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VHF PROPAGATION RESULTS USING LOW ANTENNA HEIGHTS IN TROPICAL FORESTS

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Stanford Research Institute

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Jungle						
Jungle propagation						
Tropical forest						
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FORT MONMOUTH, NEW JERSEY 07703

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It is the authors' pleasure to acknowledge the assistance of Mr. K. L. Taylor during the acquisition of the data in Thailand. Mr. Taylor worked directly with one of the authors (Shrauger) on the Manpack Xeledop (MPX) Program from its inception and contributed to many phases of this work. It also is a pleasure to mention the assistance of Mr. H. W. Parker, particularly during the acquisition of the balloon-borne Xeledop data. Mr. Parker also worked on the MPX program in Thailand after Mr. Shrauger returned from Thailand to Montana State University. The suggestions of Mr. G. E. Barker of SRI and Dr. D. F. Dence of USAECOM on an early draft of this report helped improve it considerably. Finally, the continuing support and encouragement of Mr. R. A. Kulinyi of USAECOM helped the authors complete the report on this work begun in Thailand several years ago.

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I INTRODUCTION

It has been known for many years that VHF radio waves are severely attenuated in forested environments. The earliest measurements of significance were made by the Allies during World War II in the rain forests of Panama and New Guinea;[1-3*] later, during the 1950s, additional work was done in Malaya by the British.[4-6] The most comprehensive work to date has been done under Project SEACORE, which has supported research to improve the understanding of radio wave propagation in the forest environment. Under this program, Jansky and Bailey (J & B)[7-10] and Stanford Research Institute (SRI)[11] have carried out experimental programs in Thailand, and others have done extensive mathematical modeling studies of radio propagation in the forest. A bibliography of the earlier papers (through 1965) dealing with propagation through forests is given in Ref. 12, and a relatively complete list of later papers is given at the end of Ref. 13.

The investigation described in this report is directed primarily toward the measurement of the effects of tropical forest terrains on VHF-propagated waves for the special case where low-gain antennas at low heights are used over relatively short ranges (< 0.5 mile). The results are especially relevant to tactical net radio communications and to communications for certain sensor applications. These data are presented in a manner to help verify models used to predict the propagation of VHF radio waves over relatively short distances in the forest environment.

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*Superscripts denote references listed at the end of the report.

The experiments reported here are referred to as "Xeledop" experiments because of the name given to the radio transmitter that was used.* The Xeledop transmitter was initially developed to be towed behind an aircraft and to serve as a free-space source of signals to measure the three-dimensional radiation patterns of full-scale radio antennas.[14] This technique was originally used to measure antenna patterns at HF, but later was extended to permit measurements in the VHF range (50 to 100 MHz). It was realized that this VHF transmitter could be carried on a man's back inside a forest and used in the investigation of the effect of vegetation on VHF propagation. Earlier experience on the SEACORE program in trying to use standard U.S. Army manpack radio sets in measuring of the effect of trees had underscored the need for a stable VHF transmitter for forest propagation studies (i.e., the drift frequency and variation of power output of the AN/PRC-10 manpack radios made them very difficult to use in experimental work). It was also realized that a system containing dipoles would be more tractable to analysis than one using the antennas supplied with the radio sets (usually whip antennas with matching or loading circuits and with relatively inaccessible antenna terminals). Preliminary experiments[15] with a VHF Xeledop used in a manpack configuration in a eucalyptus grove in California were so encouraging that a VHF Xeledop intended solely for manpack use was constructed and sent to Thailand.

The VHF manpack Xeledop (MPX) system was first used in Thailand to study propagation over open rice paddy terrain (open delta) near Bangkok.[16] One objective of these first tests was to develop a systematic test procedure and collect data for a very flat, open-terrain

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*Xeledop is an acronym for Transmitting (X) Elementary Dipole with Optional Polarization.

environment of relatively high conductivity to provide a basis for comparison with future tests in forests. Next, tests were conducted on the open beach and in light foliage adjacent to the beach near the low-noise field site at Laem Chabang. Here the objective was to measure open, flat terrain of low conductivity (dry sand) both with and without underbrush (coastal brush foliage of low height). The results of the open delta, open beach, and foliaged beach measurements were presented in Ref. 16.

During the course of the manpack Xeledop test program, measurements were made at the sites shown on the map of Figure 1. Preliminary data for rubber plantations and clumps of bamboo were obtained at sites near Chantaburi; extensive measurements were made in a dry evergreen forest located east of Chonburi [Ban Mun Chit (BMC)], and again in a fresh-water swamp forest near Chumphon. Chart recordings from many of these sites showing the variation of received signal strength as a function of separation between transmitter and receiver are presented (without analysis) in Ref. 17.

In this report, emphasis is placed on the measurements made at the BMC and Chumphon sites. For specific trails at each site the variation of received signal strength as a function of distance between transmitter and receiver is recorded and analyzed for three frequencies (50, 75,* and 100 MHz) and for several combinations of polarization of the transmitting and receiving antennas. These data are then converted into radio system loss (L_s) for presentation. System loss is defined as the ratio of the power into the transmitting antenna terminals to the power available from the receiving antenna terminals. Comparisons

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*The actual frequency used was 75.1 MHz, because 75.0 MHz is reserved for aircraft beacons on an international basis.

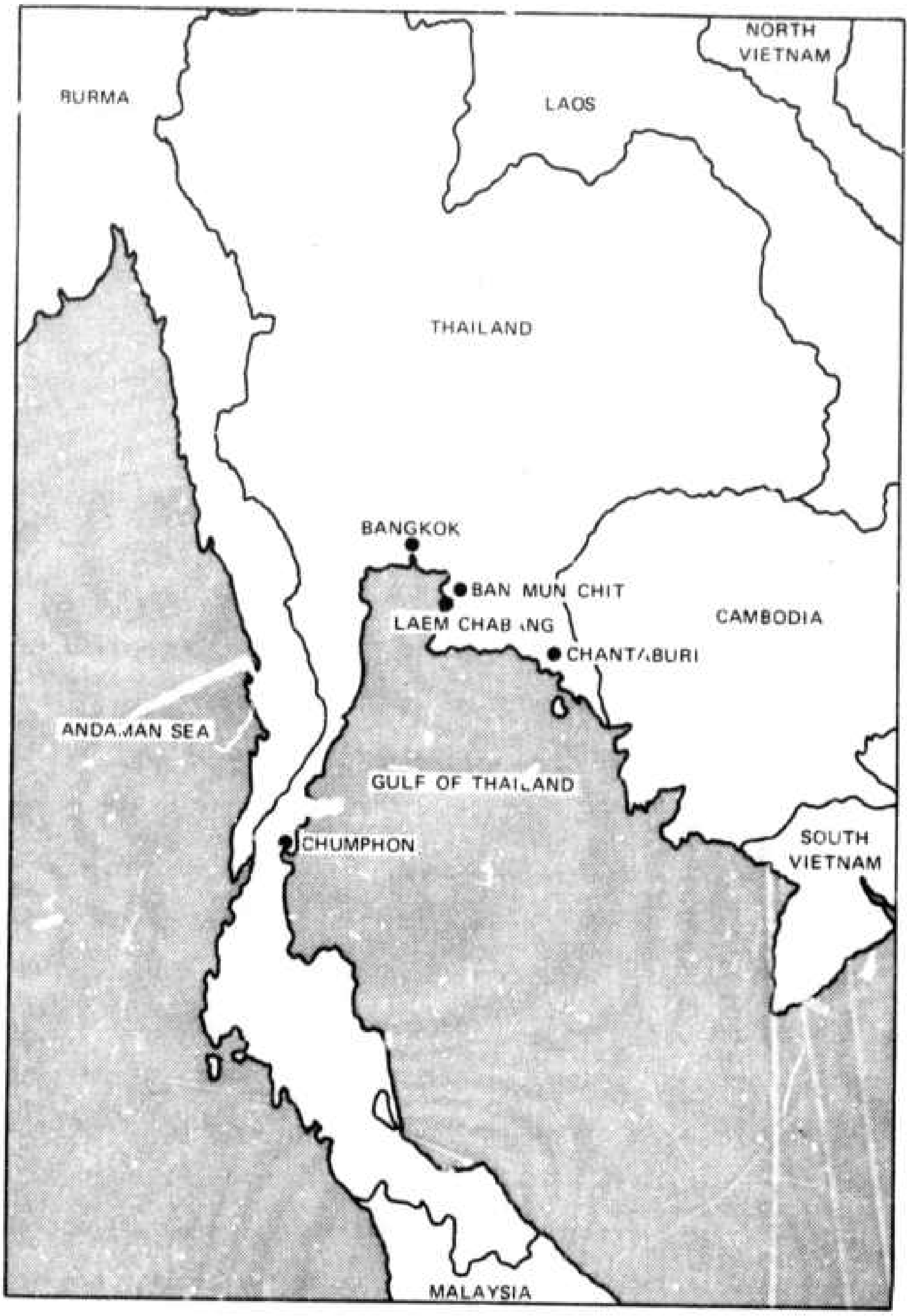

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FIGURE 1 MAP SHOWING LOCATION OF XELEDOP MEASUREMENTS IN THAILAND of the results from different terrains (and of measured and predicted performance based on forest model studies) are also included. A series of Xeledop calibration tests and their results, which make possible the presentation of manpack Xeledop data in terms of system loss, are described in Appendix A, where calibration factors are given for the data in Refs. 16 and 17 and for the data in this report. Measured antenna impedance data are summarized in Appendix B.

Some height-gain data were obtained to help in evaluating propagation models and in developing rules for extrapolating the data obtained at the standard height of 5 ft (transmit) and 10 ft (receiving) to other heights of possible interest. Some of these data for higher heights were obtained with the VHF manpack Xeledop used with a rope and pulley; other measurements were made using a special lightweight Xeledop that was elevated by a balloon. Additional data were obtained for lower heights (down to one inch).

In addition to developing a reliable measurement system and obtaining quantitative measurements of the effect of the forests on that system, it was also vital to relate these results to the performance of actual manpack radio systems. AN/PRC-25 radio sets were used to obtain propagation data on the same trails used for the manpack Xeledop measurements to provide a comparison between the two systems.

II DESCRIPTION OF MEASUREMENTS

The basic technique used in all manpack Xeledop measurements is illustrated in Figure 2. The receiving and recording equipment was housed in a van located far enough (at least 50 feet) from the test area to make any influence of this structure on the measurements negligible. This assumption was validated by field tests. The receiving antenna, which was connected to the equipment van by coaxial cable, was typically set up near the boundary of the clearing and the forest. One man carried the VHF Xeledop transmitter in manpack fashion on a surveyed trail into the forest. A second man walked several wavelengths ahead of the Xeledop and carried a small hand-held transceiver that was used to relay to the operator in the van the Xeledop transmitter's position as it was carried past each of the distance markers on the trail. The Xeledop transmitted CW signals simultaneously on the three frequencies (50, 75, and 100 MHz). These signals were received on separate antennas, and amplitude records that are proportional to the received signal were made at the same time on a multichannel chart recorder. Thus, the experimental results obtained consist of a set of calibrated paper chart recordings of received signal as a function of distance, where the distance varies from zero to at least 0.3 mile in most cases.

Figure 3 shows the manpack Xeledop being used on a trail at Ban Mun Chit.

A. Receiving Equipment

Figure 4 is a diagram for a typical receiving and recording channel. It consists of an attenuator that can be varied in steps to compensate

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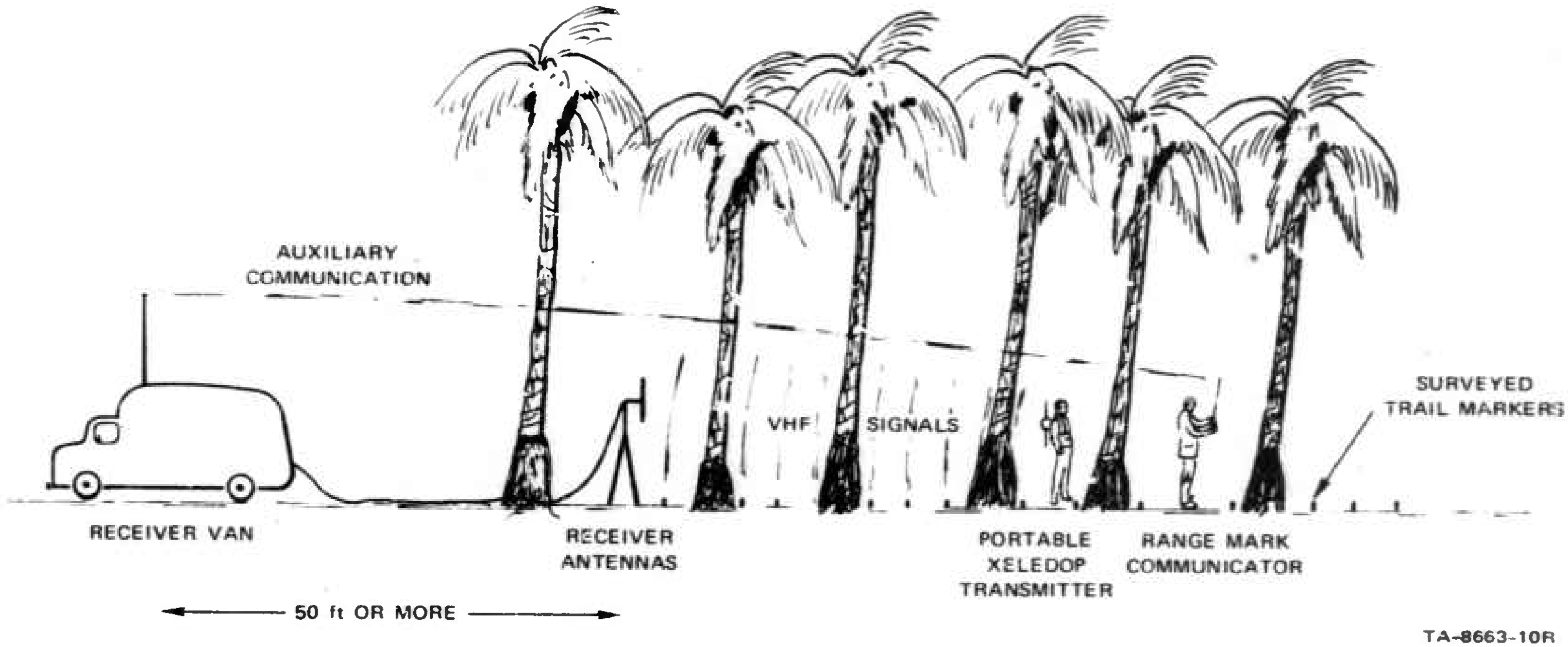
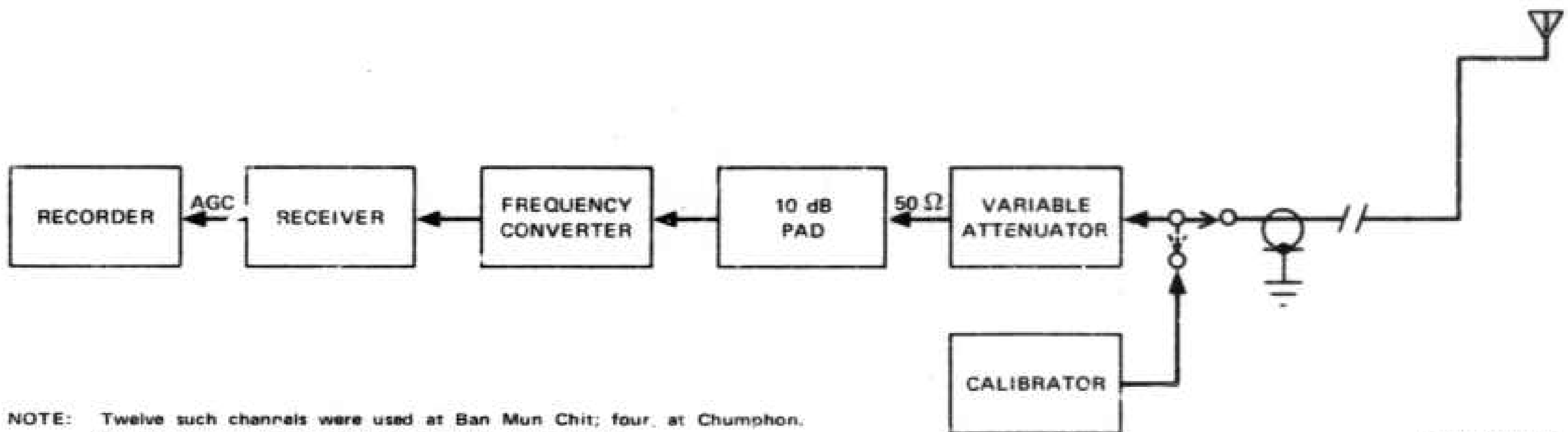


FIGURE 2 SKETCH OF MANPACK XELEDOP TEST PROCEDURE

FIGURE 3   MANPACK XELEDOP BEING CARRIED IN THE HORIZONTALLY POLARIZED POSITION AT BAN MUN CHIT



NOTE: Twelve such channels were used at Ban Mun Chit; four, at Chumphon. See equipment list for components used in each case.

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FIGURE 4 BLOCK DIAGRAM OF ONE RECEIVING SYSTEM CHANNEL for large changes in received signal strength, a fixed attenuator, a receiver, and an analog chart recorder. In the first measurements in Thailand,[16,18] balanced half-wave dipoles and a single-channel recorder were used in all measurements. Later, multichannel recording equipment and several receiving antennas were used. The receiving equipment used at the two major test sites is listed below:

<u>Ban Mun Chit</u>

Antennas

Unbalanced half-wave horizontal dipole
Unbalanced vertical sleeve dipole
Resonant balanced half-wave dipole
"Vietnam" folded dipole*

Line Attenuators

Daven push-button step attenuators

Receivers

R-390 communication receivers with Parks Electronic Laboratory Model 50 Frequency Converters

Recorders

Offner Model 504A (8 channels) and 2 each Sanborn (2 channels)
Total channels available: 12†

Calibrator

SRI Signal Generator

---

*This antenna, made in South Vietnam from a 300-ohm TV-type transmission line, employs a 300- to 50-ohm balun transformer between the antenna feed and a length of RG-58 coaxial cable (see also Ref. 19).

†This large recording capacity was available from the airborne Xeledop antenna pattern measurement program (see Ref. 19).

Chumphon

Antennas

Unbalanced half-wave horizontal dipole
Unbalanced vertical sleeve dipole
Resonant unbalanced half-wave dipole
"Vietnam" folded dipole

Line attenuators

Hewlett-Packard Model 355D

Receivers

R-390 Communications receivers with Parks Electronics Laboratory Model 50 Frequency Converters

Recorder

Sanborn Model 7714-A (4 channels)

Calibrator

SRI Signal Generator

The equipment used for Ban Mun Chit and Chumphon is shown in the photographs of Figures 5 and 6.

B. Site Preparation and Preliminary Measurements

The test procedure for each site was changed little during the course of the test program. At the beginning of the work a test trail was selected, surveyed, and prepared. Trail preparation was rather easy in some cases, such as in open terrain or along existing trails in a forest. All that was required in these cases was a survey to locate the trail zero reference points and radial range markers, and, in the case of the forest trails, some removal of overhanging branches. However, some trails had to be cut entirely through dense foliage, and this required a crew of laborers for several days. The worst case was the forest portion of Trail A at Chumphon; two weeks of preparation were required to prepare this half-mile trail before any data could be gathered.

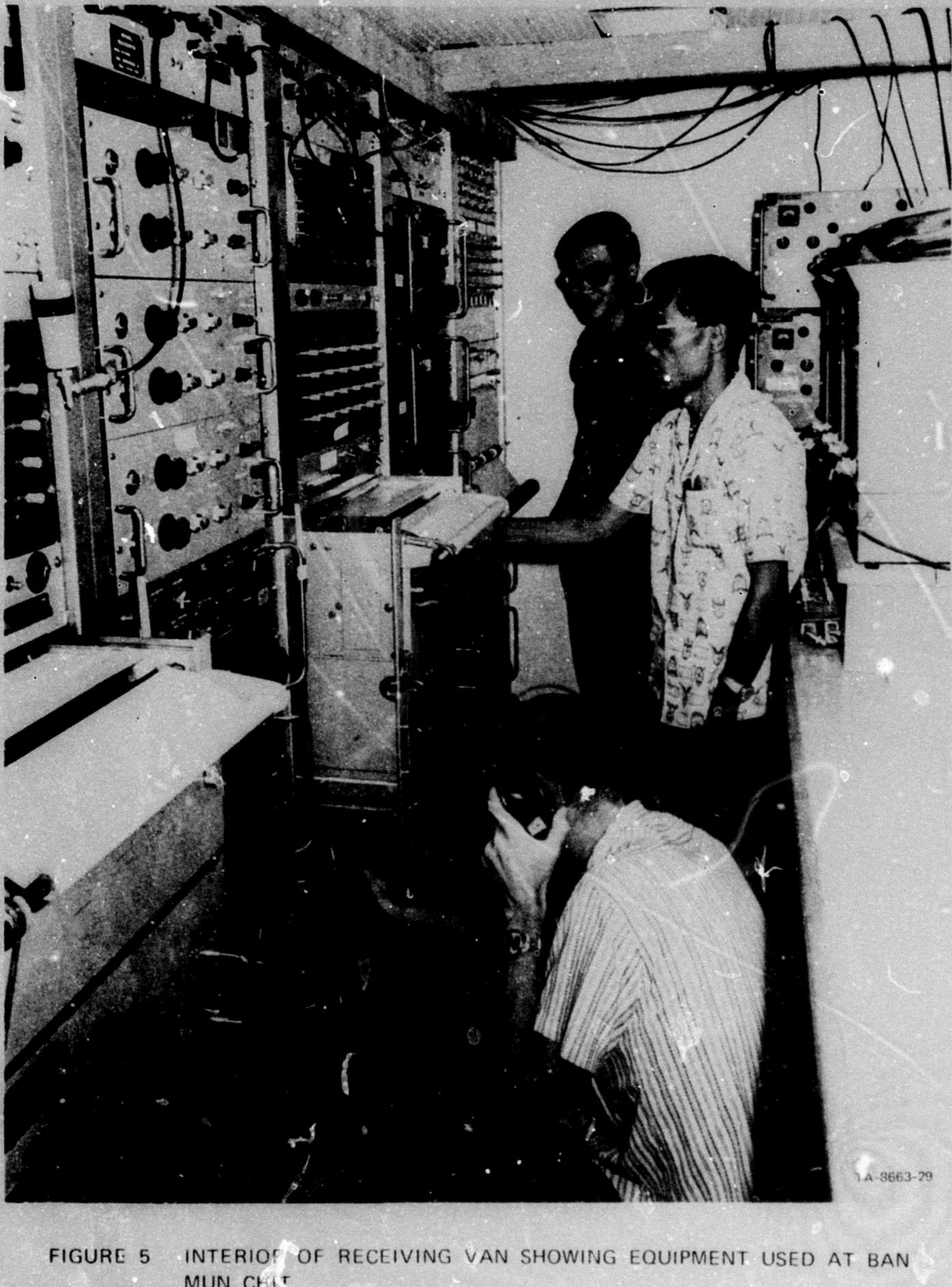

FIGURE 5 INTERIOR OF RECEIVING VAN SHOWING EQUIPMENT USED AT BAN MUN CHIT

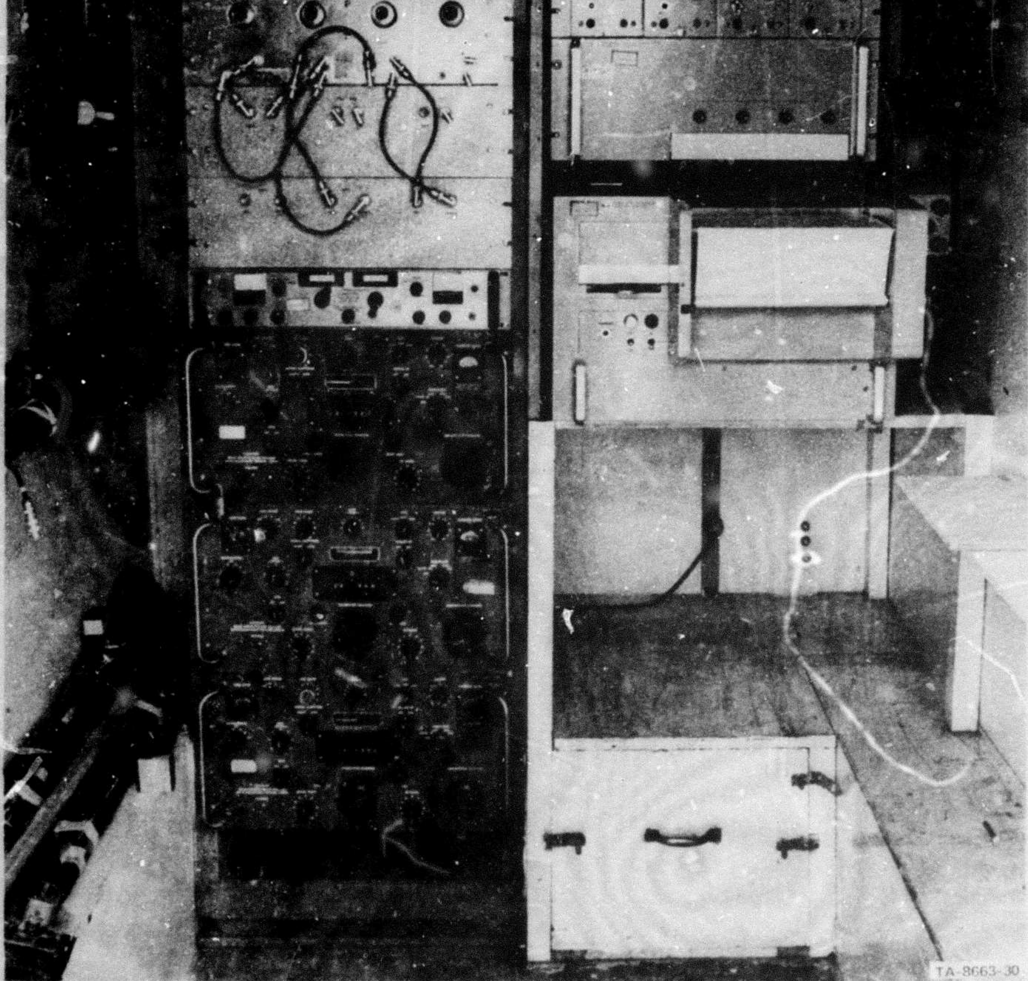

FIGURE 6 INTERIOR OF RECEIVING VAN SHOWING EQUIPMENT USED AT CHUMPHON

The next phase entailed measuring the input impedance for each receiving antenna at its location of installation. In the forest we attempted to locate each antenna in positions similar to the other antenna locations in terms of nearness to trees, branches, and so on. This was difficult to do, especially when many antennas were measured simultaneously, as was done at Ban Mun Chit. The impedance for each antenna was measured for each frequency and polarization for which it was used.* In the case of resonant receiving antennas at Chumphon, the length of each antenna was adjusted until the reactive part of the input impedance was less than 7.5 ohms.

C. Checks During Experimental Runs

Actual test runs were conducted after the previous steps had been completed. In the test phase the output power of each transmitter in the Xeledop was measured at the antenna terminals and the receivers were calibrated at the beginning of the runs. Experience has shown that the measuring system is relatively stable; the power output of the Xeledop transmitter decreases less than 1 dB for 8 hours of simultaneous, 3-frequency, CW operation. Calibration of the receiving systems always showed changes of less than 2 dB during one hour. A test run was usually 15 minutes or less in length. Since power measurements and receiver calibrations were conducted between succeeding runs, the uncertainty of receiver calibration was less than 0.5 dB.

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*Most of these impedances are tabulated in Appendix B.

III TERRAIN DESCRIPTIONS

A principal objective of the manpack Xeledop (MPX) program was to determine the effect of several tropical terrains on signals propagated in the lower part of the VHF band. The value of this type of information is greatly enhanced by knowing the characteristics of the terrain over which the data were gathered. The detailed results of terrain studies made at the MPX sites by the Environmental Sciences Group of the Military Research and Development Center (MRDC) appear in several unpublished report drafts,[20,21] and this information has been summarized in Refs. 11 and 22. In this section we will give a general description of the test terrains and summarize their characteristics to illustrate the differences.

A. Ban Mun Chit Test Site

The BMC forest test site is generally described as a secondary, dry evergreen forest. It is about 10 square kilometers in extent; however, as shown in the aerial view (Figure 7) and corresponding line drawing (Figure 8), only a small portion of this was used for these tests. The forest had been heavily logged in the past and this resulted in an open and uneven canopy; the lack of a dense canopy had allowed heavy undergrowth to predominate. Figures 9 and 10 are photos of the foliage. Figure 9 is a view of the forest edge from across the test clearing. (Note the heavy brush and the broken canopy.) The forest was classified as having a three-story canopy, but this is not readily apparent in this photo. Figure 10 is an interior view of the foliage along one of the test trails; here, again, the broken canopy and heavy undergrowth are apparent.

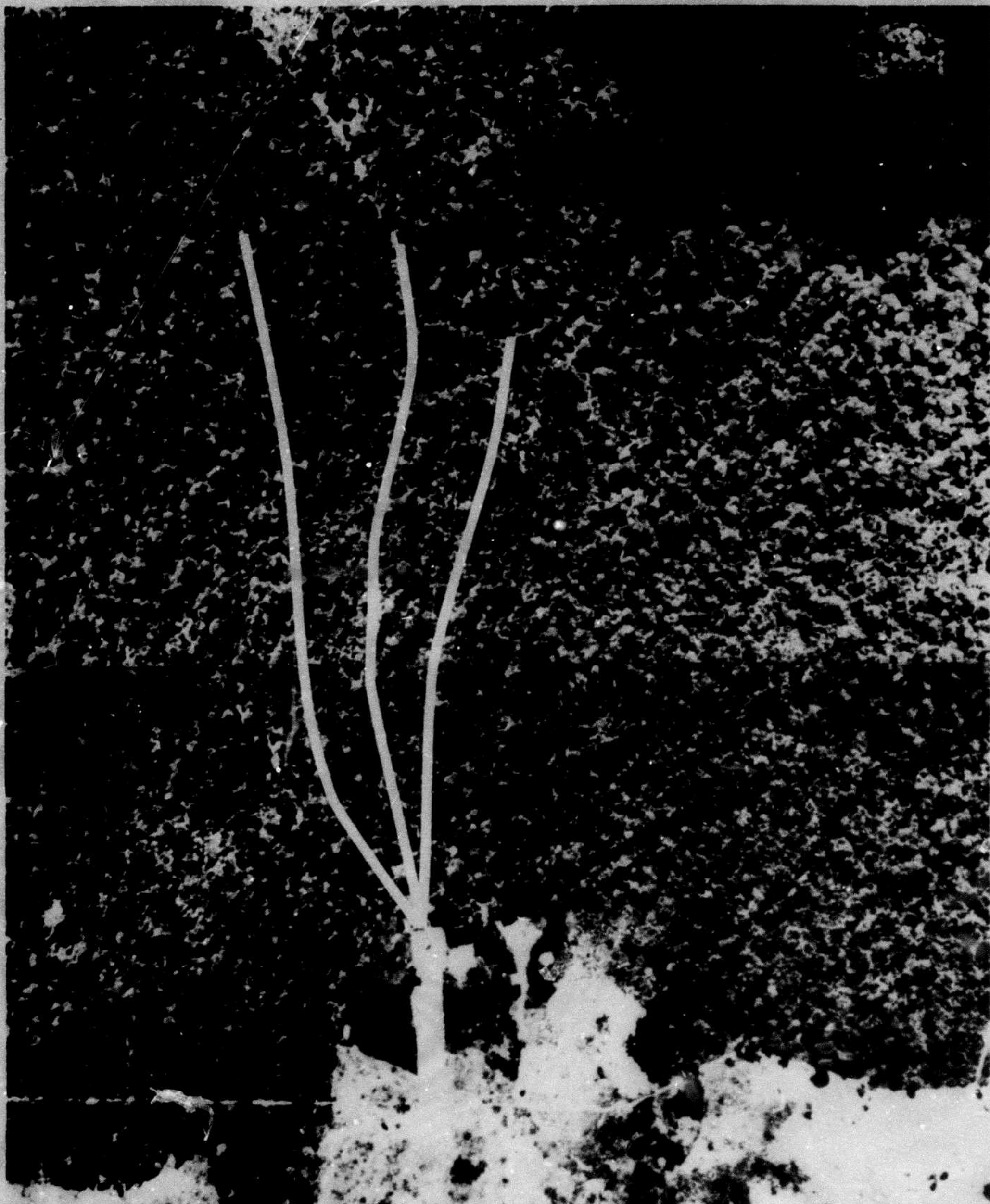

FIGURE 7 AERIAL PHOTOGRAPH OF BMC TEST SITE

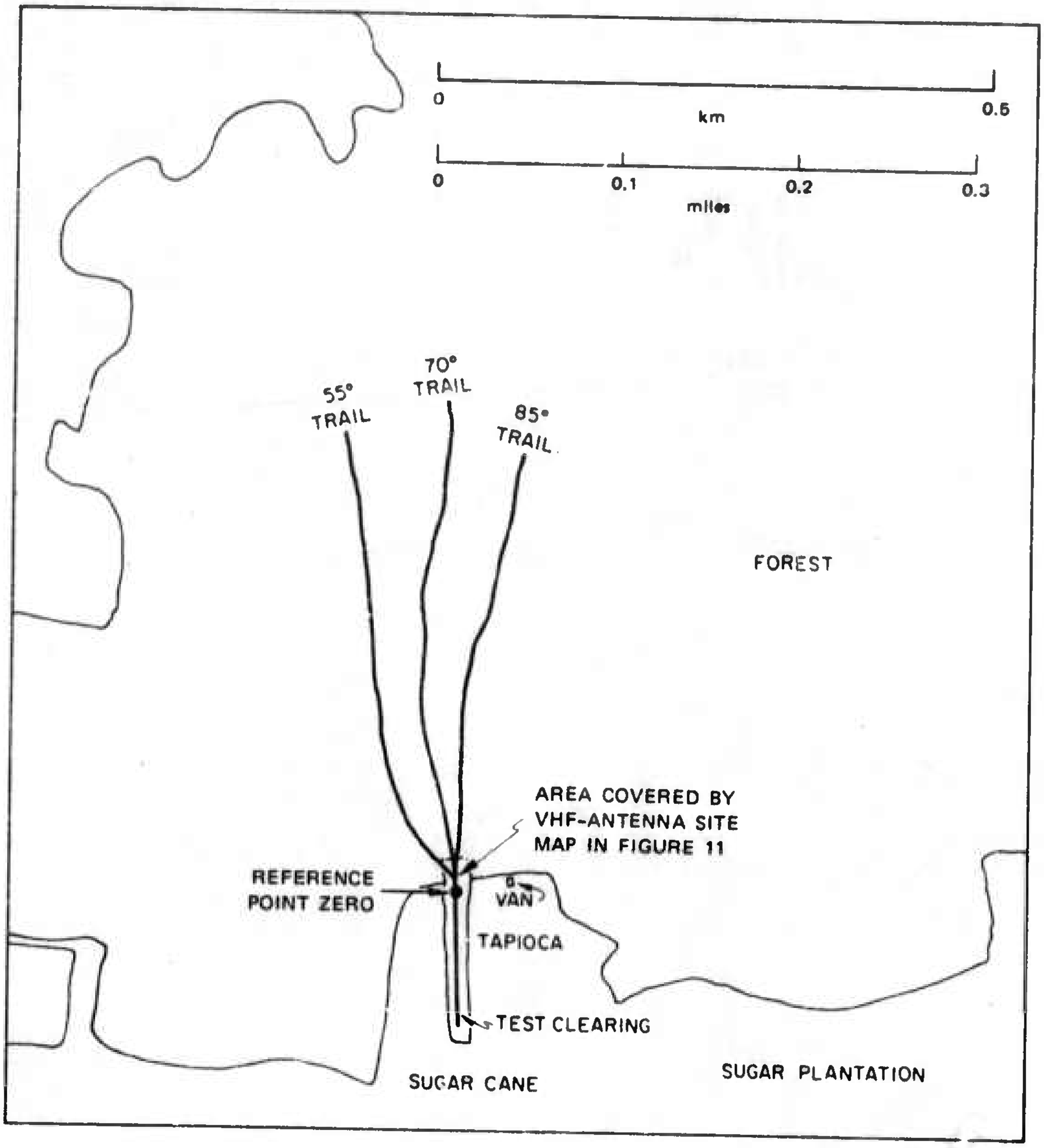

FIGURE 8 REFERENCE MAP FOR BMC AERIAL PHOTOGRAPH

Three test trails were prepared at this site. These trails, labeled 55°, 70°, and 85° (to correspond to their approximate bearings), are shown in the line drawing of Figure 8. (Note that the trails have a common zero reference or starting point about 50 feet from the forest boundary.) The trails were planned in this way to cover a rather large

FIGURE 9 VIEW OF BMC TEST SITE TAKEN FROM THE CLEARING

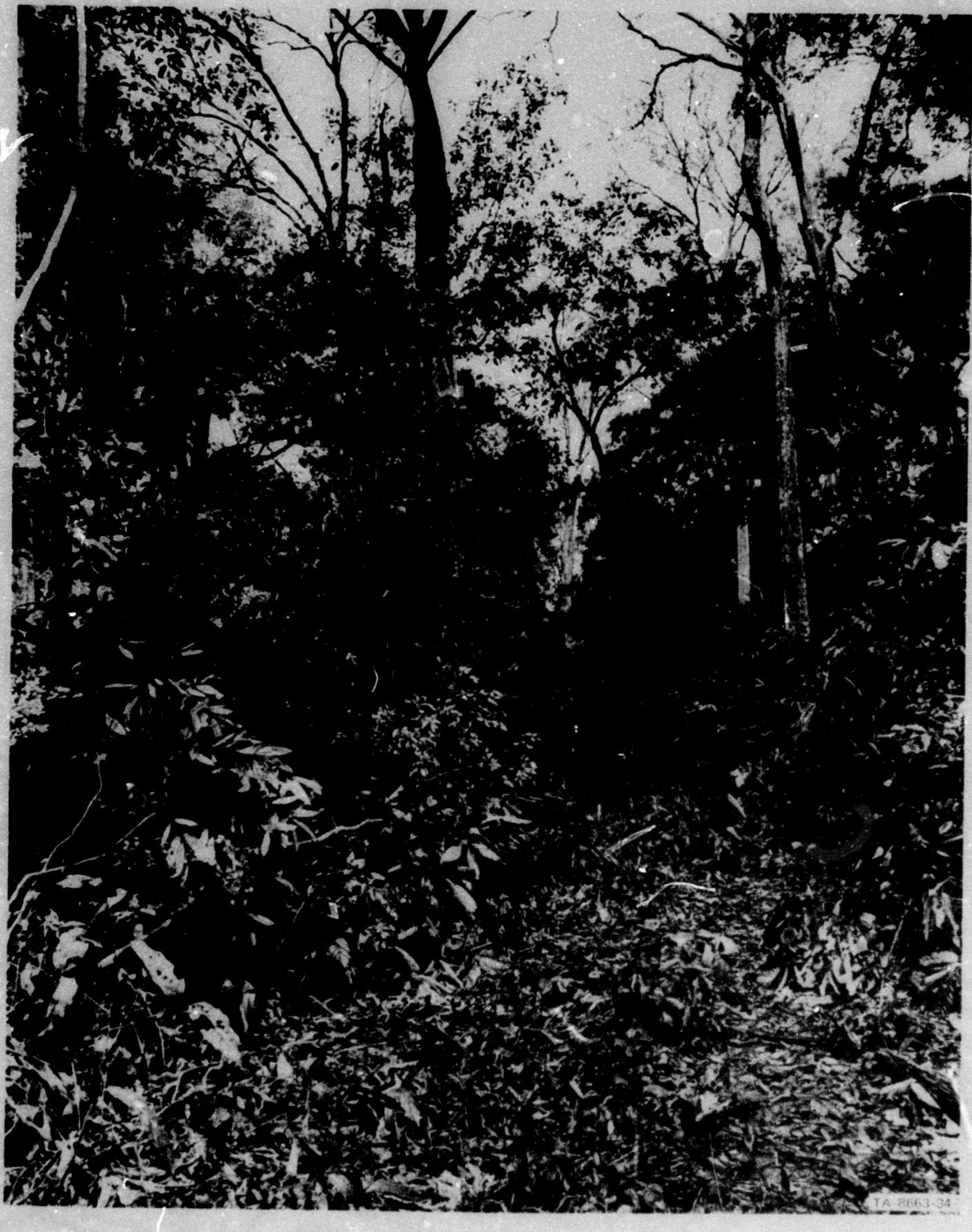

FIGURE 10 VIEW OF BMC FOLIAGE ALONG A TEST TRAIL

sector of forest to aid in interpretation and understanding of the full-scale antenna pattern measurements[19] conducted at this site.

Figure 8 shows that a trail was also prepared through the adjoining clearing. This trail, which also has its start at the common reference point, extends 0.2 mile away from the forest. Figure 9 shows the clearing. The cleared area had just recently been completely logged to provide space for planting tapioca and sugar cane. Thus the area was littered with stumps, branches, and other debris from this process. At the time of measurements, the tapioca crop was quite tall (Figure 9) and considerable work was required to prepare the "clearing" portion of the test trails.

Approximately 5 days were required to prepare the forest trails for measurements. The 70° trail required the least effort because an existing road was available along this azimuth. The other trails required extensive cutting and clearing prior to use. The trails were surveyed to determine the radial distances from Reference Point Zero. The relative elevation of the trails was also measured and the test site was found to be situated on the gently sloping hill that has its summit near Reference Point Zero. For example, the change in elevation referenced to Point Zero was a drop of 45 feet at the end of the 70° forest trail (at 0.35 mile radial distance from Reference Point Zero) and 40 feet at the end of the open trail (0.2 mile from Reference Point Zero).

The receiving antennas were located in both forest and clearing for these measurements. Figure 11 shows these locations, Figure 12 is a view of a resonant balanced vertical dipole in the forest, and Figure 13 shows an unbalanced horizontal dipole antenna in the clearing.

The soil at this test site was predominantly sandy or sandy-silty in composition. When dry, the soil was very hard. Selected foliage and soil characteristics are given in Table 1 at the end of this section.

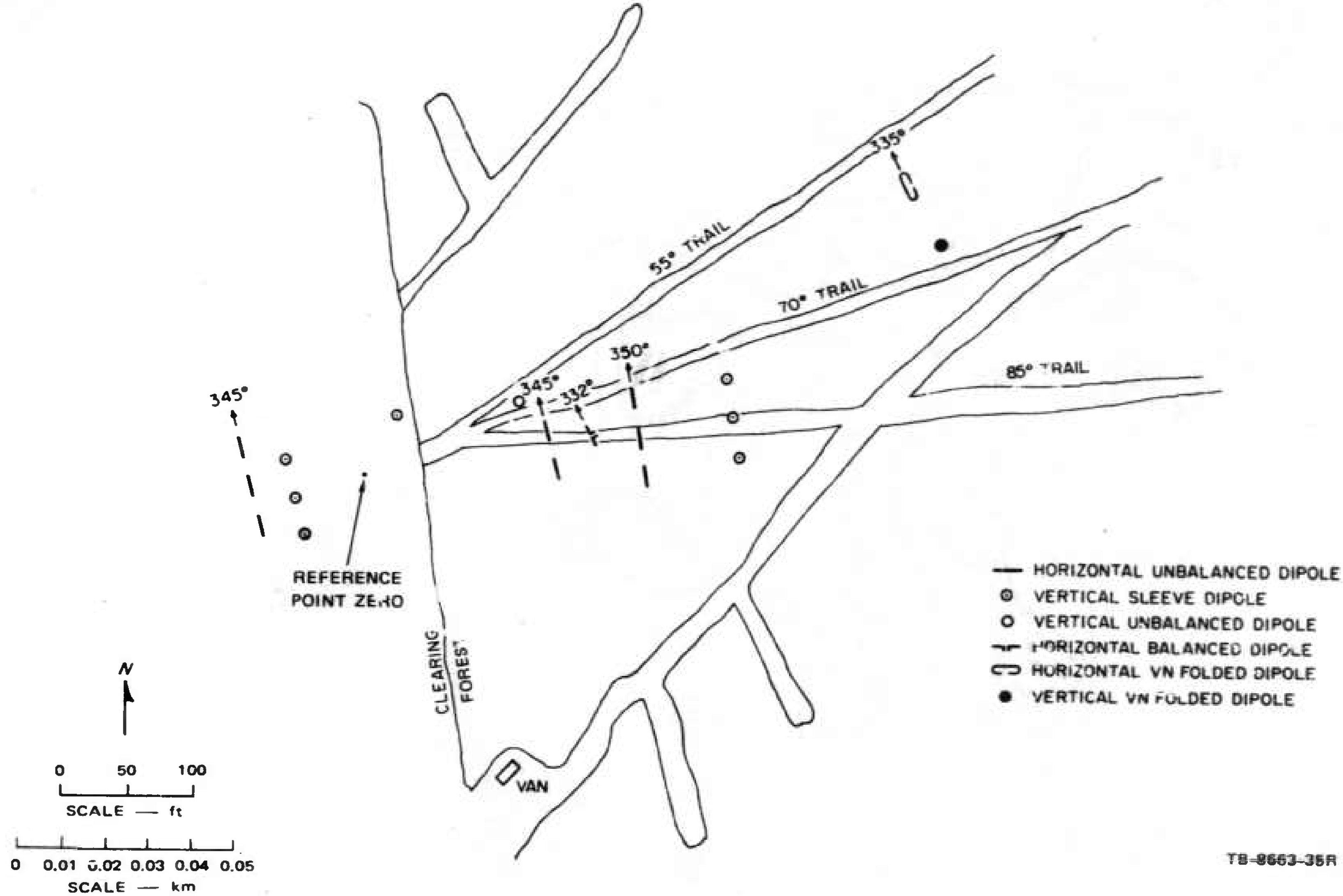

FIGURE 11 MAP OF TEST ANTENNA LOCATIONS AT BAN MUN CHIT

FIGURE 12   RESONANT VERTICAL DIPOLE AT BMC TEST SITE

FIGURE 13 UNBALANCED HORIZONTAL DIPOLE IN CLEARING AT BAN MUN CHIT

B. Chumphon Test Site

The terrain at the Chumphon* test site is generally classified as a fresh-water-swamp forest. The test area is on a low plain or basin that gathers and holds water flowing from nearby hills and other higher areas; the trees at this site are species that thrive on water.

The foliage is very uniform in height and size. Its canopy is three storied, but here the upper story is almost horizontally continuous, between 25 and 36 meters high. The middle story is 15 to 24 meters high. The lower story, which contains about 60 percent of the trees, is between 7 and 14 meters high. The lowest trees are heavily suppressed by the continuous canopy above them, yet there is considerable undergrowth present.

The undergrowth is quite uniform and consists of two layers. The upper layer is composed of tree seedlings and shrubs growing to 4 meters; the lower layer, only 0.3 meter high, produces mostly herbs. The undergrowth is relatively easy to penetrate and to remove by cutting.

Figures 14 and 15 are, respectively, an aerial photograph and reference map of the site; Figures 16 and 17 are photos of the Chumphon site foliage.

Figure 18 is another view of Trail A, which was cut through the densest area of the forest. Undergrowth along Trail A had been removed between Radial Points 15 and 26 (Figure 15). Later, after several test runs had been completed, an additional strip of undergrowth (60 meters wide, centered on the trail) was removed from Radial Point 26 to test

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*Chumphon is the name of the province and largest town near the test site. The site itself is 30 km southwest of the town of Chumphon in the Wisai Nua Forest.

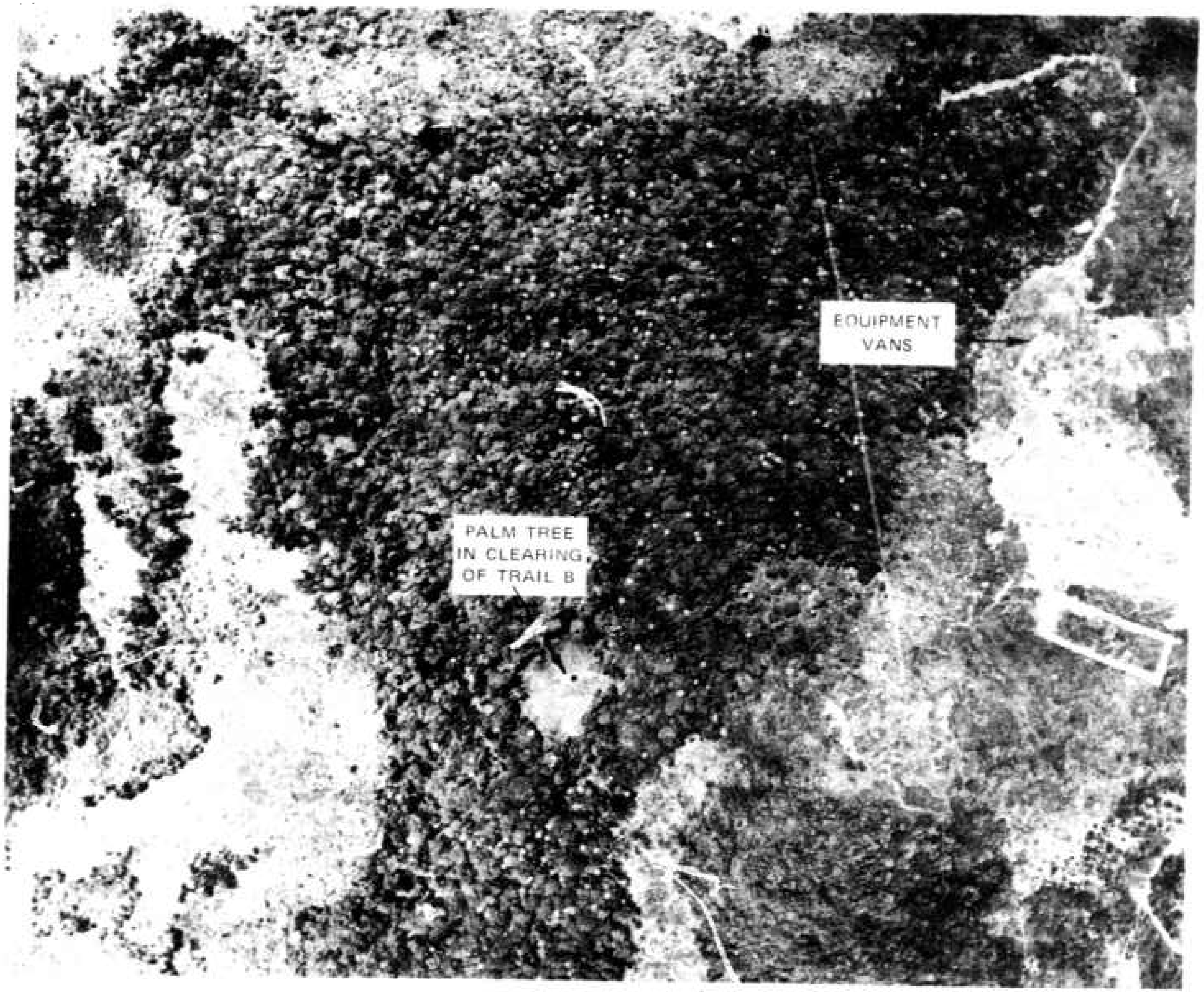

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FIGURE 14 AERIAL PHOTOGRAPH OF CHUMPHON TEST SITE

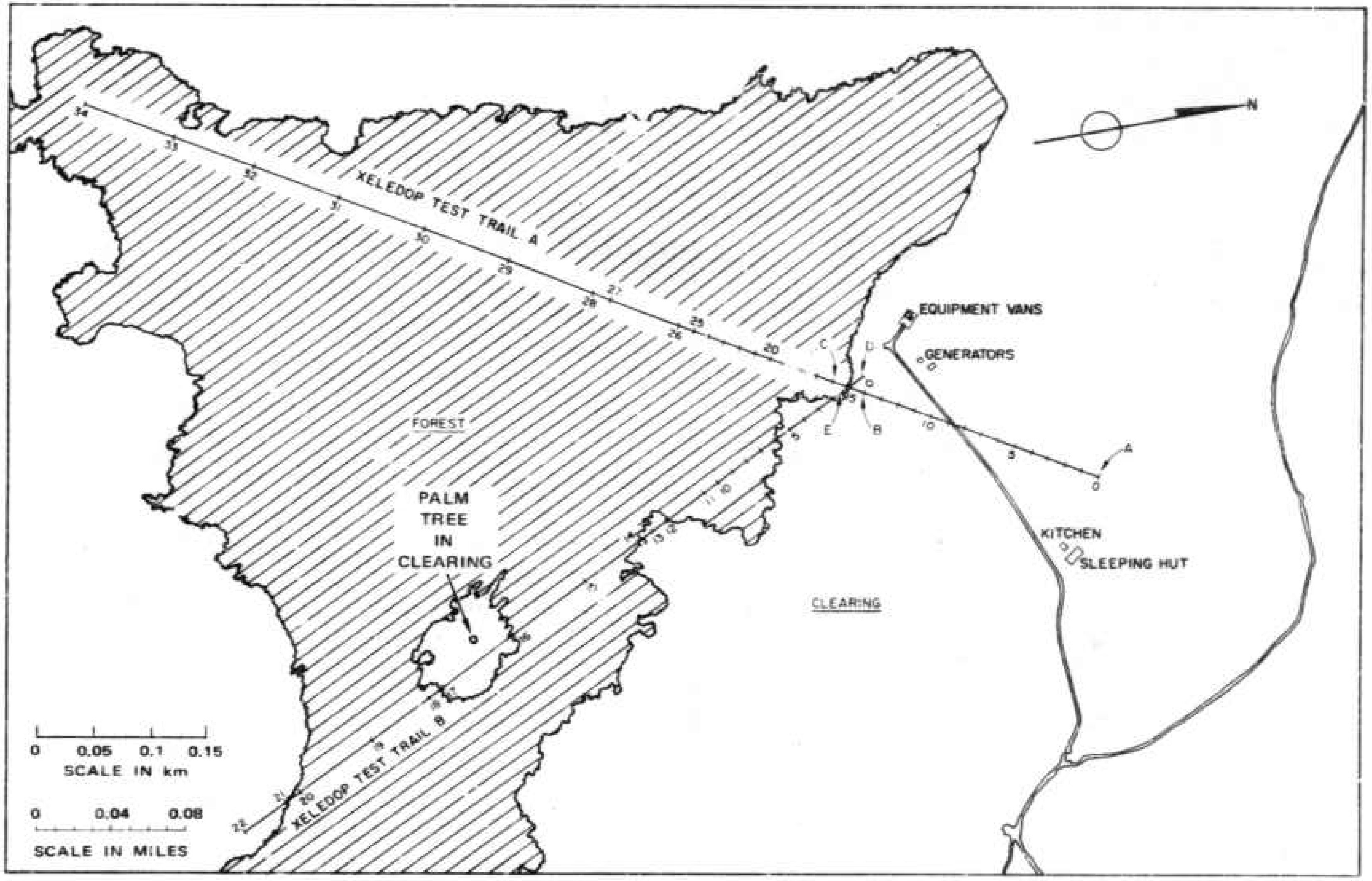

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FIGURE 15 REFERENCE MAP FOR CHUMPHON AERIAL PHOTOGRAPH

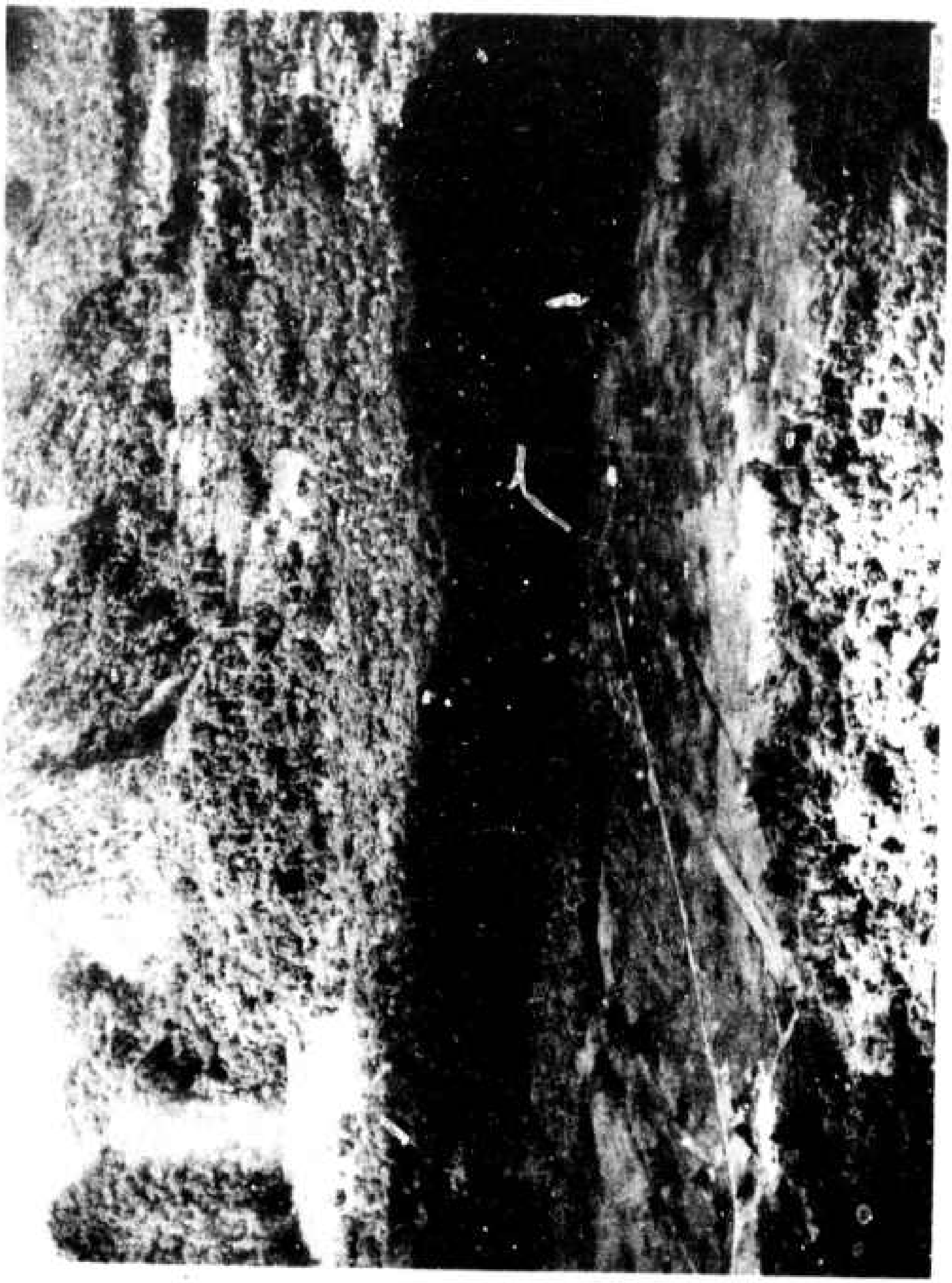

FIGURE 16 AIR VIEW OF CHUMPHON TEST AREA

FIGURE 17 FOREST AND UNDERGROWTH AT CHUMPHON TEST AREA

FIGURE 18 TRAIL "A" THROUGH CHUMPHON TEST AREA

for the effect of undergrowth on the received signals. The results of this test have already been reported.[17]*

A second test trail (Trail B) was also cut through the forest (Figure 15). This trail was selected to measure the effect of intervening clearing and forest boundaries between the transmitting and receiving equipment. Trail B had its Reference Point Zero about 50 feet into the clearing, then entered the forest, passed through two small clearings, and reached a large clearing (about 260 feet in diameter) containing a single, tall palm tree (see Figures 14 and 15). The trail continued through the forest and finally emerged on the far side of the forest.

Figure 15 shows that several receiving antenna locations (denoted by the letters A through E) were used. Most of the locations were either 50 feet inside the forest (locations C and E) or the same distance into the clearing (locations D and B). One receiving antenna location (A) was at Reference Point Zero for Trail A, and another (D) was at Reference Point Zero for Trail B. The radial points shown in Figure 15 indicate the radial distance from the trail Reference Point Zero. Although the trails curved slightly (see Figure 17), they were generally straight, and the radial points represent a reasonable approximation to the actual distance along the trail.

C. Summary of Terrain Characteristics

Table 1 is a summary of the terrain characteristics for which measurements were conducted. The terrains measured and described in Ref. 16 are also included for comparison. These are open delta near Bangkok and foliaged beach near Laem Chabang.

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*The undergrowth did not have any significant effect on the propagation at VHF.

Table 1

SUMMARY OF TERRAIN CHARACTERISTICS

Site / Description	Ban Mun Chit (see Ref. 20)	Chumphon (see Ref. 21)	Bangkok (see Ref. 16)	Laem Chabang (see Ref. 16)
Terrain category	Dry evergreen forest	Fresh-water-swamp forest	Open delta	Coastal brush
Tree statistics*				
Median height (m)	6	12	--	--
Median diameter at 4 ft (cm)	6.4	13	--	--
Canopy height (m)				
Upper	25-34	25-36	--	No canopy; the tallest scattered trees were no more than 10 m
Middle	15-24	15-24	--	
Lower	6-14	7-14	--	
Undergrowth				
Median height (m)	6	4	--	3.5
Relative permittivity†	1.06	1.04	--	1.11
Conductivity (mho/m)†	1.2×10^{-5}	6×10^{-5}	--	4×10^{-5}
Soil type	Sandy, silty loam	Silty clay, gravel	Lateric clay	Well-graded sand
Relative permittivity†	12	30	17	3
Conductivity (mho/m)†	0.016	0.085	0.18	0.0005

*As defined here, trees have diameters measured at 4 ft (breast height) ≥ 5 cm.

†Median values were obtained from the various measurements made with a transmission line probe at 50 MHz (Ref. 22).

IV DATA PROCESSING

The test data were recorded in analog form on paper strip chart recorders (see Figure 19* and Ref. 17). As the transmitter (Xeledop or AN/PRC-25) was carried along the surveyed trail, the receiving site operator monitored the analog record and noted on the strip record when the Xeledop passed each trail radial point as he received this location information over the auxiliary radio. Thus the received signal level (in dB relative to a reference voltage at the input to the receiver) was recorded as a function of distance down the trail (as indicated by the radial points) for a particular combination of terrain, frequency, Xeledop polarization, and receiving antenna type, polarization, height (usually 10 ft) and location.

The first step in reducing the data to more useful form was analog-to-digital conversion. This was accomplished with a Benson-Lehner Large Area Record Reader (LARR-V). This device was used to digitize the analog record and store the result on magnetic tape. The LARR-V operator traced the received signal record with a calibrated, moveable arm and the machine automatically recorded on digital magnetic tape the value of the received signal at predetermined distance intervals along the strip chart records.

Once the analog records were digitized and stored on magnetic tape, the data were processed to find the median for specific intervals of

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*Figure 19 is an example analog record obtained to illustrate gross propagation features.[17] The actual records used in data reduction were obtained with expanded amplitude and distance scales.

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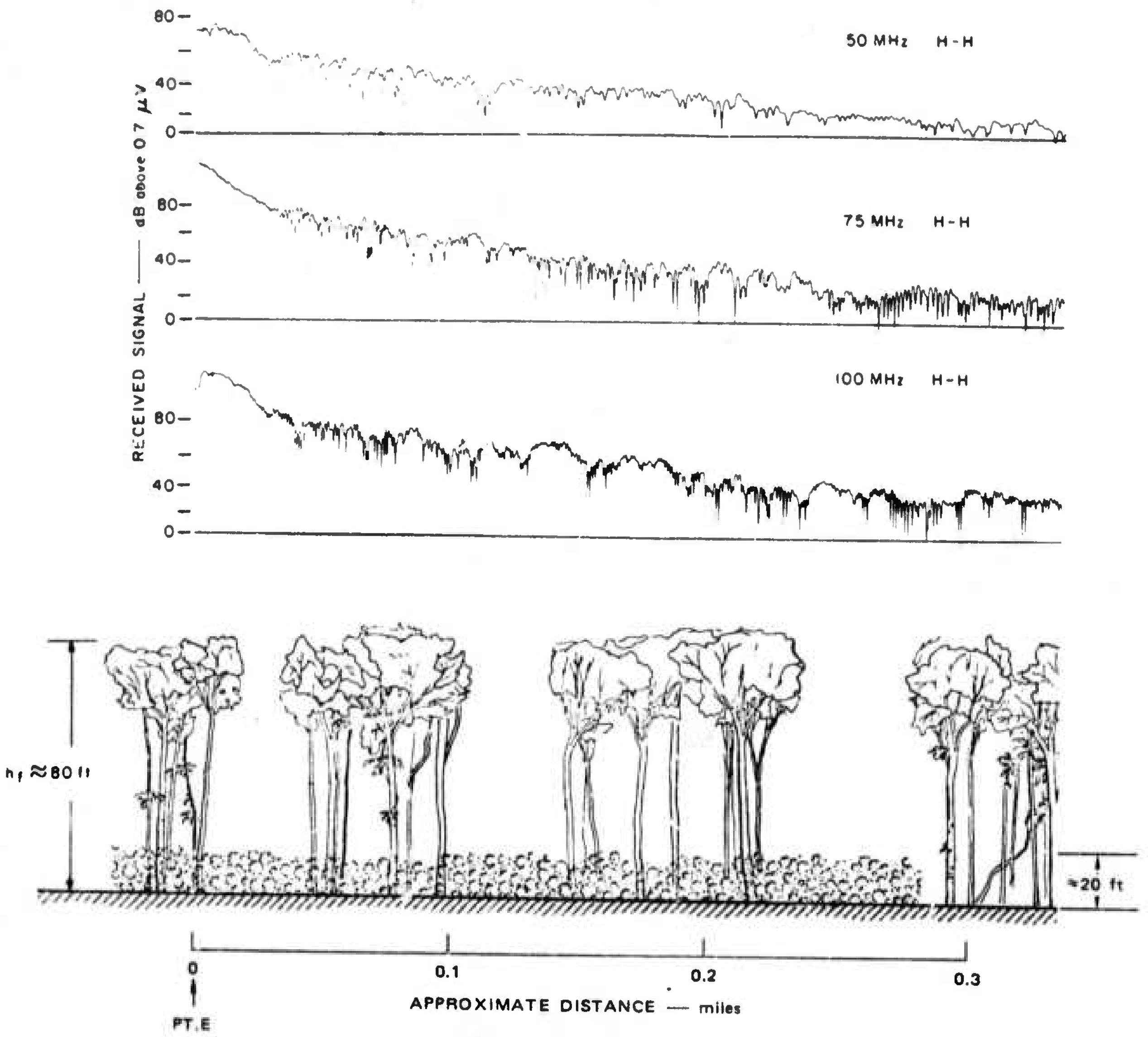

(a) HORIZONTAL POLARIZATION

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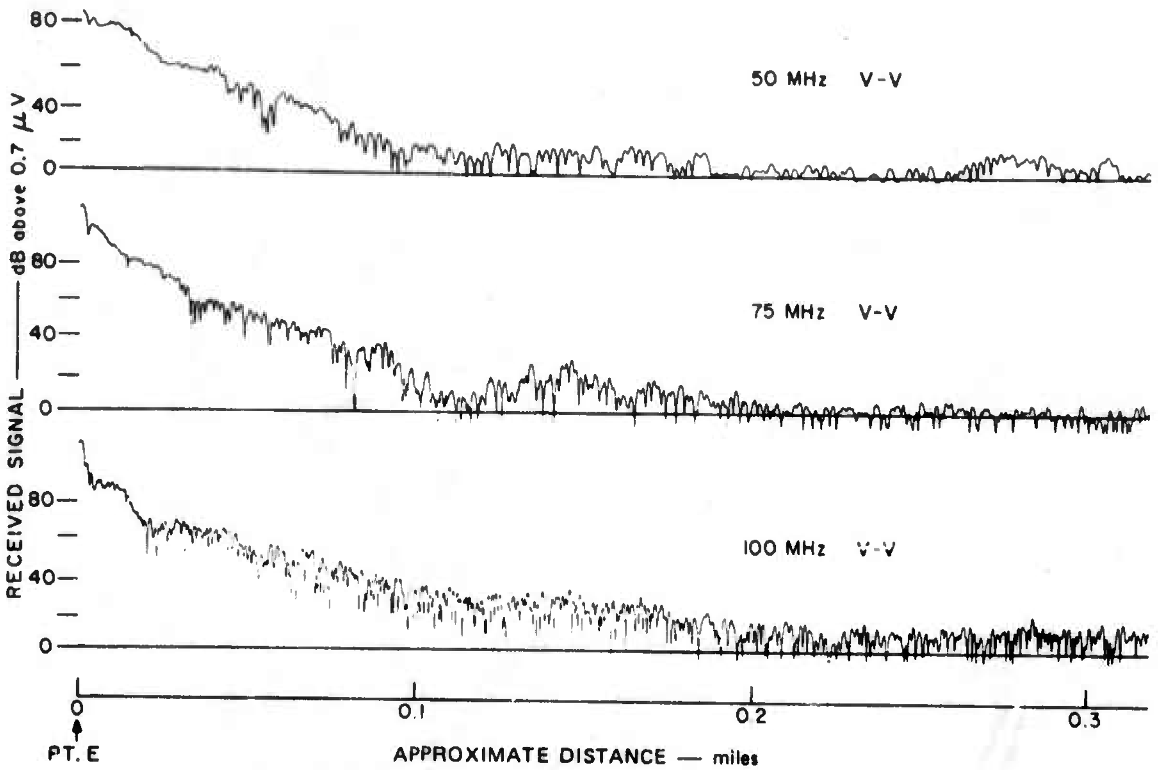
FIGURE 19 XELEDOP ALONG TRAIL; RECEIVING ANTENNAS IN FOREST



(b) VERTICAL POLARIZATION

TA-8663-242a

FIGURE 19 XELEDOP ALONG TRAIL; RECEIVING ANTENNAS IN FOREST (Concluded) distance. These computations were based on data (read with the LARR-V within ± 0.005 mile of each distance radial point. Each value presented in the results for a given nominal distance was computed from no fewer than 25 digitized amplitude readings. Each median value computed was assigned the distance of the center of the range interval read. Curves of the median received signal level as a function of trail radial point numbers (analogous to distance) were generated using an autoplotter. But these radial points were neither at constant trail distance intervals nor were they always in sequence for the full length of a given record, especially when the path included a clearing-forest interface. A number of additional steps were required to present the data as curves of the median equivalent half-wave dipole system loss, L_s, as a function of distance between the receiving antenna and the Xeledop. First, the distance scale was corrected to correspond to the true radial range from the receiving antenna to the Xeledop. This was accomplished using a map giving the locations of the trail radial points relative to the receiving antennas. It was also necessary to perform normalizations on the ordinate scale of the received signal data to convert the scale to system loss. These were normalized as described in Appendix A.

The data curves presented in this report are median values of system loss in dB. The average <u>of the dB values</u> also was computed.* It was observed that the mean of the system loss values in dB for a given case was rarely more than 3 dB different from the median for the same case. Typically for median loss was smaller than the mean loss computed in this manner. The second moment about the mean of the dB values also was computed, and it typically was less than 5 dB ± 3 dB.

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*This is not the best approach to estimating the true mean loss. It is correct to convert the dB values to a loss factor, average, and convert back to dB.

V RESULTS

A. System Loss as a Function of Distance

Figures 20 through 26 are comparisons of the equivalent half-wave dipole system loss* measured under different conditions as indicated by the figure titles. Abbreviations are used to indicate polarization and location: H is horizontal, V is vertical, F is forest, and C is clearing. The first letter always refers to the transmitter. For example, when V-V and F-C appear on a plot, it means that the Xeledop transmitter is vertically polarized in the forest while the signal is being received on a vertical antenna in the clearing.

Figure 20 shows polarization comparison for clearing-forest combinations measured on Trail A at Chumphon. The system loss is rather comparable for vertical and horizontal in the clearing for all three measurements frequencies. The most prominent feature of these plots is the relative increase in system loss for vertical polarization as the MPX is carried past the clearing-forest interface into the forest.

Figure 21 shows data from Trail A at Chumphon where both antennas were in the forest. Again the greater system loss for vertical polarization in the forest is quite evident.

Figure 22 shows data for Trail B at Chumphon. This path consisted of a combination of mixed clearings and intervening forest (see map of Figure 15, Chumphon site map). The zero reference point is RP2. Here

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*To convert these curves to basic transmission loss add 4.3 dB to the ordinate (see Appendix A).

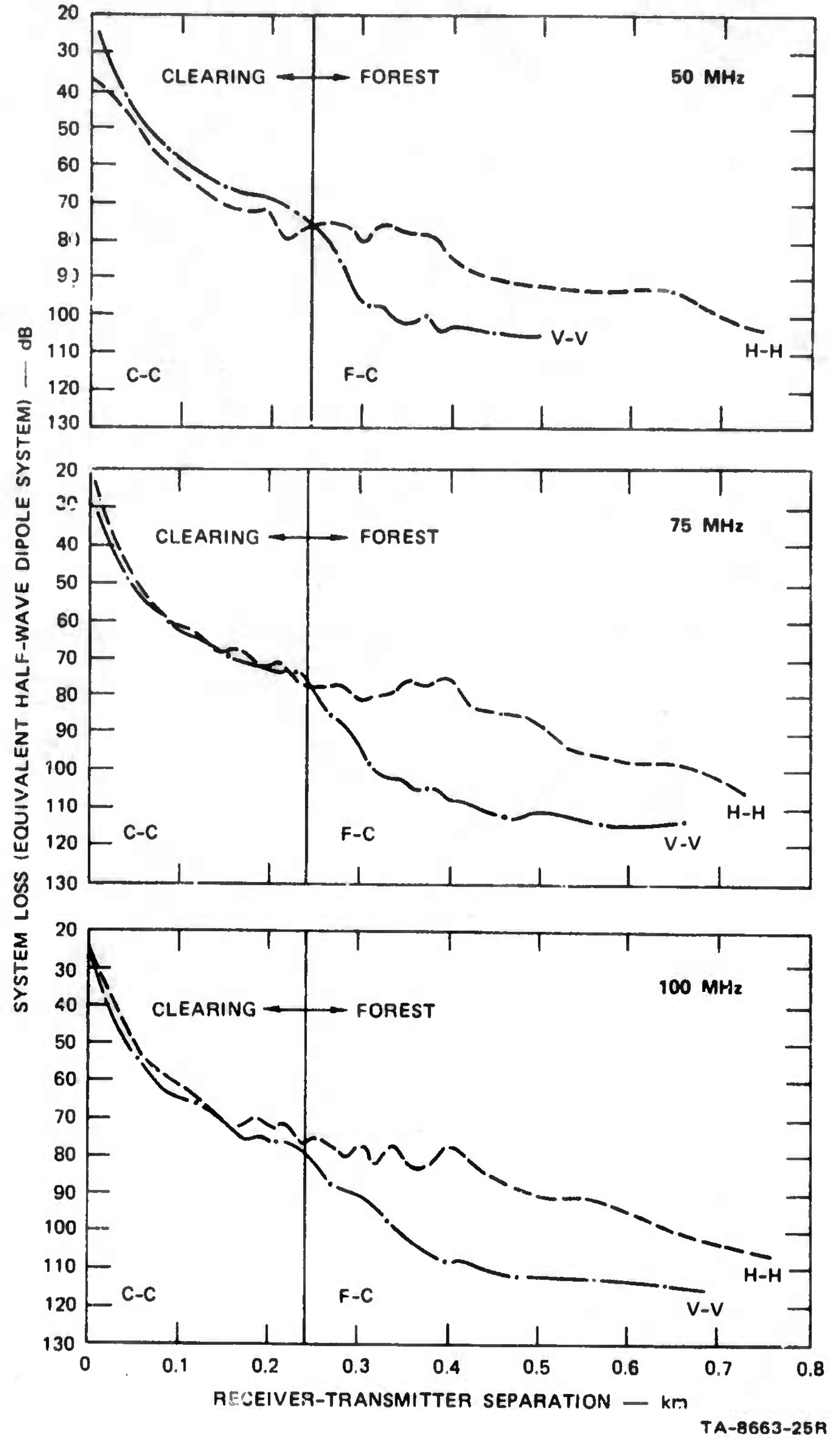

FIGURE 20 POLARIZATION COMPARISONS AT CHUMPHON—CLEARING-TO-CLEARING AND FOREST-TO-CLEARING—FOR UNBALANCED HALF-WAVE DIPOLES ON TRAIL A

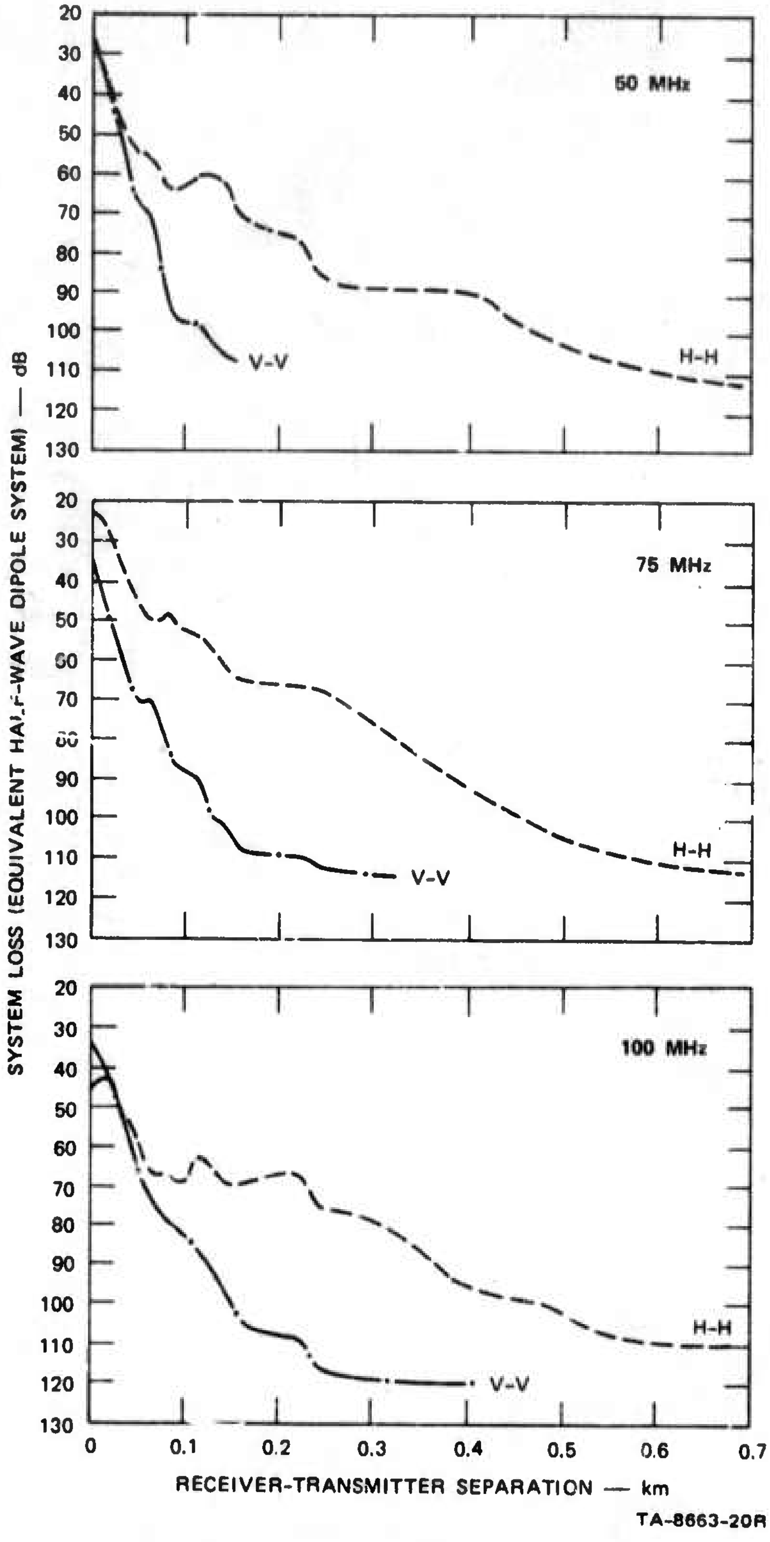

FIGURE 21 POLARIZATION COMPARISONS AT CHUMPHON FOR UNBALANCED HALF-WAVE DIPOLES ON TRAIL B

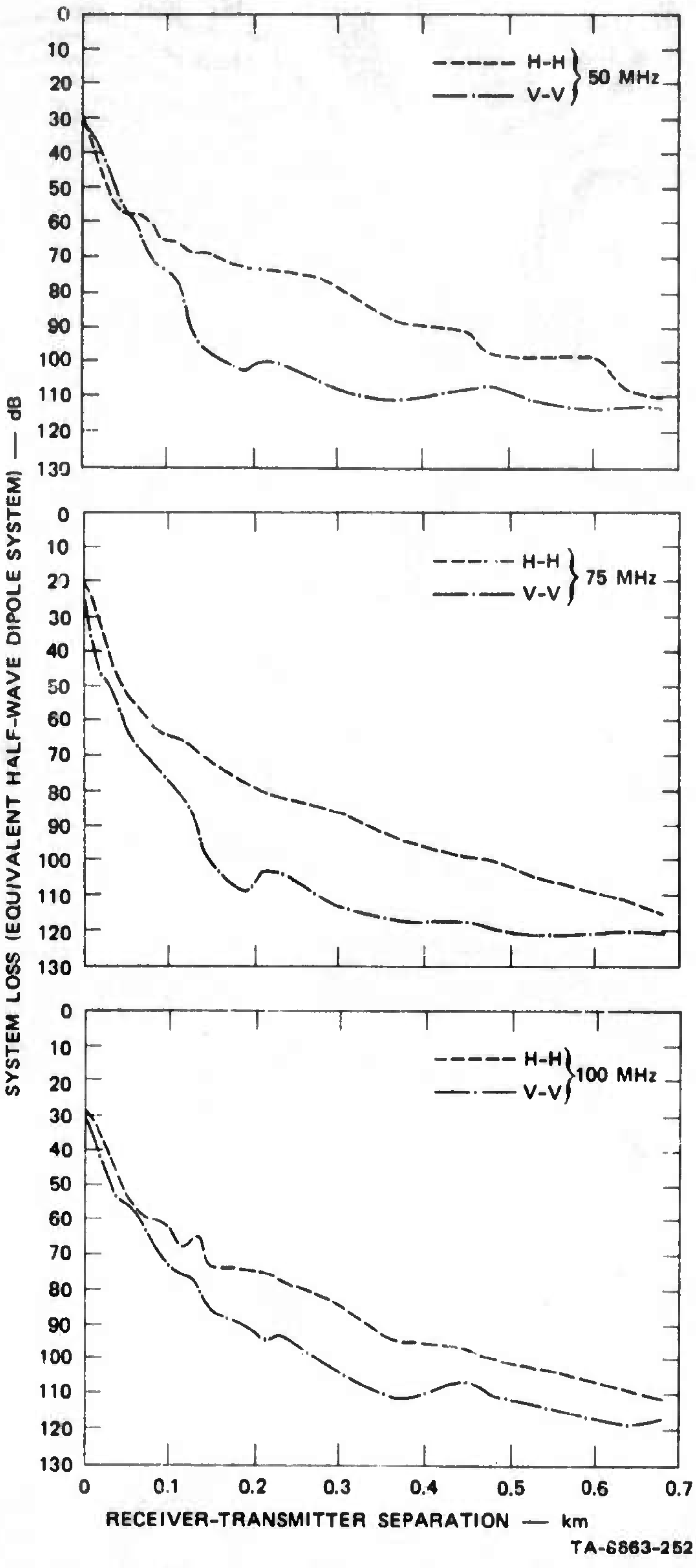

FIGURE 22 POLARIZATION COMPARISONS AT CHUMPHON—FOR UNBALANCED HALF-WAVE DIPOLES ON TRAIL B

again the horizontal polarized dipoles exhibit the lower system loss, but the effect is less pronounced than that observed on the all-forest part of Trail A. A slight tendency for less loss in the clearings can be noted in a few cases.

Figure 23 shows data taken in the "clearing" at BMC. As noted in Chapter III the clearing was not really cleared. The system losses observed here were not monotonically decreasing with increasing distance, and they were larger than one would expect for a non-vegetated path.

Figure 24 shows the forest data obtained at BMC on the 85° Trail. The data for horizontal polarization represent a smoothed curve drawn through the data obtained on three different horizontal dipoles. The median data on each individual dipole exhibited variations of ±10 dB about the curves shown. Data on horizontal polarization on the 55° Trail and 70° Trail exhibited much more variation than the data for the 85° Trail shown in Figure 24.

Little reliable data on vertical polarization were obtained in the forest at BMC. The curve for 100 MHz obtained on the 85° Trail is shown in Figure 24. The other data exhibited very large variations and are not shown for comparison with the data for horizontal polarization. The other data for vertical polarization at BMC are not given in this report because of uncertainty in the calibration.

Considerable data on cross polarizatien (V-H, H-V) were obtained at both BMC and Chumphon. At BMC the cross-polarized data in the forest were quite comparable to the matching polarization data, whereas at Chumphon the cross-polarization data showed more loss than H-H but less than V-V. The data for H-V generally exhibited somewhat less system loss than the data for V-H.

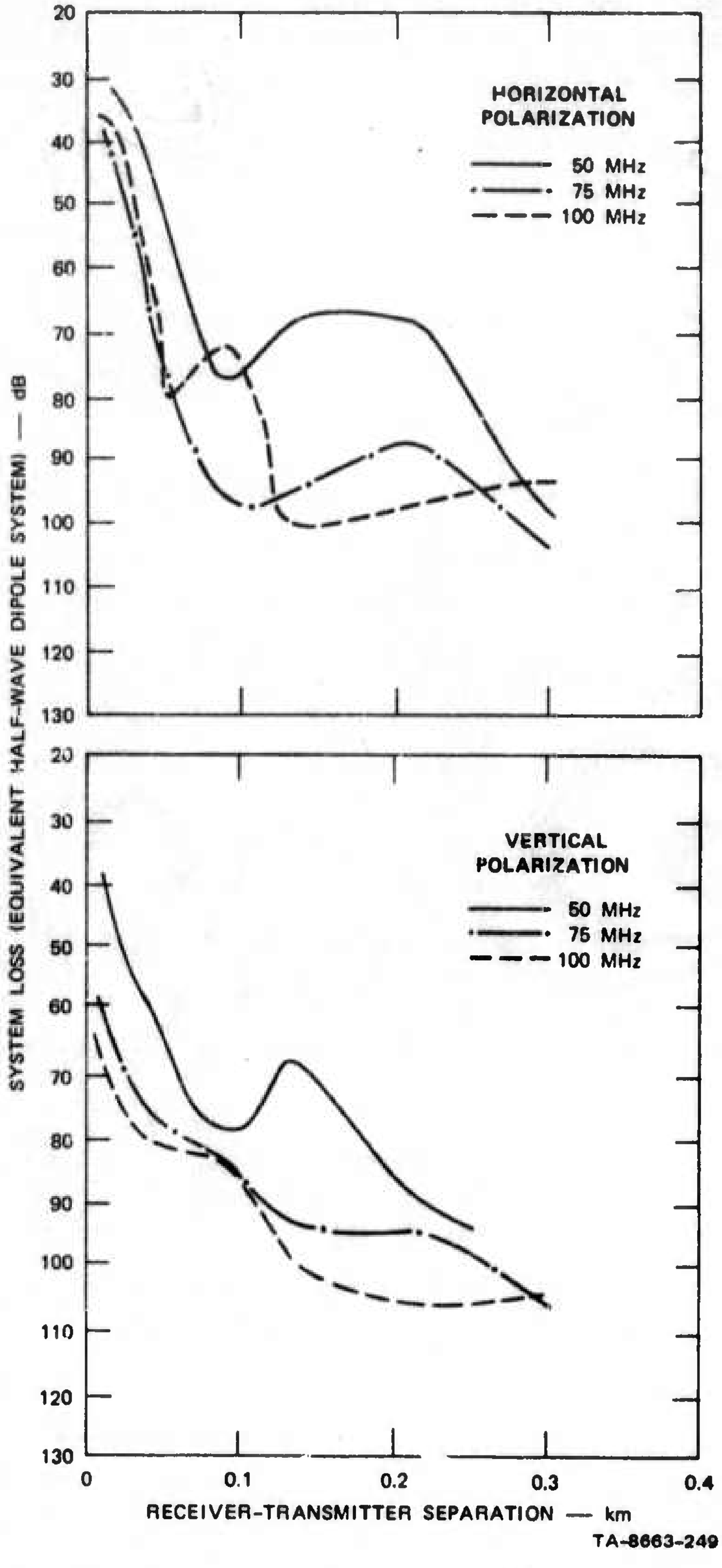

FIGURE 23 SYSTEM LOSS DATA AT BAN MUN CHIT, CLEARING

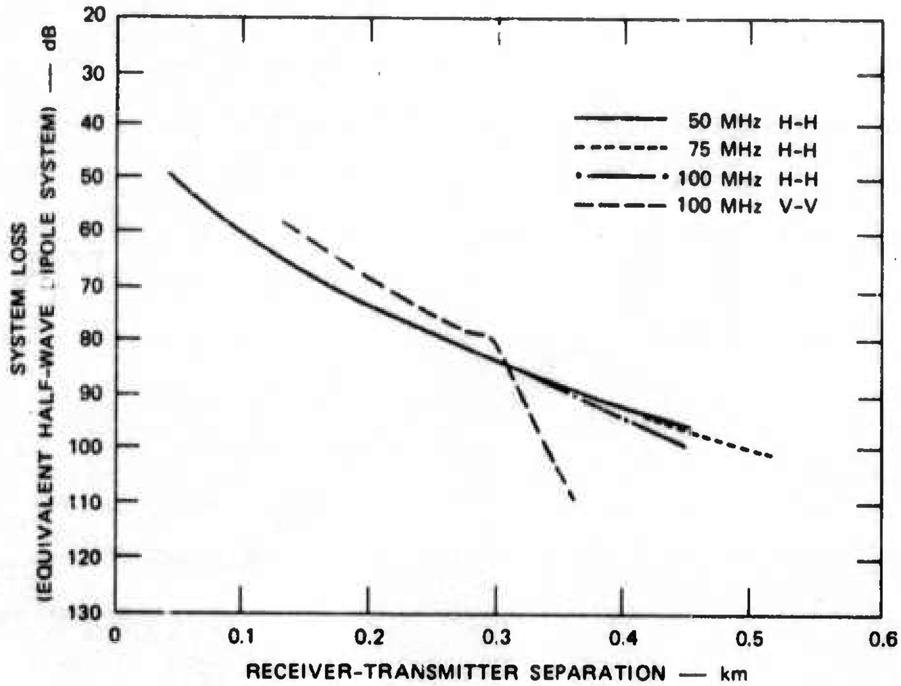

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FIGURE 24 POLARIZATION COMPARISONS AT BAN MUN CHIT FOREST-TO-FOREST, 85° TRAIL

It is possible to make a comparison of data obtained at BMC with data obtained at Chumphon. Since the BMC clearing was not really a clearing, data taken there will not be compared with data taken in the Chumphon clearing. In the forest, the data obtained on horizontal polarization was very similar at BMC and Chumphon for all three frequencies. For vertical polarization, the taller, more vertically structured forest at Chumphon produced the greater system loss at 100 MHz (see Figure 25).

Forest-to-forest propagation was modeled using the air-forest-ground slab model of Dence and Tamir,[23] and the results are shown in comparison with measured data in Figure 26.* Measured forest and ground constants and characteristics were used (see Table 1). The forest heights used in the model were 20 m and 25 m for BMC and Chumphon respectively. As can be seen in Figure 26, the model predicts a larger system loss for horizontal polarization than for vertical polarization, whereas just the opposite was observed. This is due primarily to the fact that the forest is anisotropic, having a larger effective conductivity for vertical polarization than for horizontal polarization. It would be possible to adjust the model parameters to obtain a better fit to the measured data than shown here. However, this was not done because it was desired to see how well the model would work with actual measured input data. It is concluded that the model predicts too much loss for horizontal polarization and not enough loss for vertical polarization. The closest fit with measured data was obtained at Chumphon for vertical polarization at 75 MHz. It can be concluded, however, that the model can easily be in error by as much as 30 dB at 0.3 Km.

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*The wave interference loss due to reflections in the forest (L_i) was not included for these calculations because large changes in radio system loss due to this term alone can occur for small changes in geometry, and such variations were not observed in the field when half-wave dipoles were used.

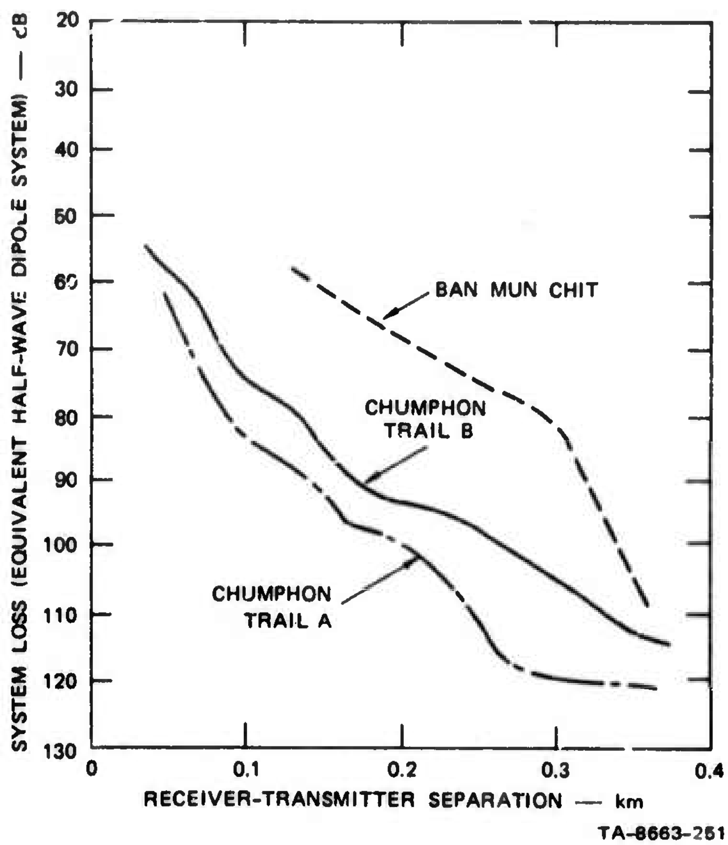

FIGURE 25 COMPARISON OF BAN MUN CHIT AND CHUMPHON DATA, VERTICAL POLARIZATION (100 MHz)

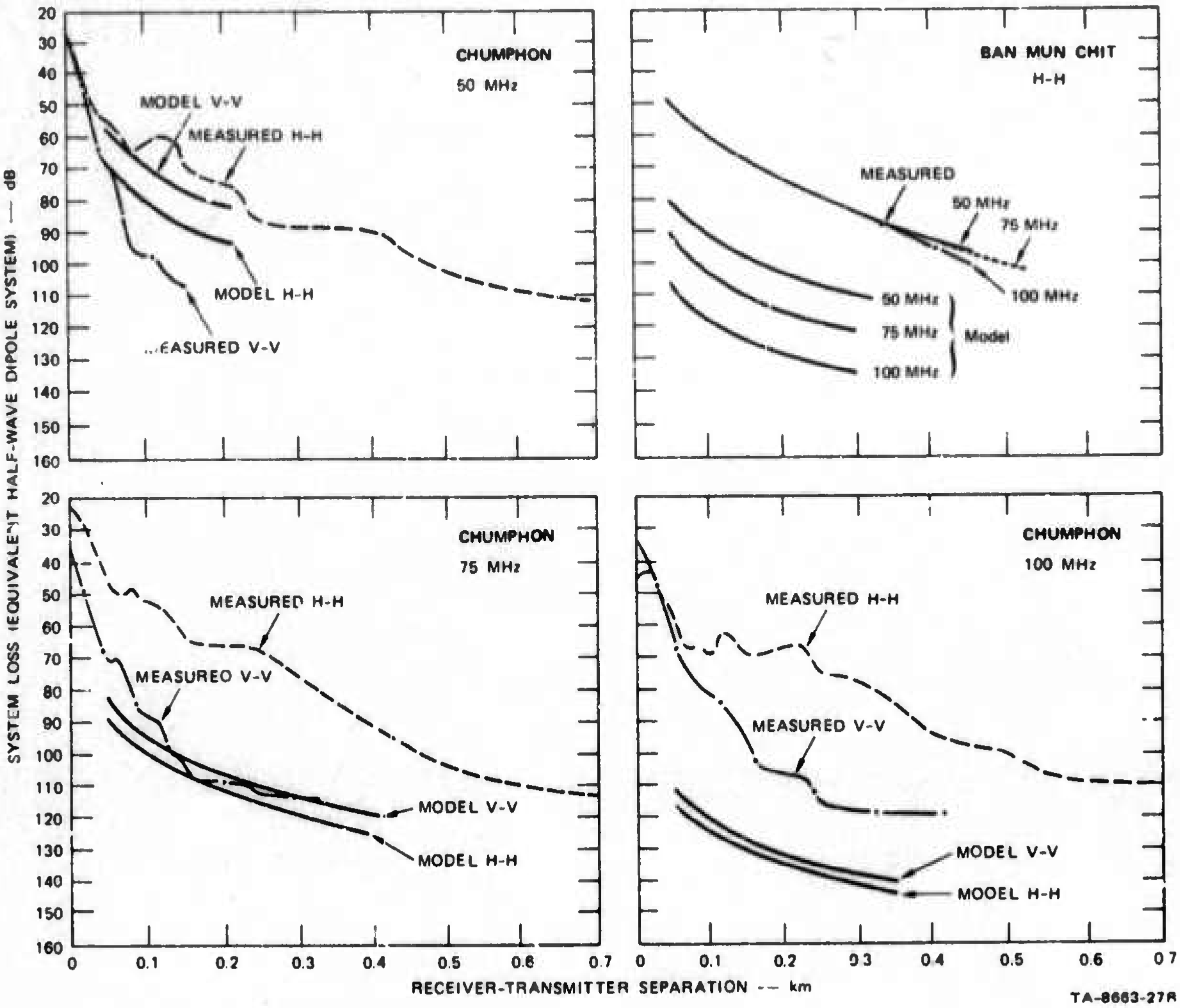

FIGURE 26 COMPARISON OF FOREST-TO-FOREST PATH LOSS MEASUREMENTS WITH AIR-FOREST-GROUND SLAB MODEL RESULTS

B. Height-Gain Tests at Chumphon Using the Manpack Xeledop

The height-gain function was measured at Chumphon by elevating the MPX with a rope and pulley arrangement. The receiving antennas (unbalanced λ/2 dipoles) were set up at 10 feet above ground at Point C on Trail A (just inside the forest--see Figure 15). The horizontally polarized antennas were aligned broadside to Trail A. The Xeledop was elevated from 5 feet to 55 feet at 0.19 mile down Trail A (in forest) and from 5 feet to 60 feet at 0.26 mile down Trail B (in clearing). An isolated palm tree about 105 feet tall and with branches only at the top was used to support the Xeledop in the clearing (see Figures 14 and 15). The Xeledop was positioned 3 feet away from the branchless palm tree trunk and was raised and lowered with the rope and pulley.

The actual observed signal levels (in dBm) with the receiving antennas at 10 feet are summarized in Table 2. Mismatch losses were negligible, and the data have been corrected for transmission line losses. The measured feed point impedances were resistive: 66 ohms at 50 MHz for both polarizations, 70 ohms ± 3 ohms for both polarizations at 100 MHz and at 75 MHz for horizontal polarization, and 89 ohms at 75 MHz for vertical polarization. The results of these tests, normalized to the value observed when both transmitting and receiving antennas were at 10 feet, are summarized in Figures 27 and 28.

The height-gain functions measured in the forest and in the small clearing are quite similar, especially for horizontal polarization. Notice also that the height-gain functions observed with horizontal polarization were somewhat more regular than those observed with vertical polarization.

Also shown for comparison in Figures 27 and 28 are computations of height-gain based on the forest half-space model of Tamir.[24] A forest height of 75 feet was assumed,* and the electrical properties of the forest were those obtained with open-wire transmission lines at the site. The agreement is good for 50 and 75 MHz ($\alpha_L \approx 0.51$ and 0.64 dB/m, respectively) but poor for 100 MHz ($\alpha_L = 2.21$ dB/m). Recall that the

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*Only 20 percent of the trees at the site exceed this height according to Ref. 22, p. 106.

Table 2

RECEIVED SIGNAL POWER WITH ANTENNAS
AT A HEIGHT OF 10 FEET*

Polarization	50 MHz		75 MHz		100 MHz	
	Trail A (dBm)	Trail B (dBm)	Trail A (dBm)	Trail B (dBm)	Trail A (dBm)	Trail B (dBm)
H-H	- 62.0	- 77.0	- 38.0	- 71.5	- 21.5	- 62.5
V-V	-104.5†	-101.5	-103.0	- 93.5	- 92.0	- 90.0
H-H > V-V‡	47 ± 3	25 ± 3	67 ± 3	20 ± 3	66 ± 3	29 ± 6

*These values were corrected for cable loss: 4 dB at 50 MHz, 5 dB at 75 MHz, and 6 dB at 100 MHz.

†This value was observed with the MPX at 35 feet. No signals were observed at lower MPX heights.

‡This row gives the median difference (in dB) of H-H > V-V observed at all heights. The bounds at 50 MHz include the entire sample, whereas at 75 MHz they are decile bounds and at 100 MHz they are only quartile bounds--indicating the increase in spread of the observations with increasing frequency.

values for forest conductivity measured with the open-wire line (OWL) at 100 MHz are suspected of being too high because the OWL was not functioning properly.[11] A value of $\alpha_L \approx 1$ dB/m seems more reasonable based on a linear variation of α_L for values obtained at lower frequencies.[11] This estimate gives a better fit to the height-gain data at 100 MHz for vertical polarization, but this value of α_L still predicts too much height gain for horizontal polarization. Notice also that the model (which, as employed, neglects the effect of the ground) tends to become inapplicable for antenna heights below about 10 feet, predicting less height-gain than observed. For a discussion of system loss caused by low antennas, see Ref. 23 and the following paragraph.

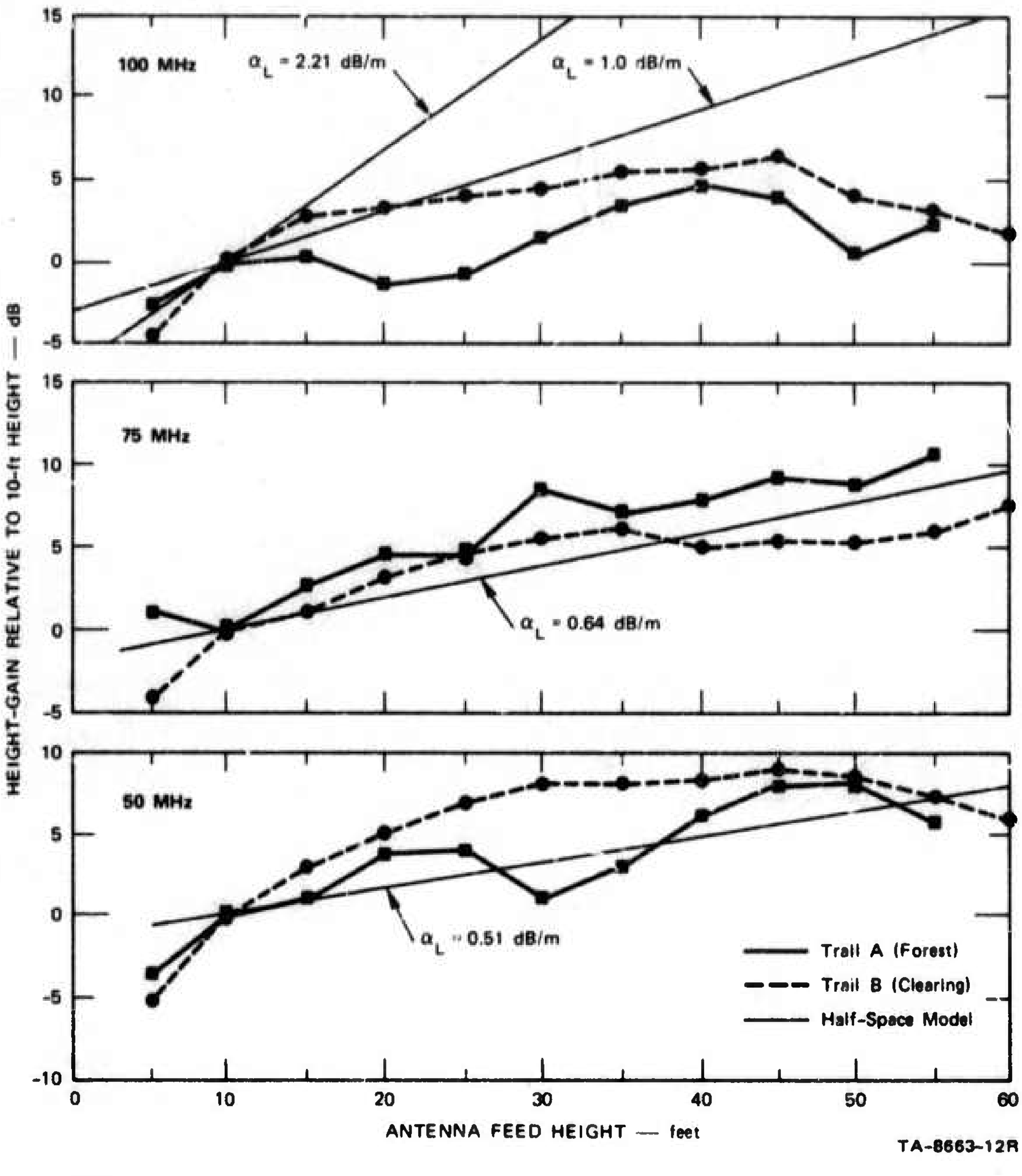

FIGURE 27 HEIGHT-GAIN EFFECTS OBSERVED AT CHUMPHON WITH MPX (Horizontal Polarization)

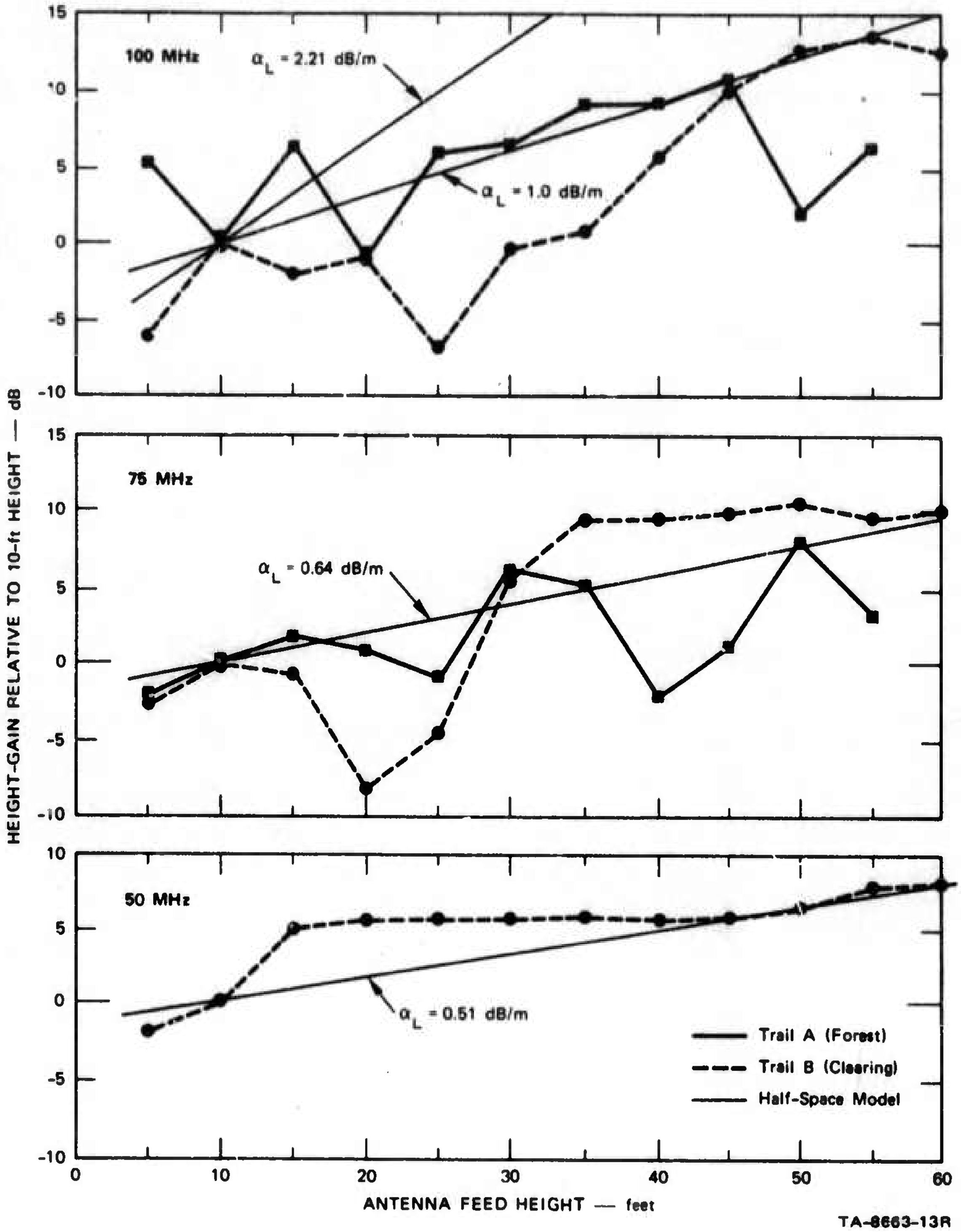

FIGURE 28 HEIGHT-GAIN EFFECTS OBSERVED AT CHUMPHON WITH MPX (Vertical Polarization)

Height-gain data were also obtained on 50, 75, and 100 MHz with the standard Xeledop receiving antennas (horizontal polarization) located near Radial Point 16 (about 40 feet inside the forest) on Trail A at Chumphon (see Figure 15). The manpack Xeledop was suspended in its horizontal configuration at about 5 feet above ground near Radial Point 20 on Trail A (about 0.4 mile further into the forest than the receiving antennas), and the received signal was measured as a function of antenna height for heights from 10 feet down to 1 inch. The results of these tests are shown in Figure 29. The data have not been corrected for mismatch loss, but the mismatch loss was less than 1 dB in each case except 100 MHz at 2 feet (1.6 dB) and 50 and 100 MHz at 1 inch (2.5 dB). The 50 and 75 MHz data repeated to within ± 1 dB, but the 100 MHz data were less repeatable. Next, the Xeledop was carried down the trail near Radial Point 20 and beyond, and the height gain again was determined by comparing a smoothed version of the received values at each height to the value at 10 feet. The values at 50 MHz exhibited excellent repeatability and agreed well with the data obtained with the Xeledop fixed. At 75 MHz there was more scatter, and at 100 MHz the scatter was even greater. Data on 7 additional runs were obtained at 100 MHz, and the values fell within the shaded area of Figure 29.

C. Balloon-Borne Xeledop Studies at Chumphon

The benefits of elevating VHF antennas to increase received signal strength in forests were probably first documented by Herbstreit and Crichlow[1] during World War II. More recently, there has been interest in the use of balloons for elevating VHF antennas. As a result, it was decided to construct a lightweight version of the VHF Xeledop for use in propagation studies with balloons. A balloon-borne Xeledop (BBX) weighing less than the MPX was made and was designed to transmit a constant output power until the batteries were exhausted, at which time

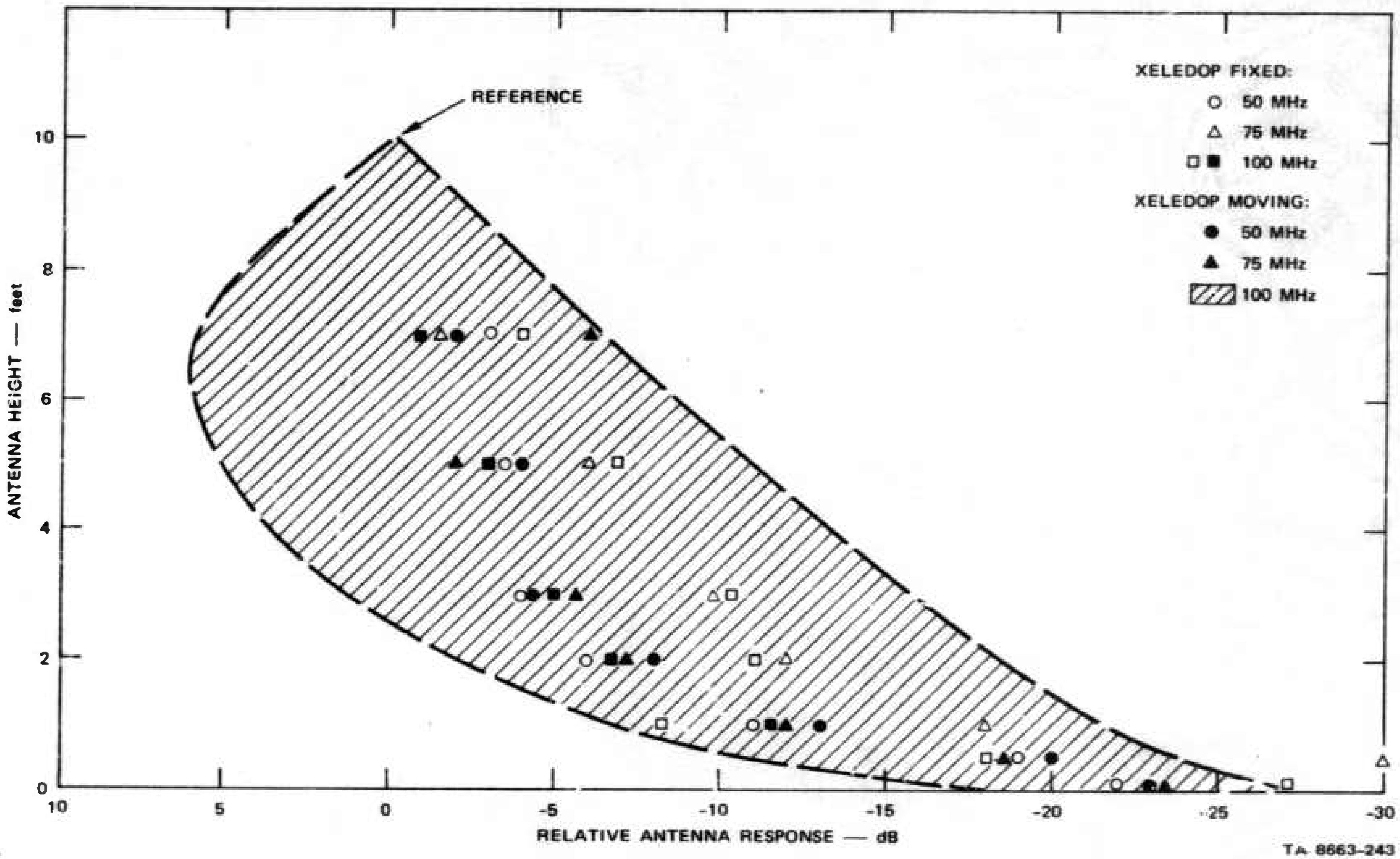

FIGURE 29 HEIGHT-GAIN MEASUREMENTS FOR VERY LOW ANTENNA HEIGHTS (HORIZONTAL POLARIZATION)

the output power would swiftly decay to zero (see Figure 30). The BBX was used with a tethered Kytoon (an aerodynamically shaped balloon, see Figure 31)* at the Chumphon site to measure received signal strength as a function of height up to about 200 feet, both with and without forest in the intervening path. The BBX typically transmitted for about 25 minutes on 50, 75.1, and 100 MHz. The efficiency of this unit was checked against that of the MPX (see Appendix A), and it was estimated that the maximum effective radiated power was +9.5 dBm at 50 MHz, +23.6 dBm at 75 MHz, and +25 dBm at 100 MHz.

For the test in the clearing (July 1967), the MPX receiving terminal was set up at Point A on Trail A and the BBX was lofted from a point 0.14 mile away (about 0.1 mile from the forest-clearing interface--see Figure 15). This test was made for vertical polarization, and the results are shown as the solid line in Figures 32, 33, and 34. The received signal level increased essentially monotonically until the BBX reached a height of about 125 feet, after which no increase was observed on up to the maximum height of about 200 feet.

Forest-to-forest tests were performed at Chumphon during August 1967. It was not possible to send up the balloon from the forest because of the canopy; consequently, the BBX was sent up from the small clearing on Trail B containing the palm tree. The receiving antennas were located at Point C on Trail A (about 50 feet inside the forest), and the horizontal dipoles were oriented orthogonal to Trail A at about 10 feet above ground. The separation between the transmitter and the receiver was about 0.26 mile for low balloon heights. The results of several flights on two different days are shown in Figures 32 through 34.

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*In practice it was necessary to use two Kytoons in tandem to elevate the BBX to 200 feet, and when the Kytoons were not even this did not suffice.

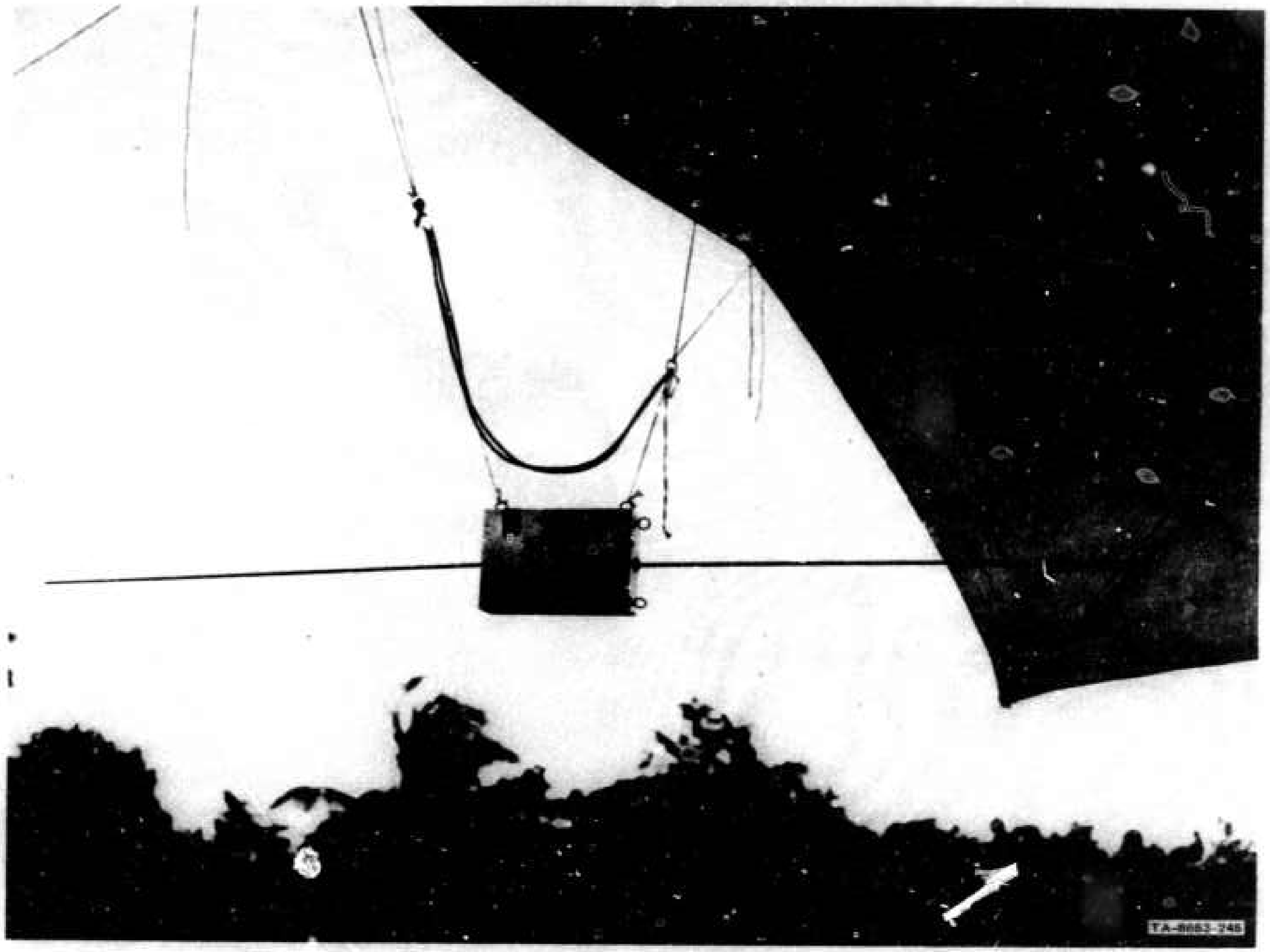

FIGURE 30 CLOSE-UP PHOTO OF BALLOON-BORNE XELEDOP (HORIZONTAL POLARIZATION TOW CONFIGURATION)

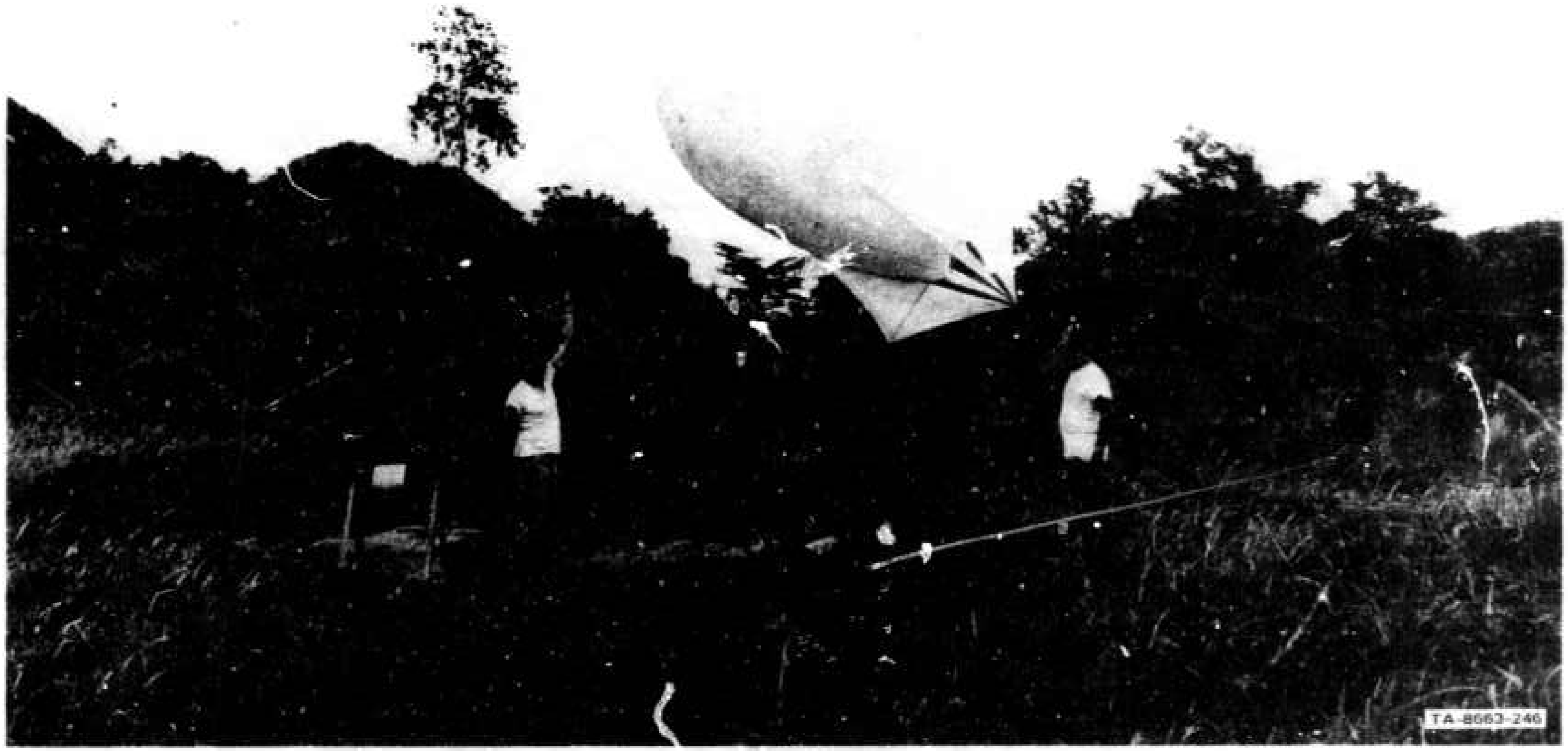

FIGURE 31 PHOTO OF BALLOON-BORNE XELEDOP IN VERTICAL POLARIZATION TOW CONFIGURATION

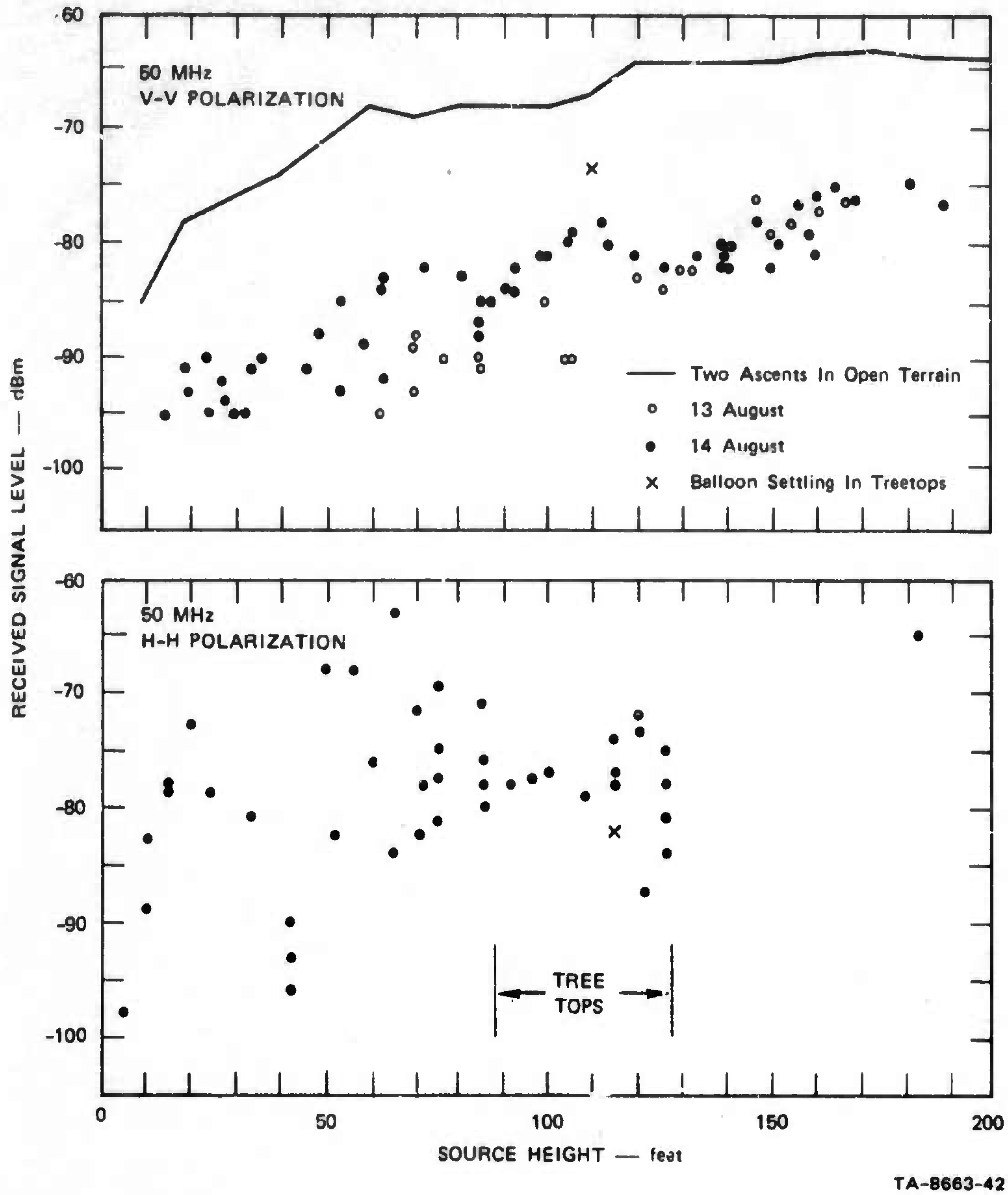

FIGURE 32 50-MHz BALLOON-BORNE XELEDOP OBSERVATIONS AT CHUMPHON

It was possible to increase the received signal level by about 20 dB or more regardless of frequency or polarization by elevating the BBX from 5 feet to 150 to 200 feet.

At a given height the scatter of the data points typically is 10 to 15 dB. Also, the height scale is only approximate (5-foot taped

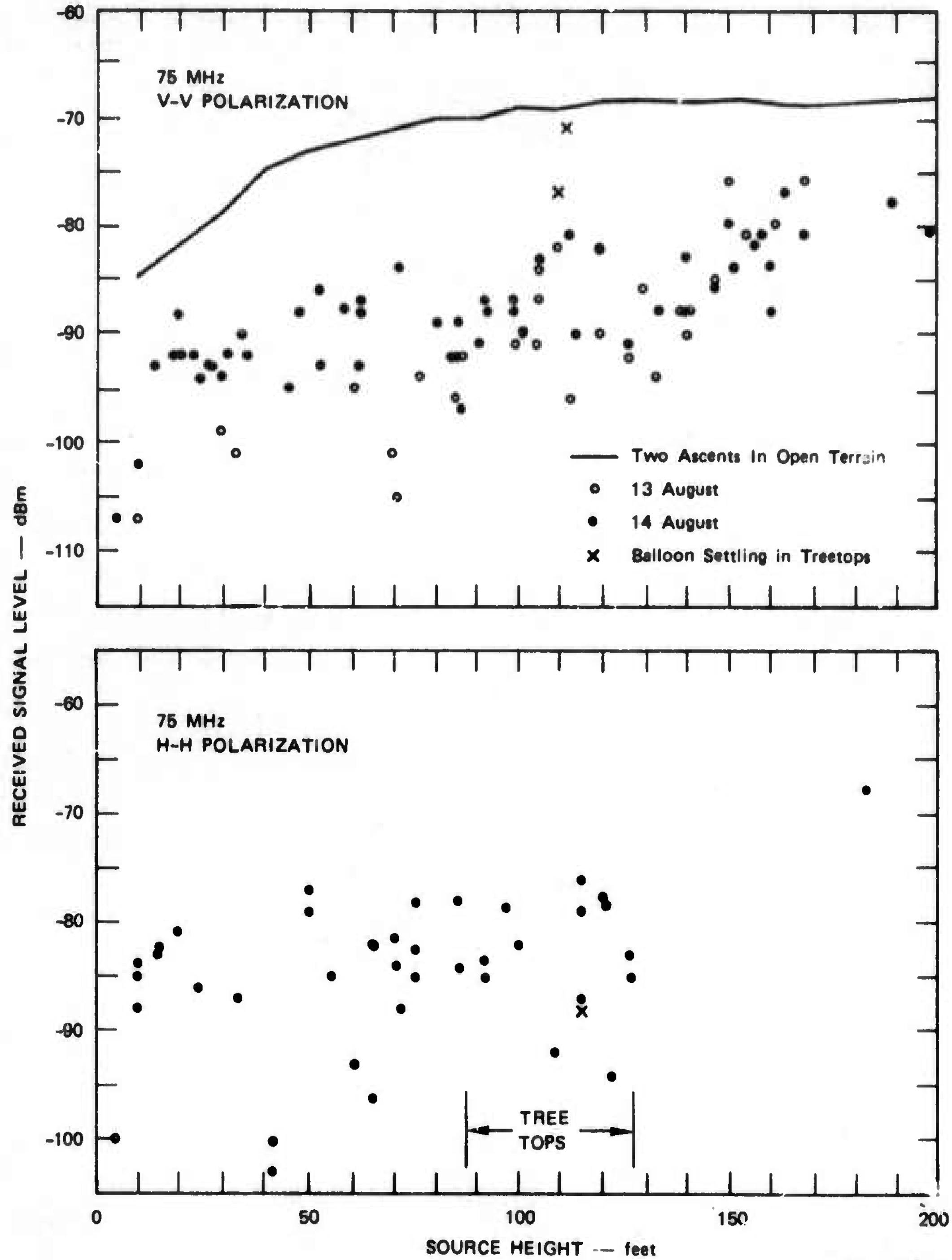

FIGURE 33 75-MHz BALLOON-BORNE XELEDOP OBSERVATIONS AT CHUMPHON

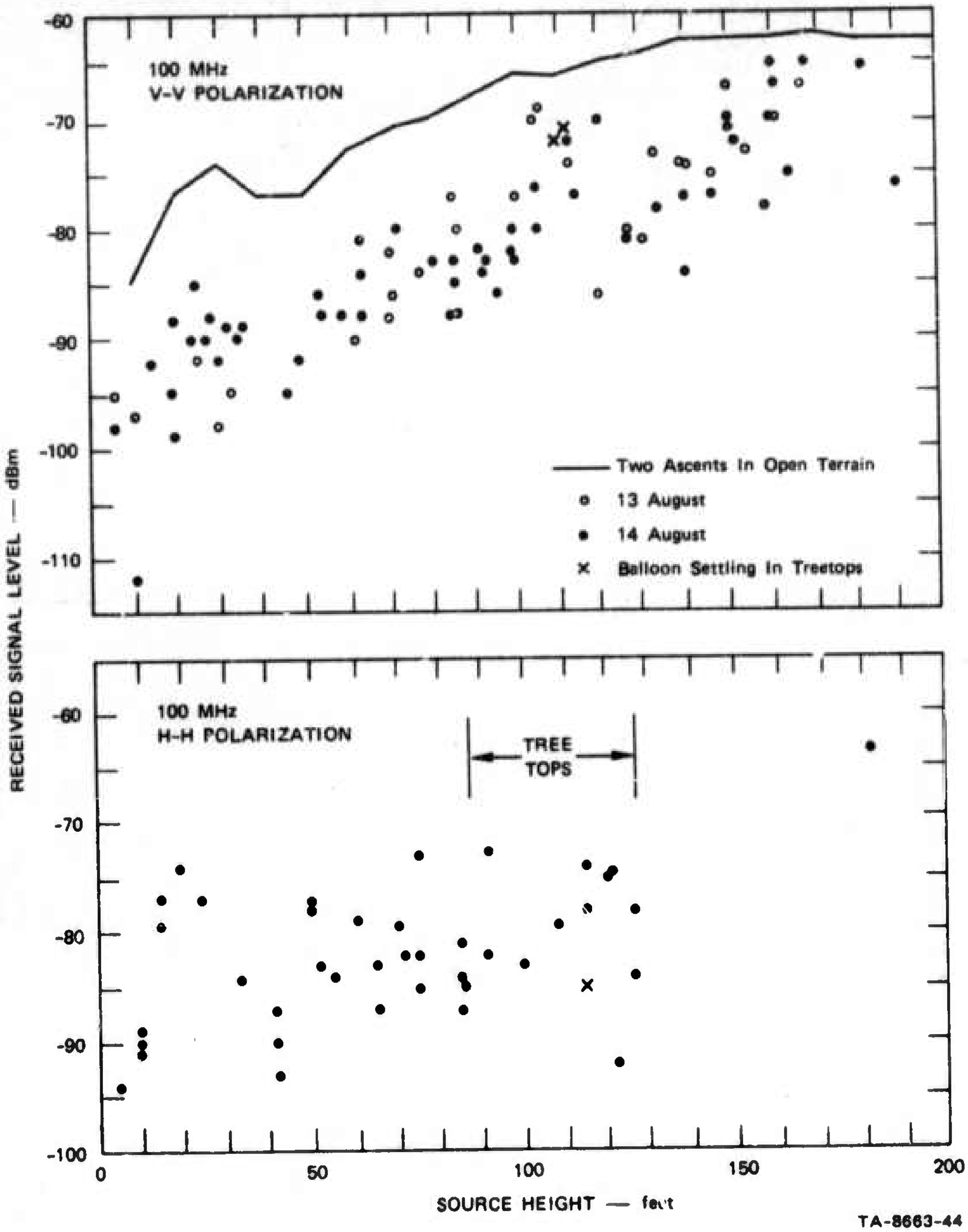

FIGURE 34 100-MHz BALLOON-BORNE XELEDOP OBSERVATIONS AT CHUMPHON intervals on the tether rope were used); the height scale probably is more accurate for the lower heights. A correction was applied for departures from the vertical. Notice that the received signal typically was greater with horizontal polarization. The data points for horizontal polarization were obtained when the BBX elements were broadside to the propagation path. The tether rope held the BBX at a fixed height, and it was twisted until the elements rotated through the position yielding the maximum signal several times before the BBX was elevated to the next height. During data reduction for horizontal polarization only the maximum values at a given height were scaled (as plotted in Figures 32 through 34). Even though the maximum signal on horizontal polarization was greater than that on vertical polarization, the minimum signal on horizontal was often less than the minimum on vertical. The vertically polarized configuration probably is superior from an operational standpoint (e.g., when elevating a relay) because the fading induced by motion of the Kytoon is significantly less, and problems of establishing and maintaining proper antenna orientation are minimized.

D. Antenna Orientation Studies at Chumphon

Some limited tests on the effects of dipole antenna orientation on received signal levels were made on Trail A at Chumphon during November 1967. The receiving antennas were set up at 10 feet above ground at Point C, and the MPX was set up at manpack height at four locations along Trail A (see Figures 15 and 35): Locations 1 and 2 near Radial Point 23 (transmitter-receiver separation of about 0.07 mile) and Locations 3 and 4 near Reference Point 29 (transmitter-receiver separation of about 0.2 mile). Two basic types of tests were performed at these four locations.

The first type of test consisted of orienting both the MPX and the receiving antenna horizontally and parallel to one another at right angles to the path between them (H-H, parallel). A received signal level was noted for each frequency, and the change in level for each frequency was recorded as the horizontally polarized Xeledop was rotated through the angle θ (see sketch in Figure 35) in 30-degree increments in a plane orthogonal to the path from its original horizontal orientation to its final vertical orientation. The results are shown on the left side of Figure 35.

The second type of test consisted of starting with the MPX horizontal and along the path and with the receiving dipole horizontal and perpendicular to the path (H-H perpendicular). The reference (0 dB) employed for this test was the same as the one employed in the previous test (i.e., H-H, parallel). The Xeledop was then rotated through the angle ϕ (see sketch in Figure 35) in 30-degree increments up to vertical in the plane containing the path. Thus the orientation at the end of the second test was the same as that at the end of the first test (V-H). The results are shown on the right side of Figure 35. For this test the data points are even more scattered. The repeatability of the 90-degree (V-H) data is reasonable.

Data on the other possible set of antenna variations, from H-H parallel to H-H end on, were not obtained during this test. Qualitative experiments performed by Hagn in 1964 in the forest north of Rayong using half-wave dipoles at 50 MHz, indicated the superiority of H-H parallel over H-H end on, but tests by Van der Laan at Chumphon in 1967 indicated that the end-on configuration was superior. In practice, one should orient the antennas for maximum received signal on the path of interest.

These data are presented as examples only, and indeed they are possibly unique with respect to data of this type obtained under SEA-CORE. Nevertheless, even though the sample size is very small, they give some clue as to the possible signal level variations that might be observed in a forest environment due to changes in antenna orientation. It might be noted in passing that theoretical calculations at VHF for polarization combinations other than H-H and V-V are at best most difficult to make with confidence.

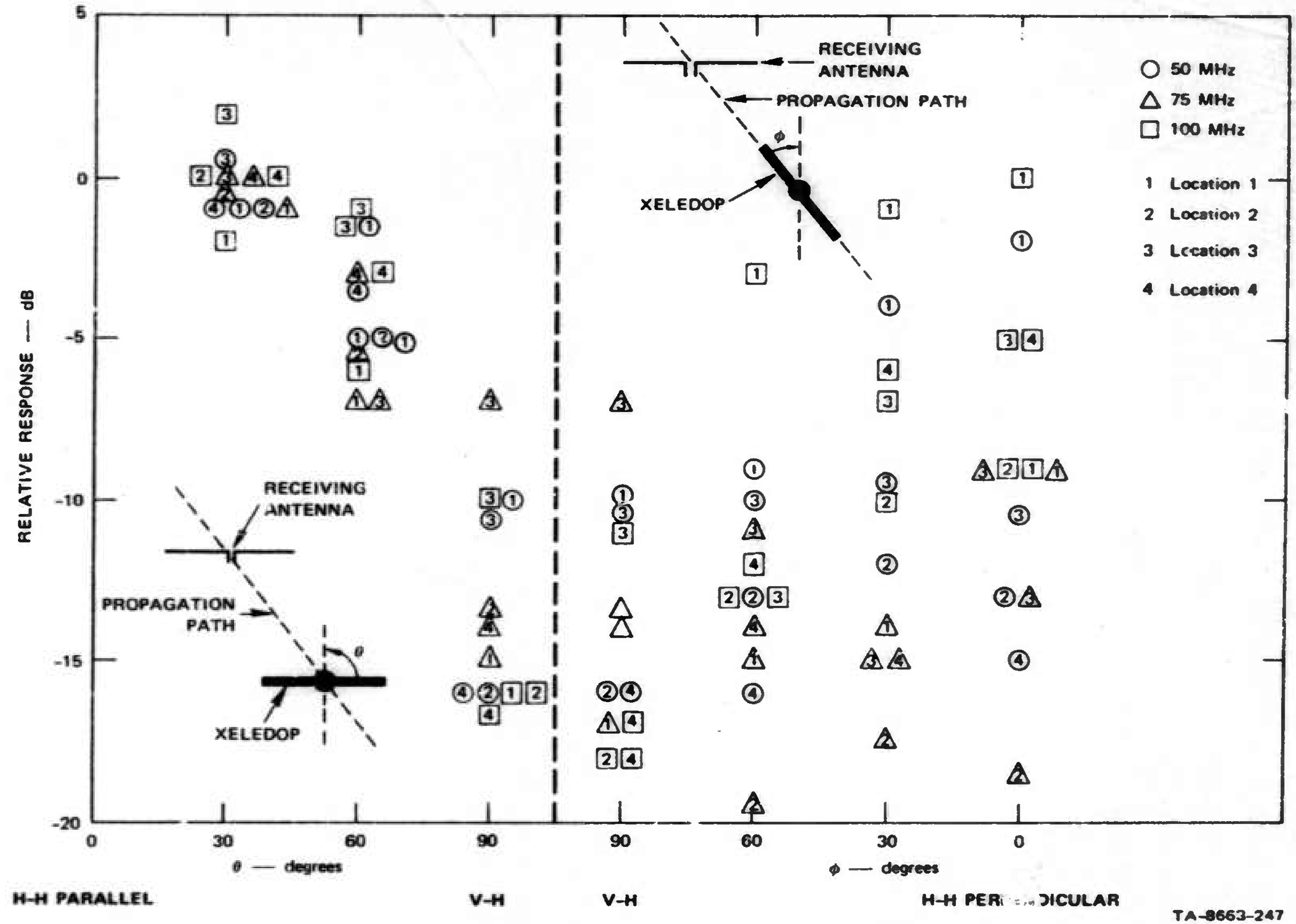

FIGURE 35 RELATIVE RESPONSE AS A FUNCTION OF ANTENNA ORIENTATION

VI COMPARISON OF THE AN/PRC-25 AND THE MANPACK XELEDOP SYSTEMS

A. Introduction

1. Objective

The objectives of the work presented in this section were (1) to relate the gain of the AN/PRC-25 system using 3- and 10-foot whip antennas to that of the manpack Xeledop (MPX) system using vertical half-wave dipole receiving antennas at the Laem Chabang (open beach) site; (2) to use MPX data obtained at the Chumphon site, along with the system scaling factor determined at Laem Chabang, to predict the received signal strength of the AN/PRC-25 system as a function of range at Chumphon; (3) to check the prediction by actual measurements at the Chumphon site; and (4) to observe on 50 and 75 MHz the difference in performance obtained at Chumphon with the 3-foot whip and the 10-foot whip antennas.

2. Background

We have emphasized the many advantages of the MPX for use in conducting several types of propagation experiments. One of these is the analogy between the Xeledop and VHF manpack radios used for field communication. We assumed that data obtained with the Xeledop system could be used to estimate the received signal level to be expected from a manpack radio system* operating at the same frequency and in similar

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*"System" can refer here either to the same type of radio at both ends of the link or to the Xeledop and its receiving equipment.

terrain. And, given some way of relating received signal levels to intelligibility, we could estimate the usable range of the manpack radio sets for various types of terrain.

It is preferable to obtain information on terrain effects using the Xeledop rather than to make the measurements directly using a given radio set for the following reasons:*

(1) Manpack radio sets are not well suited for direct measurements; they usually require some modification to record signal strength.

(2) Manpack sets usually are designed to operate with very low duty cycles and the power supply is not sufficient to allow continuous measurements.†

(3) There are many types of manpack sets, and each would have to be investigated in the terrain of interest. It is costly to do field testing, and the cost increases rapidly with additional systems to be tested.

(4) Xeledop data have already been obtained for a variety of terrains. Only a determination of the difference between the MPX system and a selected manpack radio system is necessary to make an estimate.

Therefore, we conducted an experiment to determine the feasibility of a comparison approach. The experiment consisted of obtaining the difference between received signal performances of the Xeledop system and an AN/PRC-25 system‡ over smooth, open terrain. This difference

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*It actually is preferable to use the Xeledop to check a propagation model such as the one given in Ref. 23, and then to use the model to predict the performance of systems of interest. The work described in this section should be considered as an intermediate step in such a process.

†Figure 31 in Ref. 25 illustrates the effects of the decrease in output power of the AN/PRC-25 when used to transmit continuously with its standard batteries for this type of measurement.

‡With receivers modified for recording AGC; see Ref. 17.

is applied to the Xeledop results obtained over other terrains--both forested and open--of widely different characteristics to estimate the performance of the AN/PRC-25 in these terrains. Data from the AN/PRC-25 were also taken in these terrains to provide a check on the estimates.

B. Description of the Experiment

The first portion of the experiment consisted of obtaining received signal records over the same open terrain trail used to obtain Xeledop data. Data from the two systems were scaled and compared to determine the performance difference between the two systems in terms of the median value of the received signal in dB above 1 μV at the receiver calibration points.* Next, the performance factor was applied to data obtained with the MPX over a trail in different terrain. This provided an estimate or prediction of the received signal of the AN/PRC-25 system as a function of distance down a trail in that terrain. We then took data using the AN/PRC-25 system in the different terrain to test our estimate. For this experiment, the original system comparisons were conducted at Laem Chabang, and the predictions and verifications were made at Chumphon.

The Xeledop system has been previously described. The AN/PRC-25 system consists of two AN/PRC-25 transceivers, one used for transmitting and the other for receiving (see Figure 36).

As shown in Figure 37, the AN/PRC-25 receiver has a wire labeled "AGC," which goes to the recorder. This wire is from the emitter of the fourth IF limiter stage and provides a measurable voltage that can be

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*For the Xeledop system the calibration point was the antenna feed point; for the AN/PRC-25 system it was the external (homing) antenna jack.

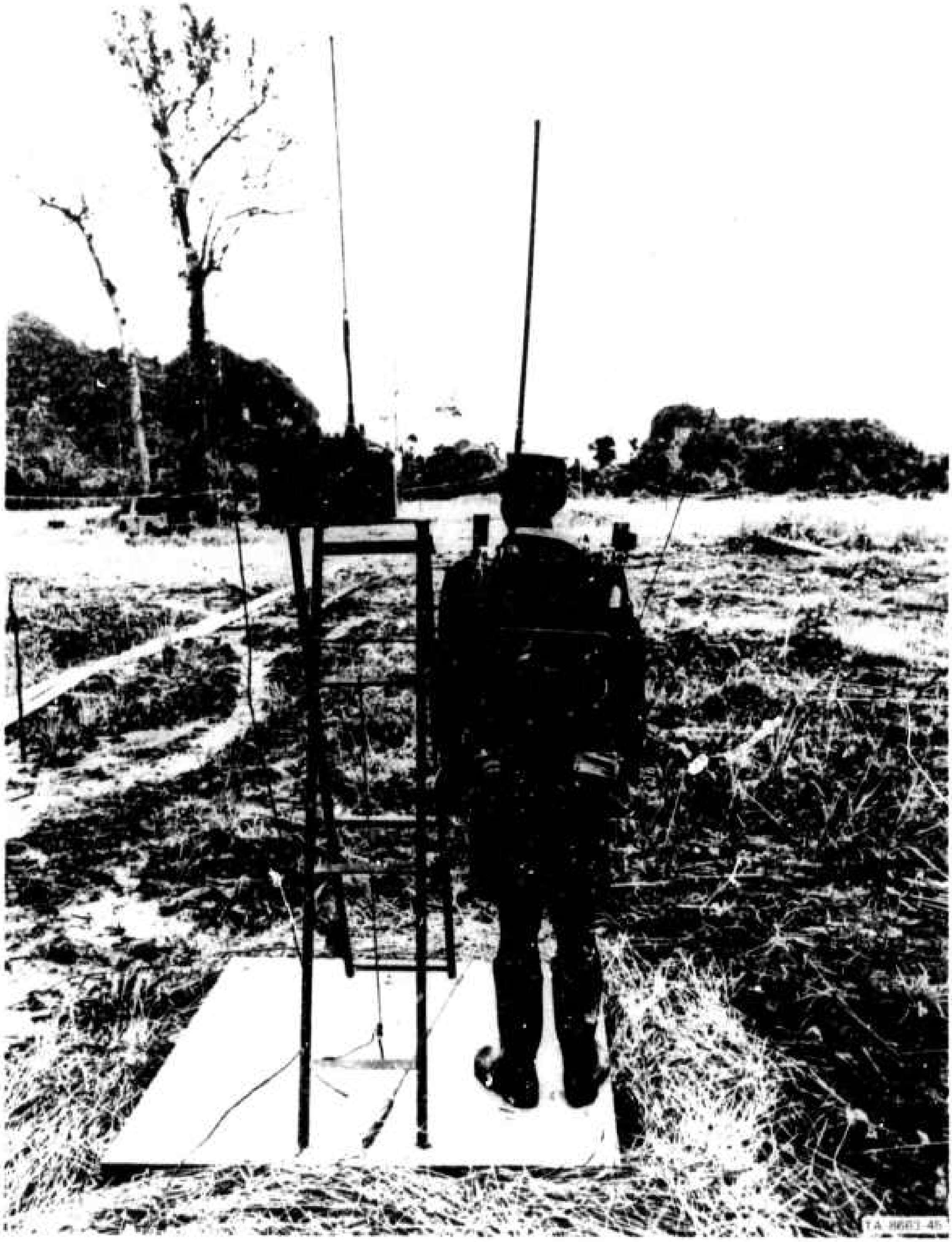

FIGURE 36 AN/PRC-25 SETS USED IN PERFORMANCE TESTS AT CHUMPHON

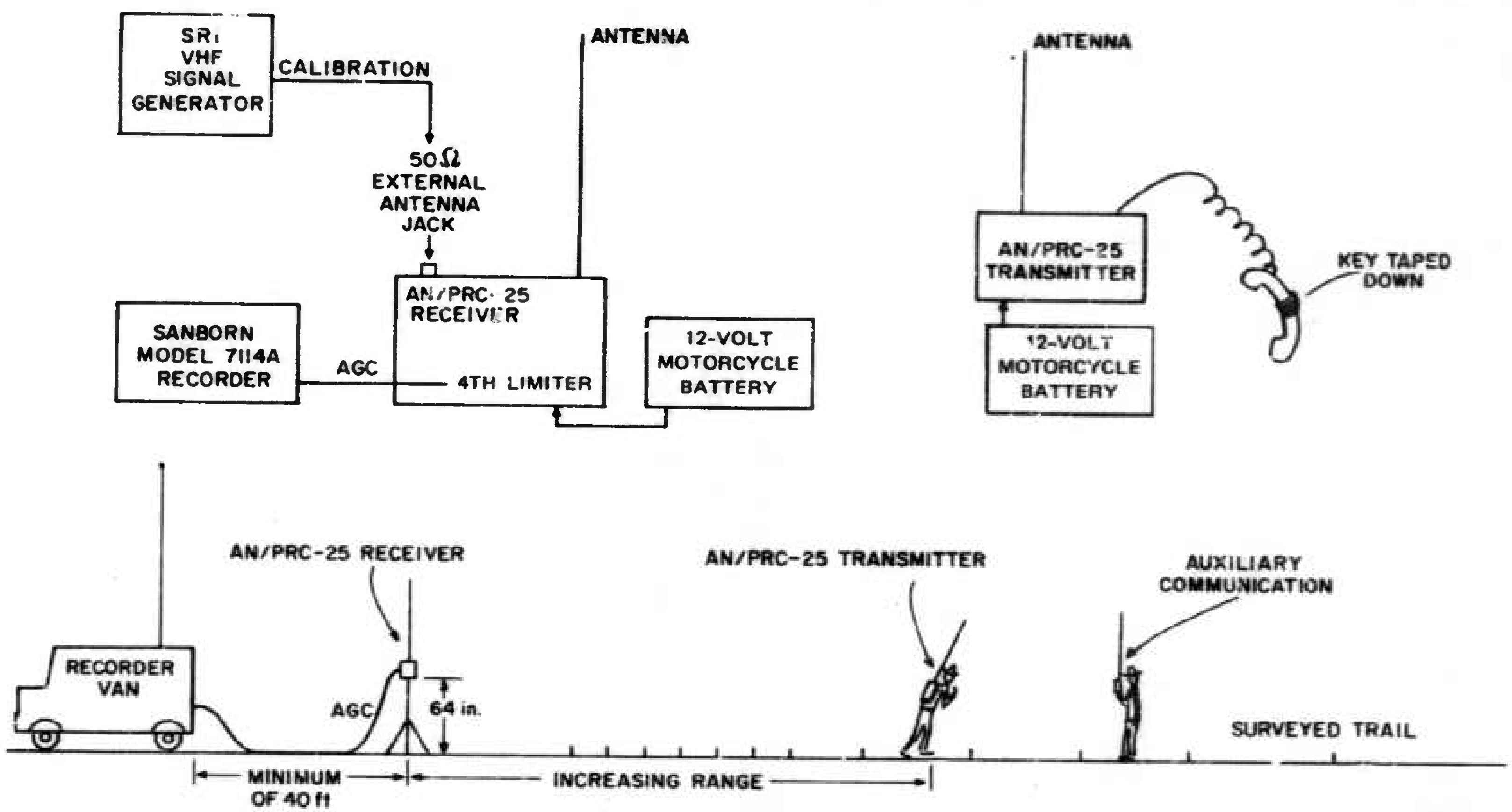

FIGURE 37 DIAGRAM OF AN/PRC-25 SYSTEM AND PERFORMANCE TESTS

related to the input signal at the homing antenna port by calibration with a signal generator. The recorded output was taken at this point to obtain data over the same range as the Xeledop. The first limiter would have been saturated at close ranges (0 to 0.2 mile), where Xeledop data are available for all frequencies and terrains measured to date. Choosing the fifth limiter would have provided AN/PRC-25 data at distances beyond the Xeledop range.

The calibration of the receivers for both systems was accomplished using the SRI VHF signal generator (crystal controlled). This unit provides a reference voltage of 0.224 volt when loaded with 50 ohms and has a 50-ohm attenuator in the output line. The receiving system used with the Xeledop is padded to present a 50-ohm input; thus, Xeledop calibration in dB is referenced to 1 mW (i.e., 0 dB = 0 dBm). All that is needed to change the reference to 1 μV is to add 107 dB to the measured data in dBm. We also corrected for cable loss but disregarded antenna mismatch losses (because we were comparing systems, not antennas) to present the data in terms of voltage appearing at the terminals of the antenna when it is loaded with 50 ohms.

The AN/PRC-25 receiving system was calibrated through the receiver's external antenna input, and therefore the received signal was measured with respect to this point. The input impedance at this jack is nominally 50 ohms, but actual measurements show a wide variation in impedance at this input. Table 3 shows the average impedance measured for each set at Chumphon, along with the power into a 50-ohm load connected to the external (homing) antenna terminal. The impedance measurements were made with all antennas removed and with the set located 5 feet above ground with the receiver turned on.

The problem caused by the receiver impedance not being exactly 50 ohms is that the reference output of the 50-ohm signal generator is something other than the desired value, owing to the mismatch. Therefore, we first corrected the measured AN/PRC-25 data by multiplying the assumed generator reference (0.224 volt) by $1 - |\Gamma|$* to obtain the actual reference level. This corrected reference was then referred to 1 µV to make the desired comparisons. The corrections were made individually for each receiver at each frequency.

Table 3

MEASURED IMPEDANCE AND POWER
OUTPUT OF AN/PRC-25

Set No.	Serial No.	Impedance (ohms)		Power* (watts)	
		50 MHz	75 MHz	50 MHz	75 MHz
1	1552	12 - j2	65 - j17	1.8	1.7
2	1414	16 - j6	49 - j23	2.2	1.6
3	1537	37 - j22	69 - j20	2.2	1.9

*The rated output of the AN/PRC-25 is 2 W on the low band (30.00 to 52.95 MHz) and 1.5 W on the high band (53.00 to 75.95 MHz). Other measurements of the output power of the AN/PRC-25 made on this contract have indicated a variation relative to the rated values of ± 2 dB at 50 MHz and ± 3 dB at 75 MHz.

The AN/PRC-25 system was further modified by using an external, relatively lightweight lead-acid storage battery for the basic power

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*$|\Gamma|$ is the magnitude of the reflection coefficient:

$$|\Gamma| = \left|\frac{Z - 50}{Z + 50}\right| .$$

supply.* This modification was made to achieve a constant transmitter output during the transmissions.

The experiment was conducted using two frequencies (50 and 75.1 MHz) and only V-V polarization. Standard 3-foot (AT-892/PRC-25) and 10-foot (AT-271/PRC) whip antennas supplied with the AN/PRC-25 were used.

C. Results

It was previously stated that the tests to determine the average difference in system performance were run at the Laem Chabang open beach test site.† We first conducted runs using the Xeledop system and then runs using the AN/PRC-25 system. These runs were all conducted during the same one- or two-day period to minimize the effects of ground parameter changes.

Figure 38 is an example of the scaled open beach results. It is for the 75-MHz long whip.‡ Two curves are shown in this figure: Xeledop and AN/PRC-25. We had three AN/PRC-25 sets available and, to include effects of equipment variation, we conducted runs using each set in both transmit and receive modes with the other sets--a total of six combinations. The median of these six runs with the 75-MHz LW is plotted in Figure 38 to use for the determination of the system difference. The variations about this median were usually less then ± 4 dB.

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*These were "Kobe" (Japanese) 12-volt motorcycle cells.

†Trail A of this site was used. This trail is described in detail in Ref. 16.

‡Only vertical polarization was used for these tests.

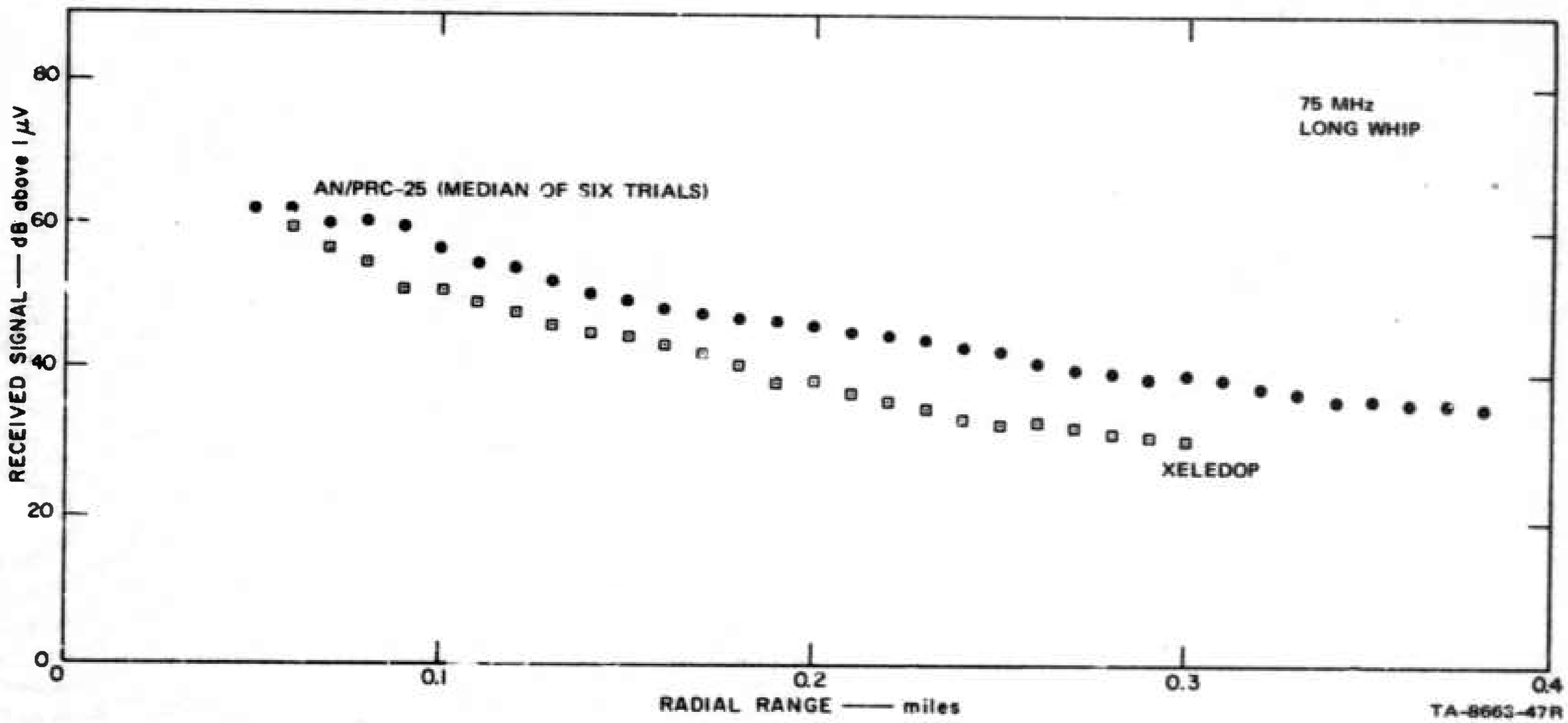

FIGURE 38 TYPICAL RESULTS OF COMPARISON OF AN/PRC-25 AND XELEDOP

The performance difference for the two systems was obtained by comparing the results at each scaled range. The mean of these differences (at the ranges where data from both systems were available) was defined as the average system performance difference used to make the predictions.*

Differences were obtained in a like manner for 75 MHz, using the short whip and for 50 MHz using both long and short whips. Table 4 is the result of the difference comparison. The spread of these results is ± 4 dB when applied to the particular radio sets used in the tests, but would probably be greater if applied to a random selection of AN/PRC-25 radio sets with the same power source used in these measurements.

Table 4

SYSTEM COMPARISON IN DECIBELS

(Xeledop System Taken as Reference)

Frequency (MHz)	AN/PRC-25, Long Whip (dB)	AN/PRC-25, Short Whip (dB)
50.0	+14.6	0.0
75.1	+ 7.0	-3.5

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*These differences (in dB) at each range were averaged. This procedure is not strictly the correct one for comparing average power (one should take the antilog, then average and convert back to dB). An alternate approach would have been to compute the difference in median received signals to obtain the performance difference. More work is required to determine the best approach for such small sample sizes for propagation data of this type.

The predicted and measured AN/PRC-25 system results are presented in Figures 39 to 42. The performance difference factors given in Table 4 are added to the median Xeledop results for Chumphon (scaled in terms of receiving antenna terminal voltage) to give the predicted curves. The measured AN/PRC-25 curves are the median values of the total of six combination sets used for runs at Chumphon. One addition to all the curves of these figures has been made--the addition of the standard deviation about the scaled median values* to show the effect of the scattered signal on the predictions. The addition does not reflect set variation, which may still be assumed to be less than ± 4 dB.

The results given in Figures 39 through 42 were collected at two receiving site locations at Chumphon. The clearing receiving location is at Reference Point Zero of Trail A. From this receiving site the Xeledop and AN/PRC-25 transmitters were carried through the open and into the forested terrain, thus providing clearing-to-clearing and forest-to-clearing transmissions. The forest receiving location was Reference Point 16 of Trail A (see Figure 15 for a map of the Chumphon site); it provided us with forest-to-forest transmissions.

Each of the four figures the upper set of curves is for receivers located in the clearing (Reference Point Zero): the lower set is for receivers in the forest (Reference Point 16). The distance shown on each set of curves is that from the receiving antenna.

D. Discussion of Results

1. Comparison of Predicted and Measured Results

The results of this experiment, presented in terms of received signal strength as a function of distance (Figures 39 to 42), show that

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*Here the second moment about the median was computed for the received signal values in dB.

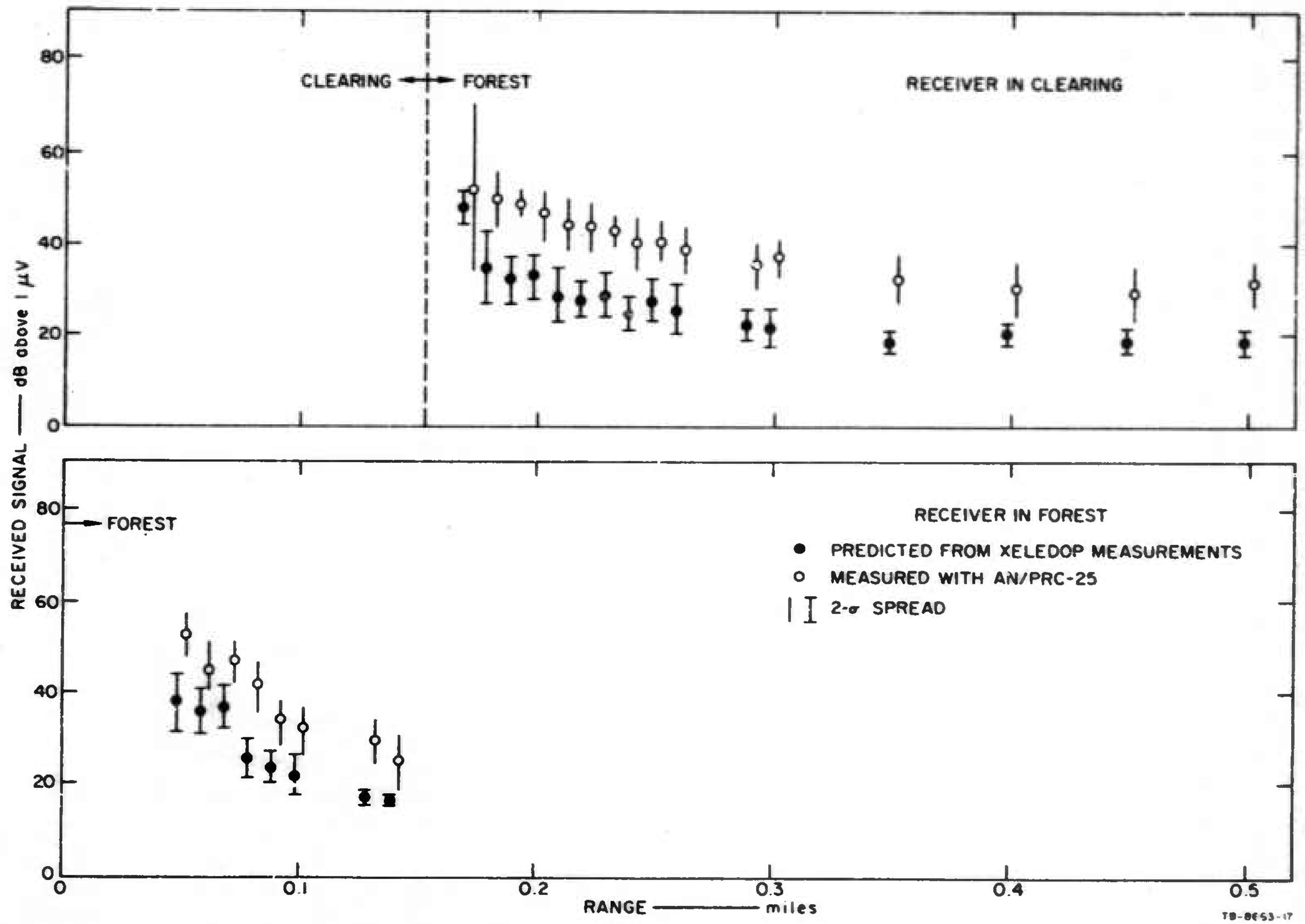

FIGURE 39 SIGNAL LEVEL RECEIVED AS A FUNCTION OF DISTANCE AT CHUMPHON WITH THE AN/PRC-25 TRANSCEIVERS (LONG WHIP ANTENNA) ON 50 MHz

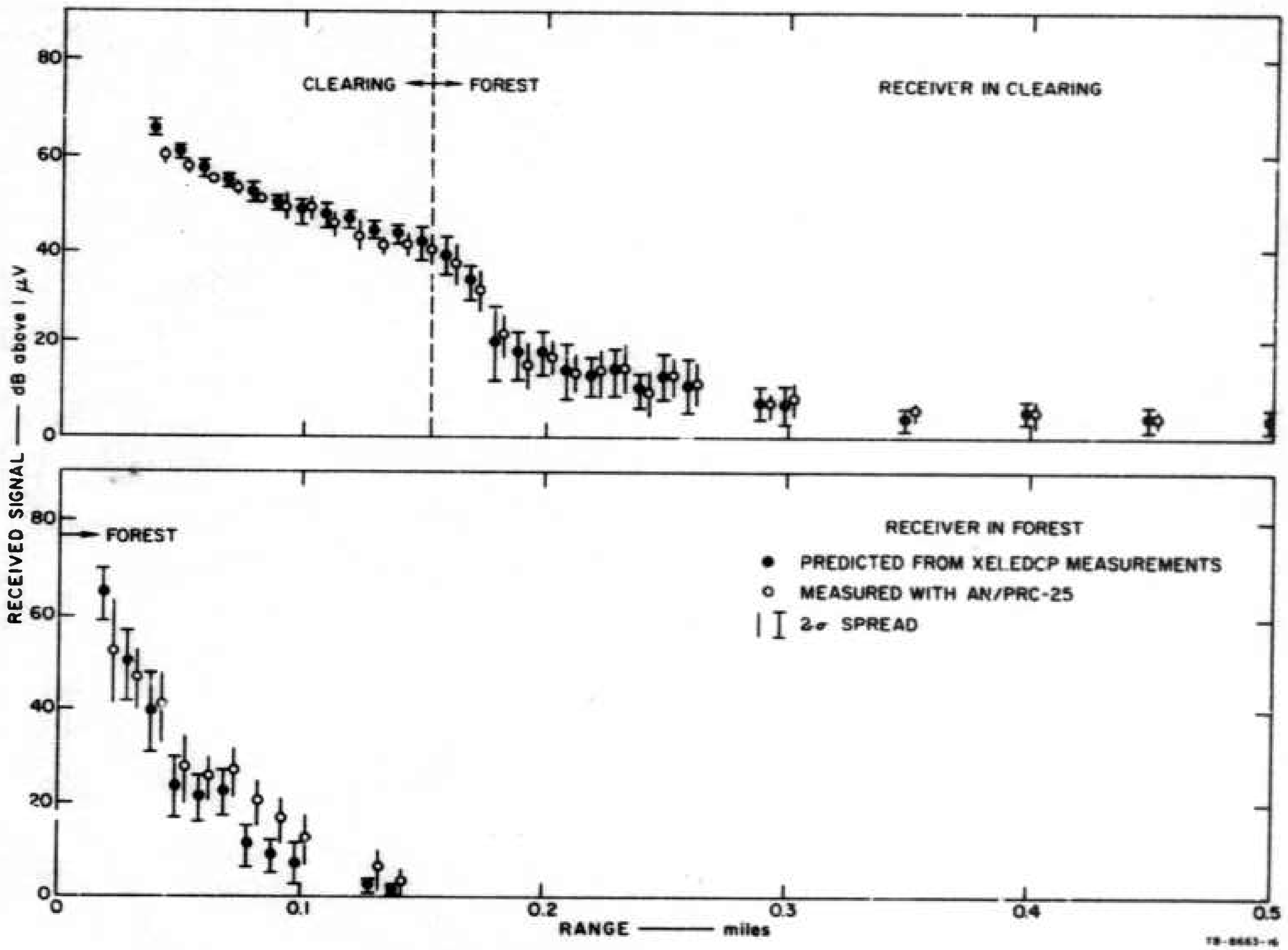

FIGURE 40 SIGNAL LEVEL RECEIVED AS A FUNCTION OF DISTANCE AT CHUMPHON WITH THE AN/PRC-25 TRANSCEIVERS (SHORT WHIP ANTENNA) ON 50 MHz

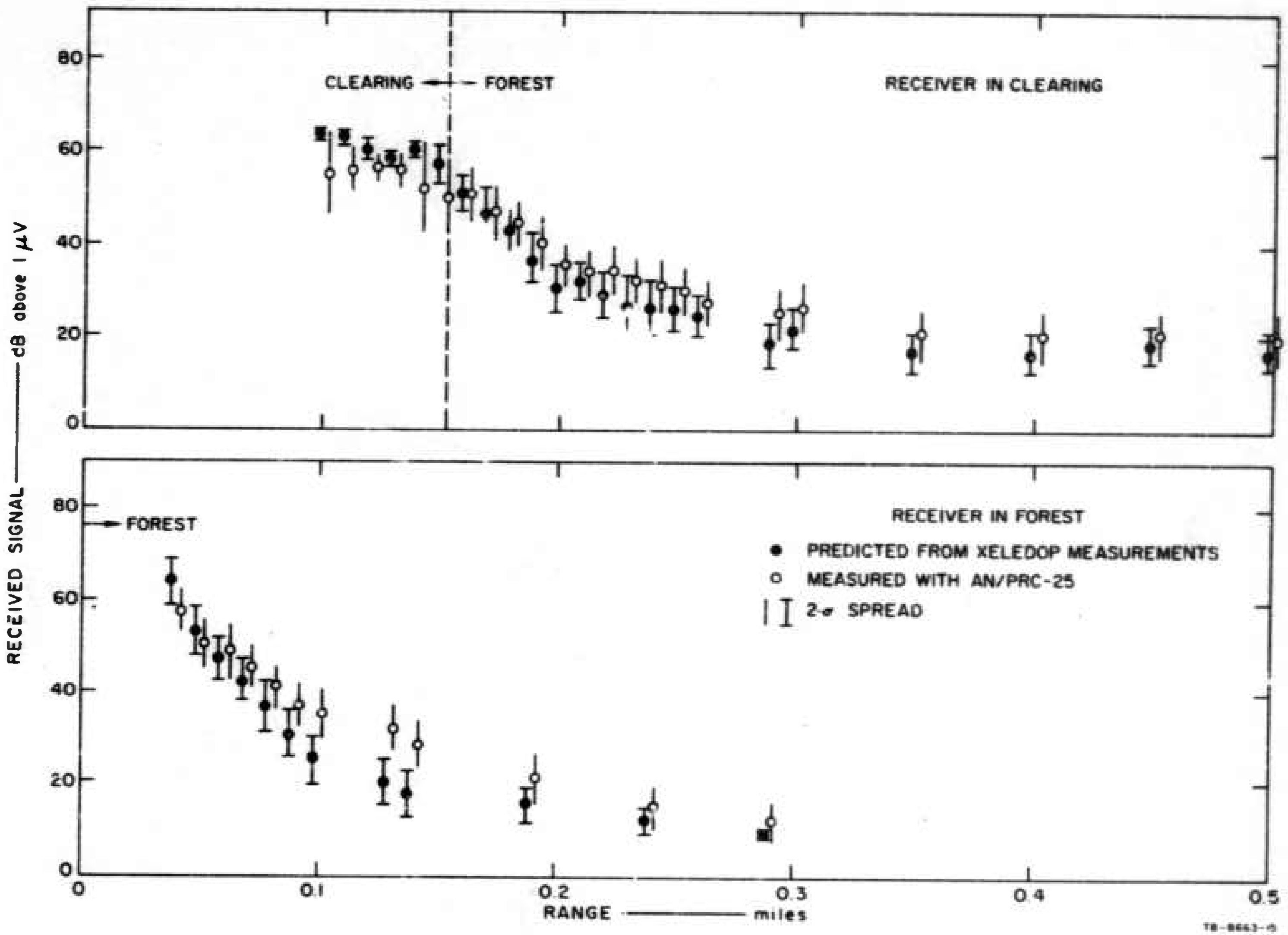

FIGURE 41 SIGNAL LEVEL RECEIVED AS A FUNCTION OF DISTANCE AT CHUMPHON WITH THE AN/PRC-25 TRANSCEIVERS (LONG WHIP ANTENNA) ON 75 MHz

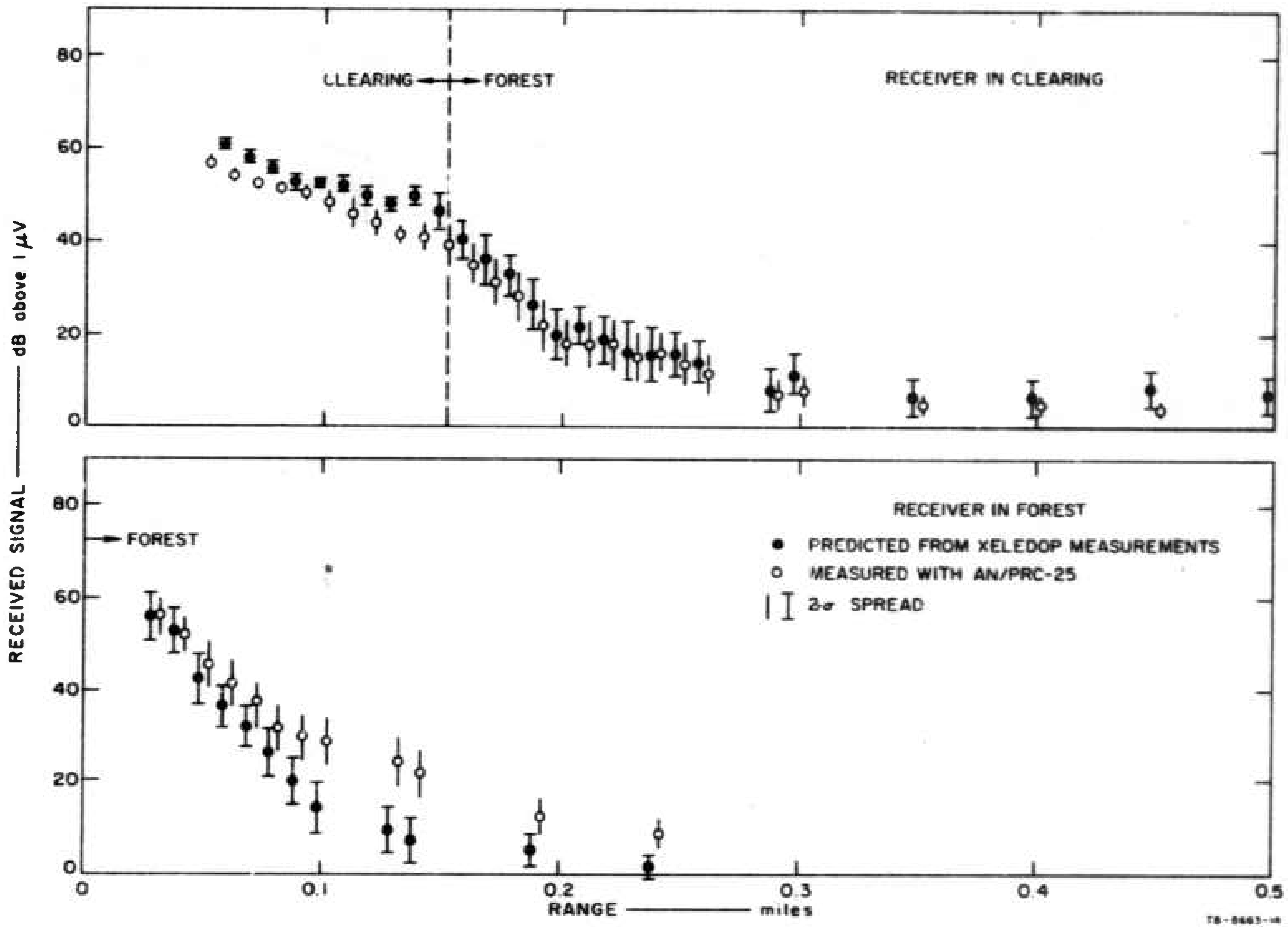

FIGURE 42 SIGNAL LEVEL RECEIVED AS A FUNCTION OF DISTANCE AT CHUMPHON WITH THE AN/PRC-25 TRANSCEIVERS (SHORT WHIP ANTENNA) ON 75 MHz

the predictions generally were too conservative and often were in error by more than the ± 4 dB, which is attributable to AN/PRC-25 set variation.

Consider first the data obtained using the short whips with the receiver located in the clearing (0.15 mile from the edge of the forest). The prediction technique worked well at 50 MHz and reasonably well at 75 MHz, indicating that the MPX and AN/PRC-25 functioned similarly at Laem Chabang and Chumphon. But for all other combinations there were significant differences in the way the two systems performed; when the transmitter was in the forest--except near the clearing-forest interface--the predicted signal level was always too low. Also, when the transmitting long whip was moved from the clearing into the forest (with the receiver in the clearing), it typically gained about 10 dB over the Xeledop prediction. When both terminals were in the forest, the AN/PRC-25 was at least 5 dB better than the Xeledop prediction with either antenna or frequency. Finally, with both terminals in the clearing, the AN/PRC-25 did not perform even as well as the Xeledop predictions had indicated. The reasons for these results are not immediately obvious, but the propagation mode structure and the relative efficiency of the Xeledop dipoles and the AN/PRC-25 whips in coupling into the propagating modes may be involved. Seemingly inconsequential factors, such as how far forward the man leans while carrying each set (see sketch in Figure 34) or which way he was walking, also may be important.

2. Comparison of Measured Results Using Short and Long Whips

It is possible to infer the increase in system efficiency obtained when a change is made from a pair of short whips to a pair of long whips by inspecting the measured data of Figures 39 through 42. When both the receiver and the transmitter are located in the forest or in the clearing, these data indicate that the improvement obtained by using a pair of long whips is about 21 dB and 7 dB at 50 and 75 MHz, respectively. These values compare favorably with results obtained in the open delta--21 dB and 9dB[25]*--but not very well with the Laem Chabang results at 50 MHz (only 14.6 dB).† However, when the receiving antenna is in the clearing and the transmitting antenna is the forest, the improvement obtained by using the long whips appears to be about 10 dB higher. This is a rather puzzling result. The implication is clear: when an attempt is made to communicate to a site in a forest with AN/PRC-25s at manpack heights, the best results are obtained with long whips on frequencies near the high end of the upper band and when one terminal

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*Similar results (to within ± 4 dB) were obtained by a substitution test at fixed ranges in the radiation field at various other sites. For these tests, the long whip was used with the AB-59/PRC-25 base, and the short whip was used without a base section. Also, the range tests in the delta[11] gave us a partial check on the relative launching efficiency of the long and short whip in open, level terrain. Recall that during these tests the AN/PRC-35(XC-3) sets were used with 3-foot whips and the AN/PRC-25 sets were used with 10-foot whips. Allowing for the differences in transmitter power (about 4 dB) and the receiver noise level (about 3.5 dB) and assuming that otherwise the sets are identical and that the distance attenuation goes as 40 $\log_{10} d$, it is possible to estimate the gain of the pair of 10-foot whips over that of the 3-foot whips by considering the different ranges achieved. The results of such a comparison indicate that the 10-foot whips were better by about 13, 25, and 15 dB at 35, 51, and 65 MHz, respectively. These values agree reasonably well with the AN/PRC-25 results stated above--especially in view of the possible set differences of the AN/PRC-25 and AN/PRC-35(XC-3).

†If the system comparison factors given in Ref. 25, p. 18, are used instead of the values measured at Laem Chabang (Table 4), then the predicted and observed values are in better agreement for the case where the receiver is located in the clearing. When the receiver is located in the forest, however, the observed values still exceed the predicted values by about 8 dB (for short whip at 50 MHz) to 13 dB (for all other antenna-frequency combinations).

is located in a cleared area at least 0.1 mile from the clearing-forest interface.*

3. Comparison of Measured Results on 50 and 75 MHz

When the receiver was located in the clearing, the short whips produced almost identical received signal levels at 50 and 75 MHz, but when the receiver and transmitters were both moved into the forest, the received-signal level on the short whip at 75 MHz was about 10 dB greater than the level on the same antenna at 50 MHz. The long whip produced essentially the same results on 50 and 75 MHz when both transmitter and receiver were located in the forest, but when the receiver was located in the clearing, the signal level on 50 MHz exceeded that on 75 MHz by about 10 dB. These are rather surprising results. They imply that changing frequency from 50 to 75 MHz--in operations with the short whip in the clearing (or clearing to forest) or with the long whip in the forest--should not produce any significant changes in performance (i.e., change in effective range). On the other hand, increasing frequency from 50 to 75 MHz using the long whip in the clearing should produce a degradation of performance when near the range limit of the set, whereas an upward frequency change using the short whip in the forest would improve performance.

E. Conclusions from Comparison Test

The agreement between the MPX-predicted values and those measured with the AN/PRC-25 is reasonable for the situation with the receiver in the clearing when the system conversion factors given in Ref. 25 are used; however, the signals received with the AN/PRC-25 when both sets

*It is interesting to note that radio operators in Vietnam with operational experience prefer the highest frequencies in the AN/PRC-25.[26]

are in the forest are significantly greater than the predictcd values. More work clearly is necessary to understand some of the peculiarities of the data obtained in this experiment. Nevertheless, predictions based on MPX data and Ref. 25 may be used to estimate the performance of AN/PRC-25s in open areas. In forested areas it evidently becomes necessary to add 10 dB (± 3 dB) to the predicted signal strength values (again using the system conversion given in Ref. 25) to get a reasonable estimate of the signal level expected with AN.PRC-25s. A reasonable extension of the range of the MPX data may be obtained where necessary (e.g., in making predictions for use of the long whip) by assuming the signal decreases as 40 $\log_{10} d$ for ranges beyond which MPX data are not available.

VII CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The manpack Xeledop (MPX) system has proven useful for measuring radio system loss over short paths (less than 1 Km) in forested terrain. The system is especially useful when at least one antenna is at manpack height. The MPX also has proven useful for obtaining height-gain data, but a light weight version of this system using a balloon is needed for obtaining data at heights above the treetops. The systems used in the experiments described in this report worked well in the tropical environment of Thailand.

The data obtained with the MPX show that greater radio system loss results from the use of vertical polarization than from the use of horizontal polarization. The data obtained with the Xeledop indicated that greater received signals were obtained at 100 MHz than at 50 MHz even though the system loss usually was greater at 100 MHz. This occurs because the matching efficiency of the MPX is significantly greater at 100 MHz. The coupling mechanism of long and short rod antennas operated in forests are not totally understood.

B. Recommendations

It is recommended that a full-scale test of the coupling of long and short antennas to the forest propagation medium be conducted to resolve the ambiguity discovered during the tests described in this report. It is further recommended that such tests include AN/PRC-25 radios (or equivalent) and that system performance tests for these radio be included.

The trade-off in matching circuit loss and propagation loss in forests should be investigated in conjunction with such a study.

Appendix A

CALIBRATION OF THE MANPACK XELEDOP SYSTEM

1. Introduction

The manpack Xeledop data reported on thus far[16,17] have all been expressed only in terms of received signal power (i.e., dB above a known voltage developed across the 50-ohm input of the receiver) without specifying the transmitter power in a precise manner. Consequently, the amplitude of the curves of signal as a function of distance is only relative. It is the purpose of this section to determine a factor for each frequency-polarization combination to convert to an absolute basis the calibration of the data previously reported on and the data in this report.

Several definitions have been advanced for describing the power loss between the transmitting and receiving antenna terminals of a radio circuit. The International Radio Consultative Committee (CCIR) has reiterated the desirability of standardized terminology and notation and has recommended that the following four loss terms be used as defined in their Recommendation 341:[27]

(1) System loss (L_s)* is defined as the ratio (in dB) of the radio-frequency power input to the terminals of the transmitting antenna (p_t) to the resultant radio-frequency signal power available at the terminals of the receiving antenna (p_a).

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*The system loss is that defined by Norton.[28] It might be noted that L_s is the negative of radio gain, as defined by Burrows.[29]

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(2) Transmission loss (L) is defined as the ratio (in dB) of the radio-frequency power radiated from the transmitting antenna to the radio-frequency signal power that would be available from the receiving antenna if there were no receiving-circuit losses other than those associated with its radiation resistance.

(3) Basic transmission loss (L_b) is defined as the transmission loss (in dB) expected between ideal (lossless, isotropic) transmitting and receiving antennas at the same locations as the actual transmitting and receiving antennas.

(4) Propagation loss (L_p) is defined as the system loss (in dB) expected if the antenna gains and circuit resistances were the same as if the antennas were located in free space.

All four of these loss terms are based in part on the available power at the terminals of the receiving antenna. As pointed out by the CCIR, this available power is sometimes a simpler and more directly useful concept than that of effective field strength--especially where the effective field is the result of a large number of received-field components, corresponding to several modes of propagation arriving at the receiving antenna at different angles and possibly with different polarizations--such as might be the case in the forest environment. It is pertinent, then, to ask which of these internationally accepted terms is the most suitable to use to describe the loss between the terminals of a radio system used in forested (jungle) terrain.

First, let us note that, of the four losses, only system loss (L_s) depends solely on quantities that can be measured in the field. Both transmission loss (L) and the basic transmission loss (L_b)* depend on

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*L_b was employed by Jansky and Bailey in reporting the results of their jungle propagation measurements in Thailand. They used two assumptions: (1) that the antenna gains relative to an isotropic radiator for the transmitting and receiving antennas as G_t and G_r (in dB), respectively, were essentially the same as if the antennas were in free space; and (2) the path antenna gain (G_p--see Ref. 27) is equal to the sum of G_t and G_r.

calculations of antenna efficiency--calculations that are difficult to make when the antennas are near the ground (or vegetation). Consequently, neither L nor L_b is particularly an attractive choice for describing the results of VHF measurements in forests in a rigorous manner. The propagation loss (L_p) requires the same measurements as L_s, plus the calculation of the radiation resistance of the transmitting and receiving antennas in free space, but these calculations are relatively simple. Hence the choice is narrowed to L_s or L_p. Since L_s relies only on quantities that can be measured in the field, it is our choice:

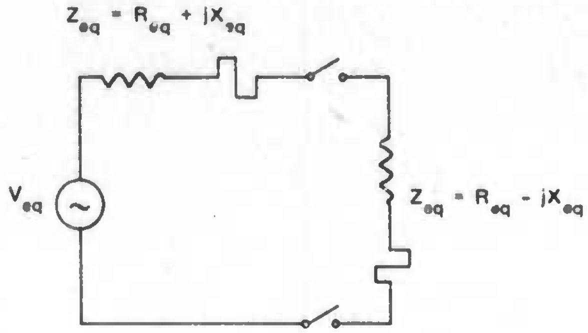
$$L_s \stackrel{\Delta}{=} 10 \log_{10} \frac{p_t}{p_a} \quad .$$

Conversion of L_s for the MPX system to L_s for other systems (e.g., systems using half-wave dipoles) and to other definitions of loss (e.g., L_b) is discussed later in this appendix.

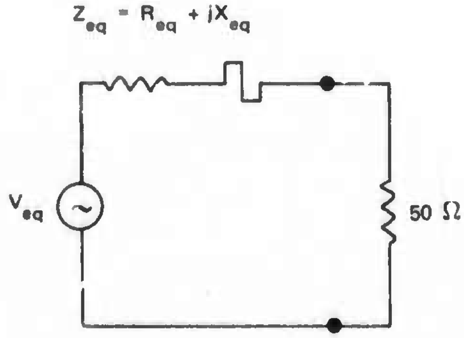
2. Power Input to Xeledop Antenna Terminals (p_t)

First, consider the input power to the Xeledop antenna, (p_t), and the variation of this power as the Xeledop is carried down the trail. This is most easily accomplished by determining an equivalent circuit for the Xeledop transmitter and by measuring the variation of the Xeledop antenna impedance as the Xeledop is placed in proximity to the carrier, trees, and so on.

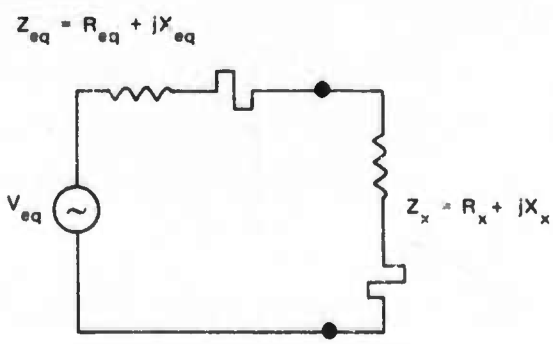
Thevenin equivalents [see Figure A-1 (a)] of the Xeledop oscillators were determined by the conjugate-match technique. A variable impedance load was placed across the oscillator (pi network) output terminals, and the power into the load was measured as the load impedance was varied in a systematic manner. The load impedance that drew the most power from the source was the complex conjugate of the equivalent source



(a) CIRCUIT USED TO DETERMINE THEVENIN EQUIVALENT IMPEDANCE (Z_{eq})



(b) CIRCUIT USED TO DETERMINE THEVENIN EQUIVALENT VOLTAGE (V_{eq})



(c) CIRCUIT USED TO CALCULATE POWER INTO XELEDOP TRANSMITTER TERMINALS (p_t)

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FIGURE A-1 VHF XELEDOP EQUIVALENT CIRCUITS impedance (Z_{eq}). Then the equivalent voltage source (V_{eq}) was determined by solving the source-load circuit of Figure A-1 (b) when a known power was delivered to a known load (50 ohms) from a source of known impedance. The results of these tests are given in Table A-1.

The power delivered by the Xeledop oscillators to a 50-ohm load was checked many times during the various field measurement programs to make sure the output remained constant. During these measurements there was less than 1 dB of variation. For example, the power of the 75-MHz oscillator varied from 0.31 to 0.37 W, and the average of 160 readings was 0.35 W (-4.6 dBW). To make sure that the power did not change substantially during daily usage, the unit was permitted to run continuously for 8 hours during a special test. There was less than 1-dB variation in output power on each of the three measurement frequencies during that test period.

In practice, the Xeledop oscillators drive the antenna through a matching/multicoupler network. For convenience, we chose to define this circuitry as part of the antenna, and losses in this circuitry have the effect of decreasing the antenna efficiency. The impedance (Z_x) looking into the Xeledop matching network [i.e., looking into the antenna terminals--see Figure A-1(c)] was measured with the Xeledop oriented vertically and horizontally in several locations at about 5 feet above ground: on a man's back in the open, on a man's back in proximity to a tree, in the open without a man, and near a tree without a man. The results of these measurements, some of which are summarized in Tables A-1 and A-6 permit the calculation of p_t, the power into the Xeledop antenna terminals.

First let us compute p_t for the case of the Xeledop on the man's back in the open by solving the circuit of Figure A-1(c). These results are also summarized in Table A-1. Computations for the other conditions will be discussed in the Section 6 of this appendix.

Table A-1

THEVENIN EQUIVALENTS OF XELEDOP OSCILLATORS AND ANTENNA INPUT IMPEDANCE AND POWER

Frequency (MHz)	Z_{eq} (ohms)	V_{eq} (V rms)	Z_x (ohms)		P_t (watts)		P_t (dBW)	
			Vertical Polarization	Horizontal Polarization	Vertical	Horizontal	Vertical	Horizontal
50.0	57.8 - j6.5	9.05	16.5 + j1.0	15.0 + j1.0	0.24	0.23	-6.2	-6.4
75.1	50.5 - j1.9	8.41	31.0 + j6.0	24.5 + j6.0	0.33	0.31	-4.8	-5.1
100.0	53.5 - j19.5	9.20	22.5 - j17.5	18.5 - j14.5	0.27	0.25	-5.7	-6.0

3. Power Available from Receiving Antenna Terminals

The power available from the receiving antenna terminals (p_a) is the power that would be delivered to a conjugate-matched load. Consider the equivalent circuit of Figure A-2 (a). With a conjugate-matched load attached to the terminals of this Thevenin equivalent of the receiving antenna, the available power is given by:

$$p_a = \frac{(v_a)^2}{4R_a} \quad .$$

We must, of course, add a load to the antenna to measure v_a, and for this we chose 50 ohms.* The value of $X_a \approx 0$ because the receiving antennas were adjusted to half-wave resonance (when horizontally polarized in the delta), and they remained essentially resonant when used vertically polarized at the Bangkok (open delta) site and when used for both polarizations with the same element lengths at the other sites.[16] Consequently, the received signal--the voltage across the 50-ohm "receiver terminal" (v_t, as reported in Refs. 16 and 17)--is related to p_a:

$$p_a \simeq \frac{v_t^2 (R_a + 50)^2}{R_a} \times 10^{-4} \quad \text{(in watts)} \quad ,$$

when v_t is in volts (rms) and R_a is in ohms.

Values of R_a for the receiving antennas as measured at the various sites are summarized in Appendix B.

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*The receiver input was padded with a 50-ohm series attenuator. This simplified the calibration, but reduced somewhat the sensitivity of the receiver and hence reduced the maximum range of measurement possible with the MPX system.

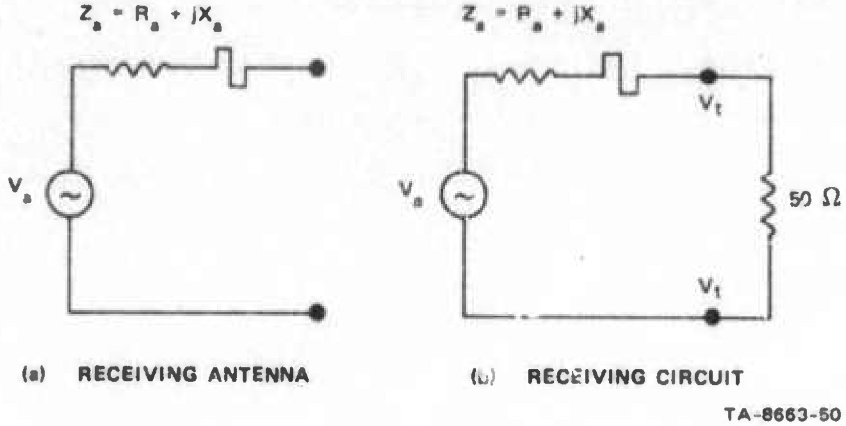

FIGURE A-2 EQUIVALENT CIRCUITS USED TO DETERMINE POWER AVAILABLE FROM XELEDOP RECEIVING TERMINALS (p_a)

4. Conversion Factors to Convert MPX Received Signal Values to MPX System Loss

Using the just-derived expression for p_a, we can rewrite the defining L_s equation in terms of the received signal v_t volts and other measurable quantities so that the MPX system loss is

$$L_s \cong 10 \log_{10} \left[\frac{p_t R_a}{v_t^2 (R_a + 50)^2} \times 10^4 \right] - L_c$$

where L_c equals insertion loss of transmission line for receiving antennas in dB.

Using p_t = 5.6 dBW ± 0.8 dB (from Table A-1), we can rewrite the above equation for both polarizations and all three frequencies as

$$L_s \cong 34.4 + 10 \log_{10} \left[\frac{R_a}{v_t^2 (R_a + 50)^2} \right] - L_c \text{ dB.}$$

The received signal v_t is given in dB above a reference value v_o. That is,

$$V_t \stackrel{\Delta}{=} 20 \log_{10}\left[\frac{v_t}{v_o}\right] \quad \text{dB},$$

so that the system loss equation becomes

$$L_s = 34.4 - V_t + 10 \log_{10}\left[\frac{R_a}{(R_a + 50)^2}\right] - 20 \log_{10} v_o - L_c \quad .$$

Consider a range of antenna resistances between R_a = 35 ohms and 75 ohms for horizontal polarization and between 100 ohms and 235 ohms for vertical polarization (Table B-1 in Appendix B). Hence, for all frequencies and both polarizations,

$$L_s \cong 10 - V_t - L_c - 20 \log v_o \quad \text{dB}.$$

Unfortunately, the same reference value, v_o, was not used at all the sites (0.6 μV at the sites of Ref. 16, 0.71 μV for the data of Ref. 17 and for the Chumphon data in this report, and 2 μV for Ban Mun Chit data in this report); thus, the final term of the equation is 124 dB, 123 dB, and 114 dB for v_o = 0.6, 0.71, and 2 μV, respectively. L_s is obtained by subtracting the received signal (V_t) from a calibration constant. This constant is given in Table A-2 (to within about ± 3 dB) for all MPX data. The stated accuracy reflects uncertainties in Xeledop input power, antenna impedance, effects of the man carrying the MPX, and in scaling the data.

The formula developed in this section allows a simple conversion of the MPX data previously published in terms of V_t into terms of system loss, L_s. The next section shows how this may be carried further to obtain a factor to convert the data to system loss for a manpack system using half-wave dipoles.

Table A-2

CONVERSION FACTOR FROM WHICH V_t IS SUBTRACTED TO OBTAIN L_s FOR MPX

Source Report	Data	v_o (μV)	Conversion Factor (dB)
Special Technical Report 26 (Ref. 16)	All data	0.6	$134 - L_c$*
Special Technical Report 36 (Ref. 17)	All data	0.71	$133 - L_c$
Special Technical Report 46†	Chumphon data	0.71	$133 - L_c$
Special Technical Report 46†	BMC data	2.0	$124 - L_c$

*$L_c = 0$ for Ref. 16.

†This report.

5. Relationship Between System Loss for the MPX System and Other Parameters

a. System Loss for Manpack System Using Half-Wave Dipoles

1) Introductory Remarks

The MPX system used matching circuits and multicouplers to transmit simultaneously on three frequencies. This arrangement greatly expedited data acquisition and permitted the use of a transmitting system that was easy to mount on a backpack in both horizontal and vertical configurations; however, it had the drawback that the system was not as efficient on any given frequency as it would have been had half-wave resonant antennas been employed. Consequently, it seemed desirable to determine by measurement the difference in efficiency between the MPX system and a system operated with relatively efficient half-wave resonant antennas under the same field conditions. Such a measurement was made at four sites using the method of direct substitution.

2) Method of Approach

The Xeledop was suspended from a wooden tower in an open area with the standard MPX receiving terminal (antennas at 10 feet above ground, and so on) set up far enough away so that the separation distance was much greater than the sum of the antenna heights. The received power level was noted, and then the Xeledop was replaced by a half-wave dipole driven by a signal generator whose output was adjusted to give the same received power (see Figure A-3, which shows the measurement setup). For this situation, $p_t g_t = p_s g_s$, where p represents the power into the antenna terminals in watts and g represents the gain of the antennas relative to an isotropic radiator. Subscripts t and s refer to the Xeledop and the standard (half-wave) antenna, respectively. The power into the standard antenna was monitored with an in-line wattmeter and was corrected for cable and mismatch losses. Let us define a calibration constant:

$$x = \frac{p_t g_t}{g_s} ,$$

which is the measured value of p_s in watts. The calibration constant can also be expressed in dB:

$$X = P_t + G_t - G_s ,$$

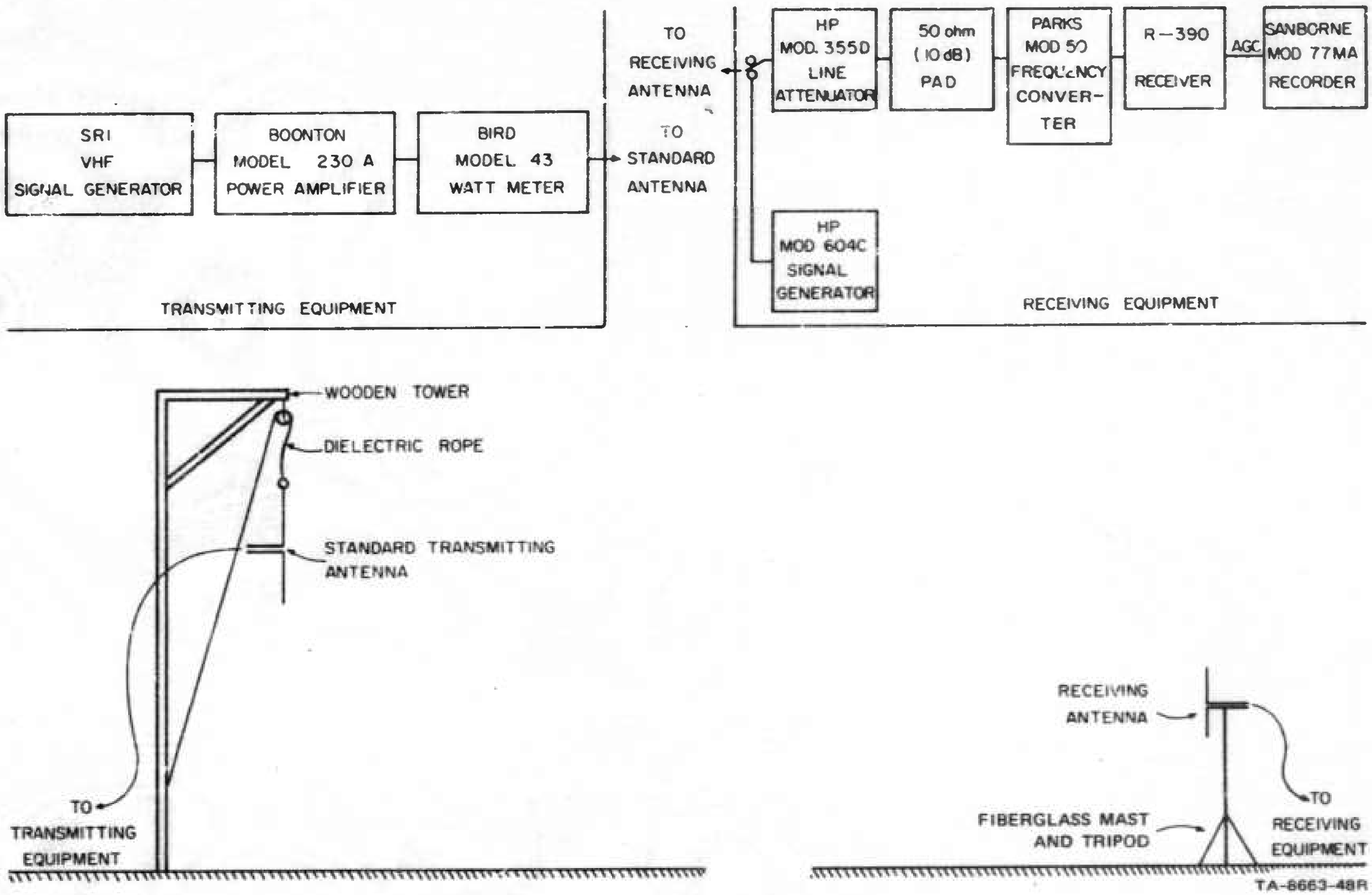

FIGURE A-3 SKETCH OF XELEDOP CALIBRATION SETUP in dBW. The substitution test then consisted of measuring X at each of the different sites.

3) Results

The above calibration test procedure was repeated for three widely different terrains with a terminal separation of R = 1791 feet (approximately 100 times the sum of the two antenna heights), using both horizontal and vertical polarizations at the normal operating frequencies of 50, 75, and 100 MHz. These sites were at Bangkok in an open area of rice paddy or river delta land; at Chantaburi, in a relatively dry open area; and at Laem Chabang, where a smooth but poorly conducting open beach was used. In addition the calibration experiment was performed in a large flooded clearing at the Chumphon field site, with R = 950.4 feet (ground conductivity was very good). The procedure was also tried with the transmitters in the forest at Chumphon. These results show how a forest environment might affect the calibration. Three transmitting heights were used; 5, 10, and 20 feet; the receiving antenna terminals were always at 10 feet. Several redundant measurements were made at each calibration site, and usually the results were within ± 1 dB.

The results of the Xeledop calibrations are given in Figure A-4. These data are presented in terms of the calibration constant X for each test combination measured. The results of an error analysis show the measurements of the Xeledop calibration constant to be accurate to within ± 1.5 dB.

Examination of Figure A-4 shows the data for all test combinations on a particular frequency to be rather closely grouped--even when we include the results of calibration in the Chumphon forest.

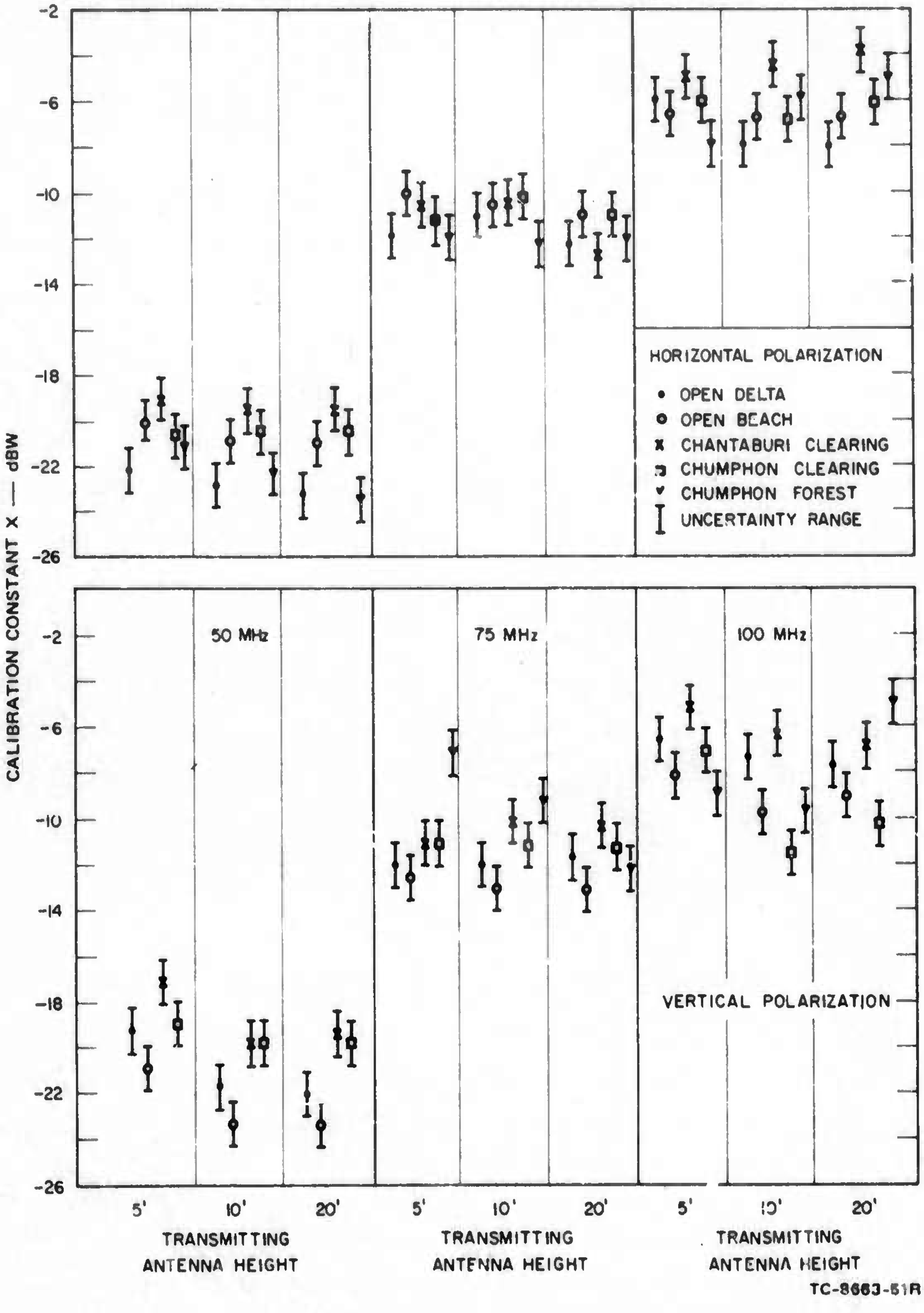

FIGURE A-4 XELEDOP TRANSMITTING SYSTEM CALIBRATION CONSTANTS

We also plotted the distribution of these data in dB on Gaussian probability paper (see Figure A-5). These plots show the data for X to be approximately log-normally distributed. Estimated values for the sample median of X and for the sample standard deviation are given in Table A-3.

Table A-3

MEDIANS AND STANDARD DEVIATIONS OF X

Frequency (MHz)	Sample Median (dBW)	Sample Standard Deviation (dB)
50	-20.8	1.8
75.1	-11.1	1.3
100	- 6.6	1.8

Note that the calibration factor X was determined with both the Xeledop and the standard antennas freely suspended rather than in the backpack configuration. Assuming that P_t does not vary significantly when the Xeledop is mounted in the manpack configuration and that G_t and G_s undergo about the same change when on the pack (see Section 6, below), we can use the data for Table A-1 to compute E, the difference in gain between the MPX antenna (with matching- and coupling-network losses charged against MPX antenna gain) and the relatively efficient half-wave dipoles. That is,

$$G_s - G_t = P_t - X = E \quad ,$$

where the gain difference, E, is the constant that must be subtracted from the system loss values for the MPX system to obtain the system loss values corresponding to a manpack system employing half-wave

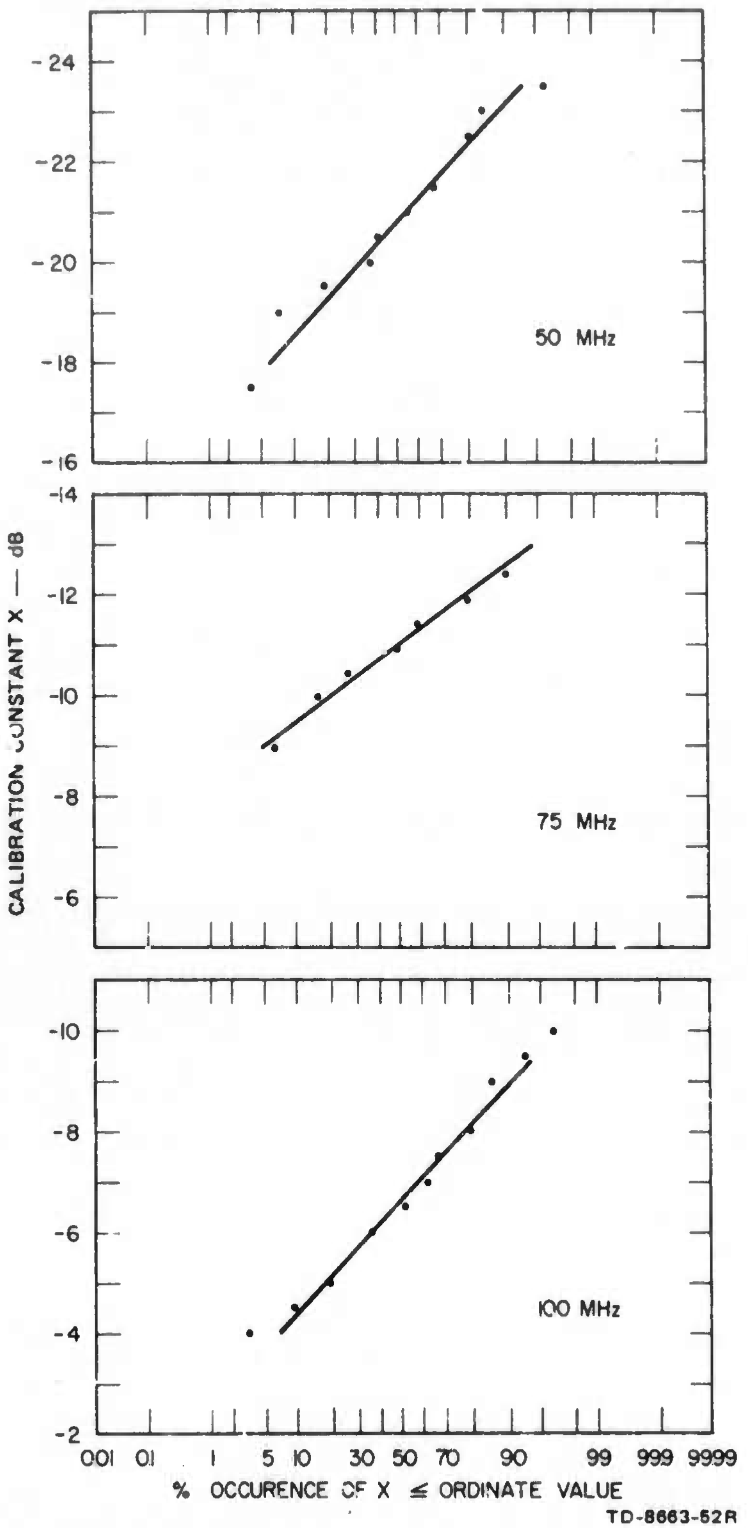

FIGURE A-5 DISTRIBUTIONS OF XELEDOP CALIBRATION CONSTANTS resonant dipoles. To within about ± 3 dB, the values of E* for all four sites and both polarizations are 15, 6, and 1 dB† for 50, 75, and 100 MHz, respectively.

Figure A-6 shows how the MPX system received signal, as reported on in the two previous reports [16,17] may be transformed to MPX system loss and to system loss for manpack systems using half-wave dipoles. Most of the data of this report have already been transformed to L_s for an equivalent half-wave dipole system. To compare the results with those of Jansky and Bailey,[7-10] it is necessary to estimate L_b. This is accomplished by adding 4.3 dB to the appropriate L_s value for the equivalent half-wave dipole system.‡ Higher accuracy than that stated in Figure A-6 can be achieved by using the calibration for each actual case of interest.

b. Relationship Between Manpack Xeledop (MPX) and Balloon-Borne Xeledop (BBX)

A lightweight copy of the manpack Xeledop (MPX) called the balloon-borne Xeledop (BBX) was constructed for height-gain tests at Chumphon. The BBX oscillators delivered 0.23 W to a 50-ohm load at 50 MHz and 0.37 W at 75 and 100 MHz, whereas the MPX delivered an average of 0.35 W at these frequencies. The radiated power of the BBX

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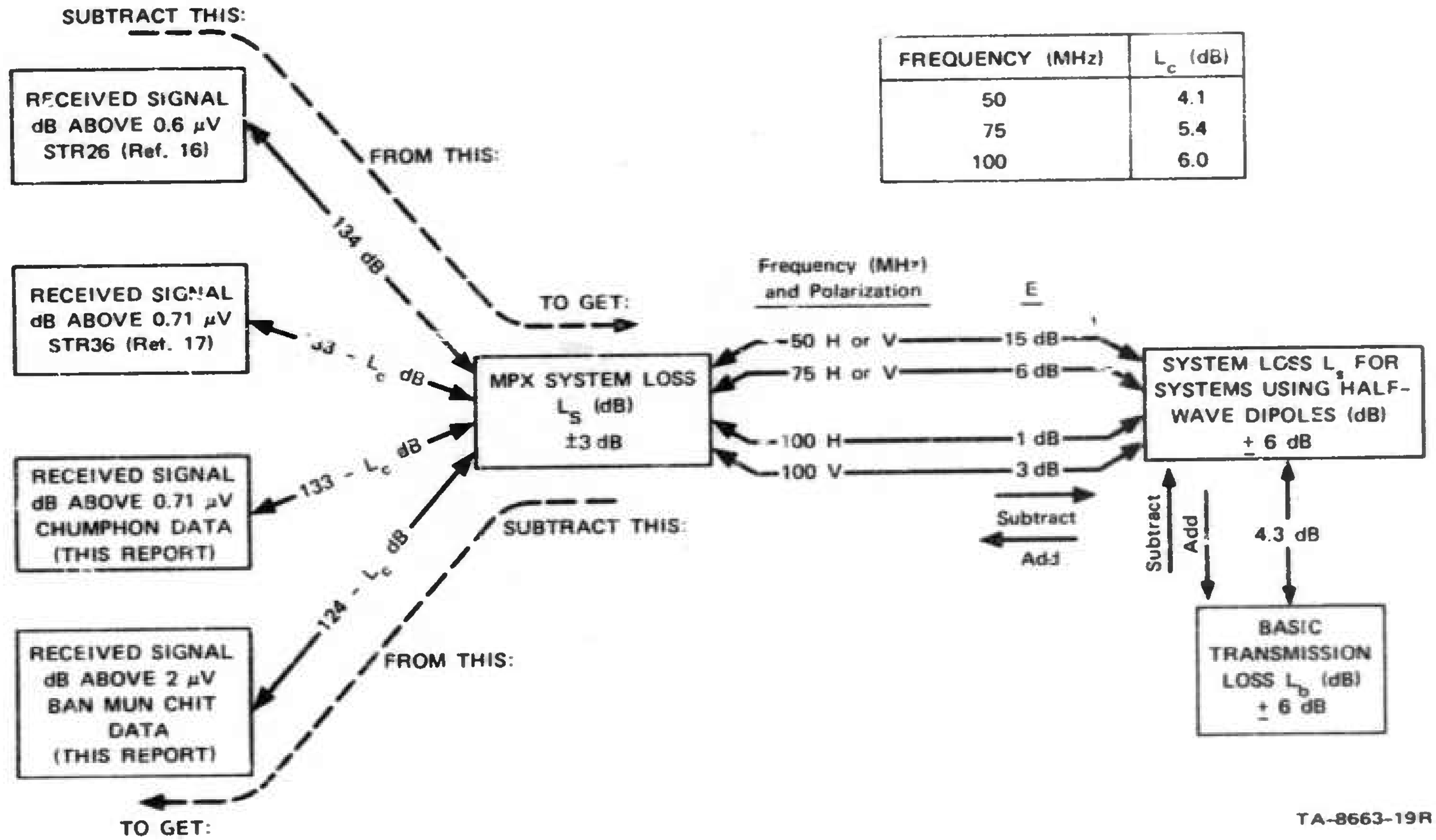
*Notice that E contains the effect of both matching and coupling circuit losses and the loss of effective length of the MPX antenna on the two lower frequencies (recall that the MPX antenna is essentially half-wave resonant at 100 MHz).

†For 100 MHz and vertical polarization, an E value of 3 dB is required to satisfy the ± 3-dB criterion.

‡Twice the free-space gain of a half-wave dipole (2.15 dB) is added to convert from dipoles to isotropic antennas.



FREQUENCY (MHz)	L_c (dB)
50	4.1
75	5.4
100	6.0

FIGURE A-6 CONVERSION OF RECEIVED SIGNAL TO SYSTEM LOSS (L_s) FOR MPX, SYSTEM LOSS (L_s) FOR HALF-WAVE DIPOLE SYSTEMS, AND BASIC TRANSMISSION LOSS (L_b)

was compared to that of the MPX at three different heights above ground at the open delta site near Bangkok. The received signal levels (in dB relative to an arbitrary reference on each frequency) are summarized in Tables A-4 and A-5. The results of this comparison (BBX minus MPX--see Table A-5) are accurate to better than ± 1dB.

Table A-4

DIFFERENCE BETWEEN RADIATED POWER OF BBX AND MPX

Height (feet)	Polarization	Difference at 50 MHz (dB)	Difference at 75 MHz (dB)	Difference at 100 MHz (dB)
5	Horizontal	1.5	4.5	1.0
	Vertical	-4.0	2.0	0.0
10	Horizontal	0.5	4.0	1.5
	Vertical	-2.0	3.0	0.0
13	Horizontal	1.0	3.5	1.5
	Vertical	-1.6	3.0	0.0

To a good approximation, the total radiated power of the BBX (in dBW) can be estimated by using the values of X, the MPX calibration factor obtained at the greater heights (10 and 20 feet used in the delta). The approximate radiated power of the BBX is -22.5 dBW at 50 MHz, -8.4 dBW at 75 MHz, and -7.0 dBW at 100 MHz. The maximum effective radiated power (in the plane orthogonal to the radiating elements that pass through the center of the BBX (i.e., in the direction of maximum gain) is greater than the values stated by about +2 dB (directivity factor).

Table A-5

RECEIVED SIGNAL LEVELS DURING
MPX AND BBX COMPARISON TEST

Polarization	Transmitter	Frequency (MHz)	Received Signal in Decibels at 5 ft	10 ft	13 ft
Horizontal	MPX	50	8.5	14.5	16.5
	BBX	50	10.0	15.0	17.5
	MPX	75	20.5	26.5	28.0
	BBX	75	25.0	30.5	32.5
	MPX	100	12.0	17.0	18.5
	BBX	100	13.0	18.5	20.0
Vertical	MPX	50	22.0	21.5	20.1
	BBX	50	18.0	18.5	18.5
	MPX	75	18.0	18.5	20.0
	BBX	75	20.0	21.5	23.0
	MPX	100	15.0	18.0	20.0
	BBX	100	15.0	18.0	20.0

6. Discussion of Errors

a. Effect of Man

1) Power into Xeledop Antenna Terminals

The power into the Xeledop antenna terminals was computed in Section 2 for the case of the Xeledop on a man's back. These computations were made using a Thevenin equivalent of the Xeledop transmitter and antenna impedances measured in the open delta. The antenna impedances also were measured with the Xeledop in the same position but without the man. The results are summarized in Table A-6. The change in p_t that occurred was negligible (less than 1 dB). Notice the change in the imaginary part of the impedances with the man present. If we consider that the man and Xeledop act as a 2-element Yagi array (the Xeledop is the driven element and the man is the parasitic element),

Table A-6

SUMMARY OF MEASURED INPUT IMPEDANCES OF THE XELEDOP ANTENNA

Polarization	Frequency (MHz)	Impedance, Z (ohms)	
		Without Man	With Man
Horizontal	50	13.5 - j1.0	15.0 + j1.0
	75	24.0 + j6.5	24.5 + j6.0
	100	23.5 - j8.5	18.5 - j14.5
Vertical	50	15.0 - j1.0	16.5 + j1.0
	75	24.5 + j10	31.0 - j6.0
	100	27.5 - j14.5	22.5 - j17.5

these data imply that the man acts as a lossy director at 50 MHz and as a lossy reflector at 75 and 100 MHz.

2) <u>Radiated Field</u>

Even though the effect of the man on the power into the Xeledop antenna terminals is negligible, it is possible that the man does have a significant effect on the effective power radiated by the Xeledop. An experiment was performed in the open delta to check this possibility. The Xeledop was suspended at manpack height from a dry wooden test stand, and the level of the received signal was noted in the far field. Next, the man stood at this location facing the receiving terminal (man toward) with the Xeledop on his back and the change in level was noted. Finally, the man stood facing away from the receiving terminal (man away) and again the level was noted. Table A-7 summarizes the changes (decreases) observed in the received signal for each man-Xeledop configuration.

The ranges of decrease were obtained during separate tests with different men carrying the Xeledop. As implied by the impedance data, the man-antenna combination acts like a 2-element Yagi with the man acting like a lossy director at 50 MHz and as a lossy reflector at 100 MHz. The data imply that the man was half-wave resonant at a frequency just below 75 MHz. These results are in general agreement with the findings of Krupka.[30]

Table A-7

LOSS IN MPX EFFECTIVE RADIATED POWER
WHEN CARRIED ON THE BACK

Polarization	Frequency (MHz)	Loss with Man toward Terminal (dB)	Loss with Man away from Terminal (dB)
Horizontal	50	1	1
	75	2	2
	100	1	1
Vertical	50	2 to 3	4 to 6
	75	5 to 7	5 to 6
	100	1 to 3	3

No distinction was made in the direction the man was walking for the data reported in Ref. 16 or in this report; however, the data in Ref. 17 and most of the data in this report were obtained with the man walking away from the Xeledop receiving terminal.

b. Effect of Trees

1) Power into Xeledop Antenna Terminals

The effects of a single tree on the driving-point impedance of half-wave dipoles have been studied on this contract.[31] The effect of the vertical tree trunk has been observed to be negligible when the dipole is horizontally polarized but significant effects occur for vertically polarized dipoles.[11,25,32] Even for this case, however, the change in input power from a 50-ohm source would be only about 1 dB. The impedance variations with the MPX were observed to be similar to, but only about 10 to 25 percent of, the variations of the half-wave dipole. Evidently the MPX terminals impedance changes were masked by the matching and coupling circuits. At any rate, proximity to a tree did not cause significant changes in p_t for the manner in which the Xeledop was employed.

2) Radiated Field

The changes in the effective radiated field of the MPX as it is carried closely past a single tree were studied in Ref. 31. The changes when the MPX is carried along a forest trail were assumed (for the purposes of this report) to be part of the propagation effect.

c. Calibration and Scaling

The receiver calibration was accurate to within ± 1 dB. On several occasions the same record was scaled by different personnel, and the results (for the median) were within ± 1.5 dB for all frequencies and range intervals. Finally, data were obtained at the same site on different days, and repeatability was surprisingly good. The scaled results were within 2 dB more than 90 percent of the time, and this included data obtained at the forest sites.

Appendix B

MEASURED IMPEDANCE SUMMARY

Appendix B

MEASURED IMPEDANCE SUMMARY

The input impedance was measured for each antenna location, polarization, and type. Two pieces of equipment were used for this. At Ban Mun Chit, the impedances were measured using an Alford automatic Smith-Chart Impedance Plotter, and at Chumphon the equipment was a Dielectric Products Co. Smith-Chart Impedance Plotter. Table B-1 summarizes the measured results for the antennas used in obtaining the system loss of Section V-A. All antenna heights were 10 ft.

Table B-2 lists measured impedances for the standard antennas used during Xeledop calibration and gain measurements.

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Table B-1

MEASURED IMPEDANCES OF MANPACK XELEDOP RECEIVING ANTENNAS

Antenna Type	Polarization	Location	Frequency (MHz)	Site: Impedance at Ban Mun Chit (ohms)	Site: Impedance at Chumphon (ohms)
Vertical sleeve dipole	Vertical	Clearing	50	150 - j1.7	185 + j70
			75	180 + j250	235 - j50
			100	130 + j90	225 - j30
		Forest	50	100 + j120	220 + j105
			75	100 + j150	185 - j40
			100	135 + j150	140 + j80
Unbalanced half-wave dipole	Horizontal	Clearing	50	50 + j15	61.5 - j1
			75	45 + j30	78.5 + j17.5
			100	35 + j20	66 + j15
		Forest	50	60 + j10	62.5 - j2.5
			75	50 + j40	75 + j15
			100	40 + j20	60 + j15
	Vertical	Clearing	50	No data	71 + j0
			75	No data	74.5 + j0
			100	No data	65 - j0.5
		Forest	50	No data	70 + j1
			75	No data	89 + j0
			100	No data	70.5 + j0
Balanced half-wave dipole	Horizontal	Clearing	50	No data	37 - j1
			75	No data	65.5 - j1
			100	No data	86 + j0
		Forest	50	No data	37.5 - j5
			75	70 - j20	69 - j1
			100	40 - j5	81 - j0
	Vertical	Clearing	50	No data	42.5 + j0
			75	No data	68.5 + j1
			100	No data	86 + j0
		Forest	50	No data	45.5 - j1
			75	No data	69 + j0
			100	37.5 - j12.5	85 + j1

Table B-2

STANDARD ANTENNA IMPEDANCES*

(Measured During Xeledop Calibration and Gain Measurements)

Polarization	Frequency (MHz)	Impedance on Open Paddy (Bangkok) (ohms)	Impedance on Open Beach (Laem Chabang) (ohms)	Impedance on Dry, Open Area (Chantaburi) (ohms)	Impedance on Flooded Clearing (Chumphon) (ohms)
Vertical	50	69 + j1	73 + j0.5	73.5 - j0.5	75 + j0
	75	72.5 + j0	72 - j0.5	70.5 + j0.5	71 - j1
	100	72 + j0	66 - j0	66 + j0.5	65 + j1
Horizontal	50	60 + j0	64 - j1	63.5 - j0.5	64.5 - j0.5
	75	70 + j0	73.5 + j1	71.5 + j0.5	75.5 + j0
	100	63.5 - j0.5	63 - j0.5	59 + j0.5	58.5 + j0.5

*All impedances were measured in the clearing with antenna feedpoint 10 feet above ground. These data were obtained during the Xeledop calibration tests.

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