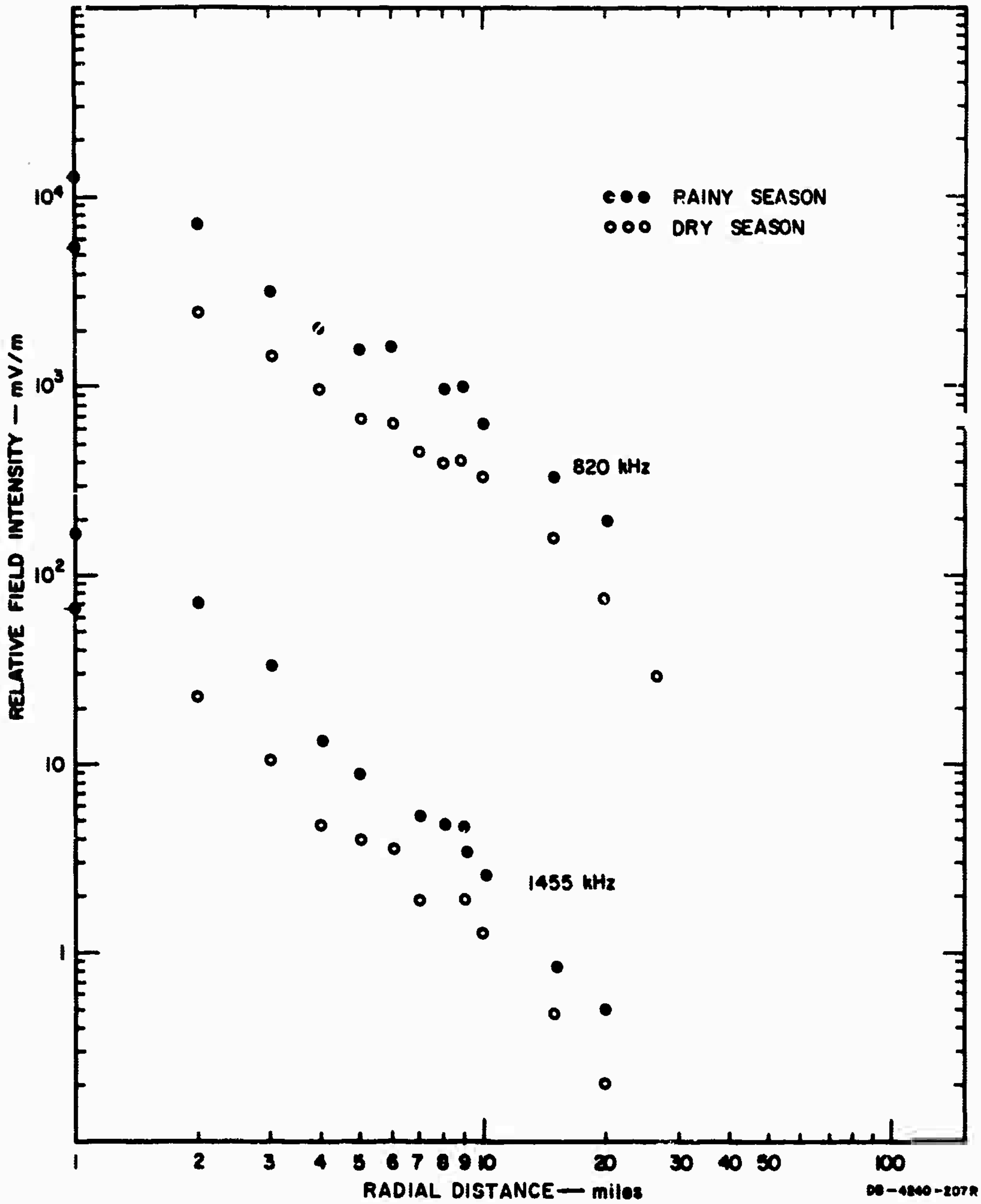

FIG. C-24 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — ROI ET TO YASOTHON AND PHAHOM PHRAI

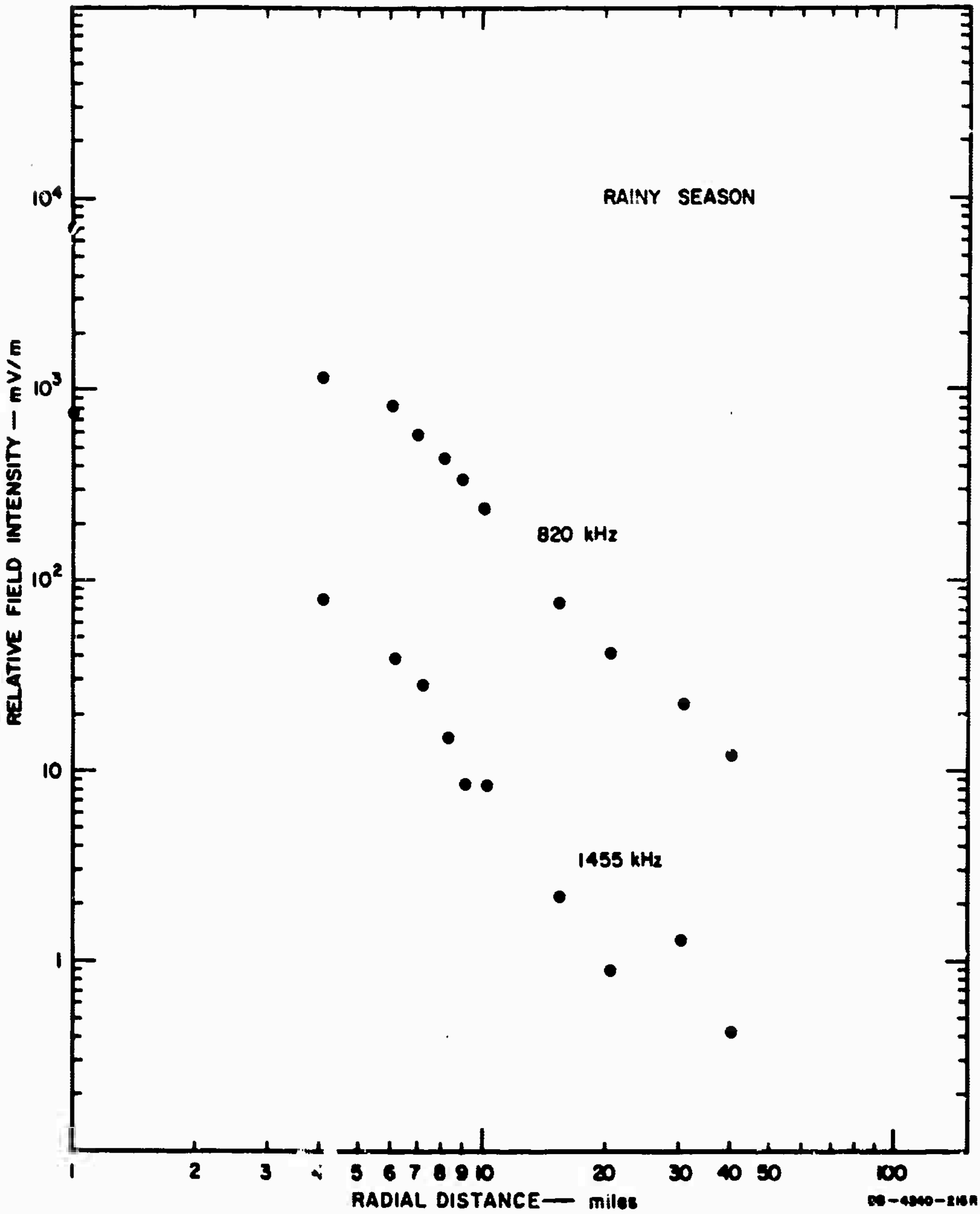

FIG. C-25 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — UBON TO PHIBUN MANGSAHAN

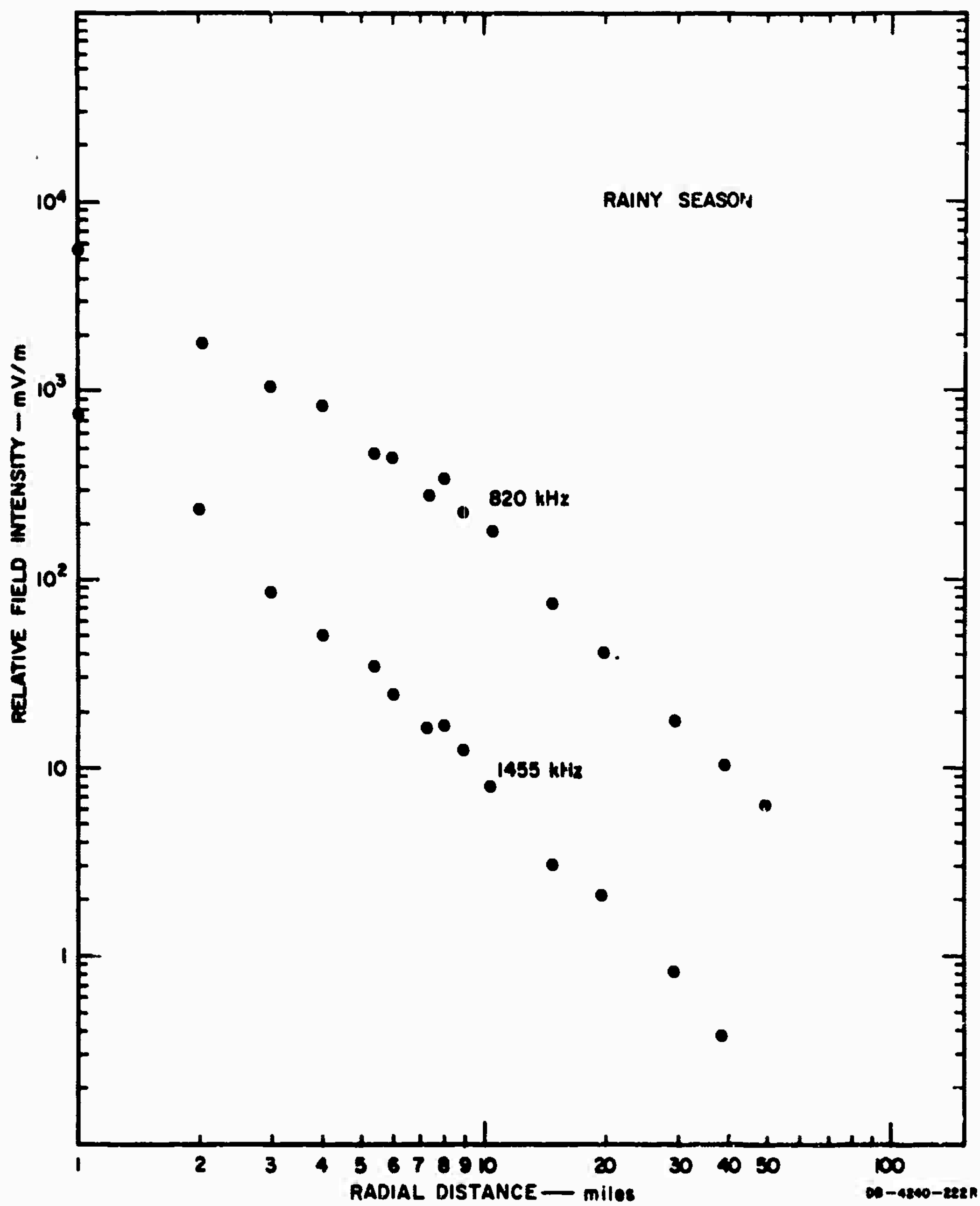

FIG. C-26. MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — UBON TO AMNAT CHAROEN

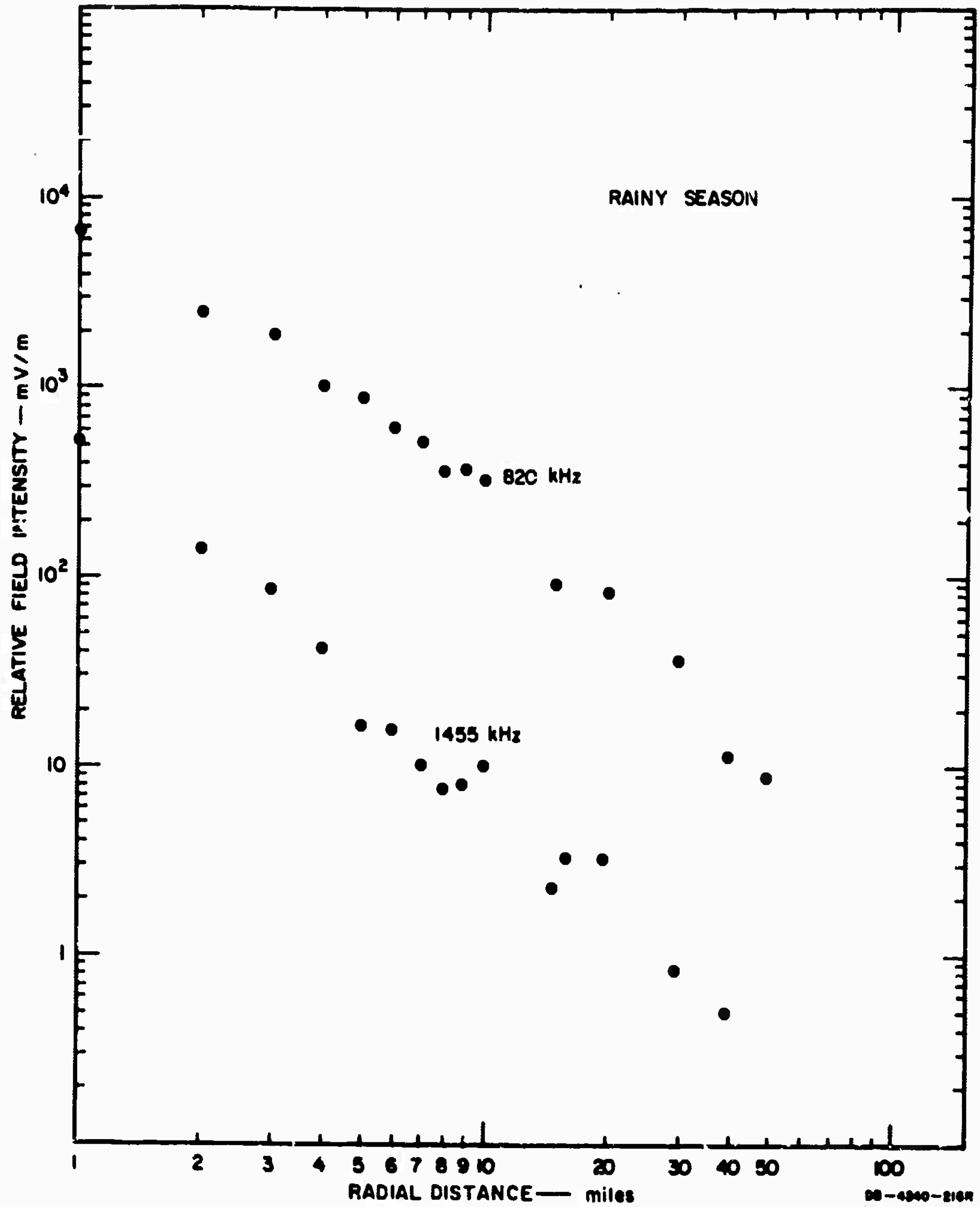

FIG. C-27 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — UBON TO YASOTHON AND ROI ET

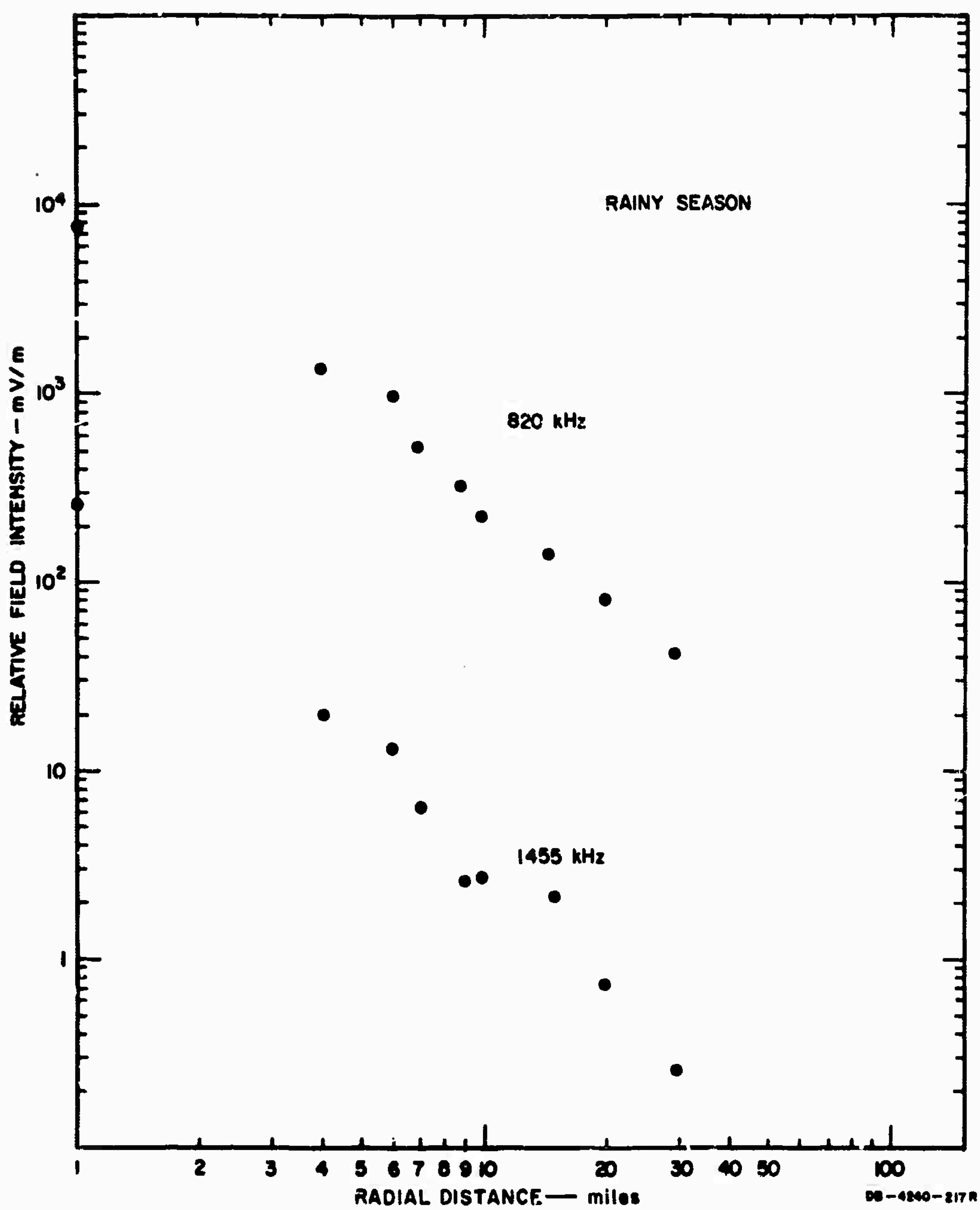

FIG. C-28 MEASURED RELATIVE FIELD INTENSITY vs. RADIAL DISTANCE — UBON TO DET UDOM

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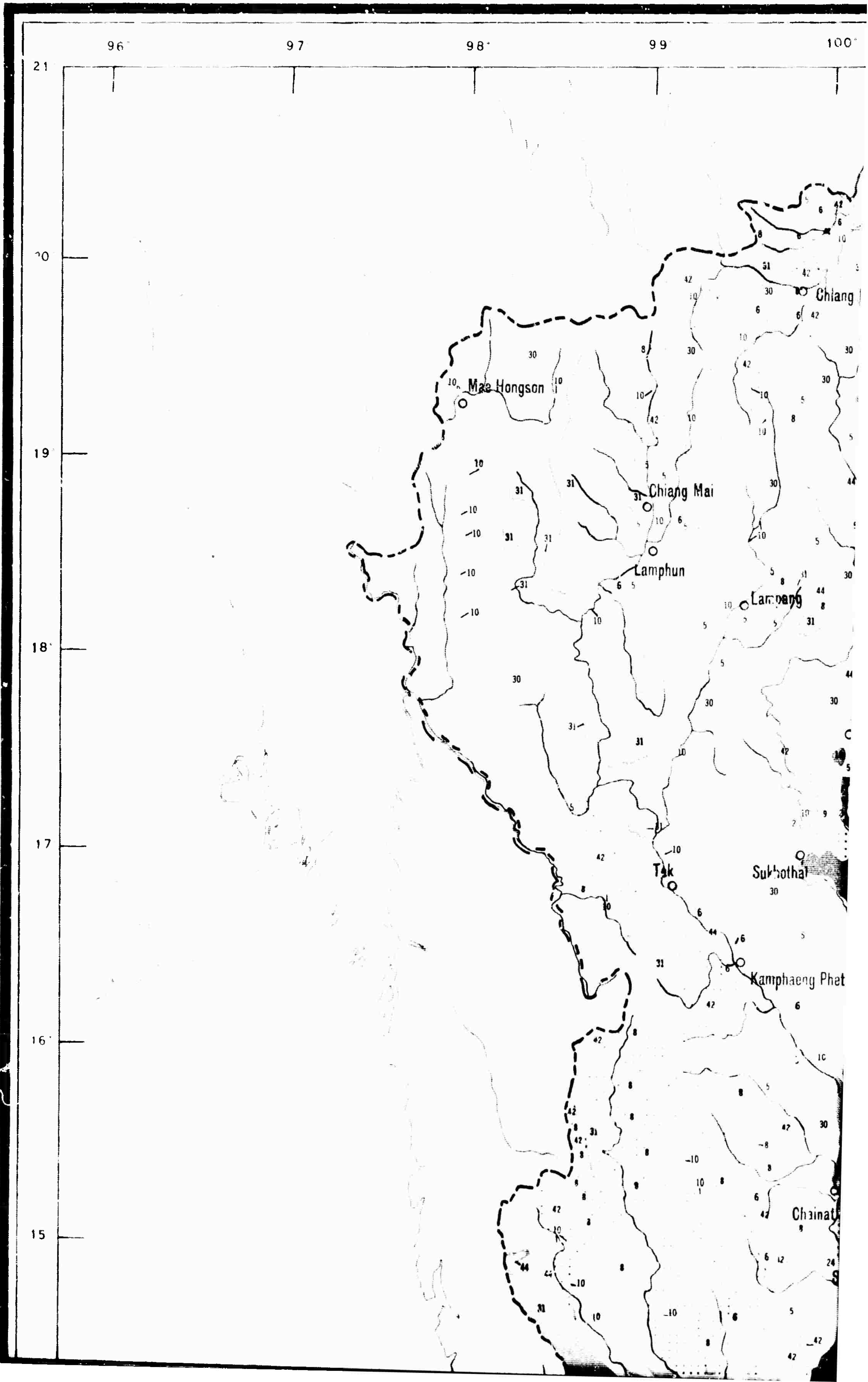
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Kamphaeng Phet
Chainat

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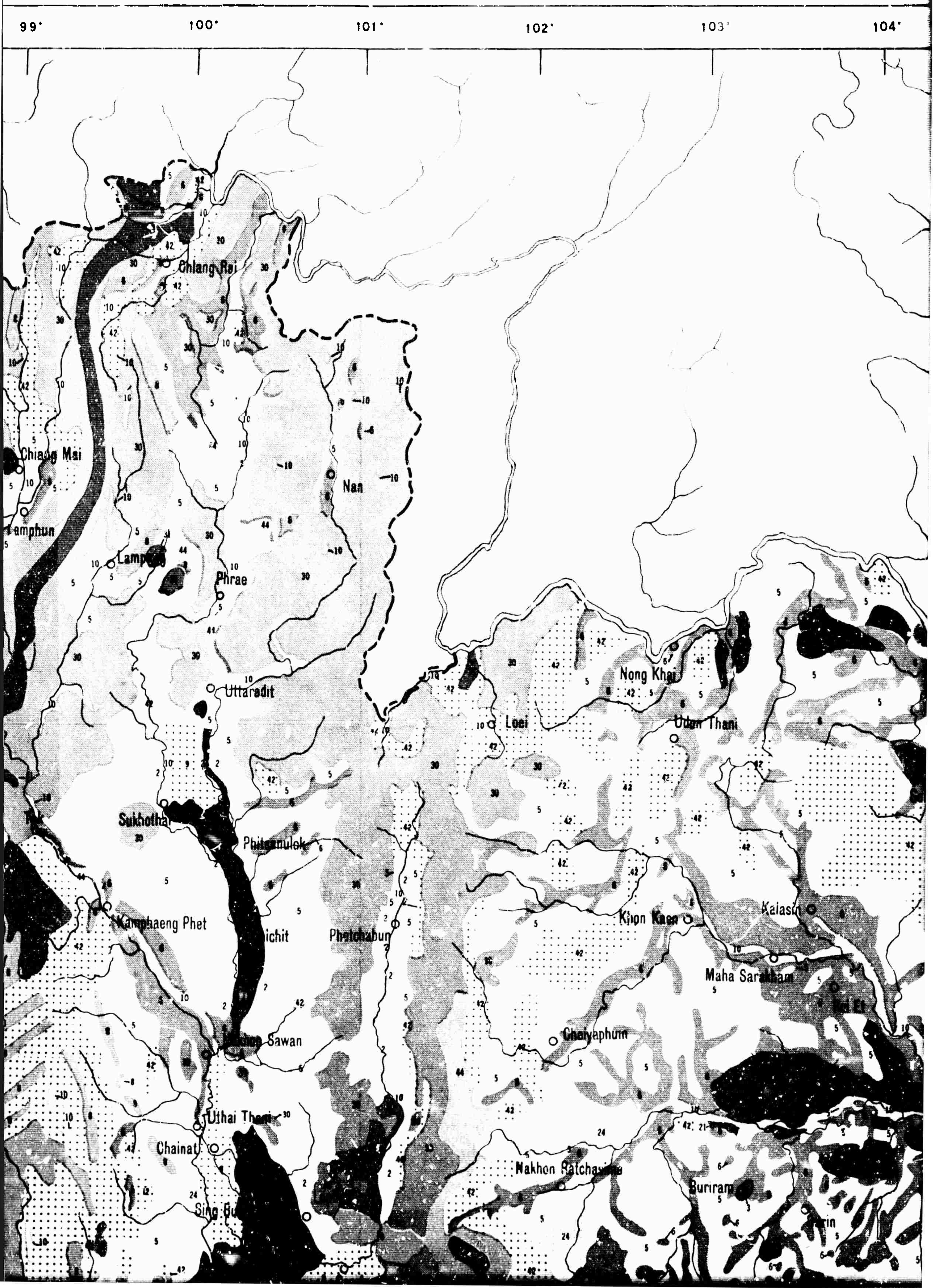

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Maha Sarakham
Chaiyaphum
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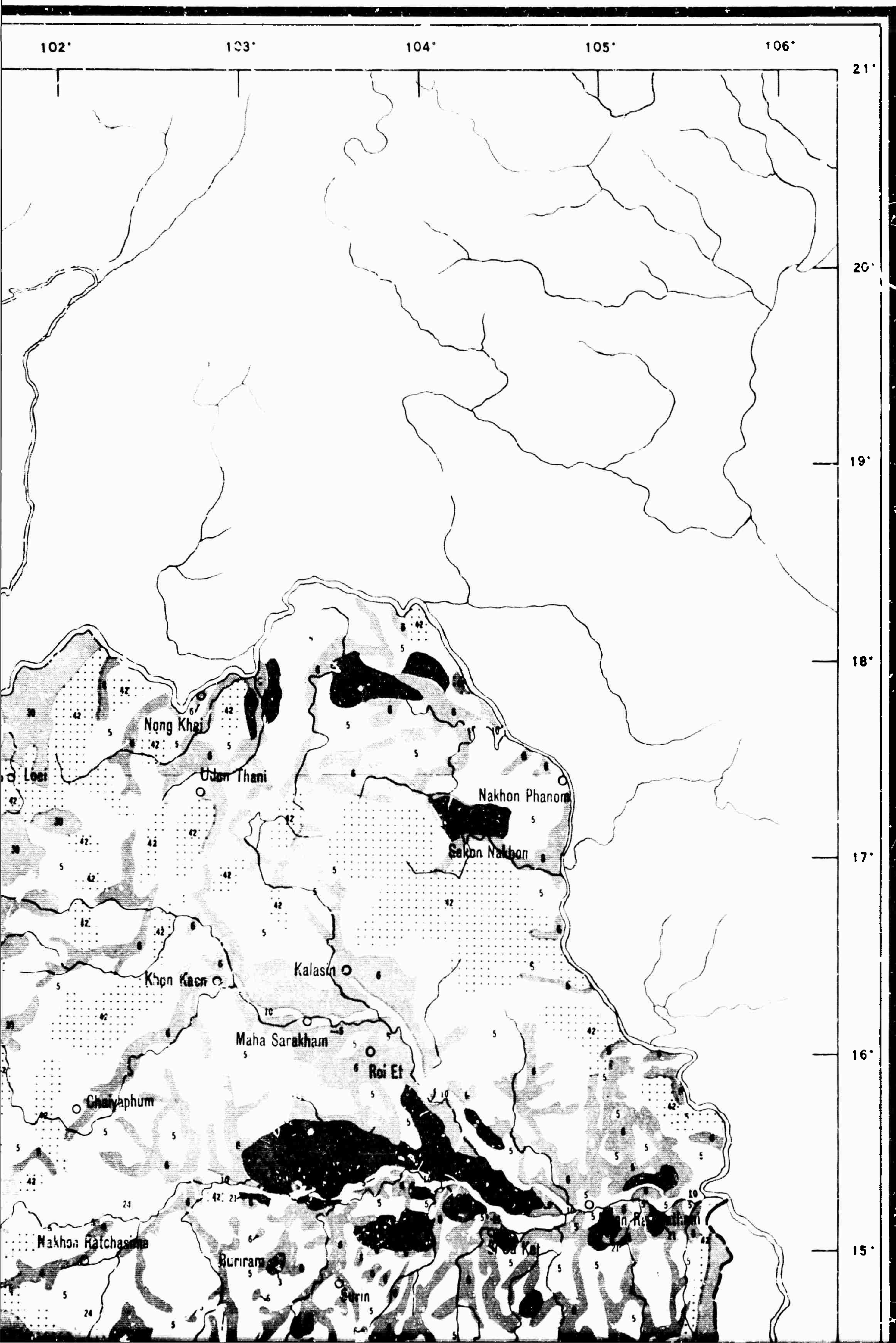
Chainat
Buriram



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Buriram
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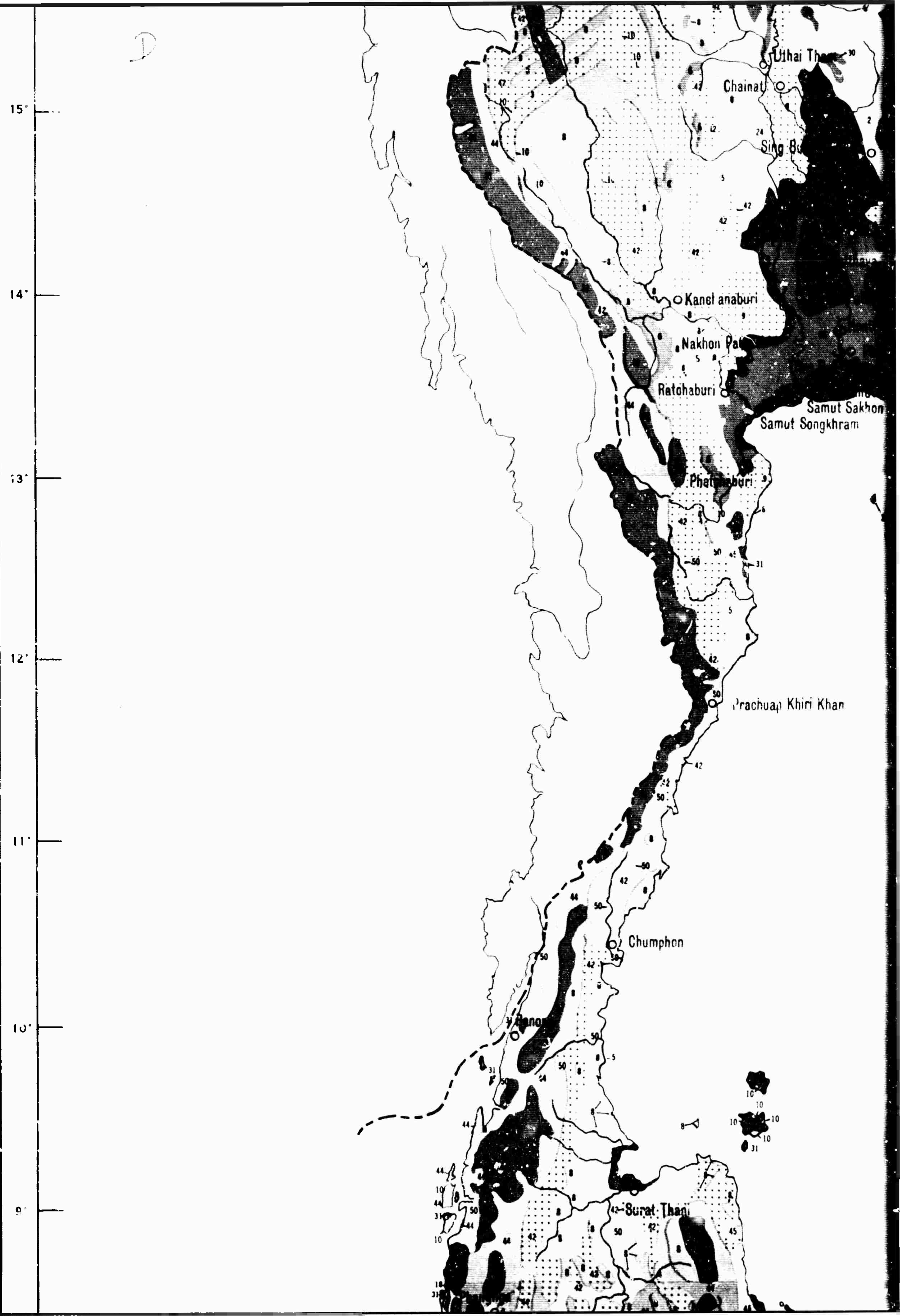

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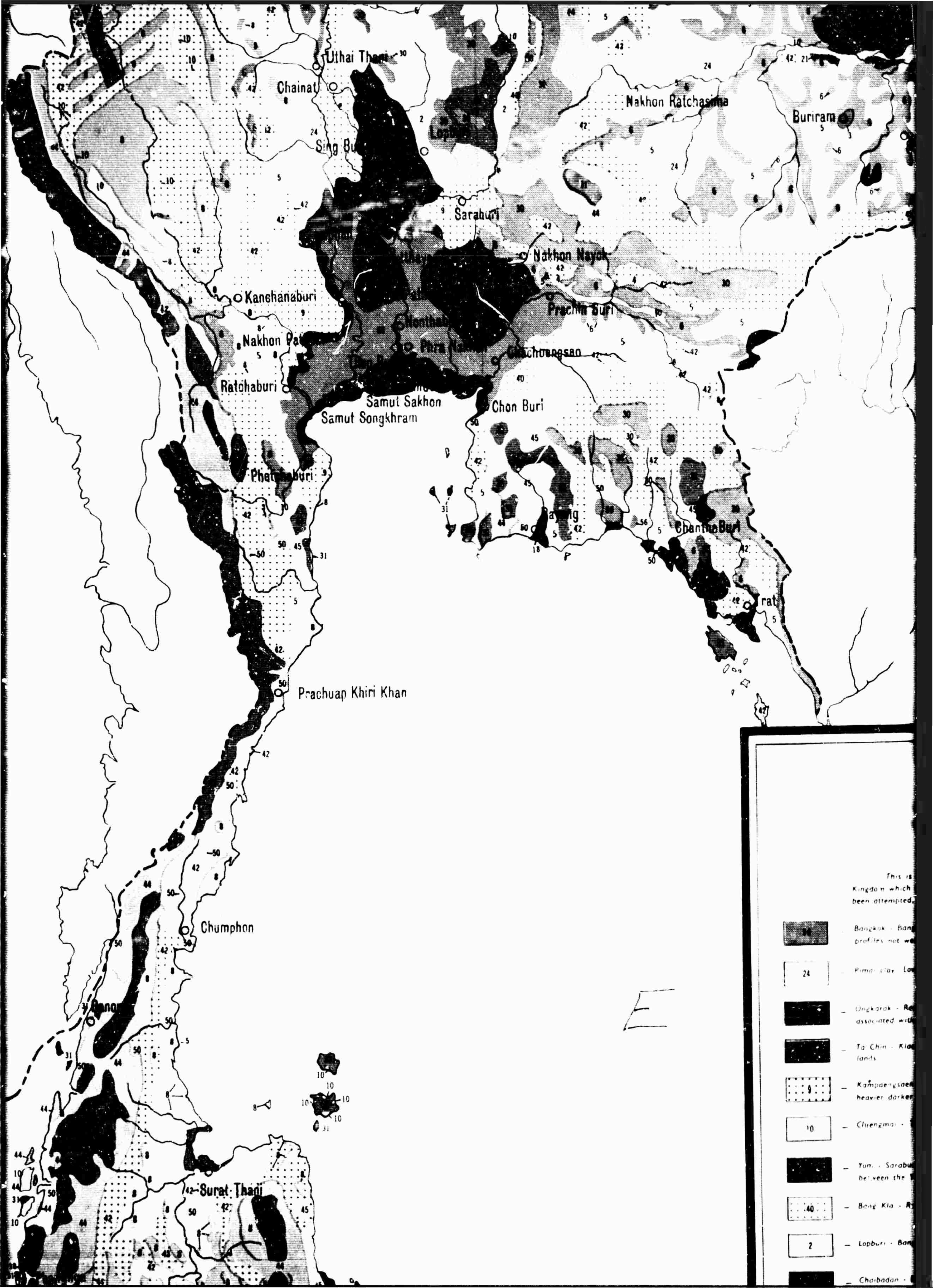
Surat Thani



Uthai Thani
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Buriram
Sing Buri
Lopburi
Saraburi
Nakhon Nayok
Kanchanaburi
Prachin Buri
Nakhon Pathom
Phra Nakhon
Chachoengsao
Ratchaburi
Samut Sakhon
Samut Songkhram
Chon Buri
Phetchaburi
Chanthaburi
Trat
Prachuap Khiri Khan
Chumphon
Surat Thani
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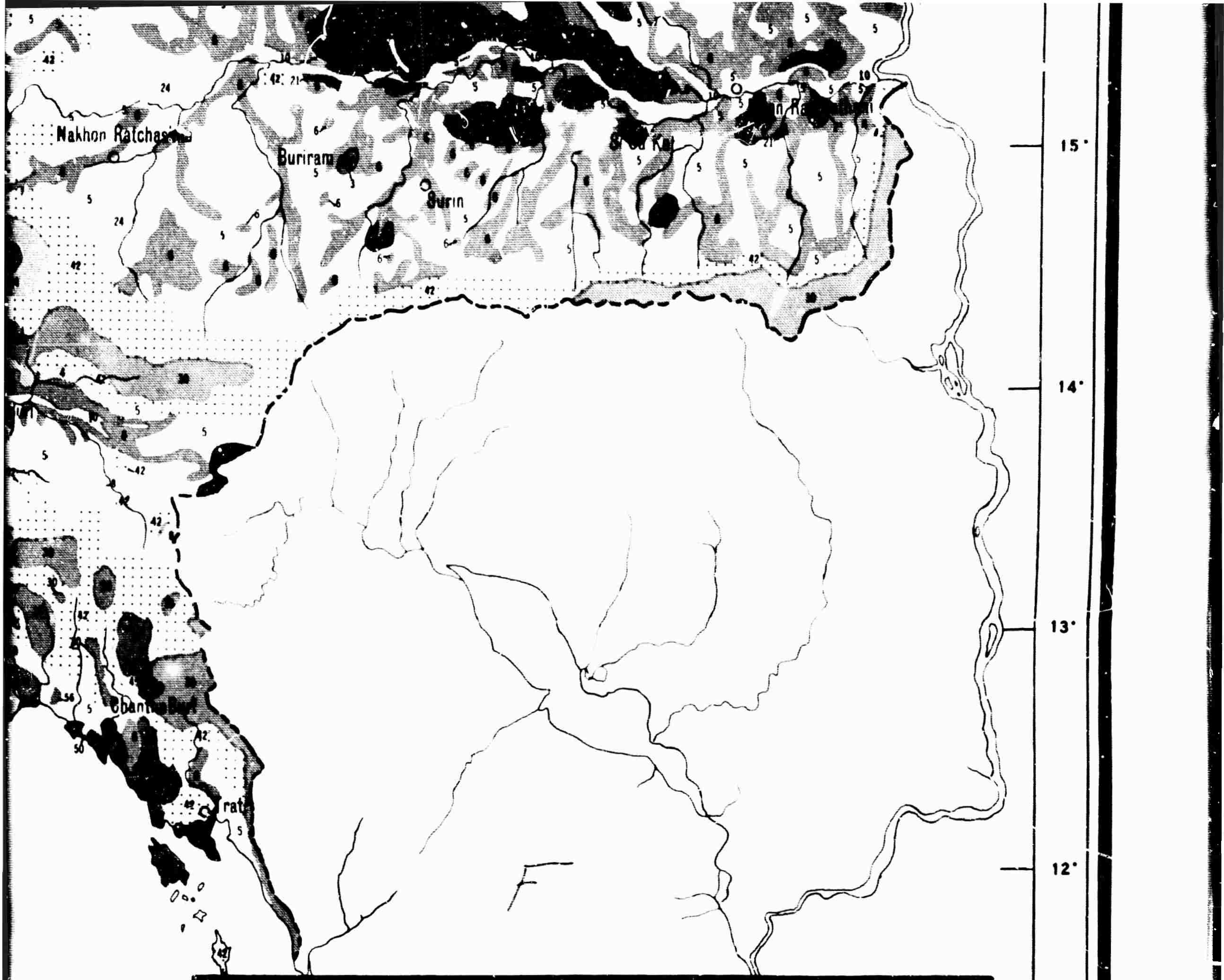
Ta Chin
Kampaengsaen
Chiengmai
Yun
Bang Kla
Lopburi
Chaibadan

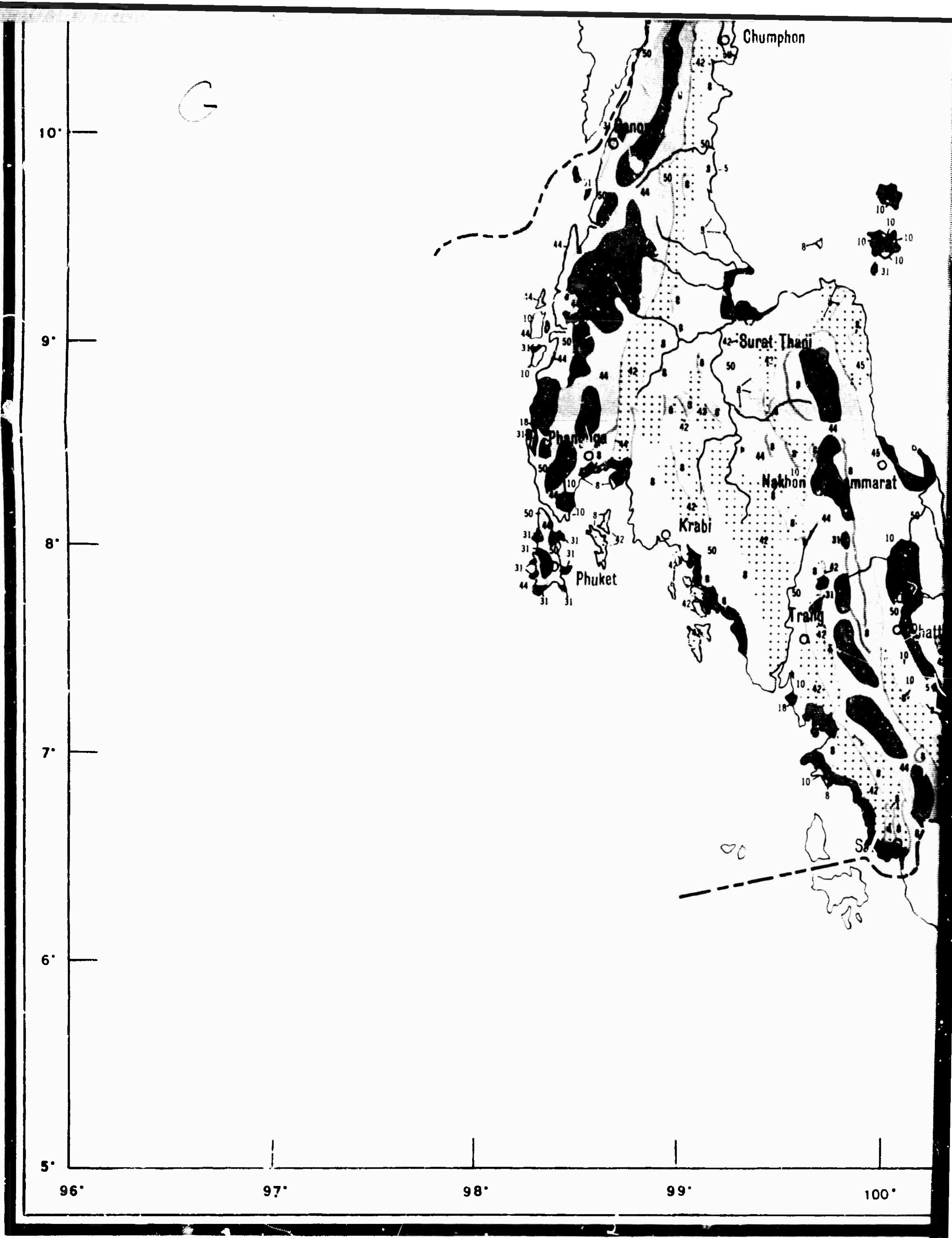


THAILAND

SCALE 1/2.500.000
SHOWING
SOIL ASSOCIATIONS

This is an attempt to assemble available data and to estimate the conditions in those parts of the Kingdom which have not been visited. Generalizations from petrographical, geological, and botanical data have been attempted. The errors are doubtless many and serious. Much more field work is needed.

- *Bangkok - Bangkhen Damnern Saduak - Pra kanong - Minburi - Sam Ruan: mostly low humic glei with profiles not well developed, clays generally. Rice Fruits. Vegetables on ridged beds.*
- 24 – *Pimai clay. Low humic glei. Rice*
- – *Ongkarak - Rangsid - Lad Lum Kaeo - Nong Sala. Cat clays, low humic glei. Soils very acid often times associated with aluminum toxicity. Rice. Fruits, vegetables on ridged beds.*
- – *Ta Chin - Klaeng. Solonchaks and gray hydromorphic soils. Coastal saline soils, mangrove swamps and grass lands.*
- – *Kampaengsaen - Nakorn Pathom. Gray podsolic and low humic glei. Medium textured soils. With strips of heavier darker soils. Upland crops, fruit trees, rice and vegetables.*
- 10 – *Chiengmai - Ta Muang - Ratburi. Recent alluvial soils and some terraces. Upland crops, fruit trees, rice, et*
- – *Yom - Saraburi. Alluvial, low humic glei, hydromorphic, and brown podsolic. Flat lands, natural levees, swamps between the Yom and Nan rivers as well as the lands in the upp central plain. Upland crops, rice, fruit trees*
- 40 – *Bang Kla - Roi Et - Bangkok. Low humic glei. Rice, fruit trees.*
- 2 – *Lopburi - Bangkok - Pimai. Rendzina, low humic glei. Rice, upland crops, fruit trees.*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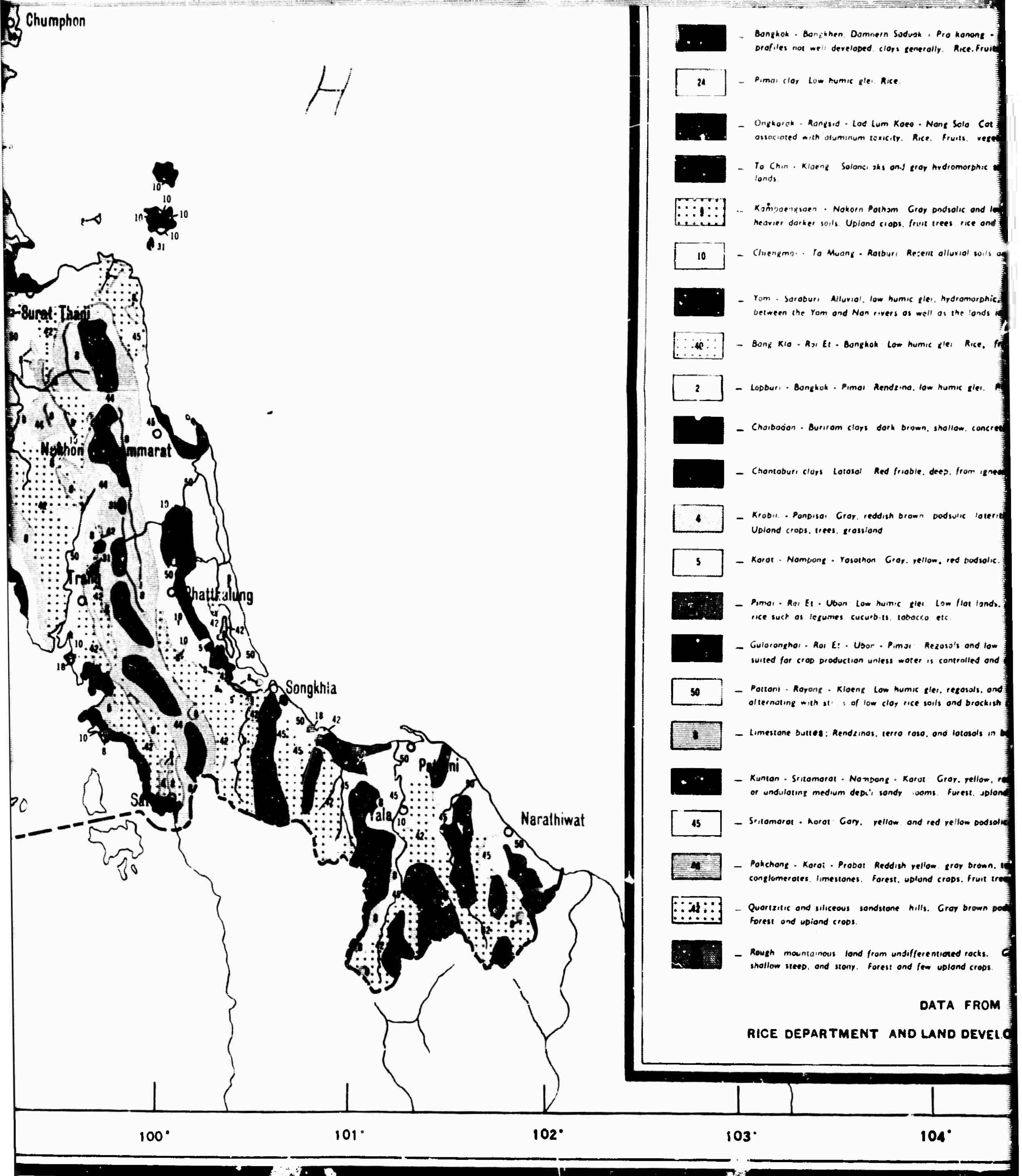

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Songkhla
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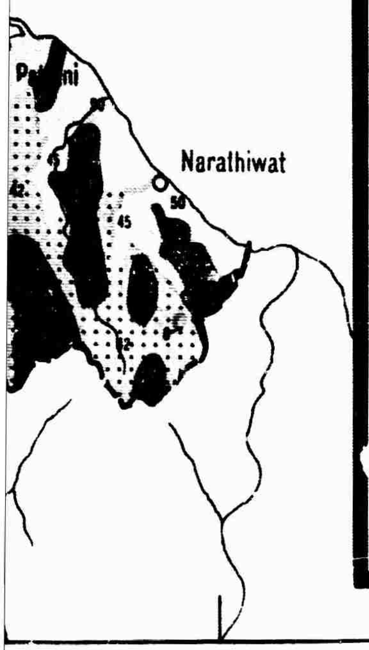
Yala
Narathiwat
Bangkok - Bangkhen. Damnern Saduak - Pra kanong -
profiles not well developed clays generally. Rice. Fruit
Pimai clay Low humic glei. Rice.
Ongkarak - Rangsid - Lad Lum Kaeo - Nong Sala Cat
associated with aluminum toxicity. Rice. Fruits. vege
Ta Chin - Klaeng Solonchaks and gray hydromorphic
lands.
Kampaengsaen - Nakorn Pathom Gray podsolic and lo
heavier darker soils. Upland crops, fruit trees rice and
Chiengmai - Ta Muang - Ratburi Recent alluvial soils
Yom - Saraburi Alluvial, low humic glei, hydromorphic
between the Yom and Nan rivers as well as the lands
Bang Kla - Roi Et - Bangkok Low humic glei Rice,
Lopburi - Bangkok - Pimai Rendzina, low humic glei.
Chaibadan - Buriram clays dark brown, shallow, concre
Chantaburi clays Latosol Red friable, deep, from igne
Krabi - Panpisai Gray, reddish brown podsolic lateri
Upland crops, trees, grassland
Karat - Nampong - Yasothon Gray, yellow, red podsolic.
Pimai - Roi Et - Ubon Low humic glei Low flat lands.
rice such as legumes cucurbits, tobacco etc
Gularonghai - Roi Et - Ubon - Pimai Regosols and low
suited for crop production unless water is controlled and
Pattani - Rayong - Klaeng Low humic glei, regosols, and
alternating with st s of low clay rice soils and brackish
Limestone buttes; Rendzinas, terra rosa, and latosols in
Kuntan - Sritamarat - Nampong - Karat Gray, yellow,
of undulating medium dep sandy ooms Forest, uplan
Sritamarat - Karat Gary, yellow and red yellow podsoli
Pakchong - Karat - Prabat Reddish yellow gray brown,
conglomerates, limestones. Forest, upland crops. Fruit tre
Quartzitic and siliceous sandstone hills. Gray brown po
Forest and upland crops.
Rough mountainous land from undifferentiated rocks.
shallow steep, and stony. Forest and few upland crops.
DATA FROM
RICE DEPARTMENT AND LAND DEVEL
100°
101°
102°
103°
104°

- Bangkok - Bangkhen, Damnern Saduak - Pra kanong - Minburi - Sam Ruan : mostly low humic glei with profiles not well developed, clays generally. Rice, Fruits, Vegetables on ridged beds.
- 24 – Pimai clay. Low humic glei. Rice.
- Ongkorak - Rangsit - Lad Lum Kaeo - Nong Sola. Cat clays, low humic glei. Soils very acid often times associated with aluminum toxicity. Rice. Fruits, vegetables on ridged beds.
- To Chin - Kloeng. Solonchaks and gray hydromorphic soils. Coastal saline soils mangrove swamps and grass lands.
- Kamphaengsaen - Nakorn Pathom. Gray podsolic and low humic glei. Medium textured soils With strips of heavier darker soils. Upland crops, fruit trees, rice and vegetables.
- 10 – Chieng [illegible] - Ta Muang - Rotburi. Recent alluvial soils and some terraces. Upland crops, fruit trees, rice, etc.
- Yom - Saraburi. Alluvial, low humic glei, hydromorphic, and brown podsolic. Flat lands, natural levees, swamps between the Yom and Nan rivers as well as the lands in the upper central plain. Upland crops, rice, fruit trees.
- 40 – Bang Kla - Roi Et - Bangkok. Low humic glei. Rice, fruit trees.
- 2 – Lopburi - Bangkok - Pimai. Rendzina, low humic glei. Rice, upland crops, fruit trees.
- Chaibadon - Buriram clays. dark brown, shallow, concretionary from igneous rocks. Upland crops, fruit trees, rice.
- Chantaburi clays. Latosol. Red friable, deep, from igneous rocks.
- 4 – Krabin - Ponpisai. Gray, reddish brown podsolic lateritic. Shallow with abundant ferruginous concretions. Upland crops, trees, grassland.
- 5 – Korat - Nampong - Yasothon. Gray, yellow, red podsolic. Upland crops, forest, grassland, fruit trees.
- Pimai - Roi Et - Ubon. Low humic glei. Low flat lands, from clays to sandy loams. Rice, upland crops after rice such as legumes, cucurbits, tobacco, etc.
- Gularonghai - Roi Et - Ubon - Pimai. Regosols and low humic gleys. Flat grassy plains. Flood hazard. Not suited for crop production unless water is controlled and or fertilizers applied. Rice.
- 50 – Pattani - Rayong - Kloeng. Low humic glei, regosols, and hydromorphic soils. Coastal soils, sandy ridges alternating with strips of low clay rice soils and brackish nipa swamps.
- Limestone buttes: Rendzinas, terra rosa, and latosols in between. Forest, rubber, fruit trees, upland crops.
- Kuntan - Sritamarat - Nampong - Korat. Gray, yellow, reddish brown and yellow podsolic. Steep and shallow or undulating medium depth sandy loams. Forest, upland crops.
- 45 – Sritamarat - Korat. Gary, yellow and red yellow podsolic. Forest, fruit trees, upland crops.
- 44 – Pakchang - Korat - Prabat. Reddish yellow, gray brown, terra rosa. Loams and clays from shales, slates, conglomerates, limestones. Forest, upland crops. Fruit trees.
- 42 – Quartzitic and siliceous sandstone hills. Gray brown podsolic. Soils usually shallow and in some places, stony. Forest and upland crops.
- Rough mountainous land from undifferentiated rocks. Gray brown, red podsolics and lithosols. Soils usually shallow steep, and stony. Forest and few upland crops.

DATA FROM

RICE DEPARTMENT AND LAND DEVELOPEMENT DEPARTMENT



PRINTED BY ROYAL THAI SURVEY DEPARTMENT 1964

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Stanford Research Institute 333 Ravenswood Avenue Menlo Park, California 94025	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

ELECTRICAL GROUND CONSTANTS OF CENTRAL, EASTERN, AND NORTHEASTERN THAILAND

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Special Technical Report 29

5. AUTHOR(S) (First name, middle initial, last name)

Termpoon Kovattana

6. REPORT DATE February 1967	7a. TOTAL NO. OF PAGES 162	7b. NO OF REFS 8

8a. CONTRACT OR GRANT NO. DA 36-039 AMC-00040(E) b. PROJECT NO. Order No. 5384-PM-63-91 c. ARPA Order No. 371 d.	9a. ORIGINATOR'S REPORT NUMBER(S) Special Technical Report 29 SRI Project 4240 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency Washington, D.C.

13. ABSTRACT

In this report two methods suitable for measuring electrical ground constants in Thailand are described. The ground conductivity was measured at the broadcast frequencies of 820 kHz and 1455 kHz using the field-attenuation method. The ground dielectric constant was measured by the wave-tilt method at the high frequency of 27 MHz. Details are given for constructing the necessary equipment, and procedures for the collection and analysis of the data are outlined. The ground conductivity and ground dielectric constants in central, eastern, and northeastern Thailand were measured. The report also contains recommendations for improvements in equipment and measurement procedures.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ground Constants						
Dielectric Constant						
Wave-Tilt Method						
HF and VHF						
Conductivity						
Signal Attenuation Method						
Norton's Curves						
Broadcast Band						
Soil Description						
Central, Eastern, and Northeastern Thailand						
SEACORE						