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PLRS GROUND-TO-GROUND PROPAGATION MEASUREMENTS

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Radiowave propagation measurements at 420 MHz to 450 MHz were made in the field during October and November 1979, for the purpose of evaluating the performance of a single link of the Army's Position Location and Reporting System (PLRS) over short ground-to-ground communication paths obstructed by foliage and terrain. Tests were conducted under a variety of conditions set by variables that included antenna height, path length, foliage situation, terrain-obstacle height, and frequency channel.

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Message throughputs of 50 percent o' greater were achieved over most forested paths up to 2 km long, and over m. . simple diffraction paths up to 2.3 km long. However, PLRS failed to communicate on a medium-density, 800-m long foliage path with low antenna heights, and on a 300-m long terrain obstacle path. For simple foliage-obstructed paths, excess path loss (EPL) at antenna heights above undergrowth was found to correlate well with measurable tree-trunk density. EPL was measured to decrease with increasing antenna height in almost all cases.

Round-trip errors in ranging (TOA) measurement over the single link reached values as great as 10 percent on most foliage paths. For 88 percent of the seventeen propagation paths over simple terrain obstacles, range errors were less than 5 percent; however, in two cases these errors, caused by multipath, reached values of 22 percent and 370 percent.

Experimental results are compared with theoretical models and other foliage-loss field measurements. Extrapolation of measured-path-loss data are used to determine maximum communications range for a single PLRS link operating in forested environments.

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CONTENTS

ILLUSTRATIONS

TABLES

I INTRODUCTION

During October and November 1979, radiowave propagation measurements were made in the field using a military digital communication system called Position Location Reporting System (PLRS). The purpose of the measurements was to evaluate experimentally the capability of the PLRS equipment and signal structure to communicate over short paths, obstructed by foliage and terrain. A PLRS terminal was installed in each of two vans along with the necessary support and test equipment, antennas, and towers. The vans were located at a variety of sites in and around Eglin AFB, Florida and Arnold AFS, Tennessee to conduct propagation measurements.

Hughes Aircraft Company outfitted the vans with electronic equipment and carried out the propagation measurements in the field. SRI International planned the tests, observed the field operations, and made an independent reduction and analysis of the data collected during the field operation.

Path-loss measurements were made by measuring PLRS link margin. That is, for each path measurement, attenuation in front of the receiver was increased until the message throughput rate (MTR) reached a value of 50 percent. Dependent variables recorded were attenuator setting (AS), MTR, and time of arrival (TOA) range.

Path-loss measurements were made under a variety of conditions set by independent variables, which included antenna height, path length, foliage situation, obstacle height, and frequency channel. During the field operation 187 measurements were made over 78 different paths at 9 sites.

Path-loss and ranging (TOA) measurements were made over a single path at one time. Hence the measurements do not directly predict overall PLRS performance of a network of hundreds of PLRS units deployed in a tactical situation. The data results are more appropriate for use as inputs for a network model based on single paths.

II SYSTEM DESCRIPTION

A. PLRS Terminals

PLRS is a digital position location system operating in the UHF band and is designed for use in a tactical situation. The system uses a synchronized spread spectrum (short-pulse) waveform for communications in one of eight frequency channels in the 420 MHz to 450 MHz band. In normal operation successive transmissions are hopped among the channels. The system operates with many units in the network at one time using time division multiple access (TDMA). The transmitted bursts are spread to a 3-dB bandwidth of 3 MHz by modulation with a pseudonoise code sequence. The transmitter operates at a peak power of approximately 100 W, and the receiver has a nominal sensitivity of -105 dBm.

The PLRS equipment used during the propagation tests consisted of two basic user units (BUU), one installed in the van and the other used outside the van as a "manpack;" two user read out (URO) devices; two selectable power adaptors (SPA); a modified portable test unit (PTU) with associated teletype terminal; and two PLRS manpack antennas. The PTU was installed in one van and the BUU, in the other van. Both terminals were set up to transmit and receive, but path-loss measurements were made in only one direction by the PTU receiving the messages. A complete description of the PLRS system is given by Texas Instruments (1979).

During the test measurements the PLRS equipment did not use the frequency hop capability, but simply stepped sequentially through each of the eight allocated center frequencies (spaced 3 MHz apart) listed in Table 1.

Both hardware and firmware modifications were made to the PTU to meet the requirements of the propagation measurements. These requirements are that the PTU be capable of delivering an RF power output of

Table 1

PLRS FREQUENCY CHANNELS

Channel	Frequency (MHz)
0	425.75
1	428.75
2	431.75
3	434.75
4	437.75
5	440.75
6	443.75
7	446.75

100 W and that the unit have the capability of controlling the received RF signal-power level input to its RF assembly, which contains the receiver. The requirements were satisfied by adding a BUU power amplifier to the PTU and by reconnecting the controllable step attenuator already used by the PTU.

The PTU firmware was modified to allow the PTU to command the BUU to transmit 100 messages for each attenuator setting for each frequency channel. In addition, the PTU firmware was modified to add a routine to format and print the test-data sheet with the test results for each MTR measurement on the teletype terminal.

The PTU firmware also allowed a set of 16 TOA measurements made for each frequency channel. Each TOA measurement was round trip. From the set of 16 the printout listed the high, the low, and the average from which the indicated range was calculated.

Note that this TOA measurement and the following calculated indicated range procedure is not a normal PLRS operation, but was specifically set up for these propagation tests. The normal PLRS network TOA measurement procedure involves multiple locations and a process of multilateration that is much more complicated, but more accurate.

B. Vans and Support Equipment

The vans are Dodge CB400 commercial units with a maximum gross weight of 11,500 lbs. The vans have been modified with insulation, air conditioning, windows, and lighting. Cabinets, benches, and shelving has been added to provide storage and mounting space for the electronic equipment.

The power subsystem consists of a power distribution panel and two gasoline-engine-driven, 7-kW, 60-Hz generators. The generators are mounted in sound-proofed boxes aft of the wheel wells. Access is provided externally by removable hatch covers. 400-Hz power (not used by PLRS equipment) is provided by a 400/60-Hz rotary converter in each van.

In addition to the PLRS equipment, electronic test equipment including an oscilloscope, signal generator, spectrum analyzer, oscilloscope camera, and power meters are mounted on the tie-down shelving above the equipment benches.

A 3-section, telescoping 65-ft antenna tower is carried collapsed horizontally on the roof platform. The tower mount design allows the tower base to be swung to the ground so that the tower can be erected while attached to the van. After adjustments are made for leveling the tower, an antenna mounted on top of the tower can be positioned from 22 ft to 65 ft high by a motorized lift mechanism.

Antenna heights below 22 ft are provided by a tripod placed on the ground, on the van roof platform, or by a short, fixed pipe that is mounted on the van roof. Figure 1 is a photo of one of the vans and its antenna tower.

Voice communications between the two vans were provided by a citizen's band transceiver mounted in each van with an antenna mounted externally on the van. In addition, for backup, Motorola Handitalkies (146 MHz FM) were used in the vans with externally mounted antennas.

FIGURE 1   VAN AND ANTENNA TOWER PHOTOGRAPH

C. Antennas

PLRS uses three different types of antennas in the overall system. All are vertically polarized and omnidirectional in the horizontal plane. The manpack antenna can be used mounted directly on the manpack or mounted on a mast for use by a surface vehicle. The master unit antenna is similar, but with 3 dB more gain (a more narrow beam in the vertical plane). The airborne unit antenna is a blade type mounted on an aircraft surface. Its gain depends on the surface location of the mount. The manpack antenna was used for all foliage-and terrain-obstacle propagation measurements.

The PLRS unit in each van is connected to a vertically polarized manpack antenna, which is a center-fed vertical dipole 1.2-wavelengths long. The PLRS antenna has a gain of 5.6 dB over isotropic averaged over the 420-MHz to 450-MHz band. Figure 2 is a vertical plane pattern taken at 435 MHz. The exact lobe structure and size depends on the frequency and the proximity to a ground plane. The horizontal plane pattern is isotropic.

The PTU and BUU are connected to their respective antennas by flexible coaxial cable and semiflexible, low-loss, foam-dielectric-line 1/2-in. diameter, a total length of about 75 ft. The total cable loss for each van is 1.5 dB to 2.0 dB.

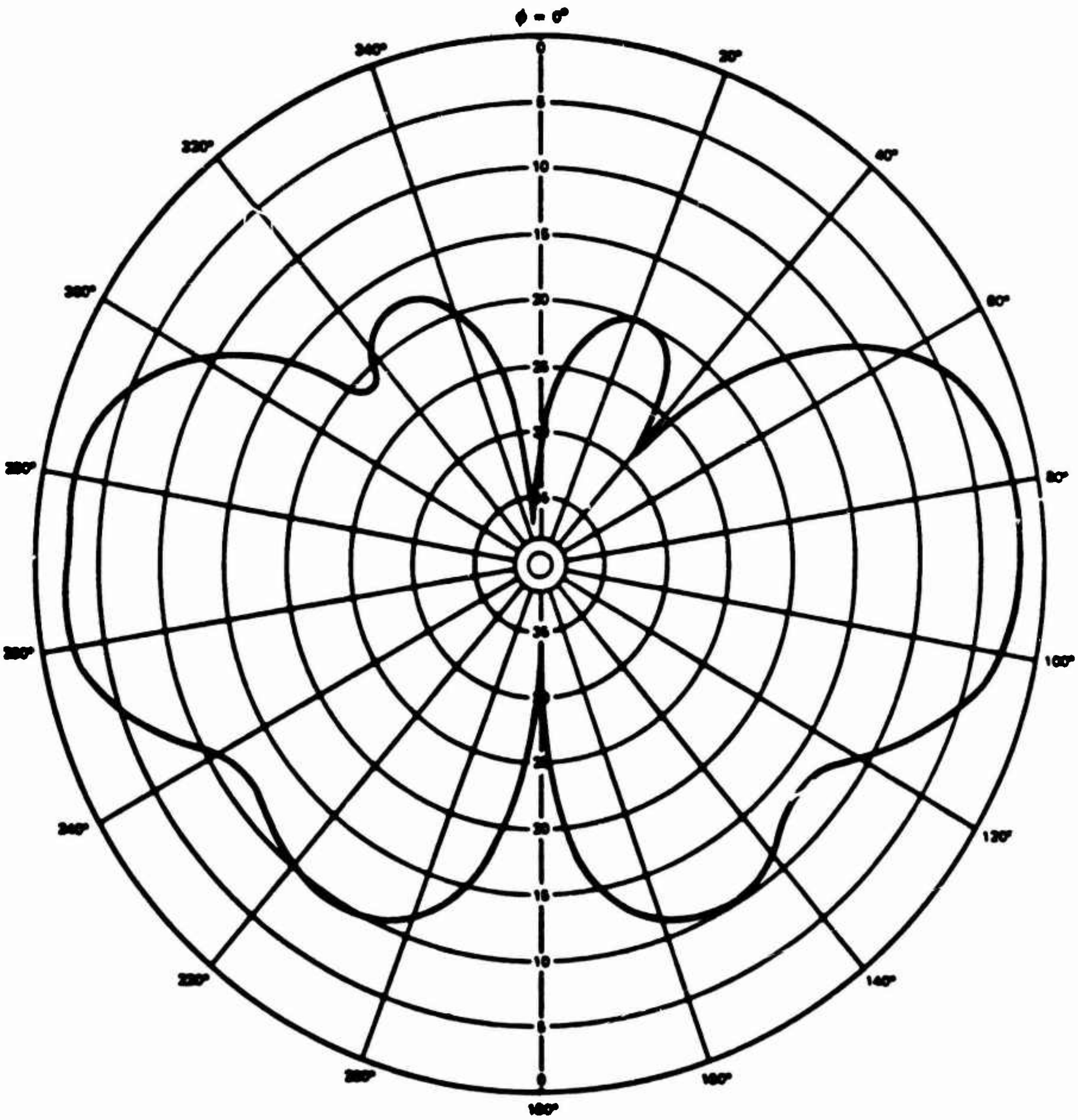

FIGURE 2 ANTENNA PATTERN IN THE VERTICAL PLANE

III SYSTEM CALIBRATION AND OPERATION

Every day of the field measurements operation, the two vans were parked next to each other near the site for the day's measurements. After the electronics in the van were warmed up, the vans were connected by a 40-ft coaxial cable and 60-dB fixed attenuator. The PLRS units were checked out and then synchronized.

Next a start of the test day collocation (STDC) test was performed. The purpose of the STDC test was to verify the system sensitivity, operability, and resetability. This was achieved by carrying out a PLRS Readiness Test, which is a system self-check. A sensitivity check was made by measuring the test system link margin through the coaxial cable and attenuator for each frequency channel. Figure 3 shows a plot of MTR versus AS for three frequency channels for the day, 16 October 1979. The MTR goes from 90 percent to 10 percent with an AS change of about 4 dB. The AS that produces a 50-percent MTR is defined as the test link margin. The BUU power amplifier power output was measured by use of the spectrum analyzer coupled through a directional coupler. An example is shown in Figure 4.

After the STDC test was completed, the vans were moved into position for the first path-loss measurement at spots previously selected. The antennas were raised into position by the three-section tower and path measurements made. Figure 5 is a copy of a data printout from the PTU terminal for a path measurement made during the day, 22 October 1979. The data of primary interest is listed following "TIME" and it includes the indicated average range, TOA high, average, and low for 16 measurements. The TOA units are 12.5 ns and the TOA values includes a large offset that is subtracted during the indicated range computation. The indicated range values must be corrected by subtracting 62 m to correct for cable delays. TOA measurements are made at zero AS. The channel number and the MTR for 100 messages follow for each of eight AS listed

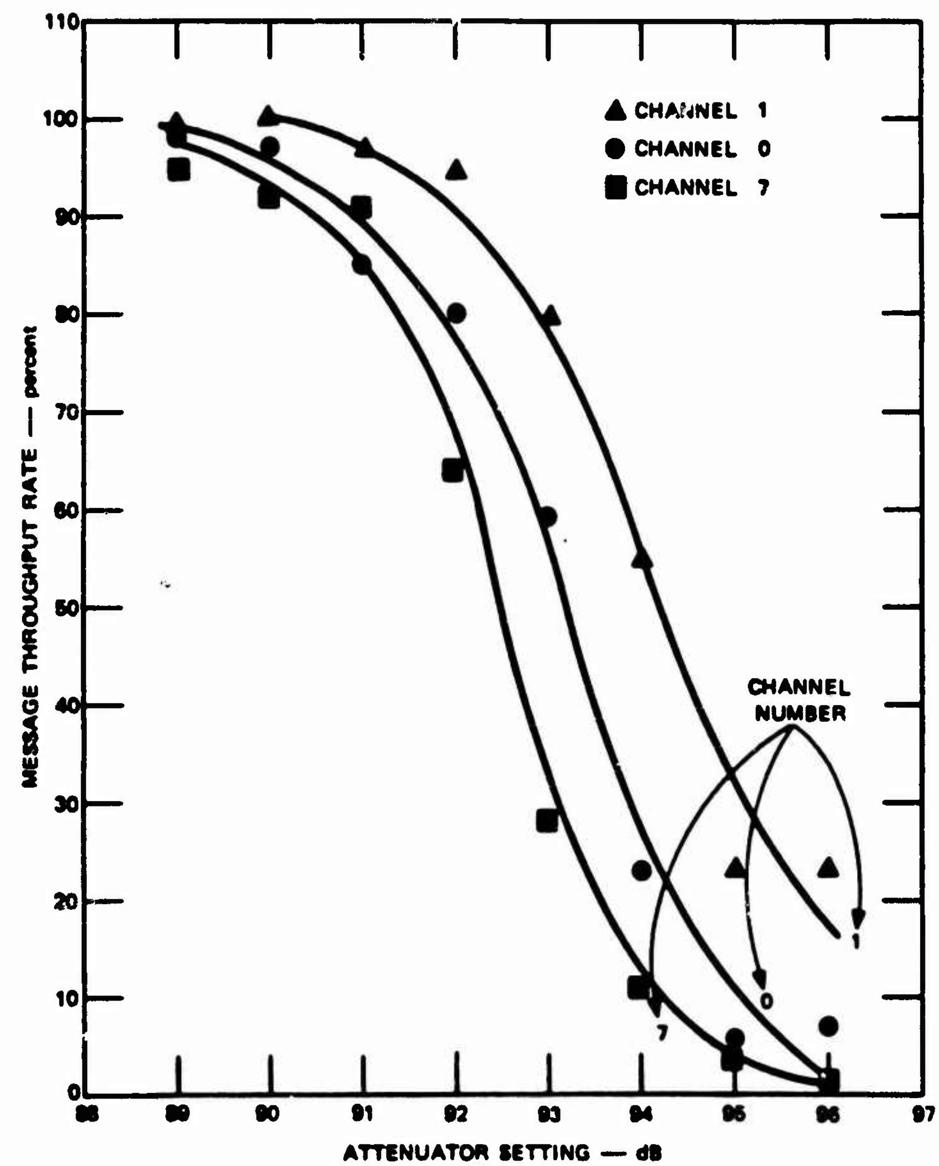

FIGURE 3 PLRS CALIBRATION FOR 16 OCTOBER 1979

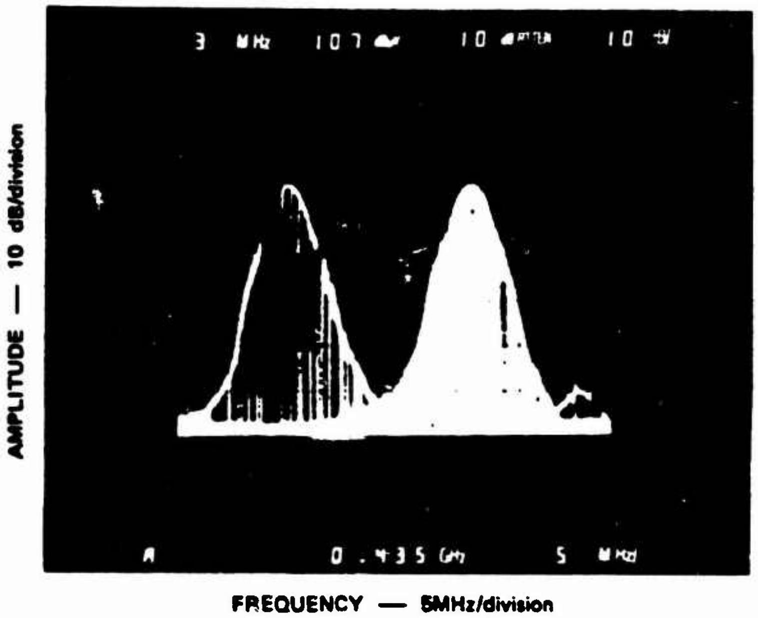

FIGURE 4 BUU POWER AMPLIFIER OUTPUT SPECTRUM FOR TWO CHANNELS

above. All of the above are listed for each of eight frequency channels. In addition to the path loss measured data, temperature, humidity, wind/rain conditions, path length (estimated from a map or physically measured), and location data were recorded.

Path measurements were made at each of several antenna heights. Then one of the vans was moved laterally 10 m and path measurements were repeated at the same set of antenna heights. This procedure allowed for an estimation of the effect of a slight antenna spatial shift on the measured path loss.

```
( PTU IN )
ST  A ,048,02

********************            CHANNEL ALL START = 048  INC = 02   POWER 0


( PTU IN )
FR S7 H1 V35

( BUU OUT)  FR S7 H1 V35

( BUU IN )  FA S7 H1 V35

( BUU OUT)  FA    ROGER

( PTU IN )
EX 8

( TIME    )  22 13 38:23
  RANGE      TOA-HI  TOA-AV  TOA-LO CHAN ATTN= 048 050 052 054 056 058 060 062

  0.017 KM  33,313  33,311  33,310   0  THRU= 099 099 100 100 099 0081024 004  59.2
  0.011 KM  33,310  33,308  33,307   1  THRU= 100 097 100 098 098 0831643 006  59.7
  0.012 KM  33,310  33,308  33,306   2  THRU= 100 099 100 098 099 0851016 001  59.0
  0.012 KM  33,311  33,308  33,307   3  THRU= 100 099 100 099 097 0861036 000  59.4  59.0
  0.012 KM  33,311  33,308  33,306   4  THRU= 099 100 100 099 098 0831033 001  59.3
  0.011 KM  33,310  33,308  33,306   5  THRU= 100 100 099 097 092 0621019 001  58.6
  0.012 KM  33,311  33,309  33,308   6  THRU= 099 096 099 099 091 0571009 000  58.6
  0.008 KM  33,308  33,306  33,304   7  THRU= 098 092 098 098 039 0511004 000  58.0
                                                                                    Tree Top level
********************            TEST # = 11    PTU SITE = D1  PTU ANT = 35'  AT [illegible]
                                           Clear
********************            WEATHER = Light  TEMP =          HUMIDITY =
                                          Breeze
********************            BUU POWER = 0  FOLIAGE = Heavy     A
```

FIGURE 5   PLRS PTU DATA PRINTOUT EXAMPLE

IV DATA REDUCTION AND ANALYSIS

Each set of eight (frequency channels) path measurements or calibration data was reduced to a single average value. First each frequency channel data was interpolated to find the AS that corresponded to a value of 50-percent MTR. Then the average was computed for all eight values. This average AS is the test link margin for the set of independent variables selected for that measurement. Note that operational link margins will exceed the test link margins measured in this field measurement program by 3 dB to 4 dB, the amount of cable loss in the PLRS test set-up.

The fourteen STDC test sensitivity measurements were reviewed first. The mean value was found to be 93.6 dB with a standard deviation of 0.22 dB. The very low standard deviation indicates that the PLRS system amplitude stability over the three-week field operation was more than adequate for the task.

All of the reduced test link margin (AS) data was then grouped by site and path length. All of the path-loss measurements made under free-space or nearly free-space conditions were plotted in Figure 6. The straight line is the calculated path loss as a function of path length. The measured AS data was plotted by normalizing the two data points at 200 m to place them on the calculated path-loss line, which fixed the AS scale with respect to the calculated path-loss scale.

An alternate procedure would be to calculate the path loss from the AS by the following equation:

$$AS\ (\text{link margin}) = P_T - L_T + G_T - L_P + G_R - L_R - R_{TH}$$

where

P_T = Transmit power in dBm

L_T = Cable loss to the transmit antenna in dB

G_T = Transmit antenna gain in dBi

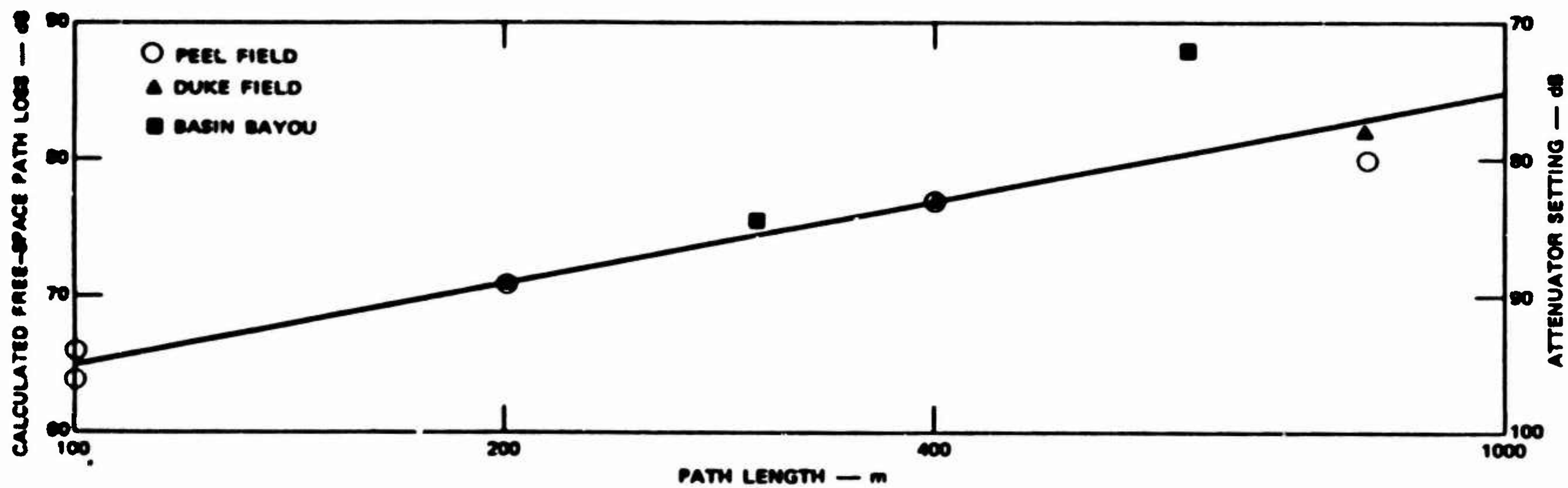

FIGURE 6 FREE SPACE PATH LOSS DATA

L_P = Path loss between antennas in dB

G_R = Receive antenna gain in dBi

L_R = Cable loss to the transmit antenna in dB

R_{TH} = Receiver threshold in dBm

Although perfectly valid, this latter method depends on the accuracy of the antenna gain data. Discrepancy between the two methods is 1 dB and is not significant.

The Peel and Duke Field free-space data was taken with the antenna height 20 ft over the treetops. The Basin Bayou free-space data was taken at maximum antenna height that was over most, but not all the treetops and that resulted in some excess path loss (EPL). EPL is defined as any path loss exceeding line-of-sight, free-space path loss. Once the relationship between free-space path loss and AS is set, the EPL for all path measurements made may be readily calculated. The "negative" EPL data at 800 m apparently results from some constructive interference from the treetops reflection path with the direct path. This apparently is demonstrated only on the long paths where the treetop reflection path is at grazing incidence.

Although the MTR normally goes from 90 percent to 10 percent with a received signal level change of 4 dB, the system cutoff characteristic changes when the propagation path becomes non-line-of-sight. Multipath and phase distortion that are caused by ground foliage and terrain obstacles in turn cause the normal system cutoff characteristics shown in Figure 3 to become stretched-out or distorted. For measurements made where the EPL was 0 dB to 20 dB, the system cutoff was increased 1 dB to 2 dB. Where the EPL was 20 dB to 40 dB, the system cutoff increased 6 dB to 10 dB. In 27 cases out of 187 total or 14 percent, the system was greatly confused by multipath conditions and the system cutoff reached as much as 40 dB or more. Those situations are subject to greatly varying interpretation and their data points have been flagged with the symbol, $ on the tables. The accuracy of EPL values is obviously degraded by the system cutoff stretch out by about 1/2 of the cutoff increase. Thus 86 percent of the EPL values are accurate to ±5 dB or better. The accuracy of the other 14 percent is no better than ±10 dB.

V FIELD MEASUREMENTS

The field measurements were made over a three week period in October and November. The first two weeks were spent at three sites, Peel Field, Duke Field, and Basin Bayou, respectively, on the Eglin AFB reservation. Description of those sites and others in the Eglin AFB reservation are given by Presnell (1979a). The Eglin sites were chosen primarily to allow path measurements over and through ground foliage in a variety of situations, but without significant variations in terrain height.

At the end of the first two weeks the vans were driven to the Arnold AFS area near Tullahoma, Tennessee. The last week was spent making path measurements at a variety of sites described by Presnell (1979b). All but one of the sites near Arnold were selected to provide propagation paths over terrain obstacles.

The following site and data descriptions are listed generally in the order that sites were visited.

A. Peel Field

1. Site Description

The infield of this airstrip is slash pine, planted in 1964, thinned in 1977. It is of medium density with random tree spacing and with light underbrush. The tree-trunk density (basal area) measured about 80 ft^2/acre* and the tree heights measured 32 ft to 40 ft. This site was chosen as suitable for a variety of clearing to clearing or foliage immersion measurements (across the infield). Figure 7 is a photograph showing the trees in the infield and part of the runway. The runways are at least 150 ft wide and the areas on the outside of the

*Measured by the angle method developed by Bitterlich (1948).

FIGURE 7 PEEL FIELD PHOTOGRAPH

runweys are naturally forested although the eastern end is quite sparse. The one-story buildings are considerably removed from the runway. Figure 8 is a topographical map of the field showing the location of the four paths where meesurements were made. As the elevation contours indicate the ground slope was about 10-ft over the longest path (800 m).

2. Data

a. Path-Loss Meesurements

The measured test link margins (AS) are listed in Table 2 for each combination of path length and antenna height. The double numbers ere the result of a 10-m lateral position shift and indicete deta sensitivity to a specific location.

The calculeted (as described in Section IV) EPL data are listed in Table 3 for each combination of path length and antenna height. Antenna heights are also described relative to the trees. The EPL data are also plotted in Figure 9 as a function of peth length on a linear scale, parametric in antenna height. Only the treetop antenna height, which produces the lowest nonzero set of EPL values, appeers to behave in a lineer fashion; that is, the line can be extrapolated beck through the zero origin.

Figure 10 is a plot of the test link margin deta contained in Table 2. The right-hand scele is total path loss, which is the sum of EPL and the calculeted free-space path loss.

A number of foliage situations were tested using the 400-m peth length at Peel Field. First both vens were backed up to the edge of the trees and the antennas set at a height of 13 ft, about 1/3 of the tree height. This siting was used to simulate a foliage immersion to immersion situetion. The EPL measured 36 dB, as shown in Table 4. One ven was moved out awey from the edge of the trees, 20 m elong the propagation path line; this siting simuleted a foliage immersion to clearing situation and the EPL measured 35 dB. Then the van was moved to 40 m from the trees with no measured change in EPL. Finally, the

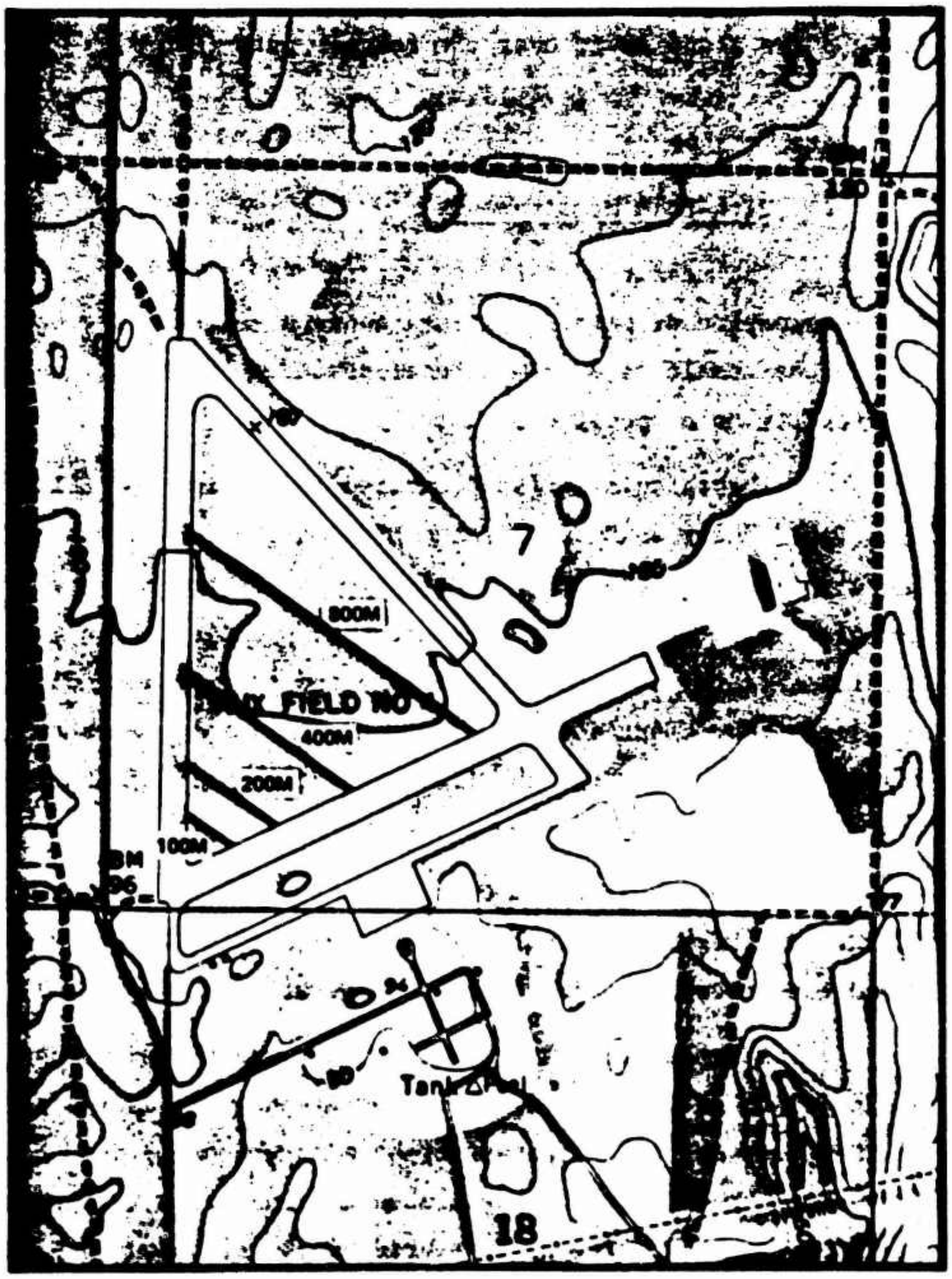

FIGURE 8 PEEL FIELD TOPOGRAPHICAL MAP

Table 2

PEEL FIELD TEST LINK MARGIN

Antenna Height[a] (ft)	Test Path			
	100 M (dB)	200 M (dB)	400 M (dB)	800 M (dB)
60	95	89	84	80
30	92 to 96[b]	84 to 85	74	58 to 60
22	87 to 88	71 to 74	52 to 68 $[c]	39 to 50 $[c]
13	71 to 75	--	47	--
6	73 to 78	--	44 $[c]	< 0 $[c]

a Measured to antenna base, center of antenna is 2 ft higher.
b Indicates that at least 2 measurements were made for the given nominal range; the values given are the extremes.
c The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut off stretch-out conditions.

Table 3

PEEL FIELD EXCESS PATH LOSS

	Antenna Height[a] (ft)	Test Path			
		100 M (dB)	200 M (dB)	400 M (dB)	800 M (dB)
Free Space	60	0	0	0	-3
Tree-tops	30	-1 to 3[b]	4 to 5	9	17 to 19
Upper Canopy	22	7 to 8	15 to 18[b]	15 to 31 $[c]	27 to 38 $
Trunks	13	20 to 24	--	36	--
Under-growth	6	17 to 22	--	39 $	> 77 $

a Measured to antenna base, center of antenna is 2 ft higher.
b Indicates that at least 2 measurements were made for the given nominal range; the values given are the extremes.
c The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut off stretch-out conditions.

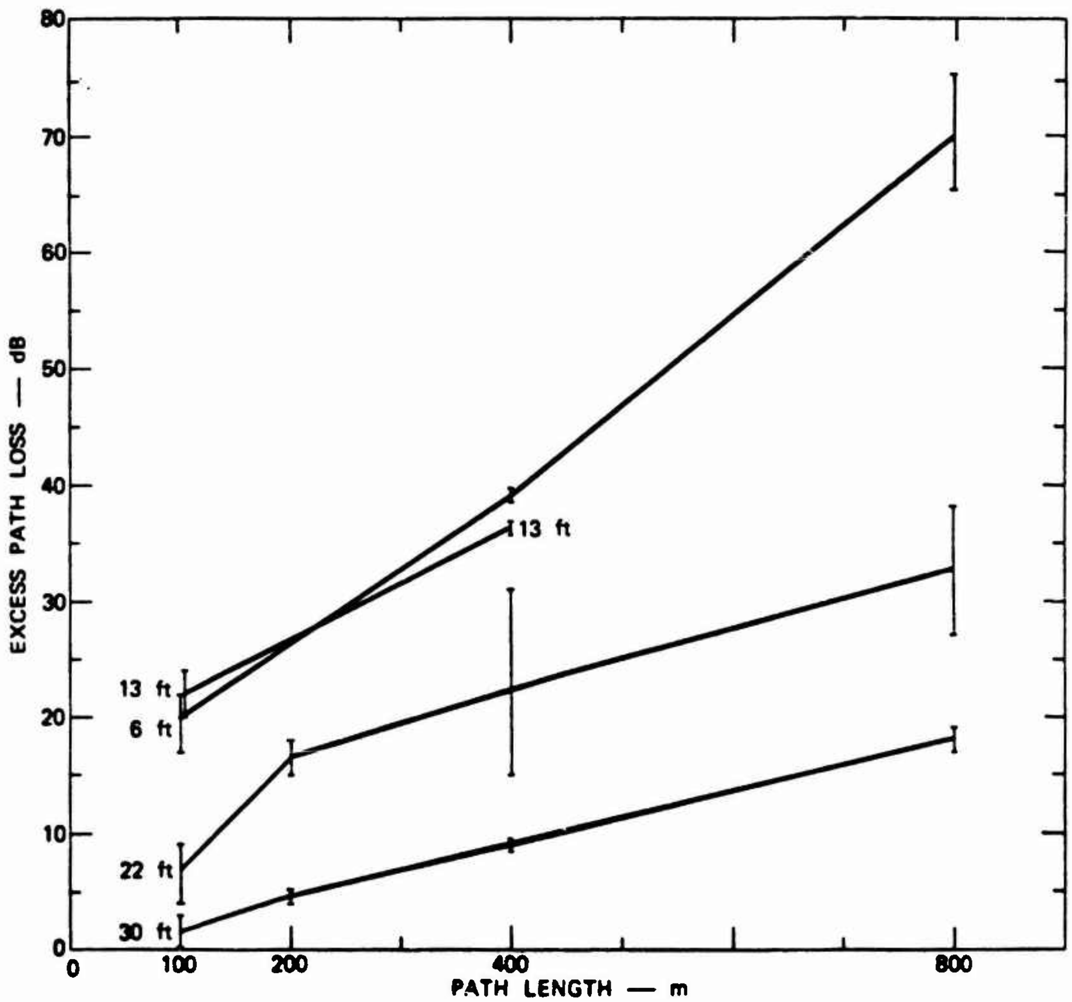

FIGURE 9 PEEL FIELD EXCESS PATH LOSS VS PATH LENGTH

first van was moved out 20 m and then 40 m. All of the EPL values are within experimental error of each other and indicate that there is no advantage in using available clearings for an antenna height of 13 ft and a 400-m path length.

Figure 11 shows the effect of average ground foliage loss on the variation of loss between frequency channels. The EPL for each individual channel is plotted and grouped by path length and made parametric in antenna height. Loss variation between channels is shown to increase with average EPL and, therefore, path length and reaches a maximum of 15 dB in the worst case.

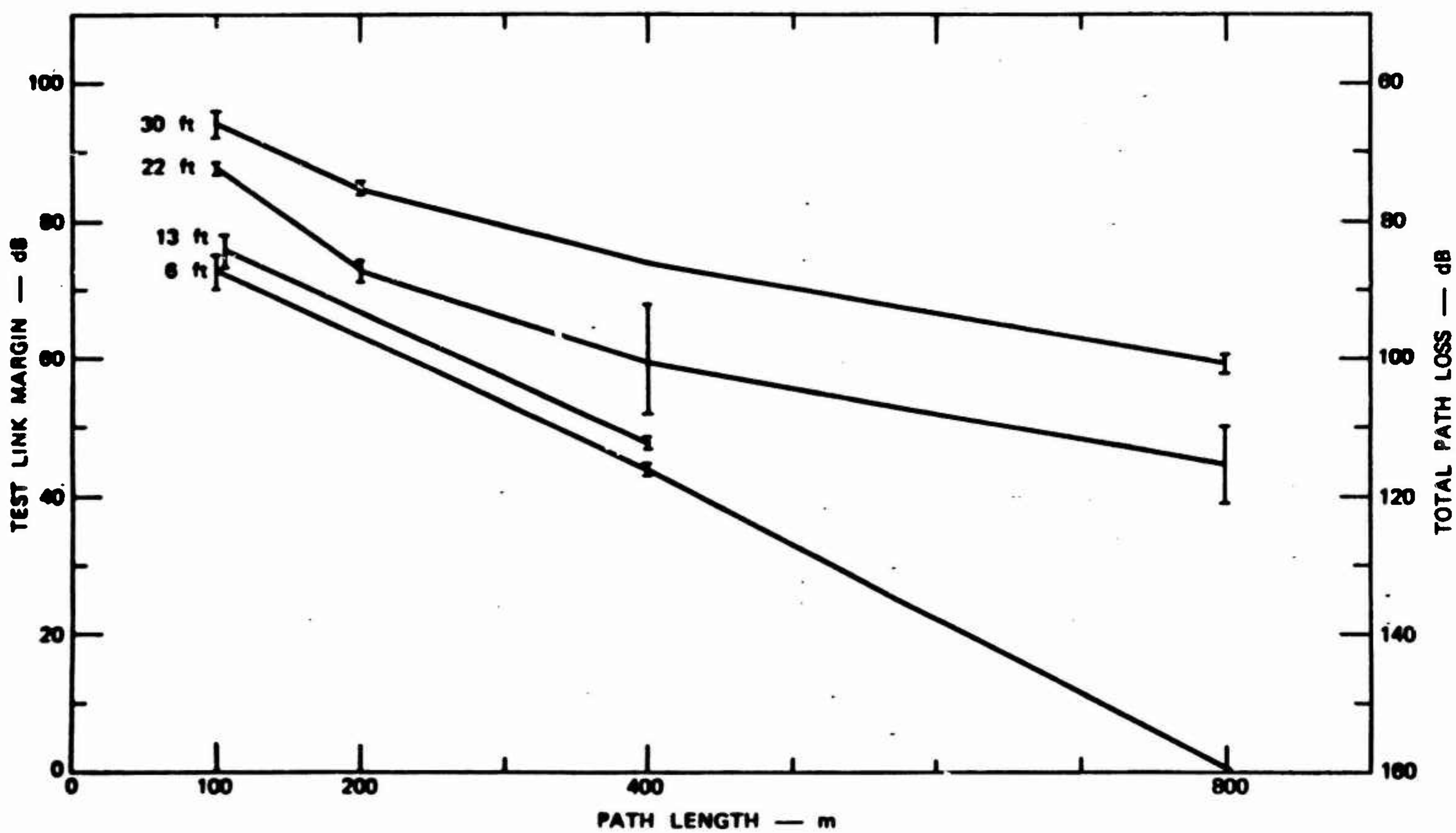

FIGURE 10 PEEL FIELD TEST LINK MARGIN VS PATH LENGTH

Table 4

PEEL FIELD FOLIAGE SITUATION AT 400-M PATH
(Antenna Height--13 Ft)

Type of Path	Distance From Trees (m)		Excess Path Loss (dB)
	Van 1	Van 2	
Immersion to immersion	0	0	36
Immersion to clearing	0	20	35
Immersion to clearing	0	40	35
Clearing to clearing	20	40	36
Clearing to clearing	40	40	34

b. Ranging Measurements

One of the first tests carried out at Peel Field was to make path measurements over a tape-measured length of 100 m on the runway. The results indicated that the TOA (ranging) measurements under free-space conditions were very accurate. The indicated average range values, once corrected by a fixed offset of 62 m, were accurate to at least ±2 percent. The actual foliage path length at all sites was never directly measured by tape, but rather calculated by taping distances along the roads or pathways and using an assumed angle between the roads, a method good enough only for nominal path length values.

Figures 12 and 13 are plots of indicated range (corrected) for the nominal 400-m and 800-m paths, respectively, at Peel Field. Each frequency channel is plotted independently, but grouped by decreasing antenna height and, therefore, increasing EPL. The figures indicate that at 65-ft antenna height (zero EPL) the indicated ranges of 365 m and

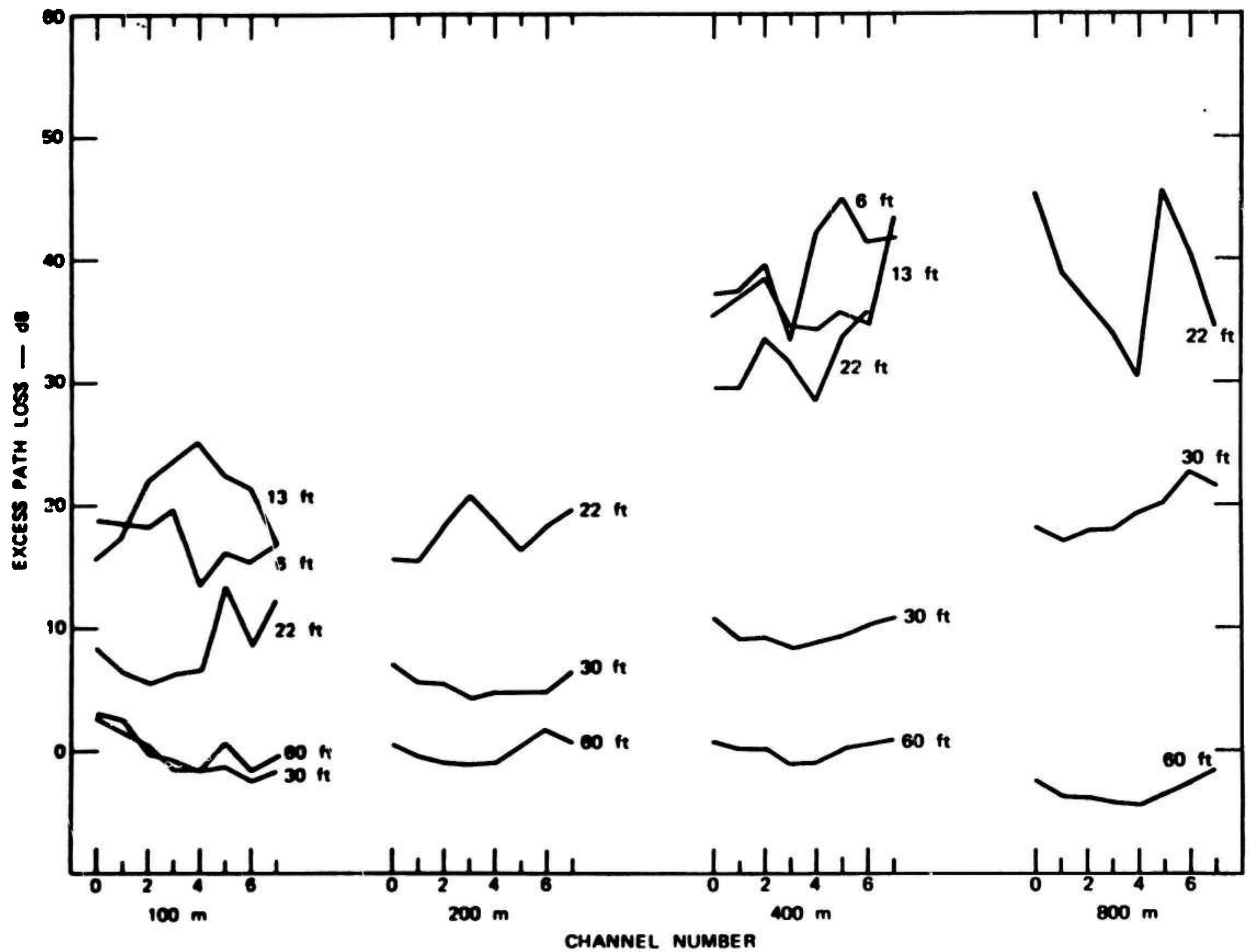

FIGURE 11 PEEL FIELD EXCESS PATH LOSS VS FREQUENCY CHANNEL

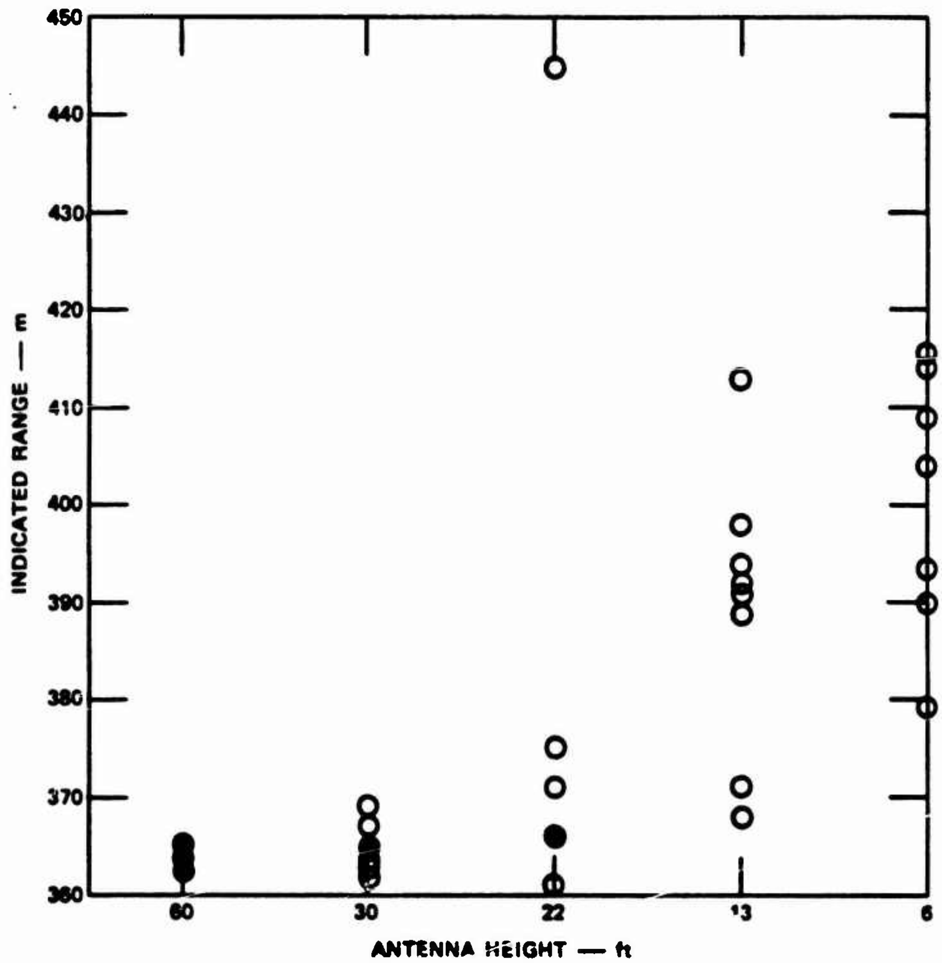

FIGURE 12 PEEL FIELD INDICATED RANGE VS ANTENNA HEIGHT, 400-m PATH

725 m respectively are the true ranges and those data points are tightly grouped. As the antenna height decreases the indicated range data become spread and the average value increases. At 6-ft antenna height the indicated range error is +35 m, and the data is spread ±20 m. For the 800-m path the 65-ft antenna height (zero EPL) range data show an average of 725 m and a standard deviation of 1.4 m. At the 6-ft antenna height the indicated range error is +52 m and the standard deviation has increased to 12 m.

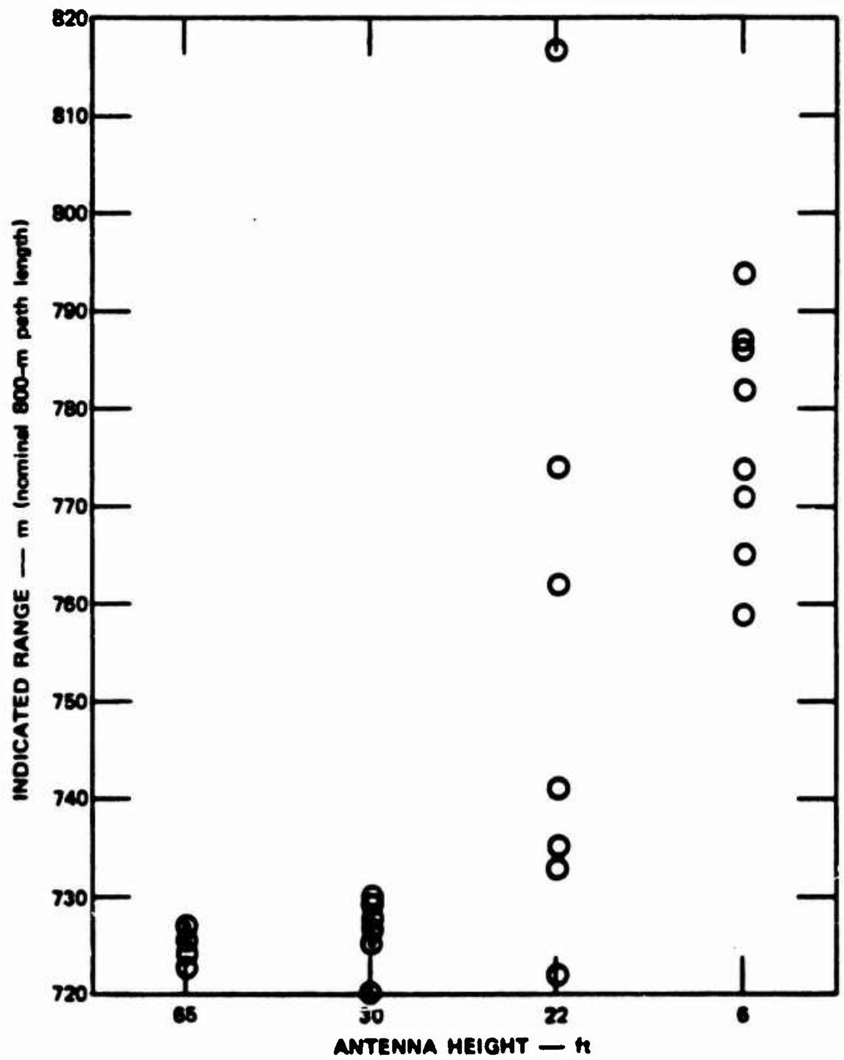

FIGURE 13 PEEL FIELD INDICATED RANGE VS ANTENNA HEIGHT, 800-m PATH

B. Duke Field

1. Site Description

At this location is a high density stand of Choctawhatchee sand pine, planted in 1965, never trimmed or pruned. The tops are heavy with green foliage. The large amount of low branches (mostly without needles) make for very heavy apparent density. The tree-trunk density measured 110 ft^2/acre with tree heights 30 ft to 35 ft. The trees are individually in rows and planted in strips 190-m wide running approximately north to south. They are separated by smaller strips of the original growth, mostly scrub blackjack oak, bluejack oak, and longleaf pine that are not as tall as the planted pines. The trees on each side of the road almost converge over the road in spots providing a tunnel effect. Figure 14 is a photograph taken from the road. Figure 15 is a topographical map showing the location of the paths where measurements were made. The elevation contours indicate that the ground slope is about 15-ft down over the north half of the 800-m path and nearly level over the shorter paths.

2. Data

a. Path-Loss Measurements

The measured test link margins (AS) are listed in Table 5 for each combination of path length and antenna height. The double margin numbers are the result of a 10-m lateral position shift and indicate data sensitivity to a specific location. The double antenna height numbers indicate a measurement made from an antenna on the tower to an antenna at a differing height on a tripod or the manpack on the ground.

The calculated EPL data are listed in Table 6 for each combination of path length and antenna height. The EPL data for some of the paths are plotted in Figure 16. The 800-m path data were taken across four different strips of trees, and, therefore, the 800-m EPL data cannot be compared to the shorter paths in a meaningful way.

b. Ranging Measurements

Measurements were made at three path lengths (nominally, 200 m, 400 m, and 800 m) at Duke Field. The ranging data at 65-ft antenna heights showed that the true path lengths were 203 m, 380 m, and 750 m, respectively. Indicated range values were spread and increased in the same way as the Peel Field data as shown in Figures 12 and 13. Also the data showed similar occasional wild points (deviation greater than ±20 percent). Indicated range data taken at low antenna heights

FIGURE 14 DUKE FIELD PHOTOGRAPH

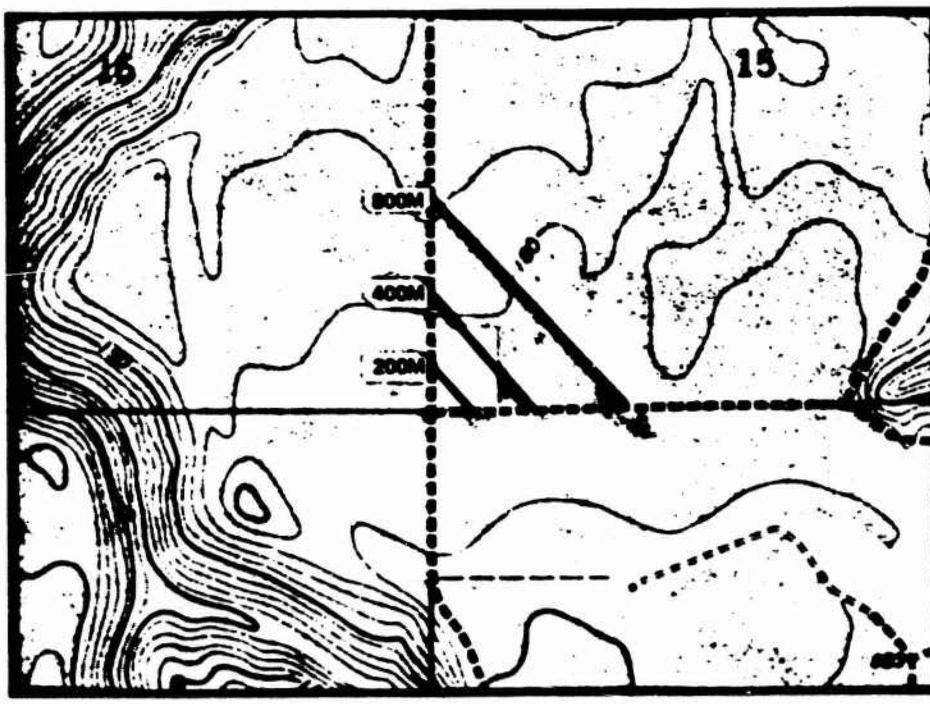

FIGURE 15 DUKE FIELD TOPOGRAPHICAL MAP

Table 5

DUKE FIELD TEST LINK MARGIN

Antenna Height[a] (ft)	Test Path		
	200 M (dB)	400 M (dB)	800 M (dB)
65	89	83	78
35	80 to 81[b]	61 to 68	59
22	61 to 63	48 to 51 $[c]	40 to 41
35, 6[d]	63	53	45
35, 1	--	55	41
22, 6	--	45 to 49	35
22, 1	--	45 to 47	30 to 32

a Measured to antenna base, center of antenna is 2 ft higher.
b Indicates that at least 2 measurements were made for the given nominal range; the values given are the extremes.
c The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut off stretch-out conditions.
d Two different antenna heights are indicated.

showed indicated range errors of +19 m, +28 m, and +10 m, respectively. The 800-m path showed less range error because, as discussed above, that path was across four strips of trees, two of which were low density and short.

C. Basin Bayou

1. Site Description

At this location a low to medium density stand of slash pine was planted in 1952 and thinned in most areas later. The areas in which

Table 6

DUKE FIELD EXCESS PATH LOSS

	Antenna Height[a] (ft)	Test Path 200 M (dB)	400 M (dB)	800 M (dB)
Free space	65	0	0	-1
Tree-tops	35	8 to 9	15 to 22	18
Upper canopy	22	26 to 28[b]	32 to 35 $[c]	36 to 37
	35, 6[d]	26	30	32
	35, 1	--	28	36
	22, 6	--	34 to 38	42
	22, 1	--	34 to 36	45 to 47

a Measured to antenna base, center of antenna is 2 ft higher.
b Indicates that at least 2 measurements were made for the given nominal range; the values given are the extremes.
c The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut off stretch-out conditions.
d Two different antenna heights are indicated.

the measurements were made had tree-trunk densities varying from 0 up to 90 ft^2/acre with an average of about 50 ft^2/acre and with tree heights varied from 50 ft to 70 ft. Many logging trails have been cut through the area at irregular angles. The trees are mostly bare trunks from 40 ft on down. The area has relatively little underbrush and most of it is below 8-ft high and distributed in an irregular way. Visually this site appears very sparse with good visibility up to 200-m distance. Figure 17 is a photograph taken in the area. Figure 18 is a topographical

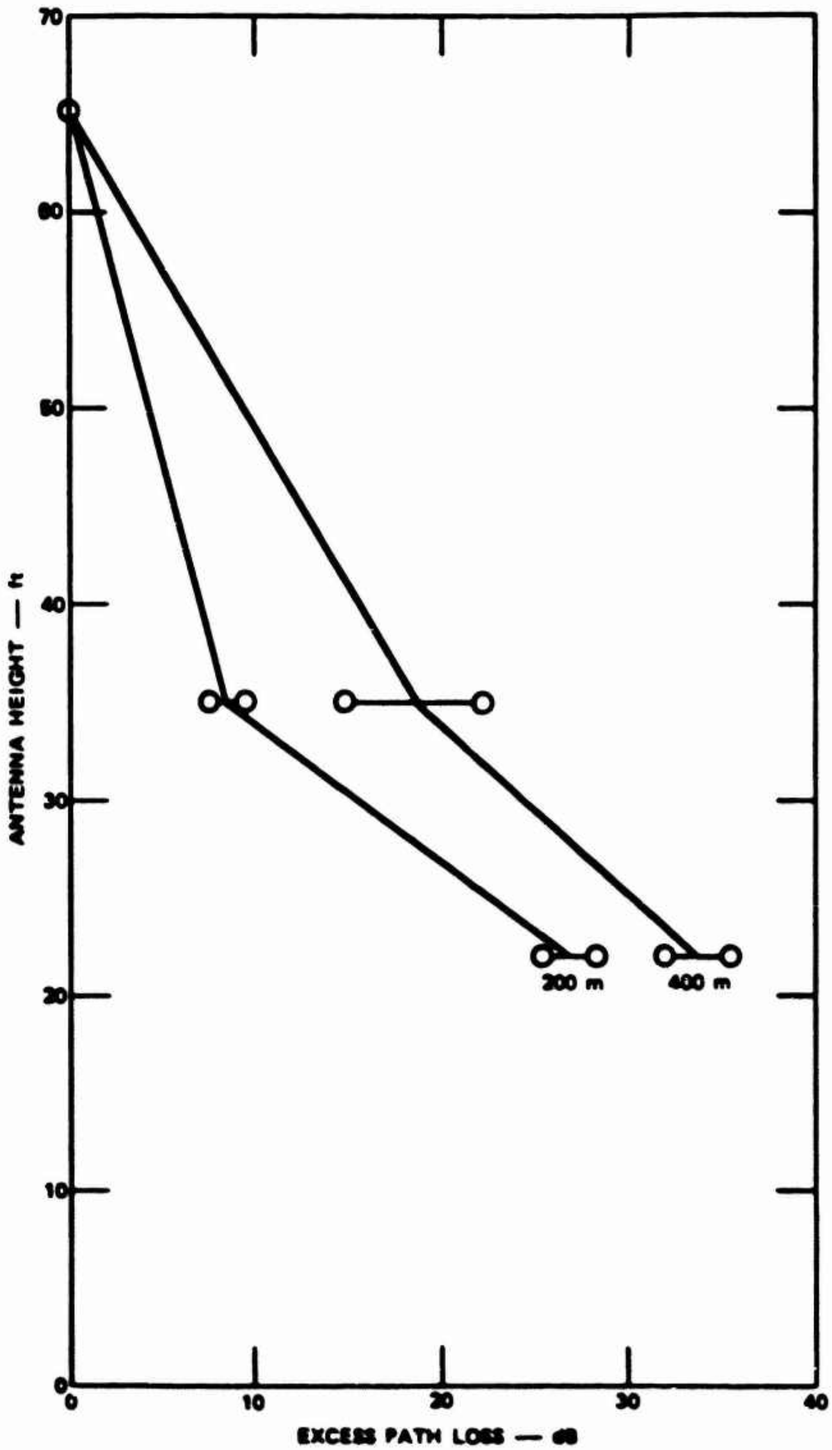

FIGURE 16 DUKE FIELD ANTENNA HEIGHT VS EXCESS PATH LOSS

FIGURE 17 BASIN BAYOU PHOTOGRAPH

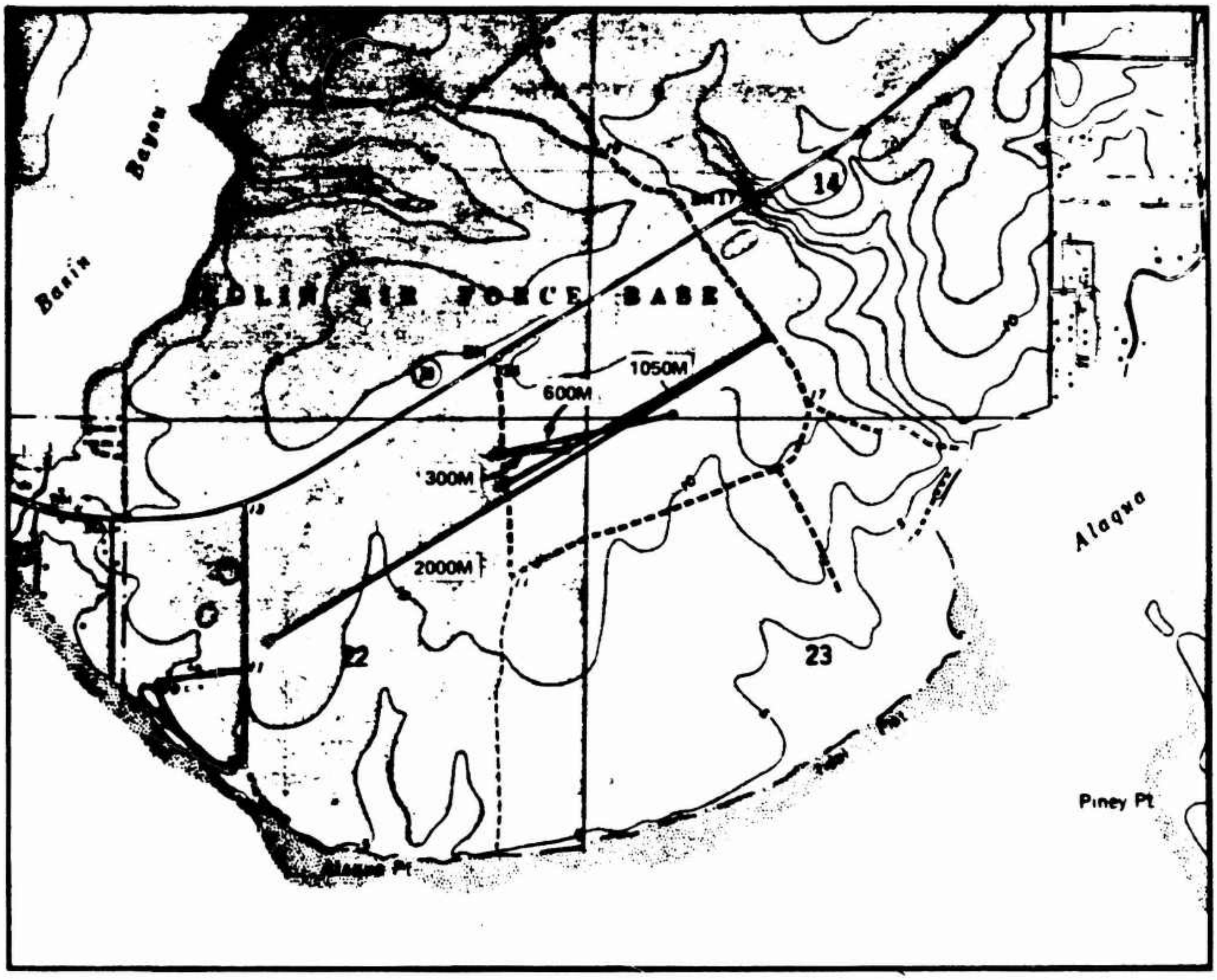

FIGURE 18 BASIN BAYOU TOPOGRAPHICAL MAP

map of the area, showing the location of the paths where measurements were made. The elevation contours indicate that the ground slope is about 10 ft over the 2-km path and nearly level over the shorter paths. The tree planting is irregular in almost all areas. One limited region that only the 2-km path included has the trees planted in rows.

2. Data

a. Path Loss Measurements

The measured test link margins (AS) are listed in Table 7 for each combination of path length and antenna height. The double

Table 7

BASIN BAYOU TEST LINK MARGIN

Antenna Height[a] (ft)	Test Path				
	300 M (dB)	600 M (dB)	Wet 1050 M (dB)	Dry 1050 M (dB)	2000 M (dB)
65	84	72	59 to 60	61	53
50	76	62 to 65[b]	47	49	40
35	72	60 to 63	41 to 46 $[c]	50	26
22	72	62 to 64	40 to 43	47	13
65, 6[d]	--	--	--	--	31
65, 1	--	--	40 $	--	28
50, 6	--	--	39	--	--
50, 1	--	--	37	--	--
35, 6	--	53 $	40 $	--	--
35, 1	--	51	39	--	21
22, 6	--	38 to 55	38 $	--	--
22, 1	--	50 to 53 $	35	--	--

a Measured to antenna base, center of antenna is 2 ft higher.
b Indicates that at least 2 measurements were made for the given nominal range; the values given are the extremes.
c The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut off stretch-out conditions.
d Two different antenna heights are indicated.

margin numbers are the result of a 10-m lateral position shift and indicate data sensitivity to a specific location. The double antenna height numbers indicate a measurement made from Van 1 with an antenna on the tower to Van 2 with an antenna at a differing height on a tripod or the manpack on the ground.

The calculated EPL data are listed in Table 8 for each combination of path length and antenna height. Because the tree distribution is so irregular in the area where the path measurements were made, the EPL data is not expected to be linearly related. At the 1050-m path, data were taken on both a dry day and on a day after a morning rain. Comparison of the EPL data indicates a 1-dB to 7-dB increase, caused by wet foliage and trunks, depending on antenna height.

The EPL data are plotted in Figure 19 to indicate the variation of EPL with antenna height. The data indicate that there is no significant reduction of EPL below the upper canopy in the trunk area where there is no green foliage and the number of branches is greatly reduced for the path lengths measured. No explanation for this effect is obvious.

The variation of EPL with antenna height for the 2000-m path differs greatly from the other paths. However, because the foliage density and undergrowth is highly variable from path to path at this site, the unusual character of the 2000-m path is not thought to be significant.

b. Ranging Measurements

Measurements were made at four path lengths (nominally, 300 m, 600 m, 1050 m, and 2000 m) at this site. The ranging data at 65-ft antenna heights showed that the true path lengths were 287-m, 601-m, 1052-m, and 2039-m long. Indicated range values were spread and increased in the same way as the Peel and Duke Field data. Indicated range errors for all combinations of antenna heights and path lengths were calculated and the values ranged from 0 to +102 m in a way that showed no obvious trends except that indicated range errors were usually larger at tree trunk heights than at upper canopy heights.

3. EMI Test

On the afternoon of the last day of the visit to Basin Bayou a brief test was carried out to look for electromagnetic interference

Table 8

BASIN BAYOU EXCESS PATH LOSS

	Antenna Height[a] (ft)	Test Path				
		300 M (dB)	600 M (dB)	Wet 1050 M (dB)	Dry 1050 M (dB)	2000 M (dB)
Tree-tops	65	1	7	15 to 16	14	16
Upper Canopy	50	9	14 to 17[b]	28	26	29
Trunks	35	13	16 to 19	29 to 34 $[c]	25	43
Lower Trunks	22	13	15 to 17	32 to 35	28	56
	65, 6[d]	--	--	--	--	38
	65, 1	--	--	35 $	--	41
	50, 6	--	--	36	--	--
	50, 1	--	--	38	--	--
	35, 6	--	27 $	35 $	--	--
	35, 1	--	28	36	--	48
	22, 6	--	24 tc 41	37 $	--	--
	22, 1	--	26 to 29 $	40	--	--

a Measured to antenna base, center of antenna is 2 ft higher.
b Indicates that at least 2 measurements were made for the given nominal range; the values given are the extremes.
c The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut off stretch-out conditions.
d Two different antenna heights are indicated.

(EMI) between PLRS and Joint Tactical Information Distribution System (JTIDS). After both systems were warmed up and STDC tests carried out, the vans were positioned for the 1050-m path. The JTIDS antennas were mounted on the towers and set at a height of 22 ft. JTIDS had a test

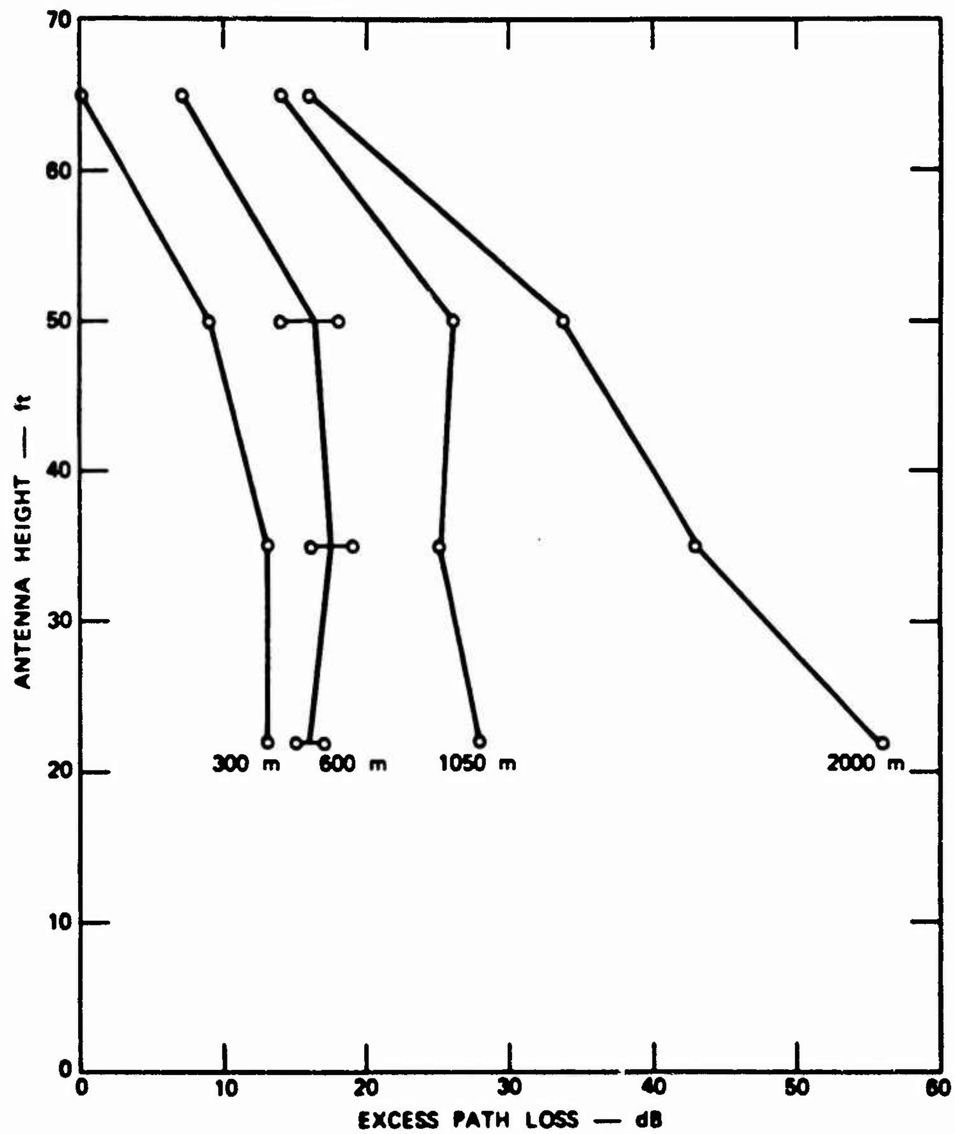

FIGURE 19 BASIN BAYOU ANTENNA HEIGHT VS EXCESS PATH LOSS

link margin of about 20 dB. In the first van the PLRS PTU and the JTIDS terminal were operated inside the van. The PLRS antenna for the PTU was mounted on the front of the roof of the van at a height of 10 ft. The PLRS BUU was operated outside the other van as a manpack with an antenna height of 1 ft. The manpack was positioned 50-m north of the other van. PLRS had a test link margin of about 50 dB. No effect was found on the PLRS test link margin when JTIDS was switched on or off. During these tests the spectrum analyzer was used to look at both JTIDS and PLRS received signals. No interfering signals were found in the JTIDS operating band. Interfering signals were found in the PLRS operating band, but they were determined to originate from the FPS-85 radar located about 10 mi away and not from JTIDS.

The van at the western position was moved east so that the path length was reduced to 500 m and again JTIDS was switched on and off. This time the PLRS test link margin changed by about 3 dB.

No obvious EMI was expected between the two systems because the third harmonic of the PLRS transmitter falls above the JTIDS operating band. This EMI test was not intended to be an exhaustive evaluation. A more detailed test should be conducted especially at lower link margins and under conditions more nearly simulating a typical tactical situation.

D. Arnold Grid

1. Site Description

The Arnold Grid is laid out in rectangular blocks in an area about 4 km by 1/2 km. Most of the area is free from wires and has essentially no traffic. The foliage is high density with random tree spacing. The tree-trunk density measured 120 ft^2/acre with tree heights that measured 45 ft to 70 ft. The foliage is random mixture of pine and scrub oak. The underbrush varies from light to dense. Figure 20 is a photograph taken in the area. Figure 21 is a topographical map of the area showing the location of the two paths. Figure 22 is an elevation profile for the two paths. The vertical scale is exaggerated 30 to 1.

2. Data

a. Path Loss Measurements

The measured test link margins (AS) and calculated EPL for each combination of path length and antenna height are listed in Table 9. The EPL values for the two paths (1000 m and 2000 m) are not comparable by path length for several reasons. The terrain is not as flat as shown in Figure 21. In addition, the site lacks a uniform

FIGURE 20 ARNOLD GRID PHOTOGRAPH

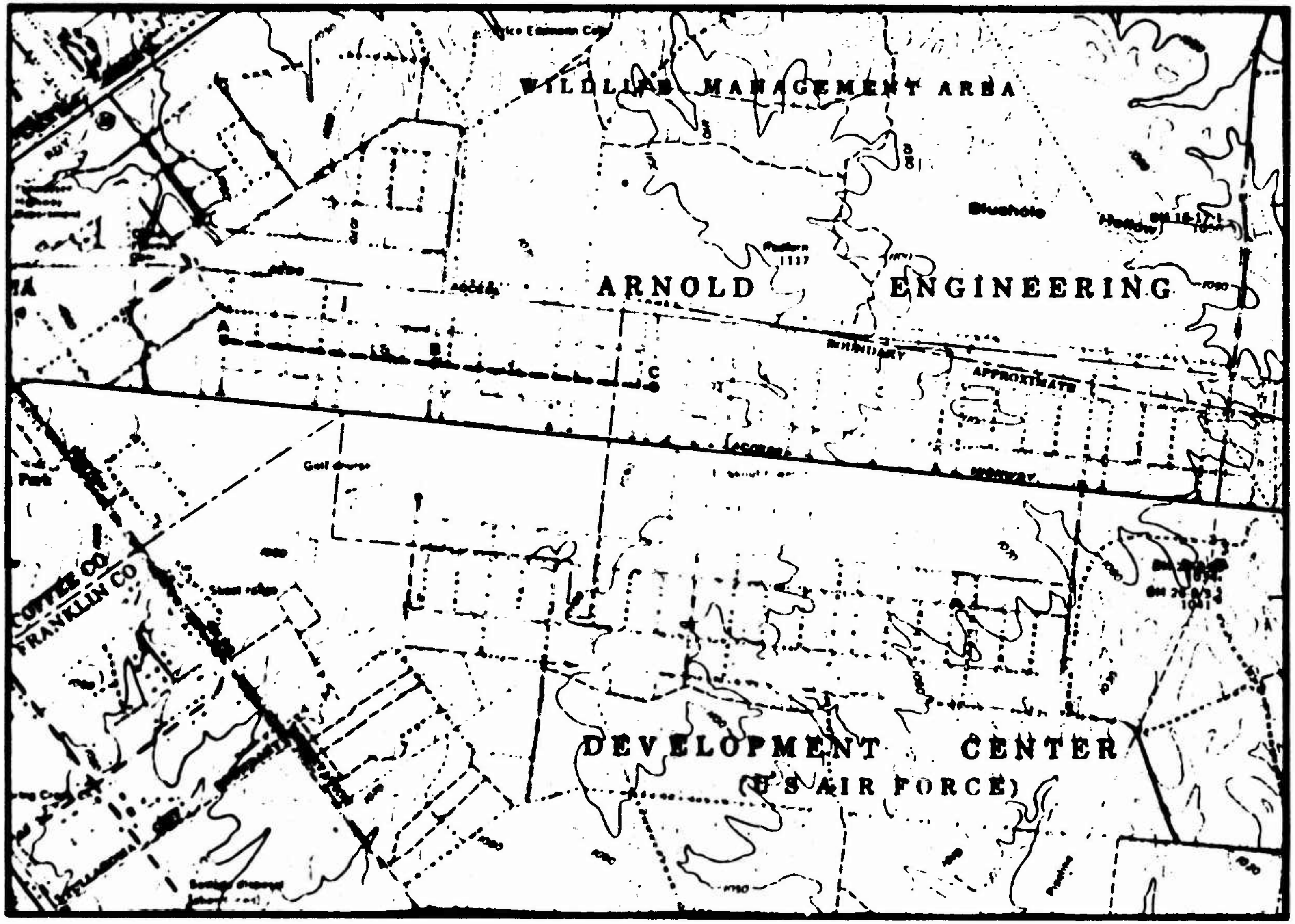

FIGURE 21 ARNOLD GRID TOPOGRAPHICAL MAP

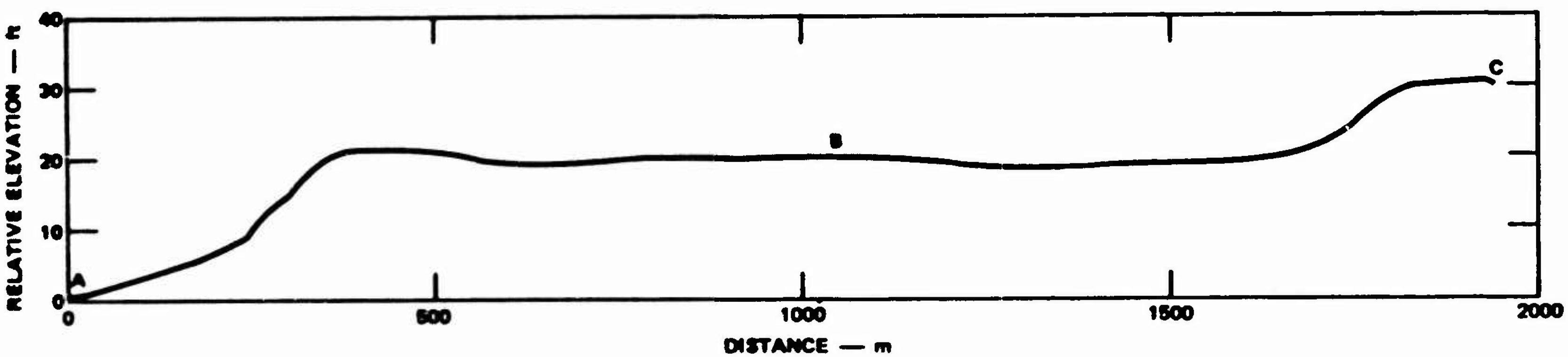

FIGURE 22 ARNOLD GRID ELEVATION PROFILE

Table 9

ARNOLD GRID TEST LINK MARGIN
AND EXCESS PATH LOSS

	Antenna Height[a] (ft)	Test Link Margin (dB)		Excess Path Loss (dB)	
		1000 M	2000 M	1000 M	2000 M
Tree-tops	60	46 to 47[b]	40	28 to 29	29
Upper Canopy	45	24 to 26	27	49 to 51	42
Trunks and Scrub	30	18 to 20	15	55 to 57	54
Trunks and Scrub	22	12 to 13	4	62 to 63	65

a Measured to antenna base, center of antenna is 2 ft higher.
b Indicates that at least 2 measurements were made for the given nominal range; the values given are the extremes.

foliage type. The long straight roads parallel to the propagation paths offer possible low-loss, indirect paths.

b. Ranging Measurements

The ranging data at 65-ft antenna heights that are shown indicated ranges of 967 m and 1958 m for the two paths. At 22-ft antenna heights the indicated range error was +66 m and +78 m, respectively.

E. Negro Hill

1. Site Description

Normandy Dam forms a lake whose water level is at 875 ft. Negro Hill arises from the lake and has a peak of 1045 ft. Most of the hill is foliated. Some of the trees had dropped their leaves by the time of the measurements. Figure 23 is a photograph of the hill taken from Position F. Figure 24 is a topographical map of the area and shows the location of five positions where the vans were placed to make path measurements. Measurements were made over the four paths indicated. Figure 25 gives an elevation profile for each of the paths. The start and end of each profile is the ground level at the position where the van was parked. The vertical scale has been exaggerated 2 to 1.

2. Data

a. Path Loss Measurements

Table 10 lists the measured test link margins for the four paths measured. Table 11 lists the calculated EPL for each combination of antenna height and path length. The EPL data for Path B-D have been plotted in Figure 26.

b. Ranging Measurements

For this site and all of the following terrain obstacle sites, it was not possible to raise the antenna to a sufficient height to have a line-of-sight path; therefore, the true range estimates were made by scaling distances from a topographical map. It is estimated that these nominal path lengths are accurate to ±5 percent. For terrain obstacle paths then, the absolute range error is unknown unless it exceeds ±5 percent.

The map scaled distances for Paths B-D, B-E, C-E, and C-F are 1550 m, 1750 m, 1880 m, and 2250 m, respectively. The corrected indicated range averaged for all antenna heights is 1595 m, 1720 m, 1874 m, and 2361 m, respectively. All of the range errors are less than ±5 percent.

The TOA data for Path B-D have been plotted in Figure 27. The 50-ft and 35-ft antenna height data show up to 9 percent (150-m) spread in the indicated range. At 22-ft antenna height the TOA data becomes more tightly grouped, which suggests that lowering the antennas does some spatial filtering of multipath that is resolved in range.

FIGURE 23 NEGRO HILL PHOTOGRAPH

FIGURE 24   NEGRO HILL TOPOGRAPHICAL MAP

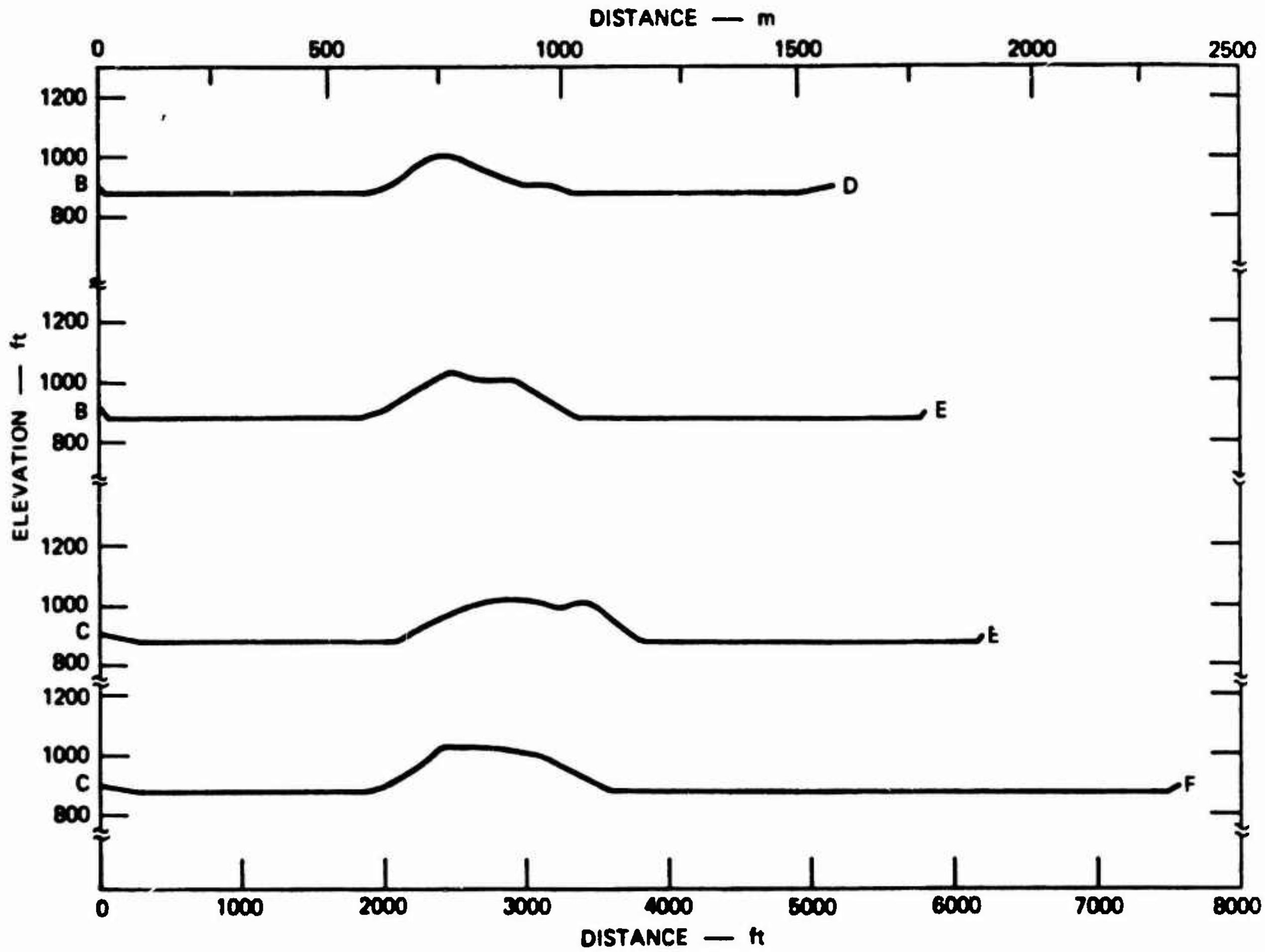

FIGURE 25 NEGRO HILL PATH ELEVATION PROFILES

F. Fuller-Davidson Ridge

1. Site Description

This heavily wooded ridge has a peak of 1108 ft. On the NW side of the ridge, Maysilles Road ends at Fuller Branch. The SE side of the ridge is accessible by Bell Road. Figure 28 is a photograph of the ridge taken from Position G. Figure 29 is a topographical map of the area and shows the location of four positions at which the vans were placed to make path measurements. Measurements were made over the three paths indicated. Figure 30 gives an elevation profile for each of the paths. The start and end of each profile is the ground level at the position where the van was parked. The vertical scale has been exaggerated 2 to 1.

Table 10

NEGRO HILL TEST LINK MARGIN

Antenna Height[a] (ft)	Test Path			
	B-D 1550 M (dB)	B-E 1750 M (dB)	C-E 1880 M (dB)	C-F 2250 M (dB)
50	33 $[b]	--	--	27 $
35	42 $	--	--	30 $
22	47	--	--	--
35, 6[c]	47	48	45	38 $
22, 6	50	47 $	45	42 $

a Measured to antenna base, center of antenna is 2 ft higher.
b The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut-off stretch-out conditions.
c Two different antenna heights are indicated.

2. Data

a. Path Loss Measurements

Test link margins for the three paths measured are given in Table 12. The calculated EPL data is listed in Table 13. The EPL data for Paths G-F and G-D have been plotted in Figure 26.

b. Ranging Measurements

The map scaled distances for Paths G-F, G-E, and G-D are 1150 m, 1420 m, and 1620 m, respectively. The corrected indicated range averaged for all antenna heights is 1401 m, 1460 m, and 1680 m. Path G-F shows a range error of +251 m or 22 percent. The other two paths show range errors of less than 5 percent. The TOA data for Path G-F have been plotted in Figure 31. At 22-ft antenna height the TOA

Table 11

NEGRO HILL EXCESS PATH LOSS

Antenna Height[a] (ft)	Test Path			
	B-D 1550 M (dB)	B-E 1750 M (dB)	C-E 1880 M (dB)	C-F 2250 M (dB)
50	38 $[b]	--	--	41 $
35	29 $	--	--	38 $
22	24	--	--	--
35, 6[c]	24	21	24	30 $
22, 6	21	23 $	24	26 $

a Measured to antenna base, center of antenna is 2 ft higher.
b The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut-off stretch-out conditions.
c Two different antenna heights are indicated.

data become more tightly grouped, which again suggests that lowering the antennas does some spatial filtering of multipath that is resolved in range.

G. Powers Bridge Drop

1. Site Description

A heavily wooded ridge with peaks up to 1100 ft lies between two sections of the Powers Bridge Road. The road runs NW along the top of the ridge, makes a U turn to the SE and comes down to the Powers Bridge. Near the bridge to the W, there is a large parking lot where one of the vans was parked (Position B). Figure 32 is a topographical map of the area and shows the location of 3 positions at which the vans were placed to make path measurements. Measurements were made over the

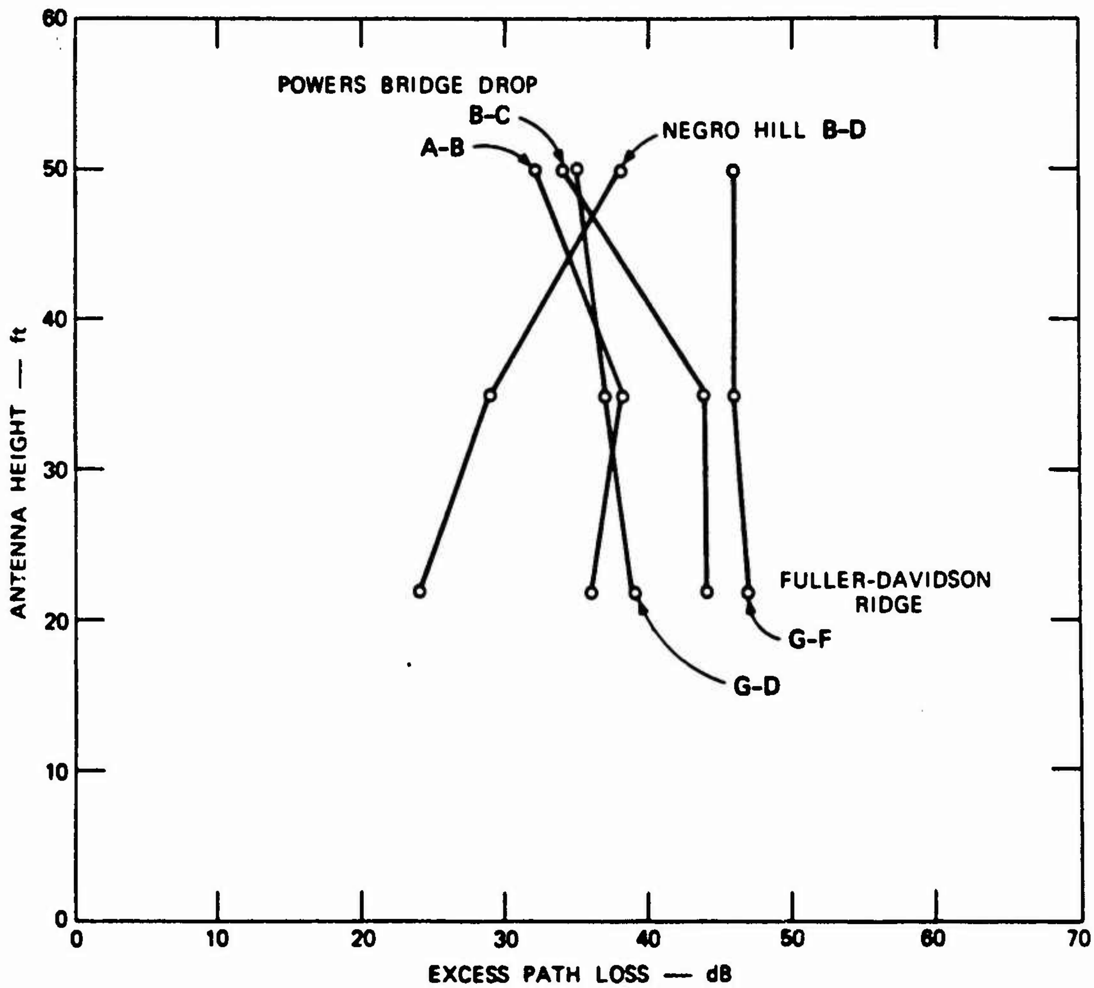

FIGURE 26 TERRAIN OBSTACLE ANTENNA HEIGHT VS EXCESS PATH LOSS

two paths indicated. Figure 33 gives an elevation profile for each of the paths. The vertical scale has been exaggerated 2 to 1.

2. Data

a. Path Loss Measurements

Data were taken at this site on two successive days. The second day it rained. The measured test link margins and calculated EPL data for the two paths measured are listed in Table 14. The EPL data have been plotted in Figure 26 versus antenna height.

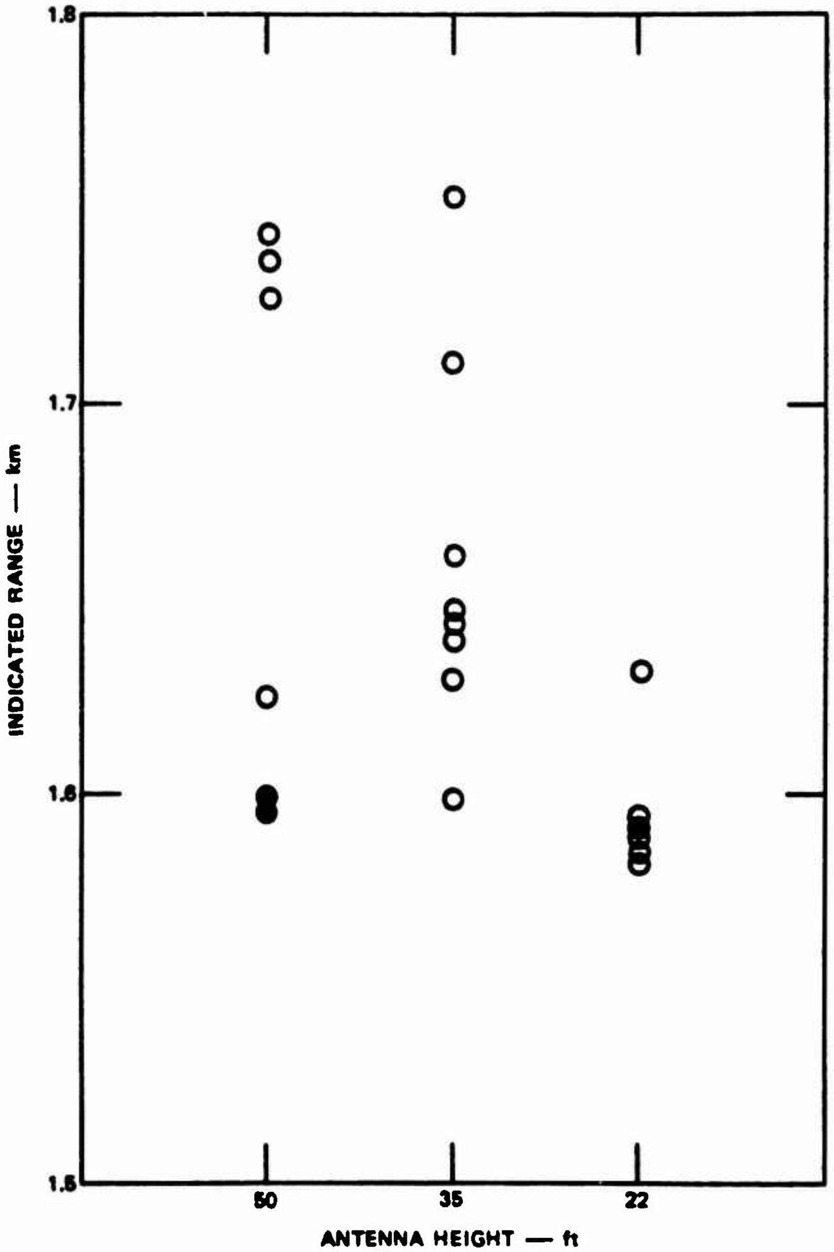

FIGURE 27   NEGRO HILL INDICATED RANGE VS ANTENNA HEIGHT, PATH B-D

FIGURE 28 FULLER-DAVIDSON RIDGE PHOTOGRAPH

FIGURE 29 FULLER-DAVIDSON RIDGE TOPOGRAPHICAL MAP

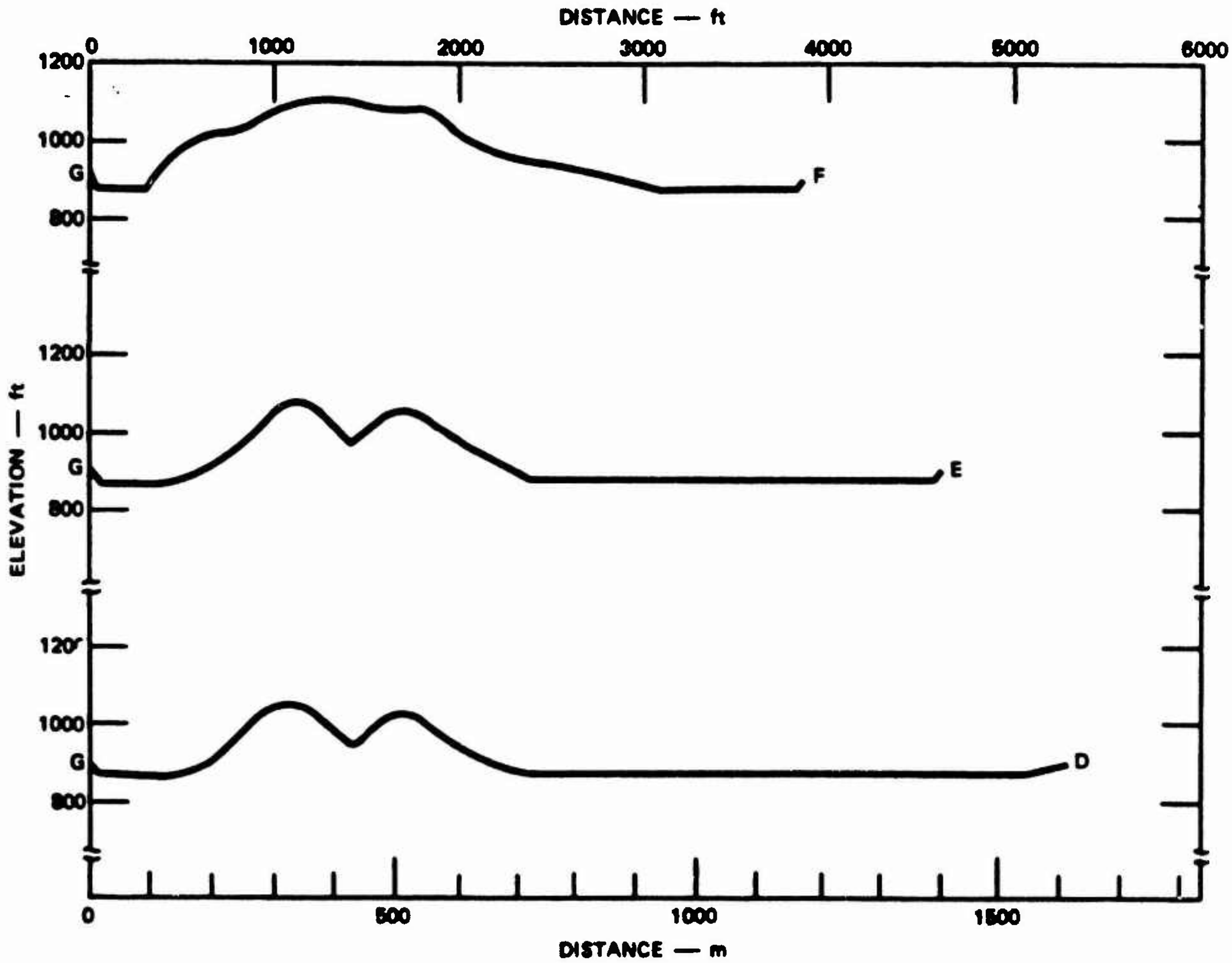

FIGURE 30 FULLER-DAVIDSON RIDGE PATH ELEVATION PROFILES

b. Ranging Measurements

The map scaled distance for Paths A-B and B-C are 750 m and 1000 m, respectively. The average corrected indicated range for 3 antenna heights was 780 m and 1020 m, respectively, less than 5 percent error.

H. Riley Creek Ridge

1. Site Description

This ridge is heavily wooded with roads right at the base on both sides. The ridge runs almost north to south providing east-to-west

Table 12

FULLER-DAVIDSON RIDGE TEST LINK MARGIN

Antenna Height[a] (ft)	Test Path		
	G-F 1150 M (dB)	G-E 1420 M (dB)	G-D 1620 M (dB)
50	28 $[b]	--	35
35	28	--	34
22	27	--	32
50, 6[c]	--	--	36
35, 6	29 $	31	35
22, 6	27 $	30	31
22, 1	--	30	--

a Measured to antenna base, center of antenna is 2 ft higher.
b The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut-off stretch-out conditions.
c Two different antenna heights are indicated.

paths up to 500 m. Figure 34 is a photograph of the ridge taken from Position C. A topographical map of the area is shown in Figure 35. It shows the location of four positions where the vans were placed to make two path measurements. Figure 36 gives an elevation profile for each of the paths. The vertical scale has been exaggerated 2 to 1. This site is unique because it provides the steepest elevation path angles to the ground.

Table 13

FULLER-DAVIDSON RIDGE EXCESS PATH LOSS

Antenna Height[a] (ft)	Test Path		
	G-F 1150 M (dB)	G-E 1420 M (dB)	G-D 1620 M (dB)
50	46 $[b]	--	35
35	46	--	37
22	47	--	39
50, 6[c]	--	--	34
35, 6	45 $	40	35
22, 6	47 $	41	40
22, 1	--	41	--

a Measured to antenna base, center of antenna is 2 ft higher.
b The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut-off stretch-out conditions.
c Two different antenna heights are indicated.

2. Data

a. Path Loss Measurements

After the STDC test the vans were moved into Positions A and C. A steady rain fell during the measurements. A link could not be established at those locations at all. For that path an EPL of greater than 82 dB was calculated (listed in Table 15). The vans were then moved to Positions B and D. Two data readouts were taken, but only one half of the frequency channels had positive link margins.

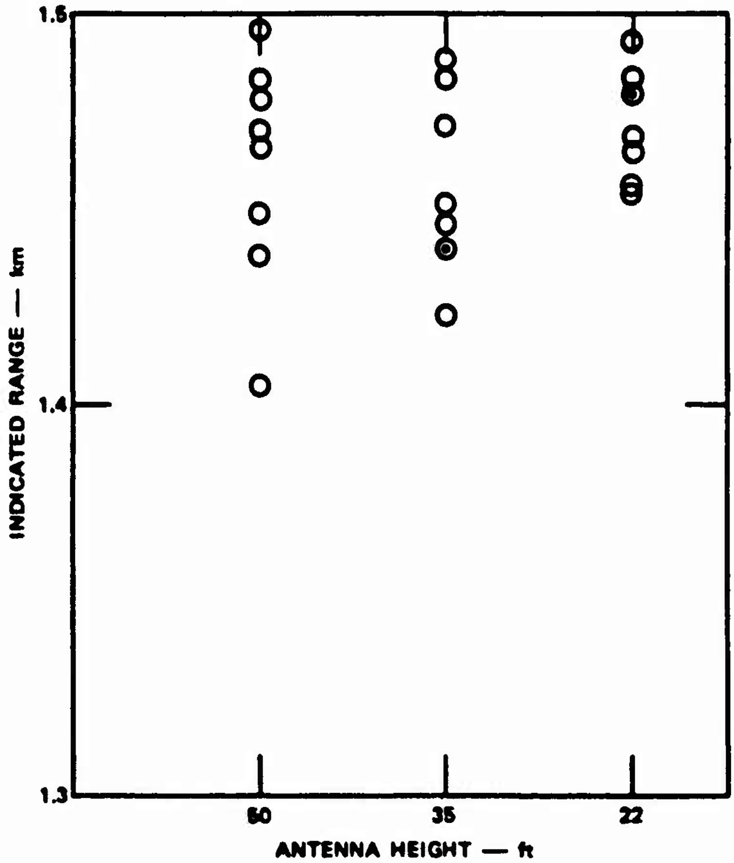

FIGURE 31 FULLER-DAVIDSON RIDGE INDICATED RANGE VS ANTENNA HEIGHT, PATH G-E

b. Ranging Measurements

The map scaled distances for Paths D-B and C-A are 300 m and 450 m, respectively. For Path D-B at antenna heights of 50 ft and 35 ft, the corrected indicated range varied from a minimum of 354 m to a maximum of 1466 m among all channels. Channel by channel the test link margin varied from less than zero to 44 dB. The maximum range channel had a test link margin of 38 dB and an indicated range error of 370 percent. The north face of Pea Ridge located to the south of Path D-B (see Figure 35) provides a good reflection surface for the very long indicated ranges recorded during the measurements.

FIGURE 32 POWERS BRIDGE DROP TOPOGRAPHICAL MAP

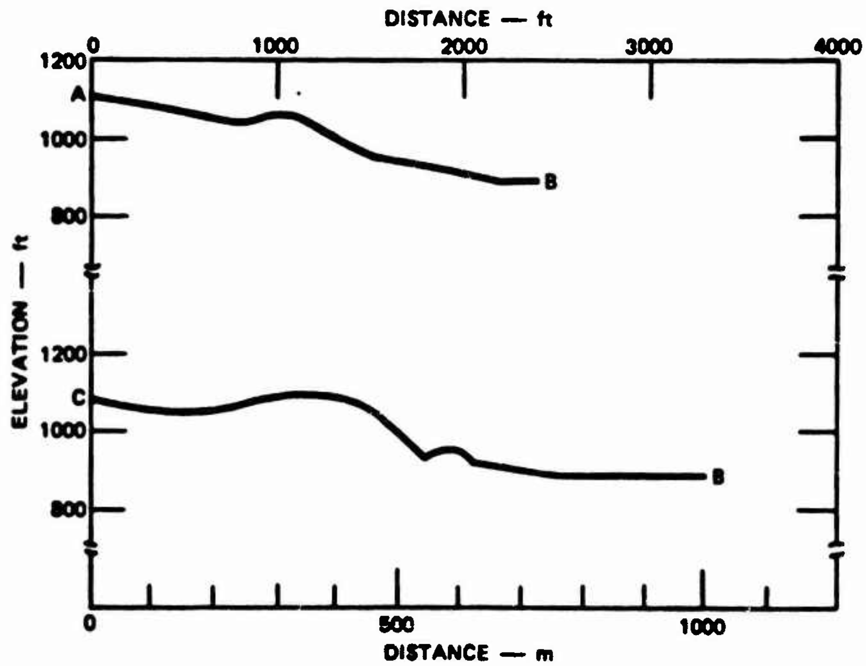

FIGURE 33 POWERS BRIDGE DROP PATH ELEVATION PROFILES

Table 14

POWERS BRIDGE DROP
TEST LINK MARGIN AND EXCESS PATH LOSS

Antenna Height[a] (ft)	Test Link Margin (dB)		Excess Path Loss (dB)	
	A-B 750 M	B-C 1000 M (wet)	A-B 750 M	B-C 1000 M (wet)
50	45	41	32	34
35	40	31	38	44
22	41	31	36	44
13	--	37	--	37

a Measured to antenna base, center of antenna is 2 ft higher.

FIGURE 34 RILEY CREEK RIDGE PHOTOGRAPH

FIGURE 35 RILEY CREEK RIDGE TOPOGRAPHICAL MAP

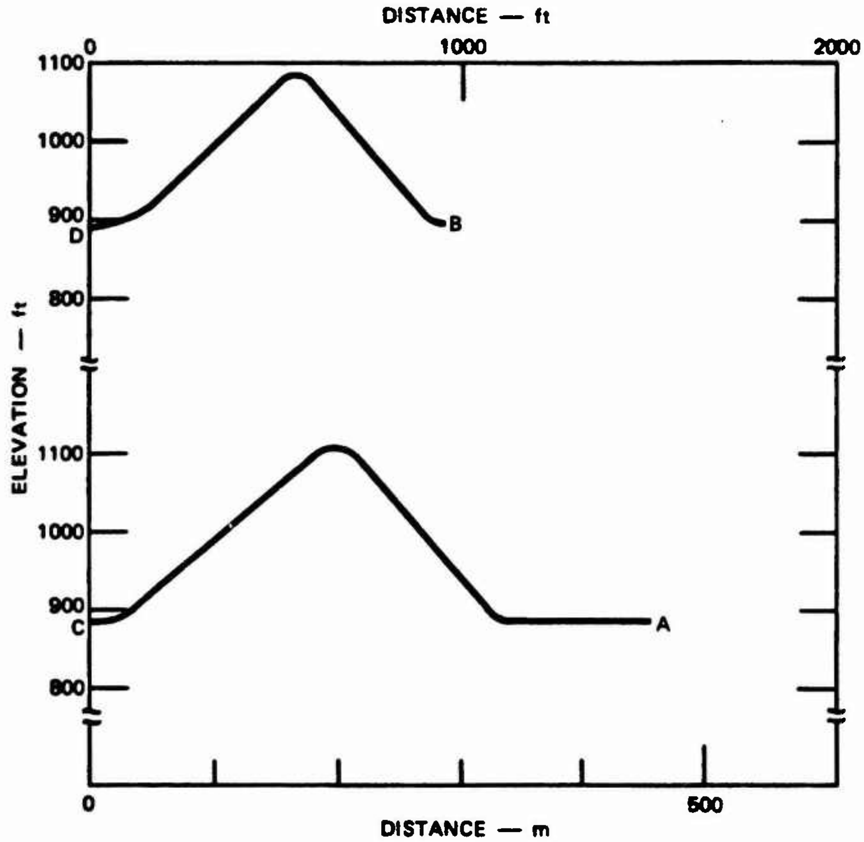

FIGURE 36 RILEY CREEK RIDGE PATH ELEVATION PROFILES

Table 15

RILEY CREEK RIDGE
TEST LINK MARGIN AND EXCESS PATH LOSS

Antenna Height[a] (ft)	Test Link Margin (dB)		Excess Path Loss (dB)	
	D-B 300 M	C-A 450 M	D-B 300 M	C-A 450 M
50	< 0 $[b]	< 0	> 85 $	> 82

a Measured to antenna base, center of antenna is 2 ft higher.

b The symbol, $, indicates that the data are subject to greatly varying interpretation because of system cut-off stretch-out conditions.

I. Meadows Hill

1. Site Description

Meadows Hill, almost 1100 ft high, is mostly clear on its west side, forested at its peak and on the east side. Access on the west side is provided by Cortner Road and two private roads. Access on the north side is provided by Red Hill Road. There are high-voltage power lines about 1.5 km to the northeast. Figure 37 is a photograph taken from Cortner Road. A topographical map of the area is shown in Figure 38. It shows the location of six positions at which the vans were placed to make four path measurements. Figure 39 gives an elevation profile for each of the paths. The vertical scale has been exaggerated 2 to 1.

2. Data

a. Path Loss Measurements

Table 16 lists the measured test link margins for the four paths measured. Table 17 lists the calculated EPL for each combination of antenna height and path length. The PLRS equipment failed to develop test link margin on only one of the four paths, the shortest Path A1-D, 950 m, which has the largest obstacle angle.

b. Ranging Measurements

The map scaled distances for Paths B1-E, A2-D, and B2-E are 1500 m, 1750 m, and 1900 m, respectively. The average corrected indicated range for all antenna heights is 1540 m, 1774 m, and 1995 m, respectively, less than 5 percent error.

FIGURE 37 MEADOWS HILL PHOTOGRAPH

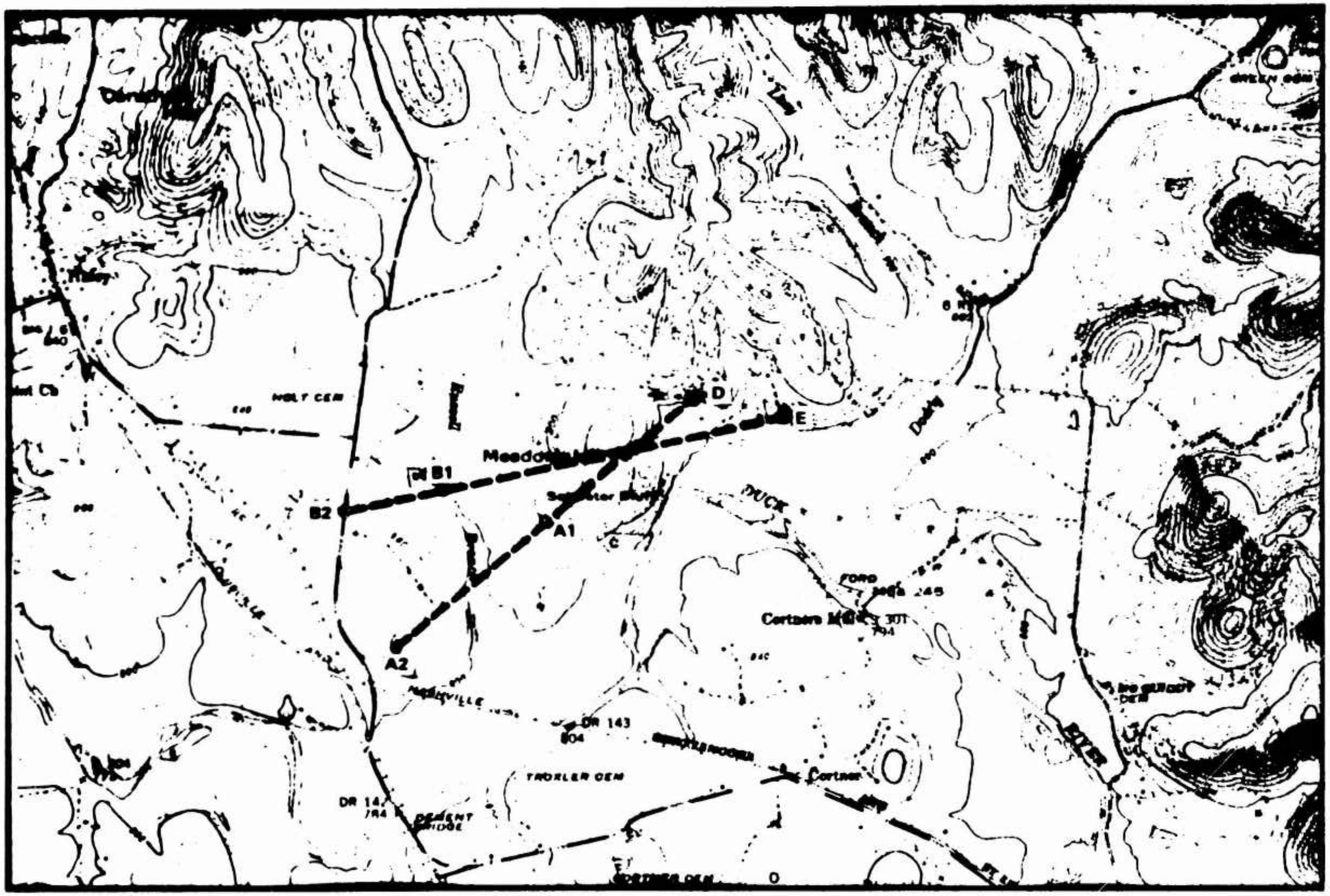

FIGURE 38   MEADOWS HILL TOPOGRAPHICAL MAP

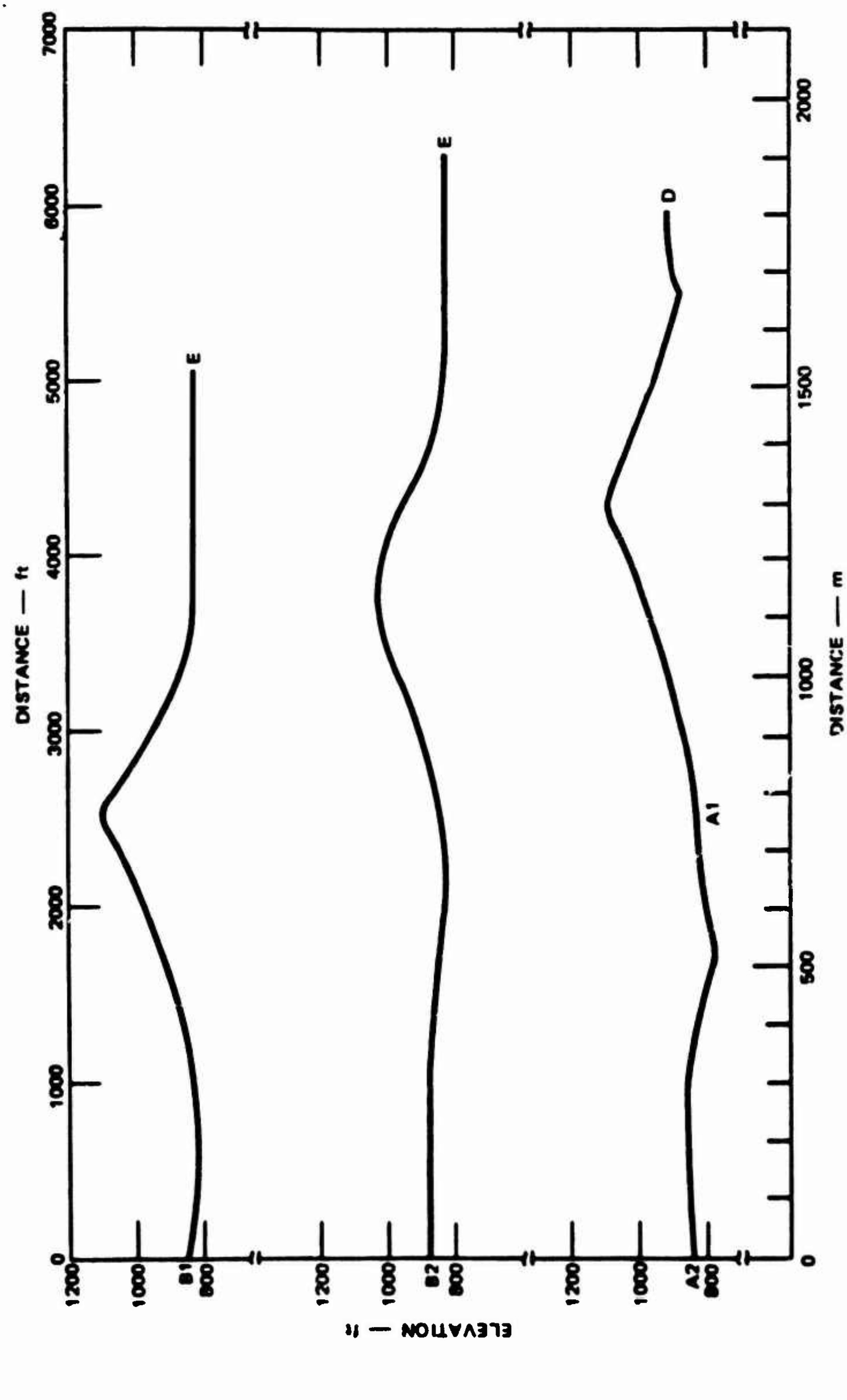

FIGURE 39 MEADOWS HILL PATH ELEVATION PROFILES

Table 16

MEADOWS HILL TEST LINK MARGIN

Antenna Height[a] (ft)	Test Path			
	A1-D 950 M (dB)	B1-E 1500 M (dB)	A2-D 1750 M (dB)	B1-E 1900 M (dB)
13	--	24	21	--
6	--	--	--	22 to 25
13, 6[b]	< 0	27	37	--
6, 13	--	--	--	29

a Measured to antenna base, center of antenna is 2 ft higher.
b Two different antenna paths are indicated.

Table 17

MEADOWS HILL EXCESS PATH LOSS

Antenna Height[a] (ft)	Test Path			
	A1-D 950 M (dB)	B1-E 1500 M (dB)	A2-D 1750 M (dB)	B2-E 1900 M (dB)
13	--	47	49	--
6	--	--	--	45 to 47
13, 6[b]	> 75	45	33	--
6, 13	--	--	--	41

a Measured to antenna base, center of antenna is 2 ft higher
b Two different antenna paths are indicated.

VI DISCUSSION

Simple optical blockage effects would lead to the expectation that EPL should be directly related to tree density. Figure 40 has been plotted using data from three Eglin AFB sites; Peel, Duke, and Basin Bayou. Only the treetop and upper canopy EPL data was used because it is more directly related to tree-trunk density, which had been measured during the original site surveys. At lower antenna heights undergrowth is highly variable from site to site and not necessarily related to trunk density. In Figure 40 data have been plotted for both the treetops and the upper canopy. The 200-m data from Peel and Duke and the 300-m data from Basin Bayou have been grouped together as has 400-m and 600-m data. 200-m and 400-m paths were not available at Basin Bayou. Figure 40 clearly indicates that, at least for short paths, EPL is directly related to trunk density at antenna heights above undergrowth level.

A review of all short and long path foliage data taken indicates that EPL almost always increases with decreasing antenna heights. Even at Basin Baycu, where it was possible, setting the antenna height at a bare trunk level did not decrease the EPL significantly.

During the propagation measurements a test was made of the effect of siting with respect to the foliage. At Peel Field using a 400-m path, data was taken with one or both vans positioned either backed up to the edge of the trees or moved 20 m or 40 m away. The EPL data are summarized in Table 4. For an antenna height of 13 ft with 35-ft trees, the EPL is not reduced by moving one or both antennas into the clearing. This indicates that for this particular situation of antenna heights and path length that the controlling propagation mode is directly through the foliage, not over the tops of the trees.

Data taken at Basin Bayou for a 1050-m path on days when the foliage and trunks were wet and compared to data taken on a dry day indicates that wet conditions can increase the EPL by as much as 20 percent in dB.

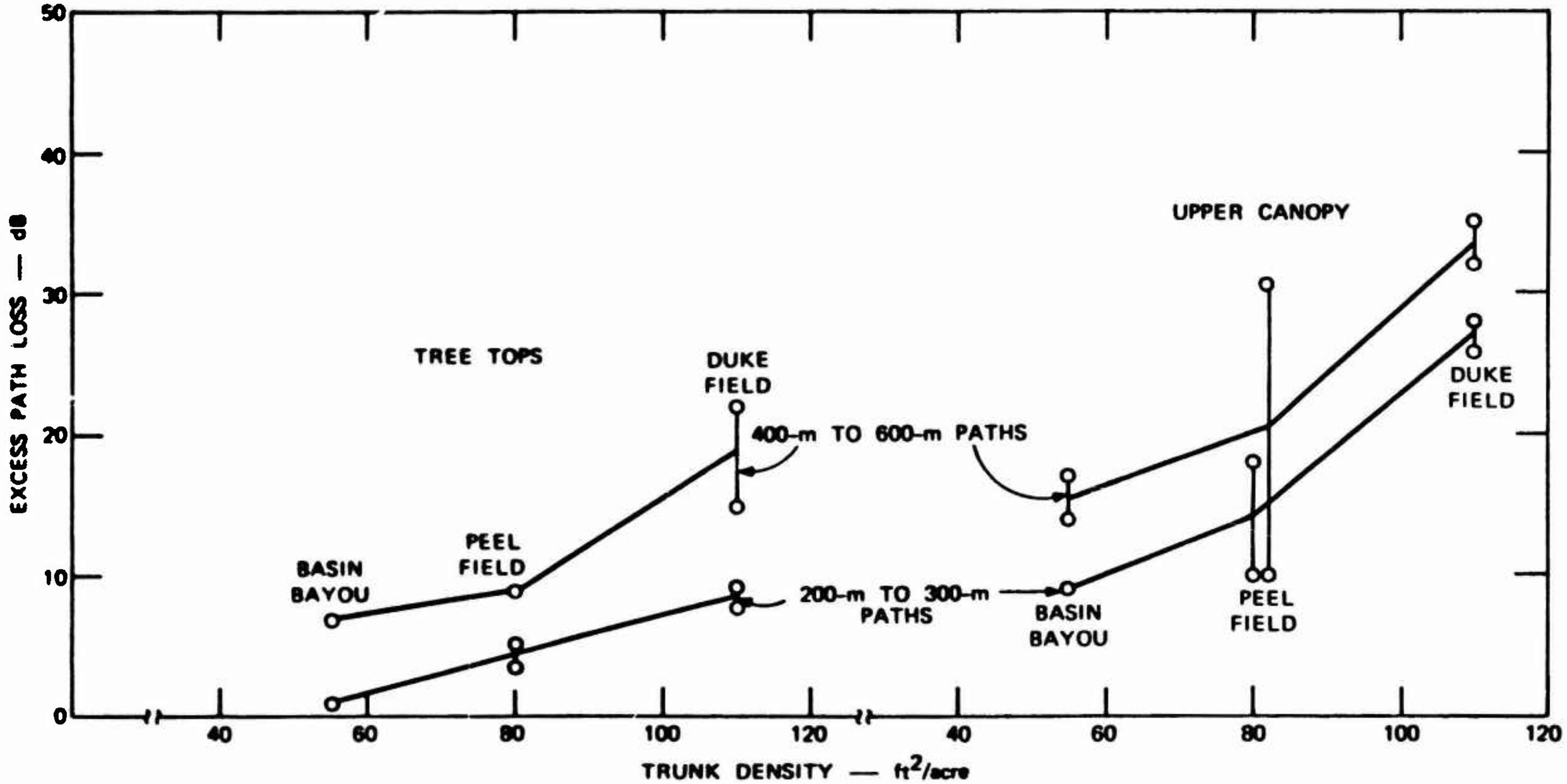

FIGURE 40 FOLIAGE EXCESS PATH LOSS VS TREE TRUNK DENSITY

TOA data taken during the foliage tests indicate that indicated range error can reach values of as much as +10 percent. Indicated range spread among the eight frequency channels can increase by a factor of 10 in foliage conditions.

A comparison of the PLRS field measurements with those made in the past by Saxton and Lane (1955), LaGrone (1960), Swarup and Tewari (1975), and others indicates that most effects observed in the past are confirmed by the PLRS measurements. These main effects are:

(a) EPL rate decrease with path length
(b) EPL increase with tree density
(c) EPL decrease with antenna height.

The value for EPL rate given by La Grone (1960), which summarized measurements made by several researchers, was 0.15 dB/m for measurements at 430 MHz. The PLRS measurements varied from 0.1 dB/m to 0.2 dB/m for a variety of test conditions and thus bracket measurements made in the past.

One of the most important effects observed during the foliage measurements was the decrease of EPL rate with increasing path length. This effect has been observed by Head (1960) and others and is an important factor in predicting the maximum range capability of PLRS. The EPL data from Peel Field shown in Figure 9 indicates that EPL rate at treetop antenna heights is essentially constant at 0.023 dB/m. At undergrowth antenna height the EPL rate is 0.2 dB/m for the shortest path and 0.09 dB/m for the longest path. At the upper canopy antenna height the EPL rate also decreases by 2:1 from 0.08 to 0.04 dB/m. The decrease in EPL rate indicates the presence of a propagation mode that does not follow the shortest (straight line) and highest-loss path. The ranging data indicates that the undergrowth level path range error is no greater than +10 percent; therefore, the propagation path must be close to the shortest (straight line) path. The only possible location can be along the treetops where the EPL rate is measured to have the lowest value. This possibility was suggested by Head (1960) and labeled the "leakage field."

The presence of the indirect-path propagation mode (leakage field) makes the prediction of the ultimate range capability of PLRS difficult. However, the test link margin data taken at Peel Field allows a reasonable attempt to be made for situations similar to that site. Figure 41 shows the test link margin data plotted versus path length and then extrapolated to zero margin to indicate the maximum possible communications range for a situation like Peel Field but with longer paths. The extrapolation is based simply on the last range segment data slope. (This extrapolation is also based on the measured test link margin. The operational link margin is greater by 3 dB to 4 dB; thus, the maximum path extrapolation should be a few percent greater.) Thus the maximum range capability of PLRS could be as short as 800 m for a 6-ft antenna height or as long as 2500 m for treetop antenna heights. Figure 42 is a plot of the required transmitter peak power versus the desired path length parametric in antenna height. This plot is a prediction based on the extrapolated test link margins shown in Figure 41. This plot underscores the relative lack of effectiveness of a factor of ten increase in transmitter power in producing increased path length capability in the presence of ground foliage.

During the 1960s a lossy dielectric slab model was developed by Sachs and Wyatt (1968) and others. The model was intended to aid in the understanding of path loss phenomena observed with a path immersed in a jungle medium. This is apparently the only theoretical model developed that is analogous to the foliage path situation. The model was originally developed for long waves (frequencies below 100 MHz), and is based solely on RF loss by absorption. It makes no attempt to take into account scattering effects. It does demonstrate the exponential loss of signal. However, it requires the average foliage conductivity as an input to the model. As it is not possible to measure that parameter directly during the field measurements, it is not possible to compare the model independently against the PLRS measurements meaningfully.

A realistic model for the propagation of UHF waves in a forest environment must consider the usually random distribution in location, size, and orientation of scattering elements. In addition the

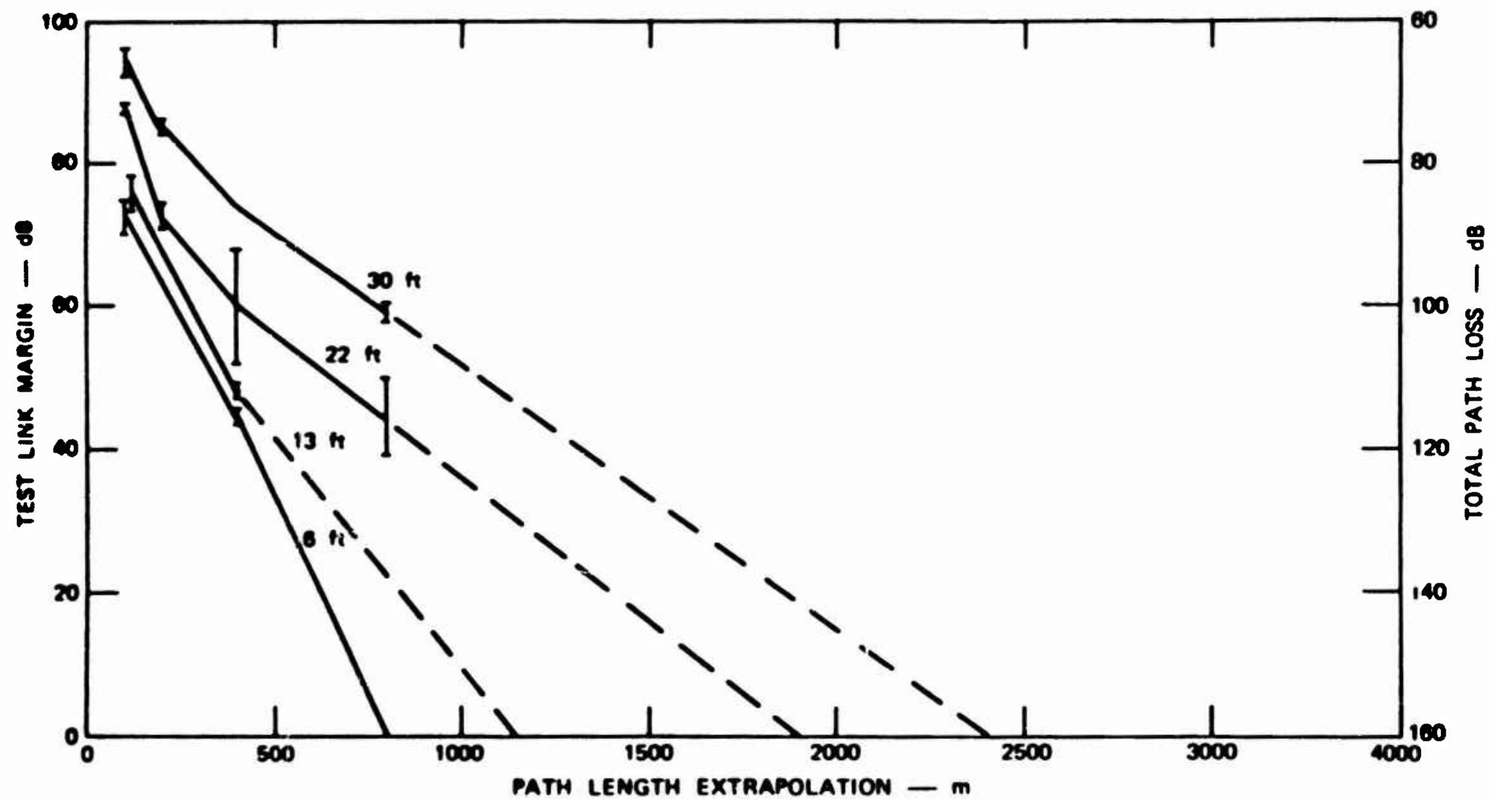

FIGURE 41 PEEL FIELD TEST LINK MARGIN VS PATH LENGTH EXTRAPOLATION

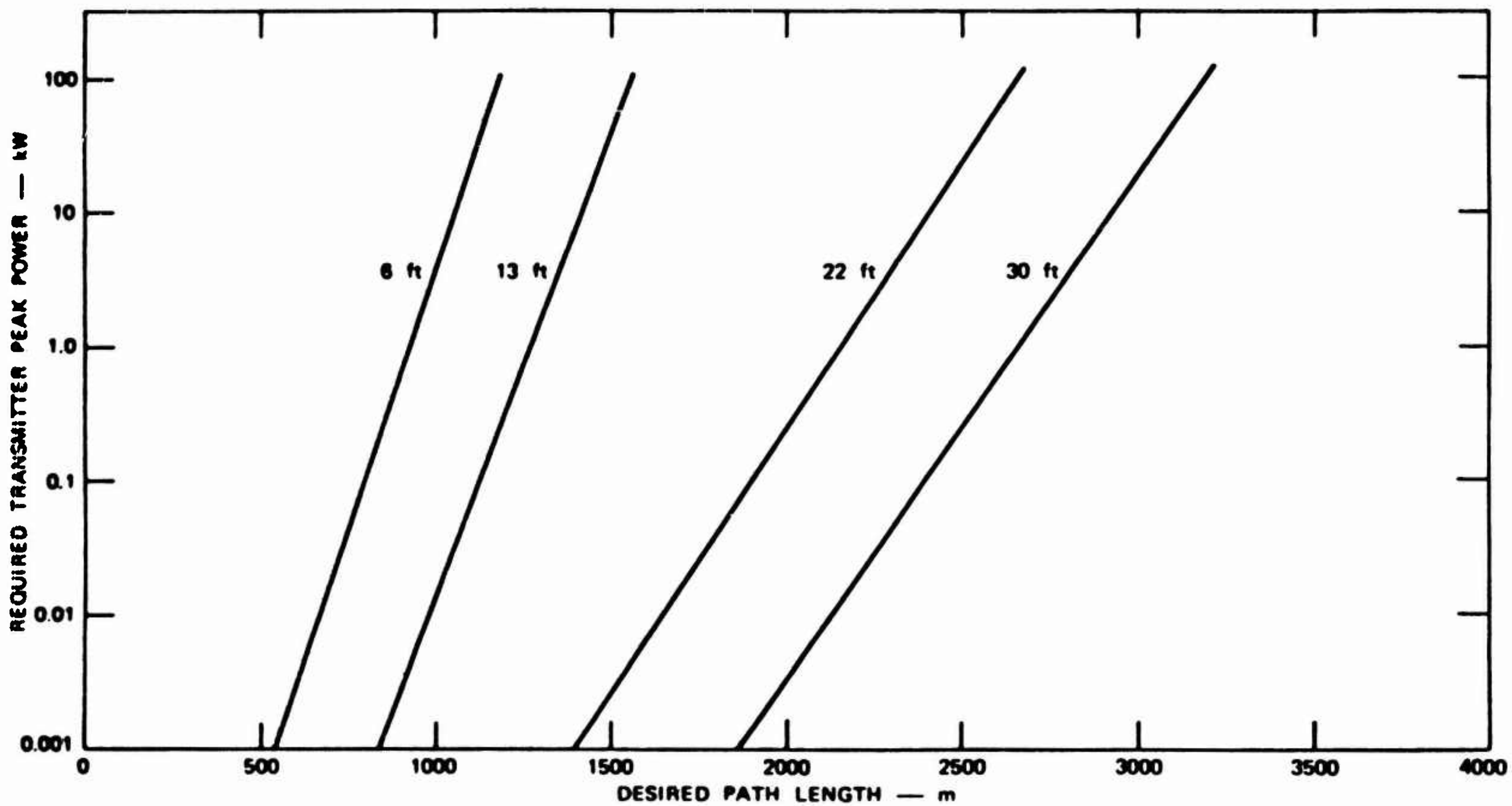

FIGURE 42 PEEL FIELD REQUIRED TRANSMITTER PEAK POWER VS DESIRED PATH LENGTH

electrical scattering, absorptive properties, and wind-induced motion of the foliage need to be included in the model. Such a complete model has not been developed thus far.

EPL data taken from the terrain obstacle path measurements have been plotted in Figure 26. EPL has been plotted versus antenna height using only the data in which equal antenna heights were used. Most of the data points lie between 30-dB and 50-dB EPL. The Negro Hill data show significantly different character from the rest of the data. The fact that EPL for that particular path drops with antenna height indicates strong spatial filtering that eliminates multipath problems, which occur at the higher antenna heights. The hypothesis that multipath modes vary as a function of antenna height is consistent with the TOA data shown in Figure 27.

The same EPL data have been plotted against obstacle angle in Figure 43. The obstacle angle is the largest of the two angles measured between the obstacle peak and the line between the two antennas. Also shown in Figure 43 is the theoretical curve for EPL caused by knife-edge diffraction as described by Bullington (1957). The average of the measured EPL data fall 15 dB to 20 dB above the theoretical curve. This difference is easily explained by the presence of trees on the tops of hills and ridges. In particular the 0° to 2° data come from the Powers Bridge Drop site at which the ridge is heavily foliated. The fact that the data do not follow a well-defined curve is explained by the lack of a clearly defined knife-edge at any of the sites.

All of the indicated range data have been reviewed to look for the presence of large errors. For the long (greater than 400-m) paths, actual path lengths must be scaled from a topographical map; a process that is limited to about ±5 percent accuracy. Comparing average indicated range with map scaled path lengths produce two obvious cases in which the 5 percent limit was exceeded. The first case is the Path G-F at Fuller-Davidson Ridge where the range error was +251 m or 22 percent. The second case is the Path C-A at Riley Creek Ridge where the range error was as much as 370 percent for a specific frequency channel. These

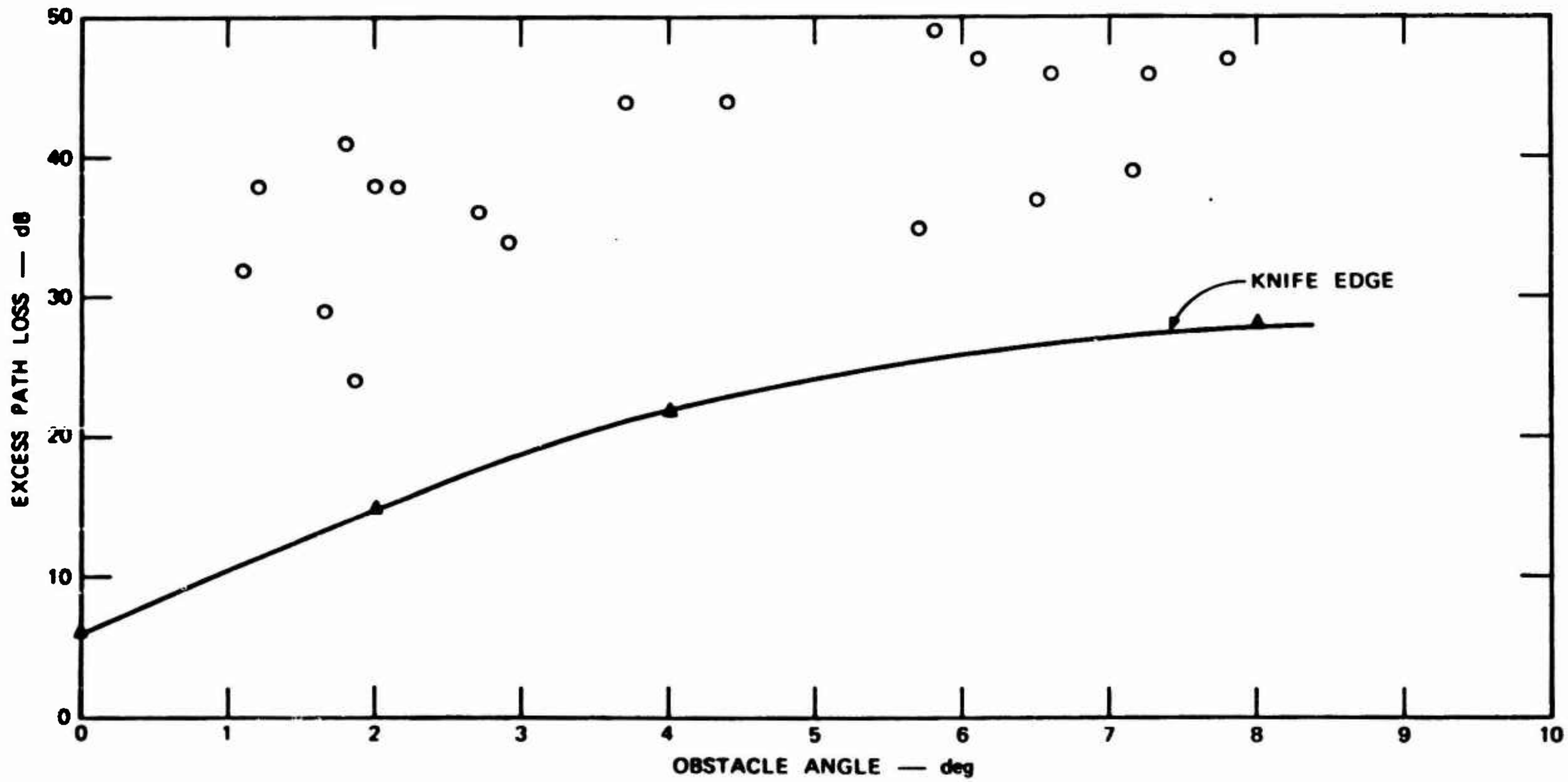

FIGURE 43 TERRAIN OBSTACLE EXCESS PATH LOSS VS OBSTACLE ANGLE

two cases indicate again that a great many path modes exist at widely varying signal levels. When the EPL for the direct path exceeds that of the longer more wild paths, the PLRS system can then detect the longer paths.

The data have been reviewed to study the spread between high TOA and low TOA and the relation to propagation conditions. During system calibration using coaxial cable to connect the BUU to the PTU, the TOA high-low spread is 1 to 2 counts (12.5 ns or 2 m per count). The TOA spread increases to 2 to 3 counts when antennas and line-of-sight propagation are used, but it does not change with line-of-site path length. For propagation through foliage with an EPL less than 20 dB, the TOA spread remains at the 2 to 3-count level. For propagation through foliage with an EPL greater than 30 dB, the TOA spread jumps to as much as 40 to 60 counts on some frequency channels, but remains at 2 to 6 counts on others. As the EPL increases up to 70 dB no real change in the TOA spread occurs.

For propagation over terrain obstacles the TOA spread can be greatly increased. For paths with EPL around 20 dB, the TOA spread can be as much as 100 counts. As the EPL increases up to 40 dB the TOA spread can be as large as 200 counts, but not consistently; again some frequency channels may have a TOA spread of only 2 to 3 counts.

The conclusion drawn from the TOA spread effects is that small spreads are caused by phase distortion or unresolved multipath effects. Large spreads indicate the presence of multipath that is resolved in range by the PLRS system.

VII COMPARISON OF JTIDS AND PLRS DATA

The effect of foliage and terrain obstacles on PLRS and JTIDS (Presnell, 1980) propagation paths is very similar. The main effect is a large increase in path loss. Figure 44 shows a plot of EPL versus antenna height for JTIDS and PLRS data taken at the Basin Bayou site for the same three paths: 300 m, 600 m, and 1050 m. Only data from three antenna heights (treetop, upper canopy, and bare trunks) are shown for simplicity. For all three antenna heights JTIDS experiences higher EPL than PLRS. The differential increase is the greatest at upper-canopy antenna height. The foliage situation, however, is not as clear cut as that figure would indicate. In Figure 45 EPL data from three sites: Basin Bayou, Peel, and Duke are shown. JTIDS EPL is consistently higher than PLRS EPL in the upper canopy. However, in the treetops the situation is more confused with PLRS EPL higher half of the time and JTIDS higher half of the time. Note that for all of the EPL data discussed in this section, JTIDS used a CP omnidirectional antenna and PLRS used a vertical omnidirectional antenna. JTIDS polarization data indicate that CP produces an EPL several dB lower than the vertical; therefore, the JTIDS EPL values would be several dB higher than actually measured if vertical polarization had been used.

The effects of the foliage situation on JTIDS and PLRS propagation was essentially the same. If the antenna height is low compared to the treetop height, moving one or both antennas into an adjacent clearing does not reduce the EPL.

The effect of foliage on both JTIDS and PLRS propagation in the frequency plane is similar. For both systems the adjacent frequency channel amplitude differential can be as much as 20 dB to 30 dB. This indicates that the controlling basic phenomena is microwave scattering at both frequencies.

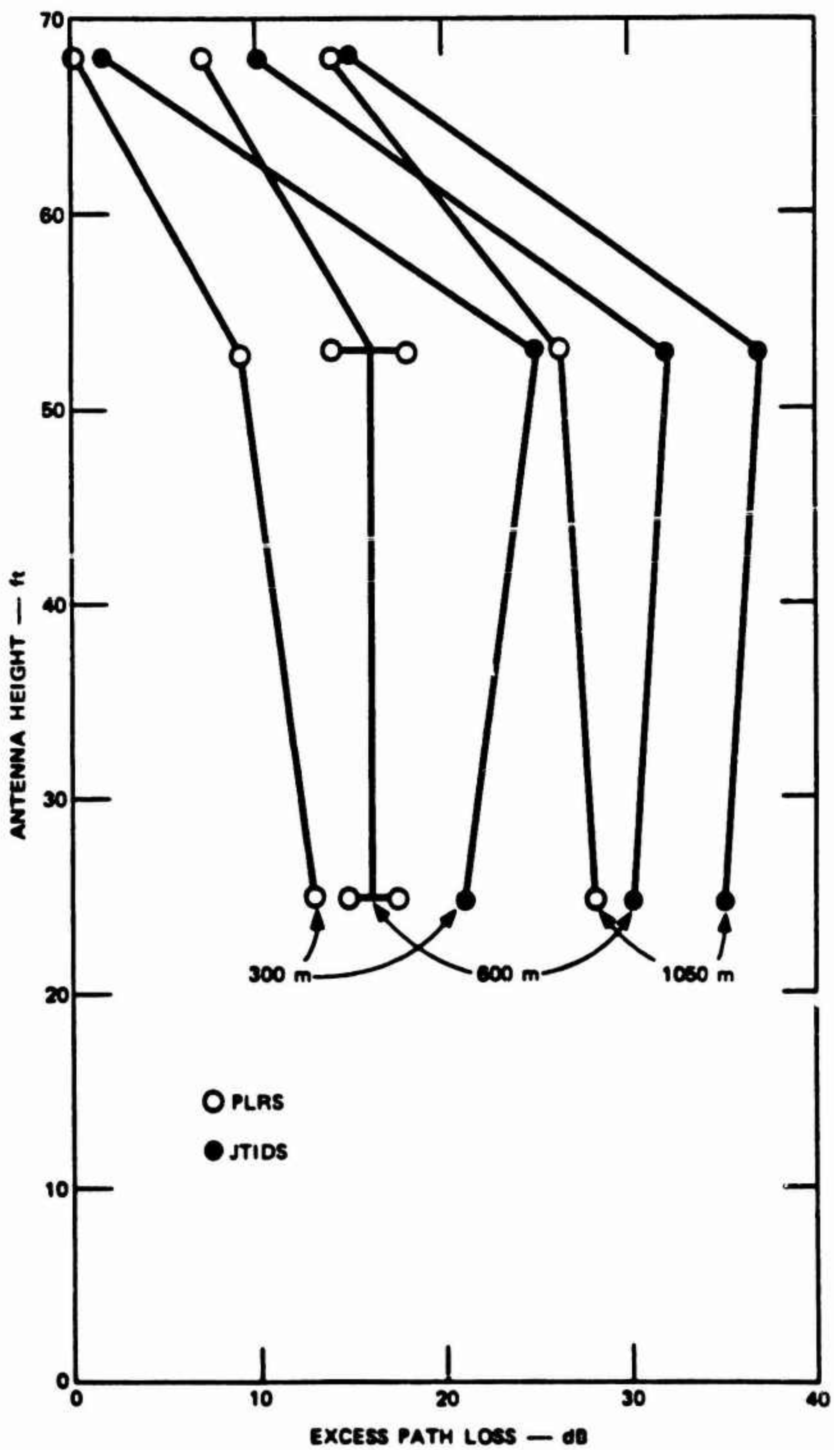

FIGURE 44 PLRS AND JTIDS ANTENNA HEIGHT VS EXCESS PATH LOSS

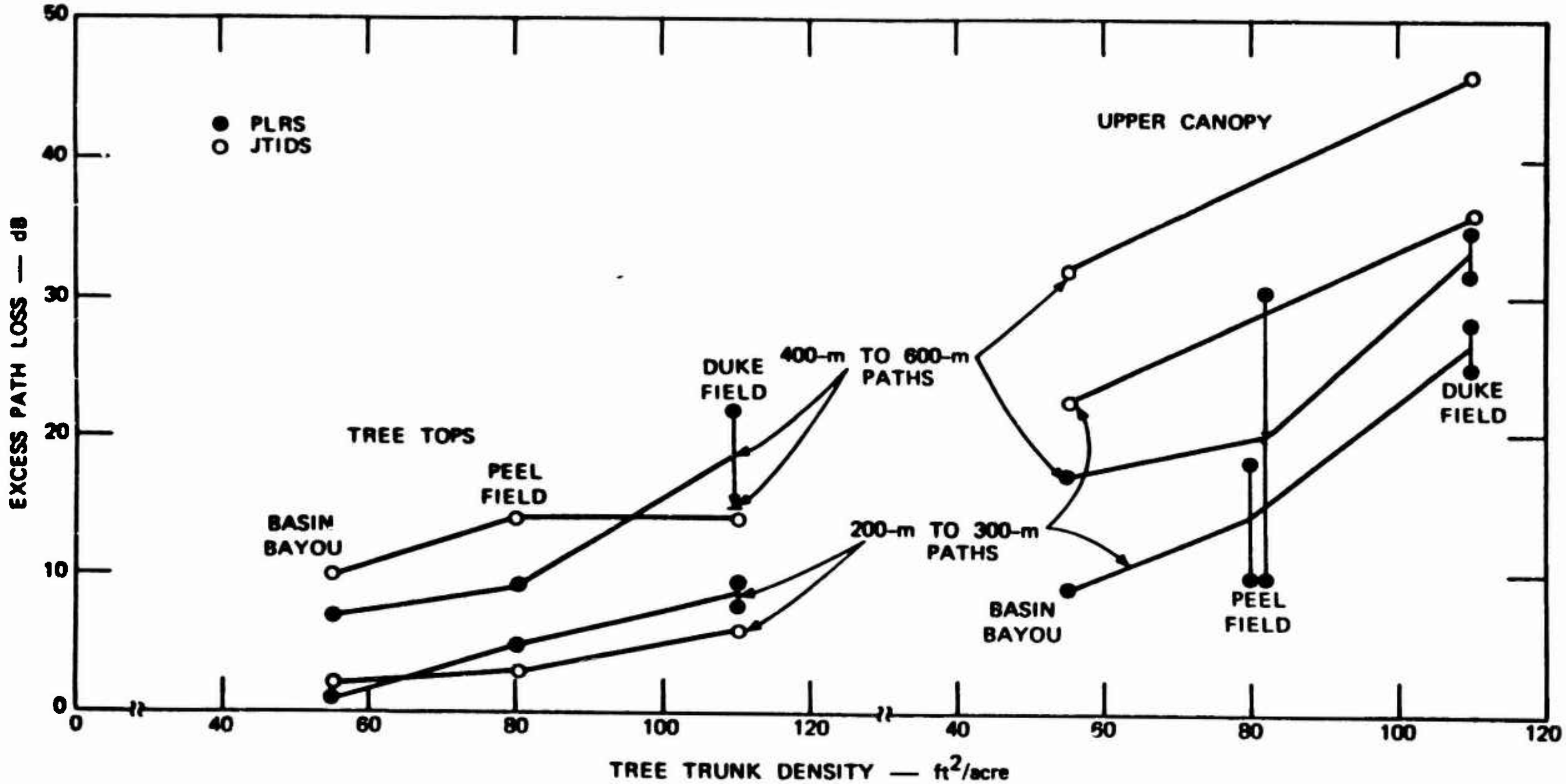

FIGURE 45 PLRS AND JTIDS EXCESS PATH LOSS VS TREE TRUNK DENSITY

Figure 46 is a plot of EPL versus obstacle angle for both systems operating with paths over terrain obstacles. As indicated PLRS has slightly higher EPL values than JTIDS on the average for a given diffraction angle. If the JTIDS antenna had been vertically polarized the terrain obstacle data would have been essentially independent of frequency.

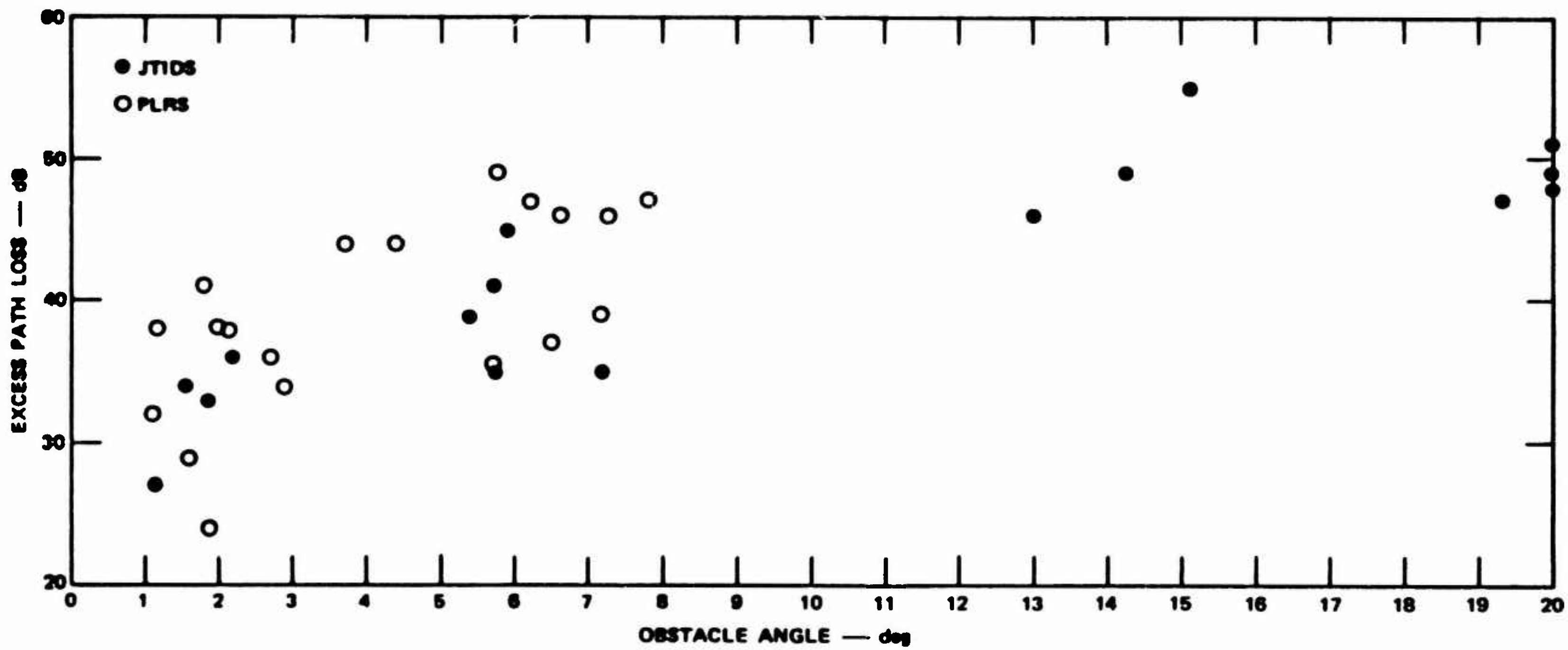

FIGURE 46 PLRS AND JTIDS EXCESS PATH LOSS VS OBSTACLE ANGLE

VIII CONCLUSIONS

Ground-to-ground propagation measurements have been made using the PLRS system. The acquired data have been reduced and analyzed. Data taken on propagation paths through foliage clearly indicate that, at least, for short paths the EPL is directly related to tree-trunk density at antenna heights above undergrowth level. Data taken at all path lengths through foliage shows that EPL almost always increases with decreasing antenna heights. PLRS successfully communicated over most of the forested paths that were attempted up to 2 km. However, at 6-ft antenna heights the maximum PLRS range capability measured 800 m under medium tree density and undergrowth conditions. EPL rate was found constant versus path length only at treetop antenna height. For all other antenna heights EPL rate decreased with increasing path length. Apparently, this is the effect of indirect path modes that are not sensed by the PLRS system until the EPL for the direct path exceeds the 30-dB level. The most plausible explanation for these indirect path modes is that the actual path is up to the treetops, along the treetop, and back down. Such a mode is consistent with TOA ranging measurements made on foliage paths. For an antenna height of 13 ft with 35-ft trees, the EPL is not reduced by moving one or both antennas into any available clearing. Wet foliage conditions can increase the EPL by as much as 20 percent in dB.

TOA data taken during the foliage tests indicate that indicated range error can reach as much as +10 percent. Indicated range spread among the eight frequency channels can increase by a factor of 10 in foliage conditions.

Ground to ground propagation measurements have been made over terrain obstacles with path length up to 2.3 km. Most of the EPL data values are between 30 dB and 50 dB and exceed the value for theoretical knife-edge diffraction loss by 15 dB to 20 dB. TOA data taken indicate

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that multipath modes vary as a function of antenna height. The variation of EPL with antenna height was not consistent from site to site.

TOA data taken during the terrain obstacle tests showed that significant indicated range error was found in two cases. The first case occurred during a solid link with the range error equal to +251 m or 22 percent. The second case occurred during a link in which only a few of the eight channels had link margin. In that situation the range error was as much as 370 percent for a specific frequency channel. PLRS failed to establish a link on a 300-m path with a terrain obstacle that had an obstacle peak angle of 13°. That case had the worst terrain obstacle of all the sites visited.

Data taken during both the foliage and terrain obstacle tests indicate that a large spread between the high TOA and the low TOA is an indication of the presence of multipath resolved in range by the PLRS system. In 27 cases out of 187 total or 14 percent, the PLRS system suffered a decrease in link margin because of multipath conditions.

IX RECOMMENDATIONS

If we presume that the ultimate goal of PLRS propagation measurements is to be able to predict a tactical net performance in the field, then there are two possible ways to proceed. The better way is to field a typical PLRS tactical net at a site that best simulates the ultimate site and make net performance measurements. The other approach is to use the single link measurements that have just been made as inputs to a computer code that simulates a PLRS tactical net operation. More single link measurements are indicated, if the sites just visited do not simulate the ultimate site adequately.

Additional recommendations include the following:

(1) Make future propagation measurements using the normal frequency hopping system, which would more closely simulate a real situation.

(2) Research the ultimate location in which PLRS will be used by measuring the foliage and terrain parameters so that future field measurements can be made at sites that are a better simulation.

(3) Evaluate procedures currently used to make propagation predictions. Change the procedures so that they can take into account the parameters just measured or make future field measurements in a way that reflects the manner in which predictions are going to be made.

(4) Carry out a study to evaluate the effect of the measured single link TOA ranging errors on a PLRS tactical multi-unit net.

REFERENCES

Bitterlich, W., "Die Winkelzahlprobe," Allgemain Forst-und Holzwirtschaftliche Zeitung, Vol. 59(1/2); 4-5 (1948).

Bullington, K., "Radio Propagation Fundamentals," The Bell System Tech. Jour., Vol. 36, No. 3 (May 1957).

Head, H. T., "The Influence of Trees on Television Field Strengths at Ultra-High Frequencies," Proc. IRE, Vol. 48, pp. 1016-1020 (June 1960).

LaGrone, A. H., "Forecasting Television Service Fields," Proc. IRE, Vol. 48, pp. 1009-1051 (June 1960).

Presnell, R. I., "JTIDS Ground-to-Ground Propagation Measurements," Final Report, Contract No. MDA903-78-C-0126, SRI Project No. 1056, SRI International, Menlo Park, CA (June 1980).

Presnell, R. I., "JTIDS Ground-to-Ground Propagation Test Site Survey--Eglin AFB," (October 1979a).

Presnell, R. I., "JTIDS Ground-to-Ground Propagation Test Site Survey--Arnold AFS," (October 1979b).

Sachs, D. L. and P. J. Wyatt, "A Conducting-Slab Model for Electromagnetic Propagation Within a Jungle Medium," Radio Science, Vol. 3, No. 2 (February 1968).

Saxton, J. A. and J. A. Lane, "VHF and UHF Reception," Wireless World, Vol. 61, pp. 229-232 (May 1955).

Swarup, S. and R. K. Tewari, "Propagation Characteristics of VHF/UHF Signals in Tropical Moist Deciduous Forest," Institution of Electronics and Telecommunications Engineers Journal, Vol. 21, No. 3 (March 1975).

Texas Instruments, Inc., "Tactical POS/NAV for the 1991 Air/Land Battle Field," Signal, Vol. 33, No. 10 (August 1979).

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