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Interim Report,

TACTICAL JUNGLE COMMUNICATIONS STUDY,

11 21 March 1963,

Work Done for USAELRDL, Communications Dept.,

Transmission Facilities Division

Antenna and Propagation Branch

Fort Monmouth, New Jersey

Contract DA-36 039-AMC-00011 (E)

by

Surface Communications Systems Laboratory

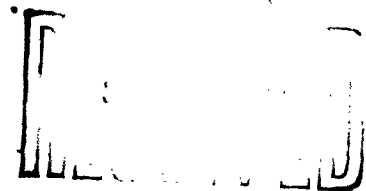Surface Communication Division

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Radio Corporation of America

75 Varick Street

New York 13, New York

10 N. Artu , H. M.   , A.   , F. Wezn
and . Krov .

TISIA E

SUBJECT: Jungle Radio Communications and Quick
Erectable Lightweight Antennas

OBJECT: Investigation of jungle radio communication
and development of suitable lightweight, quick-
raise HF and VHF antennas with masts for
use in jungle areas and other terrain where the
land characteristics severely hamper radio
communications.

CONTRIBUTORS:

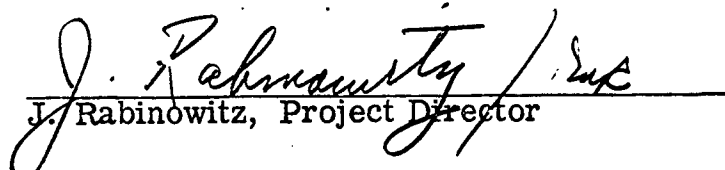| N. Artuso	S. Krevsky
H. Mason	J. Rabinowitz
R. Thowless	P. Zenchoff
F. Wezner	of N. Y. Systems Lab.
of Antenna Skill	
Center	

REPORT APPROVED BY:

J. Rabinowitz, Project Director

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SUMMARY OF RESULTS

Preset HF and VHF inter-troop communications equipment are unsatisfactory for operation in tropical rain forests. This unsatisfactory operation is a direct result of excessive path losses for ground-wave and "line-of-sight" propagation caused by dense jungle growth and tall trees. The purpose of this study is to devise antenna equipment that will improve the operational range of reliable communications between/to "man-pack" equipment in dense jungle areas.

Table VII indicates that satisfactory C W and voice ground-wave communication over smooth earth in tropical Rice Paddy type areas is possible in the noontime hours using efficient antennas. In the midnight hours, AM and SSB fail; however CW is possible. In the day time, antennas with efficiencies as low as 5% are satisfactory. Only omnidirectional vertical quarter wave antennas were considered.

Table XIV indicates that skywave transmission antennas, efficient horizontal dipoles, will provide voice communication around noon time at 8 mc about 70 percent of the time or at 3 mc only 10 to 40 percent of the time during the day. At night the satisfactory time is about 20% which is not considered acceptable.

The antenna task is in two parts,

      1. Determine mechanically acceptable HF and VHF antennas.

      2. Determine electrical performance of these antennas.

The only HF antennas considered satisfactory for tactical patrol use are shortened antennas. It is extremely difficult to use long wire center-fed dipoles or end-fed dipoles in wooded area tactics since at 3 mcs the wire should be 20 to 40 feet above ground and 160 feet long and at 6 mcs 20 feet high and 80 feet long. Because of the dense jungle limbs and vegetation, it is not a simple task to install a long wire. Hence, shortened antennas are most desirable for patrol use.

The electrical efficiency of available shortened antennas has been determined to be less than 5%. This efficiency will not suffice. Further test work and trials of shortened antennas is being done in an attempt to raise their efficiency.

Vertical antenna derived noise measurements were used in this analysis. This data gives signal strength above noise which is entirely too pessimistic since horizontal antenna noise should be much less. The means for making better estimates of this noise discrimination gain is being studied to be more consistent with the proposed horizontal antenna configurations.

Emphasis was also given to study of techniques, such as balloon borne dipoles, for obtaining useful line-of-sight VHF transmission.

SECTION 1
INTRODUCTION

1.1   JUNGLE ENVIRONMENT

In order to define the environmental conditions pertinent to this jungle communications study, it was necessary to become acquainted with the jungle, in its various forms, as it exists in the tropical areas of the world. A concept of the jungle was developed, based on the references listed at the end of this report; on discussions with Col. John R. Shirley, former AORG-UK; Major Fegan of Australia; and on the experiences of the group of engineers from RCA and USAERDL who made a field trip to Panama (refer to Appendix F) in Oct. 1962. The following paragraphs define this concept of the jungle.

Jungle vegetation may be generally classified into three categories, or types:

o   Primary jungle

o   Secondary jungle

o   A combination of primary and secondary jungle that is something between these two types.

The term primary jungle refers to virgin jungle growth which is relatively mature and has developed into the form of large trees which branch at the top, creating a canopy and reducing the amount of sunlight reaching the ground below. The vegetation below the canopy is, therefore, restricted in growth. Movement on the jungle floor, though possible without cutting, may be difficult because of vines hanging from the canopy and the abundance of fallen trees and branches. Visibility is from a few yards to 50 yards. The average height of the trees in a primary jungle is about 70 feet, but may be over 100 feet in some areas. Breaks in the canopy can usually be found within a short distance of any given location. Antenna equipment can be launched through these breaks.

Secondary jungle grows up in areas where the tall trees of a primary jungle have been destroyed, and the cleared ground is left uncultivated. Vegetation in the form of tall grass, small trees, and intertwining vines become so thick that penetration is impossible without cutting. Movement is usually restricted to established tracks which are not always suitable for vehicular use.

Terrain in tropical countries is anything from flat to mountainous, with ridges as high as 3,000 feet, with respect to nearby terrain.

Rainfall is very heavy, humidity is high, and fungus growth can be expected if preventive measures are not taken. Temperatures range from near 100°F in valleys, to near freezing on the mountains. Some tropical areas experience trade winds, although very little wind penetrates to the floor of the primary jungle.

Insect noise, in some areas, during the evening hours is considerable, but cannot be depended upon to mask noises foreign to the jungle.

In general, this report considers the jungle terrain to be anything from hilly to mountainous, in a hot and humid climate, where the vegetation can be penetrated with occasional cutting, and the canopy of primary jungle is broken sufficiently to allow the erection of an antenna.

1.2   TACTICAL OPERATIONS IN THE JUNGLE

Certain assumptions were made regarding military operations which would require jungle communication. These assumptions were made in order to establish a basis for equipment design.

Military operations against an enemy living in the jungle are extremely difficult because of the concealment that the jungle affords, and the limited mobility of any group penetrating the jungle. When military operations require that the jungle be penetrated, it is assumed that movement

would most likely be along jungle tracks. There must be a capability, however, of being able to abandon the tracks in both primary and secondary jungle. Mobility is one of the most important requirements of jungle communication. Equipment must be lightweight, small in size, and pack close to body. Carrying straps, and the pack itself must not cause fatigue or discomfort.

Usually communication by a patrol in the jungle will be restricted by conditions to rest periods, or the evening hours when the patrol stops for the night to set up its defenses and prepares to sleep. In either case the man assigned to erect the antenna will be tired and unwilling to expend much effort. It must be a simple, easy, and short job; and, once erected, it must be easily tuned.

If relay stations are to be used, the antenna installation in the jungle must be semi-permanent. This would allow the use of automatic relay equipment and would obviate the need of a guard at each station.

It is assumed that resupply by helicopter is practical when the requirement for concealment of the operation is not compromised by a hovering helicopter. It is assumed that the enemy will have observation posts on high ground and will be able to observe helicopter activity.

There will be a tendency to operate along high ground for health reasons and because of its military advantage.

SECTION II
JUNGLE RADIO PROPAGATION

2.1   SYNOPSIS

Jungle radio communication is severely handicapped by radio
wave absorption, wherever the radio wave must propagate for a considerable
distance through the dense, moist jungle vegetation. In the past, several
projects have been sponsored by various defense agencies to determine
means for circumventing the very high ground wave attenuation, without
sacrificing too much mobility for both man-pack and vehicular radios. This
work is reviewed and newly-derived information is discussed from two points
of view. First, the limitations of ground-wave HF and VHF transmission up
to 25 miles is discussed for antennas below and above the tree tops. Secondly,
low-power sky-wave transmission, with quarter or half-wave horizontal or
sloping-wire antennas only 10 to 30 feet above the ground and below the jungle
canopy, is shown to be feasible from zero to 150 miles using simplified, ion-
ospheric vertical incidence information. Several examples of expected per-
formance are given to demonstrate the prediction procedures and at the same
time provide basic information for tests in Panama for the month of October,
1962.

2.2   BASIC DEFINITIONS: RELIABILITY, GRADE OF SERVICE, AND RECEIVER SENSITIVITY

2.2.1   Reliability and Grade of Service

Reliability is measured by the number of days in a month, hours
in a day, and minutes within an hour, that a signal will be available to ex-
ceed a given grade of service. For ground-wave propagation, acceptable
service is defined in Reference 3 as the percent time availability (usually
90 percent) in days of a given month of a given SNR (signal-to-noise ratio)
which exceeds the requirements for 90 percent intelligibility, order-wire
quality for phone, or 15 wpm Manual Morse CW telegraphy. Reference 3
covers the intimate details of these definitions on page 9 under the title of

"Type-of-Service" gains, which by their definition is the ratio in db of the required signal power for the service under consideration to that of the reference service which is 0 db, or SNR of 1 in a 1 kc bandwidth. For sky wave, 8 db is added to each threshold in order to account for fading margin.

2.2.2   Required Field Strength as a Function of Required Receiver Input

The power intercepted by a receiving antenna, given the field strength, is determined (Reference 14) by the following formula:

$$P_o = P_D \, A_e \tag{1}$$

$$\frac{V_o^2}{Z_o} = \frac{e^2}{120\,\pi} \cdot A_e \tag{2}$$

$$V_o = \sqrt{e^2 \cdot \frac{A_e}{377} \cdot Z_o} \tag{3}$$

where: P_D = Power density, watts per square meter

P_o = Power intercepted by antenna, watts

V_o = Microvolts across Z_o .

e   = Microvolts per meter

377 = Impedance of free space

A_e = Effective antenna aperture

= 0.12 λ^2 for short-vertical antenna

= 0.13 λ^2 for half-wave antenna

Z_o = Receiver input impedance (50 Ω)

The formula is convenient in the following form:

$$e = \frac{8 \, V_o}{\lambda} \tag{4}$$

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2.2.3   Receiver Thresholds and Sensitivities

2.2.3.1   Threshold

The hourly median input signal-to-noise ratio required to meet the performance requirement of 90 percent voice intelligibility (order-wire quality) or 15 wpm Manual Morse CW-Average Operator 90 percent copy for 90 percent of the month's days. Ground-wave thresholds are 6 db and 23 db for CW and voice, respectively. Sky-wave thresholds are 14 db and 31 db for CW and voice, respectively, to account for fading (Reference 3).

2.2.3.2   Sensitivity

Sensitivity is defined as the rms signal at the receiver input terminals required to achieve a 10 db signal-plus-noise ratio at the receiver output terminals, for 40 percent average voice modulation index or 100 percent modulation of speech, for quasi-peak of 11 db above average level, or BFO injected 1000 cps beat note for CW. Sensitivity and threshold for various equipments are given in Table I.

Table I is derived from information in Reference 3 and from equation (4), page 6.

TABLE 1

SENSITIVITY AND THRESHOLD, VARIOUS EQUIPMENTS

Equipment	Condition	Threshold*	Sensitivity
AN/TRC-77	CW: 6 kc bandwidth	Atmospheric noise + 6 db (15 wpm Manual Morse 90 percent copy)	$1 \mu V$ for $(\frac{S+N}{N}) = 10$ db **
			Freq. mc: 3 5 6 8 db above $1 \mu V/_M$: −22 −18 −16 −14
	AM: 6 kc bandwidth	Atmospheric noise + 23 db (90 percent intelligibility, Order-Wire quality)	$2 \mu V$ for $(\frac{S+N}{N}) = 10$ db
			Freq. mc: 3 5 6 8 db above $1 \mu V/_M$: −16 −12 −10 −8
AN/GRC-19, AN/KWM-2, AN/TRC-86	AM; DSB 6 kc, or SSB 3 kc	Atmospheric noise + 23 db for DSB. Atmospheric noise + 20 db for SSB. (90 percent intelligibility, Order-Wire quality)	$0.5 \mu V$ for $(\frac{S+N}{N}) = 10$ db
			Freq. mc: 2 3 10 20 30 db above $1 \mu V/M$: −31 −28 −17 −11 −8
AN/PRC-25	FM: 35 kc IF bandwidth	*(handwritten annotation)*	$0.7 \mu V$ for $(\frac{S+N}{N}) = 10$ db ***
			Freq. mc: 30 60 db above $1 \mu V/_M$: −5 +1

Note

** Threshold is equal to sensitivity when receiver noise governs, which is the case at 30 mc and higher. Below 30 mc atmospheric and man-made noise generally govern, in which case the threshold is defined independently...

* Ground Wave Conditions Only. For Sky Wave, add 8 db to Threshold. *(handwritten annotation)*

*** The −22, −18, −18, −14db above 1 uV/M receivers sensitivities are far below atmospheric noise, as will be noted later.

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2.3 ATMOSPHERIC NOISE CONSIDERATIONS

A great deal is known about atmospheric noise reception in Panama. The NBS-CRPL group has had an advanced noise-measuring set called the ARN-2 (Reference 1) in Balboa for many years, gathering excellent long-term and short term data. This data has been digested, for prediction purposes, such as required in this report, in two useful documents, one published by the CCIR called Report #65 (Reference 2), "Revision of Atmospheric Noise Data," Geneva 1957, and the second (Reference 3) published by the Signal Corps Radio Propagation Agency in Technical Report No. 5, "Median Signal Power Required for Reception of Radio Transmissions in the Presence of Noise," Fort Monmouth, June 1961.

Two discussions of noise, in Panama, are given in two reports by Signal Corps groups on tests in Panama and tropical areas. These are (Reference 4) the CC Sig O Report No. ORB-2-3 on "Measurement of Factors Affecting Jungle Radio Communications" USA Radio Propagation Agency File No. 3312, and (Reference 5) NDRC Report C-79 Part III Final Report, synopsized in Appendix A. However, both reports are outdated. The NBS (Reference 1) information is the more recent and accomplishes in adequate detail the recommendations of both Reference 3 and 4 for more noise data. In addition, the NBS information includes detailed noise information concerning Singapore, South East Asia, an area of vital interest. It has been determined that local thunderstorms do not completely interrupt radio communications. The median noise measurements and statistics are considered adequate for determination of system performance.

Table II provides a synopsis of the expected noise in the Canal Zone on the 3 and 8 mc frequency spectrums as derived from the NBS-CCIR information, Reference 2. Reference 3 contains the identical data, reduced to a different form. Note that this is noise measured by a short vertical antenna close to the ground. When half- or quarter-wave horizontal, or sloping-wire antennas are used, the noise will be considerably less,

particularly during the night at the lower frequencies due to the low-angle discrimination of the horizontally-polarized high-angle antennas.

TABLE II
EXPECTED ATMOSPHERIC NOISE IN CANAL ZONE, OCTOBER

Local Time	N_a; 3 mc	N_a; 5 mc	N_a; 8 mc
00-04	23	18	13
04-08	13	10	8
08-12	-2	1	3
12-16	-2	1	3
16-20	13	10	8
20-00	23	18	13

N_a: Median Noise Expected db above $1 \mu V/M$ in 6 kc Band

Table III shows the required threshold signals at 3 and 8 mc, for ground and sky waves for the AN/TRC-77 used on Manual Morse CW or DSB voice (Reference 5) at a bandwidth of 6 kc.

TABLE III
HF SKY WAVE AND GROUND WAVE SIGNAL REQUIRED TO EXCEED THRESHOLD

Local Time	Ground Wave 3 mc		Sky Wave 3 mc		Ground Wave 8 mc		Sky Wave 8 mc	
	CW	Voice	CW	Voice	CW	Voice	CW	Voice
00-04	29	46	37	54	19	36	27	44
04-08	19	36	27	44	14	31	22	39
08-12	4	21	12	29	9	26	17	34
12-16	4	21	12	29	9	26	17	34
16-20	19	36	27	44	14	31	22	39
20-00	29	46	37	54	19	36	27	44

Signal Level in db above $1 \mu V/Meter$

2.4 LINE-OF-SIGHT PROPAGATION IN THE JUNGLES

2.4.1 Attenuation Through the Foliage

Only three sources of information are known which provide useful information on path loss through woods in leaf, and dense jungles. The first (Reference 6) is in the Proceedings of the IRE of June 1960 by H. T. Head on "The Influence of Trees at UHF," shown on the bottom curve of Figure 1, labeled PIRE 6-60. The second (Reference 7) is in USA Radio Propagation Agency Tech. Report No. 3 on "Ground-Wave Field Intensity vs. Distance Through Dense Jungle," shown in Figure 2. The latter information was derived from the third source, Reference 8, in which extensive measurements were made in the jungles of New Guinea and is the best information available. Figures 3 and 4 (from Reference 4) substantiate this data. A theoretical calculation was made based on EM theory (References 9 and 10) which show agreement with the original New Guinea data. Table IV lists typical known skin depths for various loss media from 2 to 100 mc. Table V lists the calculated theoretical loss per 0.1 mile and loss per 100 feet for the dense jungle foliage media using equations (5), (6), and (7). Figure 1 is a plot of the calculated loss, compared to the actual measured loss data for the jungles and mid-latitude woods as well.

The theory for the loss in foliage is essentially the same as that for loss in any medium such as sea water (Reference 10) where the field is attenuated exponentially with distance as follows:

Received field: $E = E_o e^{-d/\delta}$ (5)

Distance: $= d$, meters

Skin depth: $\delta = \dfrac{1}{2\pi} \sqrt{\dfrac{\lambda}{30 \nabla}}$ meters $= \dfrac{}{2 j \sqrt{...}}$ (6)

Wavelength: $\lambda = \dfrac{300}{f_{mc}}$ in meters

Medium conductivity: ∇ = Mhos per Meter

Loss in db: $= E/E_O = \alpha = 20 \log_{10} e^{-d/\delta} = -8.68 \; d/\delta$ (7)

when: $d = \delta$

$\alpha = 8.68$ db

TABLE IV
TYPICAL KNOWN SKIN DEPTHS FOR VARIOUS MEDIA AT 3 AND 30 MC

Medium	Conductivity Mhos/Meter	Skin Depth 3 mc Meters	Skin Depth 30 mc Meters
Sea Water	4	0.15	0.05
Wet Soil (CCIR)[20]	3×10^{-2}	1.6	0.5
Fertile Soil (CCIR)	1×10^{-2}	2.9	0.9
Dry Soil (CCIR)	3×10^{-3}	5.1	1.6
Very Dry Soil (CCIR)	1×10^{-3}	9.1	2.9
Dry Soil Minimum[10]	1×10^{-4}	29	9.2
Dry Soil Minimum[9]	1×10^{-5}	91	29
Dense Jungle Foliage	1×10^{-5}	91	29
Mid Latitude Woods	3×10^{-8}	1600	500

TABLE V
CALCULATED THEORETICAL LOSS FOR DENSE JUNGLE FOLIAGE

Frequency (mc)	Loss per 0.1 Mile	Loss per 100 Ft.
2	12.6 db	2.4 db
3	15.1	2.9
5	20	3.8
10	28	5.3
30	48	9.0
50	63	12
100	86	16

Example: $f = 3$ mc; $\lambda = 100$ Meters; $d = 0.1$ Mile $= 161$ Meters

$$\delta = \frac{1}{2\pi}\sqrt{\frac{\lambda}{30\,\gamma}} = \frac{1}{2\pi}\sqrt{\frac{100}{30 \times 1 \times 10^{-5}}} =$$

$$\frac{1}{2\pi}\frac{10^3}{\sqrt{3}} = 91 \text{ meters };$$

$$\alpha = 20\log_{10}e^{-d/\delta} = 20\log_{10}e^{\frac{-161}{91}} =$$

$$20\log_{10}(0.176)$$

Therefore:

$$\alpha = -15.1 \text{ db}$$

A final word of caution on field intensity measurements through jungles is necessary because of the likelihood of considerable profile variations. It is probably much more important in jungles, than in the open, to locate sites on hills rather than valleys because of the tremendous loss caused by the dense foliage to line-of-sight communication. Thus, any field intensity measurement is directly a function of the path profile with the foliage superimposed upon it.

For example, Figure 5 indicates some typical patrol situations.

There are two favorable conditions for the line-of-sight case:

a.   The net dense jungle cover in the path of line-of-sight is minimal.

b.   Propagation is by one path - there are no ground reflected or surface waves because they are absorbed.

Thus the field intensity obeys the inverse distance law, which is independent of frequency, and hence locating sites for "line-of-sight communications is extremely beneficial in the jungle.

2.4.2   Predicted Ground-Wave Propagation for Panama in October 1962

2.4.2.1   HF Ground Wave and Line-of-Sight

A sample calculation using the latest ground-wave transmission curves (Rec. #307, CCIR-IX Plenary Session, 1959) was made for 10 watts effective radiated power from a short vertical dipole. Since the field strength expected at 1 mile is about 85 db above $1 \mu V/_M$, at 3 mc, and the attenuation due to the foliage is over 150 db, Figure 1, ground wave below the tree tops at HF is judged hopeless. The only existing possibility is to locate the antenna above the foliage. It has been suggested that a long-wire antenna lying on the canopy would radiate sufficiently to permit useful HF "ground-wave" transmission. Study of this possibility will be made, if time and funds permit. If efficient vertical antennas can be somehow raised above the canopy, then useful SNR's at ranges up to 25 miles are easily attained with the AN/TRC-77, since the signal is the inverse distance signal which is independent of frequency, e.g. 54 db above $1 \mu V/_M$ at 25 miles.

If, however, there were no trees, ground-wave propagation over tropical cleared wet land would be as given in Tables VI and VII.

TABLE VI
GROUND-WAVE PROPAGATION OVER TROPICAL CLEARED WET LAND

Frequency mc	Field Strength at 25 Miles	TRC-77		GRC-19		KWM-2		TRC-86	
					Local Time				
		00	12	00	12	00	12	00	12
2	67	–	–	34	58	37	61	29	53
3	56	13	38	23	48	26	51	18	43
5	47	9	26	19	36	22	39	14	31
7.5	39	6	16	16	26	19	29	11	21

NOTE: <u>Soil:</u> Swampy Moist Ground, $\in$ = 4, ∇ = 0.03 Mho/$_{Meter}$

<u>Field Strength</u> Db above $1 \mu V/_M$. CCIR Rec. #307

<u>Power:</u> 1 KW ERP, <u>Noise:</u> Table II

<u>Antennas:</u> Efficient Short Vertical Monopoles, Gain of 1, located at the surface of the earth.

<u>Sample Calculation:</u> At 5 mc e = 47 db above $1 \mu V/_M$

<u>AN/TRC-77,</u> Power Output = 10 watts (CW)

therefore e = 27 db above $1 \mu V/_M$ at 5 mc.

From Table II, N_a (5 mc) = +18 db at 00 and 1 db at 12.
then received SNR = 9 db at 00 and 26 db at 12.
<u>AN/TRC-86,</u> Power Output = 15 watts (PEP)

therefore e = 29 db above $1 \mu V/_M$ at 5 mc

BW = 3 kc, therefore add 3 db.

then received SNR = 14 db at 00 and 31 db at 12.

<u>AN/GRC-19,</u> Power Output = 100 watts (AM)

therefore e = 37 db above $1 \mu V/_M$ at 5 mc;

then received SNR = 19 db at 00 and 36 db at 12.

<u>AN/KWM-2,</u> Power Output = 100 watts

and Receiver Bandwidth is 3 kc, therefore, add 3 db;

then received SNR = 22 db at 00 and 39 db at 12.

TABLE VII

GROUND-WAVE HF PERFORMANCE FOR THE TRC-77, GRC-19, ETC.

Local Times for:

Frequency mc	TRC-77(CW)		GRC-19 (AM)		KWM-2(SSB)		TRC-86 (SSB)	
	00	12	00	12	00	12	00	12
2	–	–	11	35	14	38	6	30
3	7	32	0	25	3	28	-5	20
5	3	20	-4	13	-1	16	-9	8
7.5	0	10	-7	3	-4	6	-12	-2

Performance in db that the Available SNR Exceeds the Threshold.

2.4.2.2 VHF Ground Wave and Line of Sight

Sample calculations were made for various heights of antenna for the PRC-25 based on curves in (Reference 7) Signal Corps Radio Propagation Agency Tech. Report No. 3. At 30 mc, the expected attenuation through the jungle is approximately 50 db per one-tenth mile (Figure 1) indicating an absolute necessity for operation over and above the canopy. Table VIII shows obtainable signal db above threshold for the AN/PRC-25 at various ranges for antennas above the canopy with unobstructed line of sight. For comparison, Table IX shows obtainable signal db above threshold for the AN/PRC-25 over cleared jungle ground for various antenna heights above the ground.

TABLE VIII
PERFORMANCE OF THE PRC-25 FOR CLEAR LINE OF SIGHT AT 30 MC

Range - Miles

2	5	10	20	25	40	60	80	100
70	61	55	49	48	43	40	37	35

Performance in db the Available Signal Exceeds the Threshold, T.

NOTE: Line of Sight must Prevail.

For example, from Figure 5, if the net canopy path is 50 feet + 50 feet or a total of 100 feet, having a net loss of 9.0 db at 30 mc (Table V) then at 25 miles the AN/PRC-25 signal is potentially 39 db over threshold for this idealized condition.

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TABLE IX
PERFORMANCE OF THE PRC-25 AT 30 MC, GROUND WAVE

Antenna Heights Above Ground	Range - Miles				
	2	5	10	20	40
$h_1 = h_2 = 5'$	33	17	5	-9	
$h_1 = h_2 = 25'$	41	28	15	-2	
$h_1 = h_2 = 50'$	48	33	19	17	-2
$h_1 = h_2 = 100'$	62	47	35	21	10

Moist Cleared Ground in Tropics, $\in$ = 15, ∇ = 0.01 Mhos/Meter
at 30 mc

NOTE: AN/PRC-25: Power Output = 1 Watt

T = Threshold Sensitivity = 0.7 uV (50Ω) for 10 db

$(S+N)/N$ or $T = -5db/1 uV/M$

(Receiver Noise Predominates)

Sample Calculation:

At 30 mc, d = 10 miles, $h_1 = h_2 = 25'*$:

e = 40 db above 1 uV$_M$ (Page 17, Reference 7) "Ground
Wave Field Intensity Versus Distance" elevated
half-wave vertical antennas (for 1 KW ERP).

Since the AN/PRC-25 Output ERP is 1 watt

S = 10 db above 1 uV$_{/M}$, and where T, the threshold
is -5 db above 1 uV$_{/M}$ (Table I)

then (S-T) = 15 db

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* for $h_1 = h_2 = 50'$ see page 18; $h_1 = h_2 = 100'$ see page 19;
for $h_1 = h_2 = 5'$ see page 29, all in Reference 7.

2.5 SKY-WAVE PROPAGATION IN THE JUNGLE

2.5.1 General Sky-Wave Use for Short Distances

Sky-wave propagation will provide an efficient medium for jungle communications especially during daylight hours, provided that the frequencies recommended for use are above the LUF and below the MUF as predicted herein or by the Signal Corps Radio Propagation Agency in (Reference 12). High reliability is predicted in Signal Corps Report ORB-2-3 (Page 14, Reference 4), and is possible because the attenuation through the canopy is negligible for this "vertical" mode of transmission (References 4 and 5). Night time conditions are at best, slightly more than marginal because of atmospheric noise and interference problems.

The basic propagation method occurs by means of vertical incidence from the E, Es, and F layers at 65 to 200-mile heights. The ground range for this mode of transmission is usually given as zero to 125 miles (References 4, 5 and 13).

A long-time average of 8 db has been determined as an additional threshold margin, to be added to receiver input-signal requirements, to account for fading due to sky-wave mode interference.

Although radio blackouts (sudden ionospheric disturbances) occur unpredictably on HF, sufficient information exists to sometimes give forewarning. For example, due to the 27-day solar rotation cycle, a disturbed ionosphere was predicted for 1 to 4 October and 16 to 17 October. This information is available from the U. S. Army Radio Propagation Agency, Ft. Monmouth, N. J. in the form of a monthly newsletter, or by telephone from the N. Atlantic Warning Service in Ft. Belvoir, Va. area Code 703, SO 5-6411.

2.5.2 The Expected Behavior of the Ionosphere for Panama, October 1962

Since short-distance sky-wave transmission is dependent upon vertical, or near vertical incidence reflection from the E or F layers,

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reasonable estimates of expected frequencies available can be derived from measurements taken on the site at the same relative point in the sunspot cycle and the same month of the year. Figure 6 shows the E, Es, F_1, and F_2 critical frequencies for Panama 1952 which is close to this year's expected behavior. Inspection shows that the use of the ionosphere will be good for frequencies less than 10 mc during the day and 3.0 mc during the night, except for 0200 to 0500 hours when only Es will support transmission at 3 mc and higher. Since Es will be available over 60 percent of the time during these hours, a total reliability of over 90 percent during daylight hours, and over 50 percent during night hours, is indicated, provided clear channels are used between the MUF and LUF. The detailed analysis is shown in the following tables.

2.5.3   Expected Signals, SNR's, and Reliabilities in Tabular Form

The following tables provide detail information pertaining to the analysis of expected signals, SNR's, and reliabilities.

TABLE X
MEDIAN INCIDENT SKY-WAVE FIELD INTENSITY FOR 1 KW ERP

Time	ψ	K_e	E 3 mc	F_2 3 mc	F_2 8 mc
00	--	0	55	48	48
02	--	0	55	48	48
04	--	0	55	48	48
06	88°	0.09	54	47	48
08	60°	0.45	38	35	46
10	32°	0.81	26	22	42
12	20°	0.85	24	20	41
14	38°	0.72	28	24	43
16	68°	0.45	38	35	46
18	95°	0.09	54	47	48
20	--	0	55	48	48
22	--	0	55	48	48

NOTE: Field Intensity in db above 1 uV/$_M$.

E layer height = 105 km = 65 miles

F_2 layer height = 320 km = 200 miles

K_e: Absorption factor for October 10° north latitude

RASSN (Running Average Sun Spot Number) = 25 for October 1962

ψ = Solar zenith angle for October, 10° N. latitude

(Reference: Pages 103, 110, 112 and 114, RPA Tech. Reference 13)

Sample Calculation:

At 00 Local Time

ψ = 0, therefore K = 0 and there is no absorption.

Therefore, E layer field intensity is that for an unattenuated signal on a 130-mile path (up to the E

TABLE X (Continued)

layer 65 miles up and back), and for the F
layer, a 400-mile path, 200 miles up and back.

Since half-wave horizontal antennas 30' high are
considered, radiation is almost all up; there-
fore, the relative antenna gain is 1. See page
137, Reference 13, and note antenna gain for
radiation angle of 90° (directly up overhead).

Hence: e (E layer) = 55 db above 1 uV/$_M$

        e (F_2 layer) = 48 db above 1 uV/$_M$

<u>At 12:</u>

ψ = 20°, K_e = 0.85 from pages 103 and 110 and from
pages 112, 113 and 114.

        e = 24 db above 1 uV/$_M$ at 3 mc, E   0-200 kilometers

           = 20 db   "   at 3 mc, F_2 "

           = 41 db   "   at 8 mc, F_2 "

TABLE XI
BASIC RECEIVED SIGNAL LEVEL FOR SKY-WAVE COMMUNICATION

Time	AN/TRC-77		AN/GRC-19	
	3 mc	8 mc	3 mc	8 mc
00	28 db (F_2)	out	38 db (F_2)	out
02	out	out	out	out
04	out	out	out	out
06	27 db (F_2)	out	37 db (F_2)	out
08	15 db (F_2)	out	25 db (F_2)	out
10	6 db (E)	22 db (F_2)	16 db (E)	32 db (F_2)
12	4 db (E)	21 db (F_2)	14 db (E)	31 db (F_2)
14	8 db (E)	23 db (F_2)	18 db (E)	33 db (F_2)
16	15 db (F_2)	26 db (F_2)	25 db (F_2)	36 db (F_2)
18	27 db (F_2)	28 db (F_2)	37 db (F_2)	38 db (F_2)
20	28 db (F_2)	out	38 db (F_2)	out
22	28 db (F_2)	out	38 db (F_2)	out

Signal Level in db above $1 \text{ uV}/_M$.

0 - 200 Km or 0 - 125 miles

AN/TRC-77 = 10 watts ERP

AN/GRC-19 = 100 watts ERP

Antennas: Quarter to half-wave horizontal wires about 30 feet above the ground.

(Sloping wire 7' to 30' about 6 db less)

Sample Calculation:

Figure 6 (sub Figure 51) is used to determine the MUF. When the operating frequency is above the MUF the word "out" is used in the table. When the E layer signal is larger, it is given; and when the F_2 layer signal is larger, it is given.

TABLE XI (Continued)

Table X is the signal normalized to 1 KW.   The
AN/TRC-77 signal is 20 db less and the AN/
GRC-19 signal is 10 db less.

NOTE: The E layer signal is stronger during the daylight hours at
3 mc than the F layer return.   The F_2 layer signal is stronger
at 8 mc than at 3 mc because the higher frequency suffers
considerably less daylight "D" layer attenuation.

TABLE XII

TABLE XII
SIGNAL TO ATMOSPHERIC NOISE RATIO FOR THE AN/TRC-77
AND THE AN/GRC-19

	AN/TRC-77		AN/GRC-19	
Time	3 mc	8 mc	3 mc	8 mc
00	5 db	out	15 db	out
02	out	out	out	out
04	out	out	out	out
06	16 db	out	26 db	out
08	7 db	out	17 db	out
10	8 db	19 db	18 db	29 db
12	6 db	18 db	16 db	28 db
14	10 db	20 db	20 db	30 db
16	7 db	20 db	17 db	30 db
18	16 db	20 db	26 db	30 db
20	5 db	out	27 db	out
22	5 db	out	27 db	out

Tables XII and XIII

These tables are derived from (a) Table XI, the basic received
signal for sky wave communication for each set and (b)
Table II, Expected Atmospheric Noise, N_a, in Canal Zone, October.

Thus $S/N_a = S(db) - N_a (db)$

In the case where N_a is the lowest, at noon at 3 mc ($N_a = -2$ db
above 1 uV/$_M$) it still is much higher than the receiver sensi-
tivity which is -16 db above 1 uV/$_M$ for the AN/TRC-77 in AM
reception. Therefore, the threshold figures govern, +14 db
for CW and +31 db for AM.

TABLE XIII
AVAILABLE MARGIN FOR 90 PERCENT RELIABILITY ON HF SKY WAVE

Local Time	AN/TRC-77 on CW		AN/GRC-19 (DSB-Voice)		AN/TRC-86 (SSB-Voice)	
	3 mc	8mc	3 mc	8 mc	3 mc	8 mc
00	-9 db	out	-16 db	out	-21 db	out
02	out	out	out	out	out	out
04	out	out	out	out	out	out
06	0 db	out	-7 db	out	-12 db	out
08	-7 db	out	-14 db	out	-19 db	out
10	-6 db	5 db	-13 db	-2 db	-18 db	-7 db
12	-8 db	4 db	-15 db	-3 db	-20 db	-10 db
14	-4 db	6 db	-11 db	-1 db	-16 db	-6 db
16	-7 db	6 db	-14 db	-1 db	-19 db	-6 db
18	0 db	6 db	-7 db	-1 db	-15 db	-6 db
20	-9 db	out	-16 db	out	-21 db	out
22	-9 db	out	-16 db	out	-21 db	out

Thresholds (Sky Wave)

AN/TRC-77: 15 wpm Manual Morse CW = $\pm$ 14 db

   6 kc bandwidth 10 watts ERP —

AN/GRC-19: Voice AM, order-wire quality = +31 db

   6 kc bandwidth 100 watts ERP

AN/TRC-86: Voice SSB, order-wire quality + 28 db

   3 kc bandwidth 15 watts ERP

Available Margin is derived from Table XII and the above
   Thresholds (T, db)
   Thus Available Margin is (S db - N_a db - T db).

TABLE XIV
ESTIMATED HF SKY-WAVE TRANSMISSION-TIME AVAILABILITY
(Panama, October 1962)

Time	AN/TRC-77 on CW		AN/GRC-19 on DSB Voice		AN/TRC-86 SSB Voice	
	3 mc (percent)	8 mc (percent)	3 mc (percent)	8 mc (percent)	3 mc (percent)	8 mc (percent)
00	55	out	25	out	8	out
02	55 (E_s)	out	55 (E_s)	out	out	out
04	70 (E_s)	out	70 (E_s)	out	out	out
06	90	out	65	out	40	out
08	65	out	30	out	12	out
10	70	97.5	35	85	15	out
12	60	96.5	25	80	10	65
14	78	98	45	88	25	70
16	65	98	30	88	12	70
18	90	98	65	88	25	70
20	55	out	25	out	8	out
22	55	out	25	out	8	out

Note: Time availability is based on Figure 7 "TIME

AVAILABILITY OF HF SKY-WAVE TRANSMISSION."

where: S_o = -10 db; time availability is 50 percent

(15 days in a month)

S = -20 db; time availability is 10 percent

(3 days in a month)

S = +10 db; time availability is 99.5 percent

(30 days in a month)

NOTE: This table gives the percent reliability figures derived from Figure 7 which, in turn, was derived from page 8, Reference 3. It includes the rms contribution of the noise components taken from Reference 2, CCIR Report #65. Thus the signal standard deviation is given by ∇ of 6 db and the noise by a 2 to 12 mc average ∇ of 5 db. This gives a ∇_o of $\sqrt{6^2 + 5^2}$ or about 8 db. Thus 90 percent means 27 days in a month will have SNR values exceeding the

median required threshold SNR. Table XIV is then computed using the curve of Figure 7 which relates the "Time Availability" or percentage of days in month that the median hourly SNR will exceed the threshold to the difference between the actual SNR and the median SNR in db, referred to the 90 percent threshold.

The curve cannot be applied to E_S availability, due to the inherent sporadic nature of this layer. On the other hand - Figure 6 - sub-figure 52 gives the measured percentage time availability of E_S for the Panama Canal Zone and these are specified for the times at which the other layers are not available.
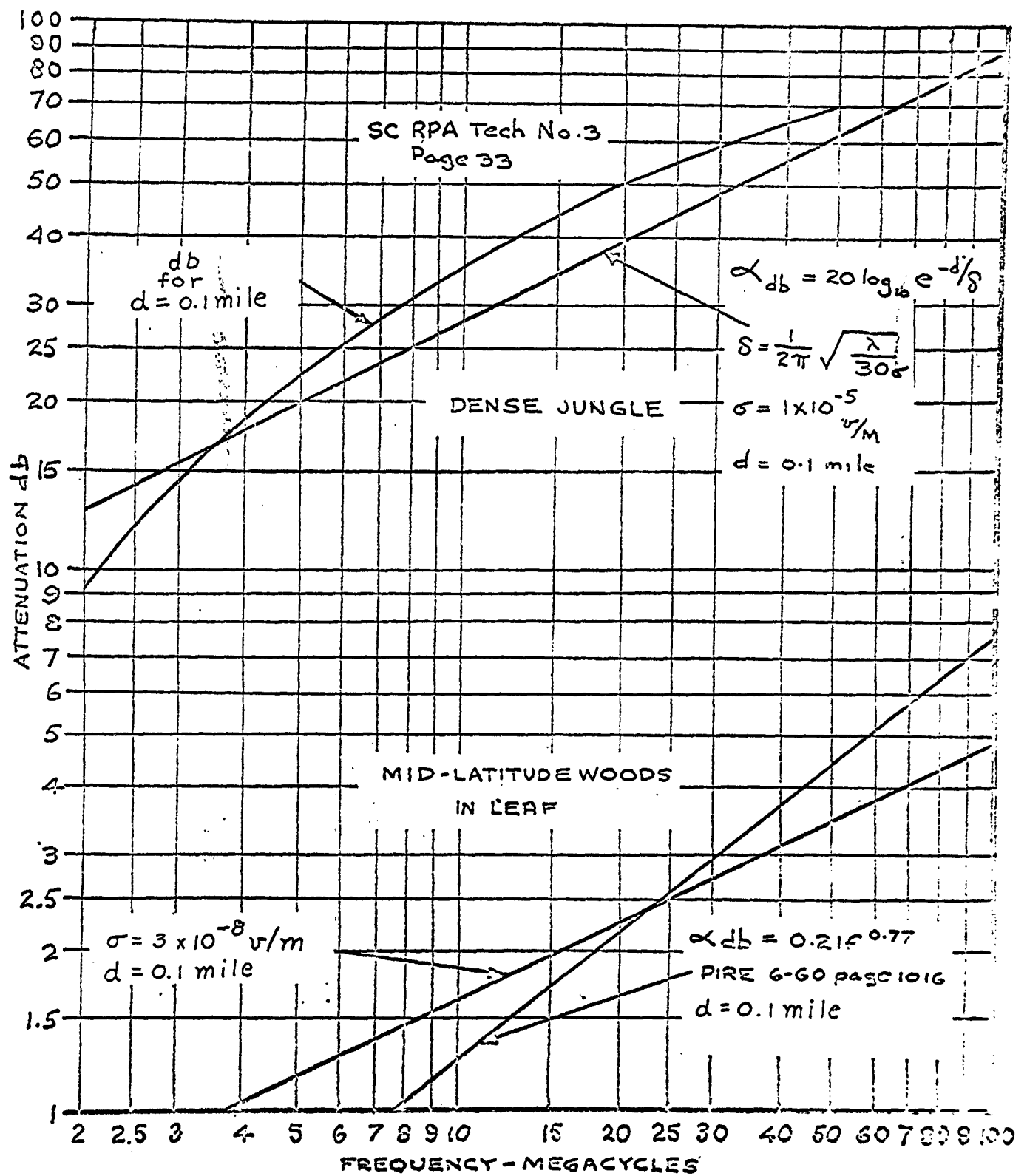
Figure 1. Radio Wave Attenuation Through Jungle and Woods

FOR VERTICALLY POLARIZED WAVES RADIATED FROM
ANTENNA LOCATED ON EARTH'S SURFACE
AT VARIOUS FREQUENCIES IN MEGACYCLES
THROUGH DENSE JUNGLE
REFERENCE LEVEL: INVERSE DISTANCE FIELD INTENSITY
AT ONE MILE = 186.3 MV/M
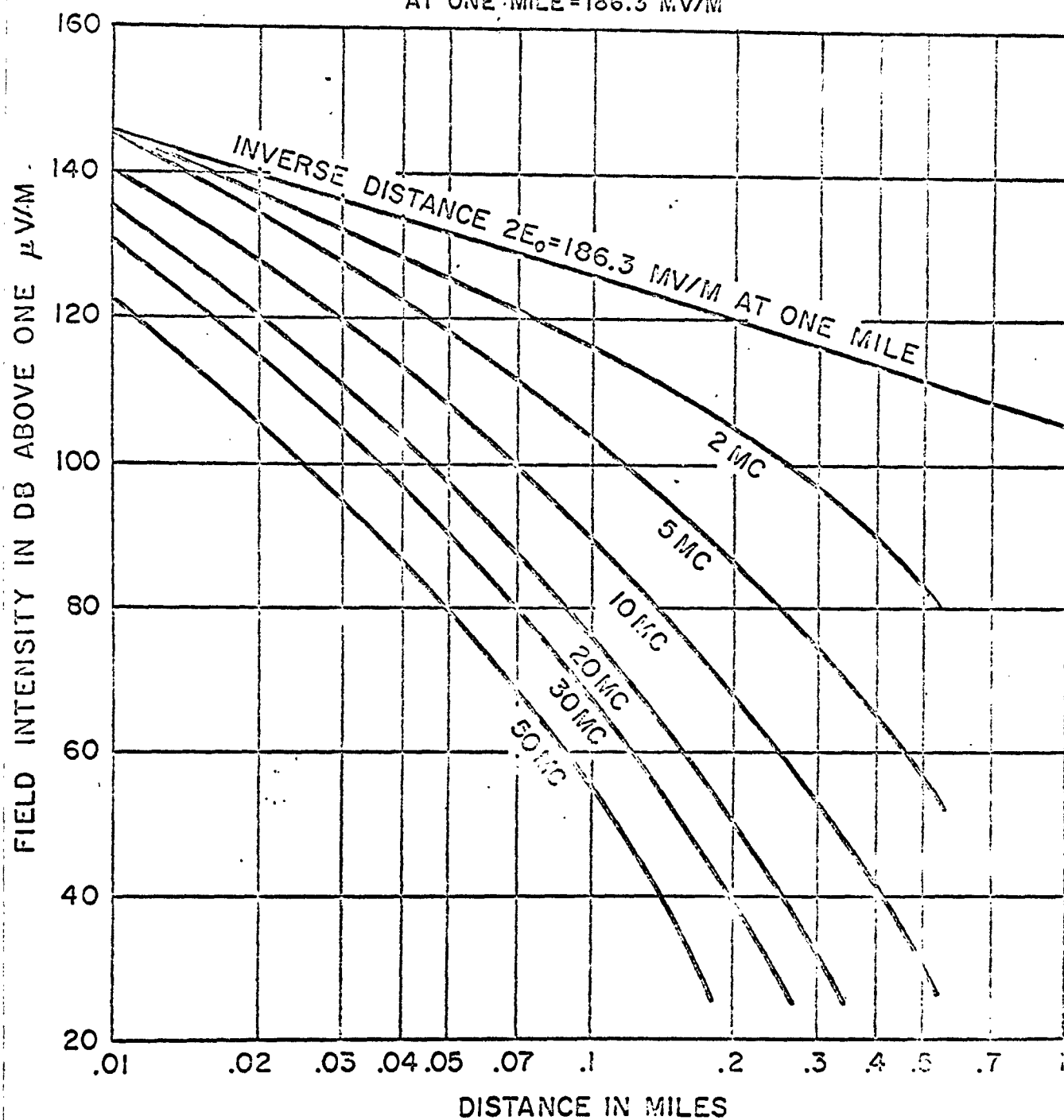
Figure 2. Ground-Wave Field Intensity vs. Distance in Jungle

SCR 694-5975 KC
VERTICAL POLARIZATION
FIELD STRENGTH VS. DISTANCE
OVER FLAT GND. (GOLF COURSE)*
THRU JUNGLE -16' WHIP ANT.*
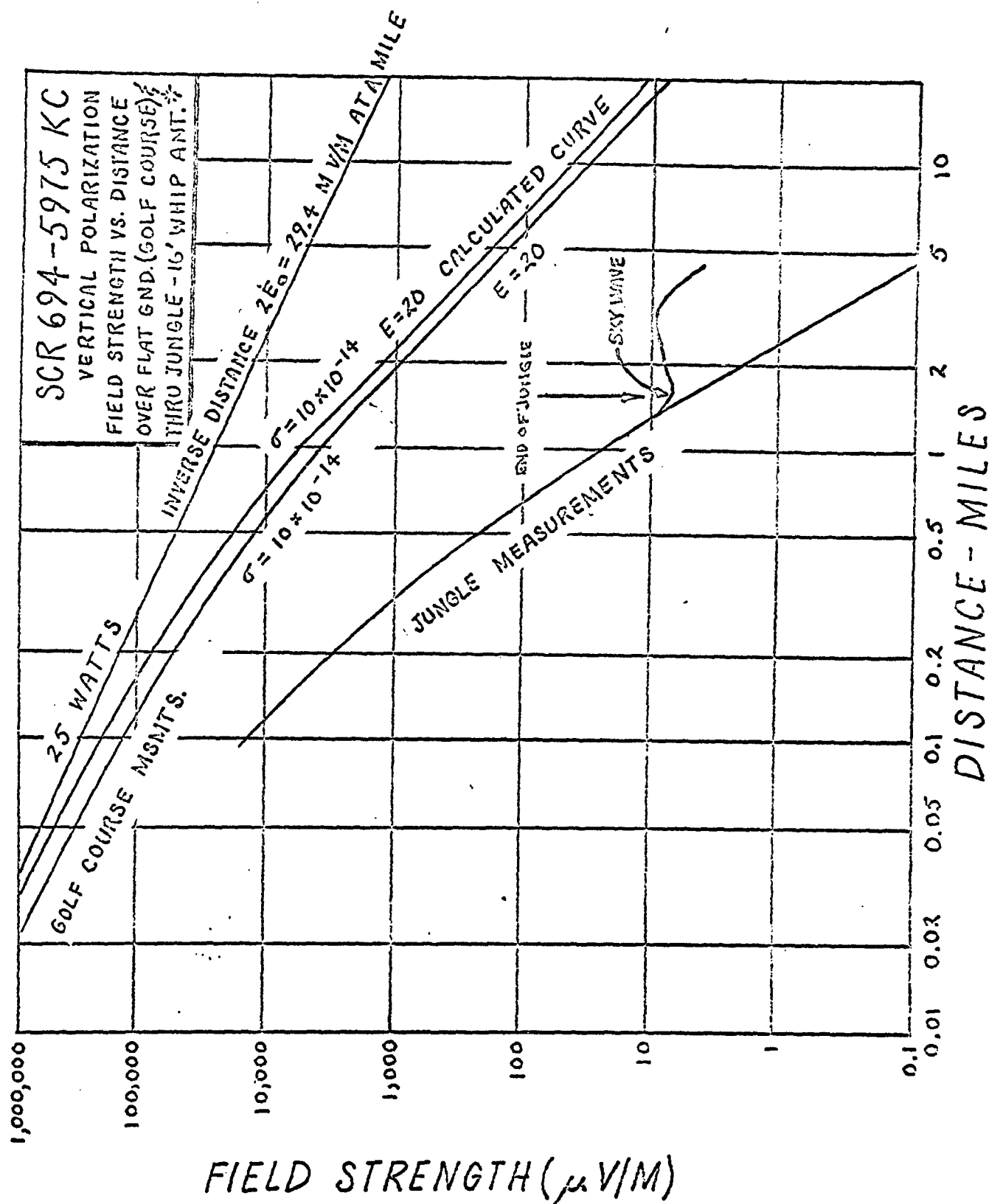
FIELD STRENGTH (μV/M)

✻ CALCULATED POWER RADIATED = 10 WATTS

Figure 3. Vertical Polarization, Field Strength vs. Distance –
SCR 694-5975 KC

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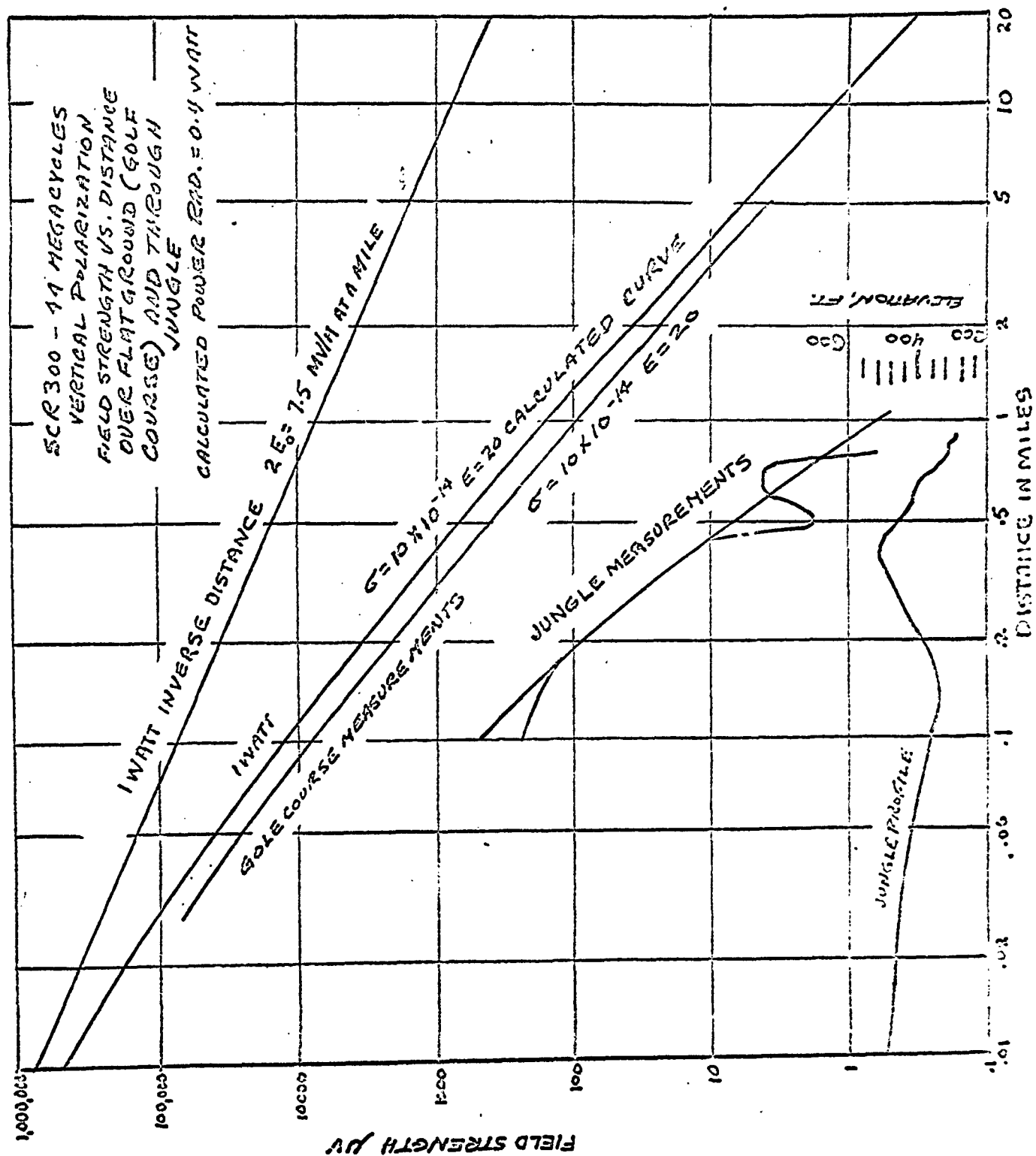
Figure 4. Vertical Polarization, Field Strength vs. Distance – SCR 300-44 MC
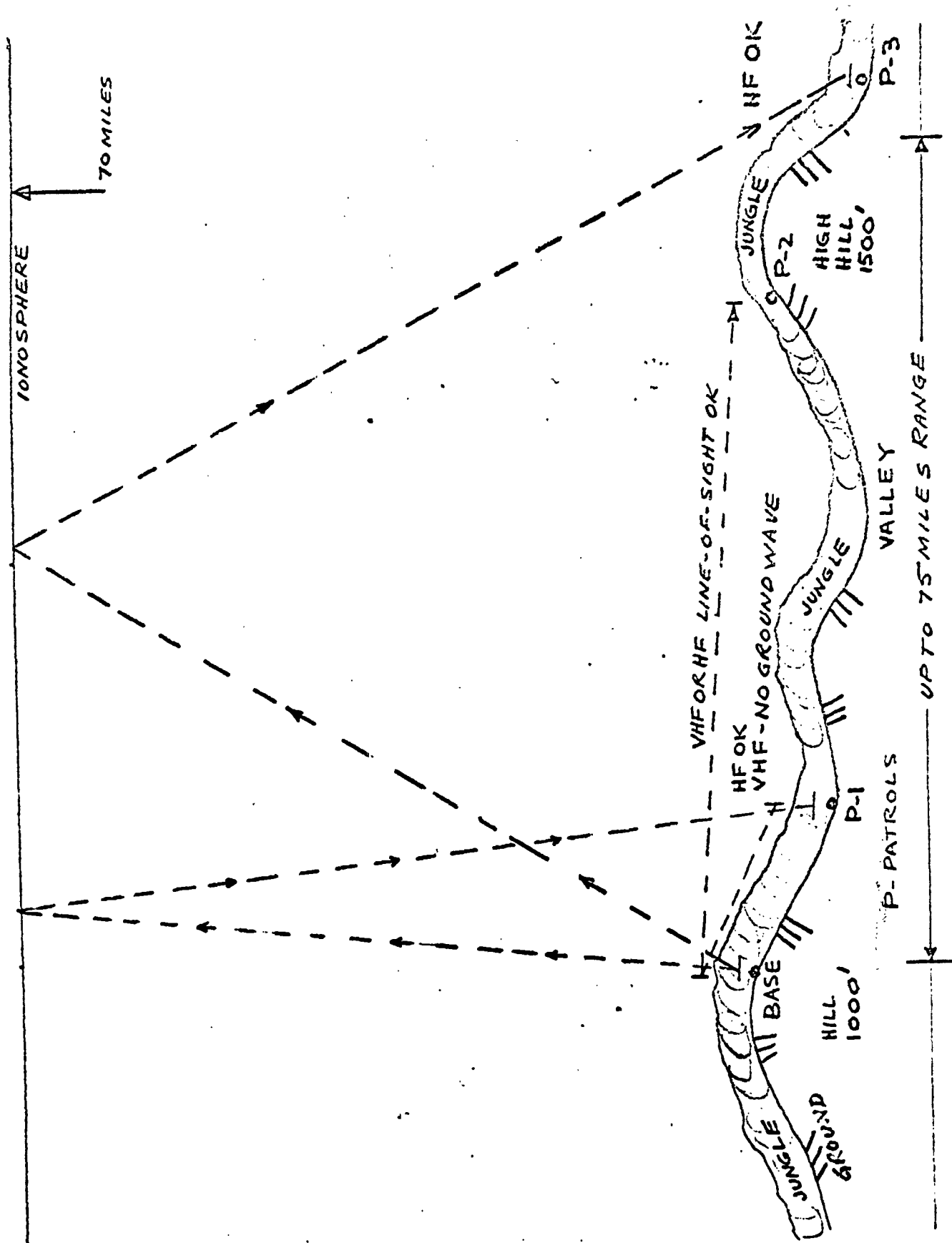
Figure 5. Likely Patrol Situations

Fig. 51. PANAMA CANAL ZONE
9.4°N, 79.9°W   OCTOBER 1952

Fig. 52. PANAMA CANAL ZONE   OCTOBER 1952
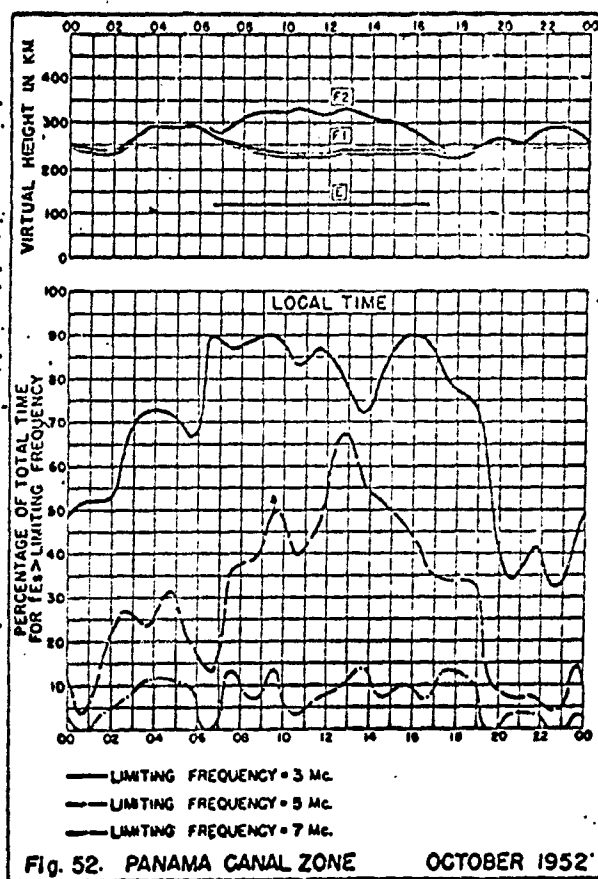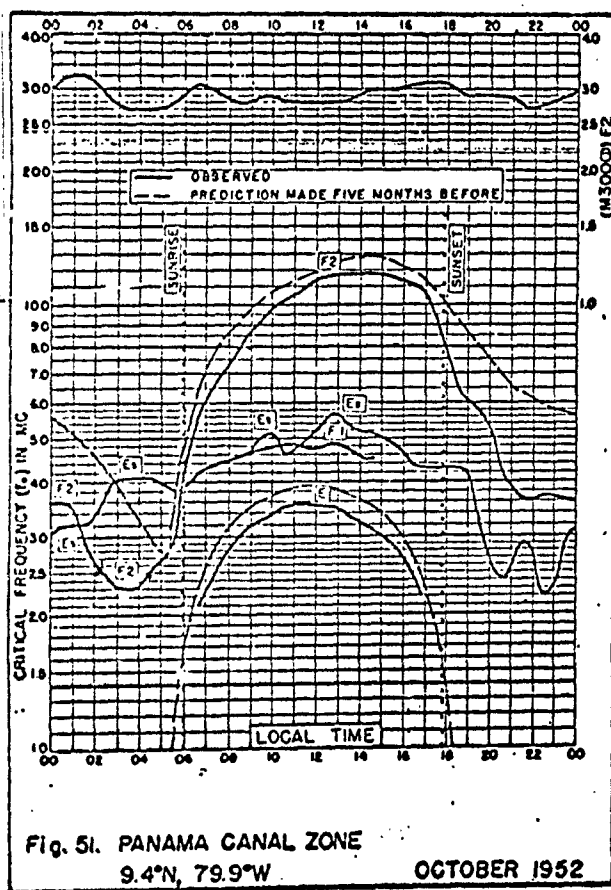
Figure 6. E_1, E_s, F_1 and F_2 Critical Frequencies for Panama, October 1952 *

TIME AVAILABILITY OF HF SKY WAVE TRANSMISSION IN MID AND LOW LATITUDES

FIGURE 2.

Figure 7. Time Availability of Sky Wave Transmission

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SECTION III
JUNGLE RADIO ANTENNAS

3.1 ANTENNA EQUIPMENT REQUIREMENTS

Based on the jungle environment, the assumed tactical operations, and the propagation problems, the antenna equipment requirements were defined as follows:

● All equipment must be portable (in manpacks which strap to the back). The pack must be as small as possible and must not exceed 5 inches in thickness. Maximum width of the pack is 12 inches; maximum length is 20 inches. Maximum weight of the pack must not exceed 25 pounds. The pack must be comfortable to carry and not cause discomfort or fatigue. The contour of the pack must be smooth and free of protuberances which would tangle in the jungle vegetation.

● Time required to erect an antenna must not exceed 10 minutes.

● Erection must be accomplished by one man with a minimum of effort. Tuning must also be done with ease.

● The equipment must be able to withstand the environment of the jungle; that is, it must withstand the temperature, humidity, fungus, and small animal attack which might be expected in the jungle.

● The desired range of communication of a jungle transmitter is 25 miles.

3.2 HF ANTENNAS FOR SKY-WAVE PROPAGATION

3.2.1 Antenna Types

The frequency spectrum ranging between three and eight megacycles is the most suitable for vertical incidence sky-wave propagation in tropical latitudes (References 4 and 5). Two general antenna types are common in this frequency range; traveling-wave types; and the resonant, or standing-wave, types. Beverage, rhombic, and fishbone antennas are

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typical traveling-wave antennas. Traveling-wave antennas are terminated in a resistive load, which makes them inherently broadband and inherently inefficient; and are long in terms of wavelength, resulting in multiple beams. Their length, inefficiency, and multiple beams eliminate them from consideration for this application.

The standing-wave types, which are lightweight and easy to package, include the half-wave wire dipole, the foreshortened inductively-loaded dipole, and the ferrite-loaded loop antenna. The latter is extremely inefficient for sizes that are practical for jungle use. For example, consider an air-core loop of 5 turns, 5 feet in diameter. The radiation resistance (which is a measure of power radiated) is given by:

$$R_R = N^2 \left(11.75 \frac{D}{\lambda}\right)^4 \qquad (8)$$

where:

N = turns, D = diameter;

At 3 mc, this gives 0.04 ohms. The antenna efficiency is given by:

$$\text{EFF.} = \frac{R_R}{R_R + R_L} \times 100\% = \frac{0.04}{0.04 + 5} \times 100\% \approx 0.8\% \qquad (9)$$

where:

R_R = radiation resistance = 0.04 ohms

R_L = loss resistance, resulting from copper losses and ground losses $\approx$ 5 ohms or more.

Thus, the efficiency is very low for this antenna. Ferrite loading reduces the antenna size, but increases the losses and the weight (Reference 15).

The loaded dipole types have some potential advantages at HF. The short physical length is useful in several respects. It can be packed into a suitable form factor for patrol activity. It can be hoisted aloft easily on a single mast or with a balloon. Its principal potential advantage

over a half-wave wire is due to the fact that the tree branches which form the dense jungle canopy start at about the thirty-foot level. If it is desirable to have horizontal antennas at greater heights, it is easier to erect the short, loaded dipole. With this fact in mind, heliwhip dipoles were used during the Panama field trip (see Appendix F) at both the base camp and field sites producing two way CW communication, thereby showing some promise. Consequently, effort was directed toward a study of the efficiency of loaded dipoles relative to half-wave dipoles.

3.2.2 Gain and Efficiency of Short Dipoles

The electric field produced by a dipole at any point in free space is given by the general expression,

$$E = j \; \frac{60 \pi \sin \theta}{r \lambda} \int_{-L/2}^{L/2} I(z)\,dz \; e^{-j Br (z)} \tag{10}$$

where:

I (z) = current distribution along the long axis of the dipole

λ = wavelength in meters

B = $2\pi/\lambda$

E = field strength volts/meter

r = distance from the center of the dipole to the point of observation

L = length of the dipole

θ = angle between the long axis of the dipole and the radial length to the point of observation

For short dipoles (L less than $\lambda/4$) and for a constant distance d, the magnitude of the field simplifies to

$$|E| = \frac{60 \pi}{r \lambda} \; I_o L_e \tag{11}$$

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where:

I_0 = current at the center of the dipole

L_e = effective antenna length = $\dfrac{1}{I_0} \displaystyle\int_{-L/2}^{L/2} I(z)\,dz$

The maximum field occurs at $\theta = 90^\circ$, for short dipoles,

$$|E|_{max} = \frac{60\,\pi}{r\lambda}\, I_0\, L_e \tag{12}$$

The effective length is maximum for uniform current distribution. For this case the effective length is equal to the physical length. Uniform current distribution can be approximated by loading the dipole with capacity at the ends, or with inductance. A short, unloaded dipole has a current distribution which decreases linearly from a peak at the center, to zero at the ends. Its effective length is, therefore, half its physical length. Thus

$$|E|_{max} = E_1 = \frac{60\,\pi}{r\lambda}\, I_1\, L \qquad \text{for uniform current} \tag{13}$$

and,

$$|E|_{max} = E_2 = \frac{60\,\pi}{r\lambda}\, I_2\, \frac{L}{2} \tag{14}$$

for short unloaded dipoles. Now, if equal amounts of power are fed to each dipole then,

$$I_1^{\,2}\, R_1 = I_2^{\,2}\, R_2 , \tag{15}$$

where R_1 and R_2 are the resistive components of the antenna input impedances and,

$$I_1^{\,2}\, (R_{1R} + R_{1L}) = I_2^{\,2}\, (R_{2R} + R_{2L}) \tag{16}$$

where:

R_{1R} = the part of the input resistance which is proportional to the power lost by radiation from the "uniform current" dipole.

R_{1L} = the part of the input resistance which is proportional to the power dissipated in the metal conductors of the "uniform current" dipole.

R_{2R} & R_{2L} = similar parameters for the unloaded dipole.

Also, it can be shown by integration of the radiated field (Reference 16, pages 2-10) that,

$$R_{1R} = 80\pi^2 \left(\frac{L}{\lambda}\right)^2 \quad \text{and} \quad R_{2R} = 20\pi^2 \left(\frac{L}{\lambda}\right)^2 \quad \text{for short dipoles.}$$

where:

$$R_{1R} = 4 R_{2R} \tag{17}$$

Therefore:

$$E_1 = \frac{60\pi}{r\lambda} I_1 L \quad \text{and} \quad E_2 = \frac{60\pi}{r\lambda} \frac{I_1}{\sqrt{\dfrac{1 + \dfrac{R_{2L}}{R_{2R}}}{4 + \dfrac{R_{1L}}{R_{2R}}}}} \frac{L}{2} \tag{18}$$

If both antennas are lossless, $R_{2L} = R_{1L} = 0$. Hence $E_1 = E_2$, which means that the directive gain (which is proportional to E^2) is the same for the ideal (lossless), optimally loaded short dipole as for the ideal unloaded short dipole.

What is the purpose then of loading a short dipole to get uniform current distribution? Obviously there is no purpose if the conductive losses

are small compared to the radiation resistance. However, for small dipoles this is not the case. Therefore, if the radiation resistance can be increased by loading, without significantly increasing conductive losses at the same time, efficiency can be improved. It is claimed that heliwhips will accomplish this.

3.2.3   Gain and Efficiency of Dipoles Above Ground

The heliwhip is supposedly more efficient than other foreshortened types. However, it is more pertinent to determine the efficiency of foreshortened dipoles at various heights above ground as compared to the half-wave wire dipole. For the application envisioned, it is ultimately important to know which antenna configuration yields maximum gain in the vertical direction. The following paragraphs detail how this determination was made.

Consider a short horizontal dipole at a given height, h, above ground. The field in the vertical direction is the sum of the direct radiation, and the radiation reflected from the ground in the vertical direction. The vertical power gain (relative to a $\lambda/2$ dipole at $\lambda/4$ above ground) can be shown to be the following, for constant power input:

$$G_o = \eta \, \frac{R_o}{80} \times \frac{\left| 1 + \Gamma e^{-j\frac{4\pi h}{\lambda}} \right|^2}{\left| 1 - \Gamma \right|^2} \tag{19}$$

(Refer to Appendix D for proof)

where:

G_o = power gain of a short dipole, in the vertical direction, relative to a $\lambda/2$ dipole at $\lambda/4$ above ground

η = short dipole efficiency = $\dfrac{R_{R_1}}{R_{R_1} + R_L}$ = $\dfrac{\text{power radiated}}{\text{power in}}$

R_{R_1} = radiation resistance of short dipole

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$R_{R_1} + R_L$ = resistive component of input impedance for short dipole at height h.

R_0 = resistive component of input impedance for $\lambda/2$ dipole at $\lambda/4$ height (for $\lambda/2$ dipole, $R_0 = R_{R_1}$, since R_L is negligible)

Γ = reflection coefficient of the ground at vertical incidence.

The magnitude and phase of the reflection coefficient can be calculated knowing the dielectric constant and conductivity for the ground (Reference 17). Values for average ground were assumed. These values are, ten for relative dielectric constant, and a conductivity of 5×10^{-3} mhos per meter.

Efficiency and input resistance are difficult to compute. Both are complex functions of ground characteristics and height above ground, among other variables. In this case, experimental measurements were considered easiest and most reliable. Input impedance measurements present no problem, but efficiency does not lend itself to simple, accurate, measurement procedures. One method of determining impedance measurements is to measure input resistance, and then calculate radiation resistance from a measurement of current distribution by means of a test probe. However, a measurement such as this requires special techniques and equipment to be accurate. A simple and quicker method was employed. This method is based on the fact that the efficiency relative to a half-wave dipole at the same height above ground, is easy to determine from relative field strength measurements. It can be shown that the relative gain in a plane perpendicular to the ground and passing through the center of the dipole, is given by:

$$G_0^i = \eta \frac{R_0^i}{80} = \frac{|E_1|^2}{|E_0^i|^2} \quad \text{(See Appendix D for proof)} \quad (20)$$

where:

G_O' = power gain (at any angle in the vertical plane) of a short dipole, at height h, relative to a $\lambda/2$ dipole at the same height

R_O' = input resistance of $\lambda/2$ dipole at height h

$\dfrac{|E_1|}{|E_O'|}$ = ratio of field strengths produced at any point in the vertical plane

It follows that:

$$G_O = G_O' \; \frac{R_O}{R_O'} \; \times \; \frac{\left|1 + \Gamma e^{-j\frac{4\pi h}{\lambda}}\right|^2}{|1 - \Gamma|^2} \quad (21)$$

This is an expression of comparative gain, in terms of three easily measured quantities (G_O, R_O and R_O') and an easily computed quantity (Γ). The resistances were measured using an RF bridge, and the field strengths were measured using a linear, calibrated, receiver connected to an auxiliary antenna, which was placed in the far field of the antennas under test. (See Appendix E for test arrangement and procedure.) Using the same measurements, the vertical gain of a half-wave dipole versus height relative to a half-wave dipole quarter-wave above ground is also determined, since this is given by the last equation with $G_O' = 1$.

The results are plotted in Figures 8 and 9. The difference between the curves is principally due to the low efficiency of the foreshortened dipole. The frequencies of 4.07 and 8.2 mc were chosen because they were available by allocation from the FCC, for operation near the ends of the 3 to 8 mc band. An adjustable, inductively-loaded 4-mc dipole (Figure 10) was bought and used instead of the heliwhip, since an adjustable heliwhip was not available, and time and funds allotted did not permit development of an optimum design for a tunable heliwhip. Nevertheless, it is believed that the inductively-loaded dipole is indicative of what would be expected from an optimum

heliwhip design. Further corroboration of this conclusion was obtained from measurement of the input resistance of a 7-mc heliwhip dipole (Figure 11) at 18 feet above ground. The input resistance was 23 ohms. Assuming the ideal uniform current distribution, the radiation resistance could not exceed 5.3 ohms. Thus, the maximum possible efficiency is 23 percent, and the vertical gain is calculated to be .16 relative to a $\lambda/2$ dipole at a height of $\lambda/4$.

A comparison of estimated and measured efficiencies for the two types is shown in Table XV. Unfortunately, due to radio interference at 7 mc, no measurement of heliwhip efficiency was obtained.

It is seen from this data that a half-wave wire dipole only seven feet above ground is more useful for sky-wave propagation than the best possible foreshortened antenna at any height. Maximum gain in the vertical direction (assuming "average ground") occurs at approximately $\lambda/8$ height. The reason that maximum gain occurs there rather than at $\lambda/4$ height is due to the variation of input resistance with height. The measured values are shown in Figure 12. Refer to the equation for gain in the vertical direction. It is noted that decreasing height from $\lambda/4$ decreases the term in parenthesis (Γ is nearly -1 for average ground). However, the input resistance for the $\lambda/2$ dipole also decreases as height begins to decrease. The two opposing effects optimize the gain at approximately $\lambda/8$ height.

Figure 12 also shows a comparison between the measurements and theoretical values computed by Sommerfeld and Renner (Reference 18). The similarity confirms the accuracy of the measurements. Observe that the input resistance of the short, loaded dipole does not vary with height. In order to understand this departure from the normal expectation, a physical explanation is helpful. The input resistance of a dipole consists of resistances proportional to power lost by radiation, and power lost in the metal conductors which form the dipole. That is, $R_{IN} = R_R + R_L$. In the presence of

TABLE XV
COMPARISON OF DIPOLE EFFICIENCIES

Antenna	Antenna Height Feet	Antenna Length Feet	Measured R_{in} Ohms	Computed R_R Ohms	Estimated Efficiency, $R_R/R_{in} \times 100$ %	Efficiency Calculated from Measured Field Strength %
4 mc inductively center-loaded dipole	7	15.2	17	.62	3.6	1.5
	14		16		3.9	2.53
	21		17		3.6	2.82
	28		15		4.1	2.93
8 mc inductively center-loaded dipole	7	12.6	30	3.7	12.3	11.5
	14		27		13.7	19.3
	21		32		11.6	15.5
	28		31		11.9	15.5
7 mc heliwhip dipole	18	16.0	23	5.3	23	--

ground, currents are induced in the ground. These in turn influence the currents on the dipole. The result is that the magnitude and phase of the current distribution on the dipole is changed, which means that the radiation resistance is changed. The equivalent conductor loss resistance also changes, but only slightly. For a $\lambda/2$ dipole R_R is much greater than R_L. It is given by

$$\frac{R_R}{R_L} = \frac{292}{\mathscr{f}\lambda}$$

where

$\mathscr{f}$ = resistance per length of the metal dipole

λ = wavelength

Thus for the $\lambda/2$ dipole, the major effect is a change in radiation resistance. The foreshortened dipole, on the other hand, has conductor resistance much greater than the radiation resistance. The net result is that the effect of the ground proximity on the input resistance is strongly attenuated by the large conductive losses.

Throughout this section it has been assumed that the power delivered to the antenna is a constant. This implies that regardless of the input impedance it is always tuned to the generator impedance and losses in the tuner are negligible. This is a reasonable assumption except for very high VSWR's on the order of ten or more. The input impedances that were measured corresponded to VSWR's of three or less. However, for very short dipoles, tuner losses will not be small and will further decrease the efficiency. This is due to the fact that the maximum Q of tuning coils is about 200 at these frequencies. When the Q of the antenna is comparable, losses in the tuner are of the same order of magnitude as the dipole losses. Foreshortening a dipole does, in fact, rapidly increase its Q (Reference 19).

3.3 HF AND VHF ANTENNAS FOR LINE-OF-SIGHT PROPAGATION

Patrol and base-camp antennas must be raised to tree-top level, or above, to achieve unobstructed propagation. In order to minimize the probability of detection, the patrol antenna should not be raised much above the tree tops. The problem is less important at the base camp, since a semi-permanent location of tents, motor pools, etc. already significantly compromises in-detectability. Therefore, the base-camp antenna may as well be raised as high as possible. VHF antennas should,preferably,be used to minimize noise and interference.

There are several ways to lift an antenna to tree-top height, in primary rain forests. One method is to drape a wire over the trees. This appears feasible with a CO_2 gun, which is relatively noiseless. Another method is by means of a balloon. As discussed elsewhere in this report, the lifting capacity of patrol balloons is limited by the balloon and gas supply, weight, and size. This creates the problem of designing a lightweight antenna and transmission line feed. The antenna weight is eliminated by using the balloon itself as the radiating element. This is done by metallizing the balloon surface in such a manner that the metallized portion forms an antenna. For example, the balloon can be shaped to form a prolate spheriod antenna or "fat" dipole, as shown in Figure 13. An antenna such as this has the added advantage of providing broadband impedance characteristics over an octave bandwidth. This eliminates the need for a tuner near the antenna. Other broadband, omnidirectional antenna types are also possible. These include biconical, bow-tie, and discone antennas (Reference 16).

The selection of a transmission line for feeding the antenna involves a compromise between weight and attenuation. Table XVI gives weight and attenuation data for small-diameter coaxial cables. An even better compromise is possible if specially-constructed, balanced, two-wire

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line is used. The weight of the line, and attenuation is kept low by punching holes in the dielectric ribbon. See inset of Figure 13.

TABLE XVI
TABLE OF WEIGHT AND ATTENUATION OF TRANSMISSION LINES

Type	Dimensions	Z_o	db/Attenuation 100' at 50 Mc	Wt./100' in lbs.
RG 58 coaxial	.195" O.D.	53.5	3.1	2.7
RG 122 coaxial	.160" O.D.	50	4.5	2.0
RG 174 coaxial	.100" O.D.	50	6.6	0.75
Special Balanced Line	Wire Dia. = .040" Center-to-center spacing = .080"	150	1.0 (Est.)	1.2 (Est.)

The alternative to balloon erection, in the jungle, is to shoot the end of a long wire over the trees so that it naturally drapes itself on the tree tops. The wire is excited by a generator between the other antenna-end and ground. This method was tried during the Panama trip using an M-1 rifle and grenade launcher to shoot up the wires. Impedance measurements indicated resonance for wires 1/4 and 3/4 wavelengths long. Anti-resonance occurs at 1/2 wavelength. Resistance and reactance change with frequency is roughly comparable to a monopole above perfect ground. These conclusions are tentative, since the measurements made were necessarily limited. The data comparison is shown in Table XVII. Further impedance and field strength tests must be conducted before it can be definitely determined that this approach provides efficient launching of horizontally-polarized energy above the trees.

TABLE XVII
LONG WIRE ANTENNA DATA COMPARISON TO MONOPOLE

Wire Length	λ	Frequency	Electrical Length (degrees)	Monopole Impedance (very thin monopole) (Reference 16 Page 3-4)	Measured Imp. of Wire Draped Over Trees
125'	470'	2. 1	96°	46 + j80	100 + j90
	394'	2. 5	108°	80 + j170	130 + j300
	328'	3. 0	137°	300 + j460	300 + j600
150'	274'	3. 6	197°	400 − j680	210 − j530
	219'	4. 5	248°	40 − j120	160 − j83
	197'	5. 0	274°	(Not calculated)	260 + j220

The design of a balloon, for erection of the base camp antenna, is less restricted by the size of the balloon and the weight of the gas supply. However, it is important to raise the antenna as high as possible, since the radio horizon limits the range, and is a function of antenna height above ground. Allowing for some refraction, the range is given by:

$$\text{Range (miles)} = \sqrt{2 \text{ height (feet)}}$$

An antenna height of 300 feet corresponds to 24-miles range, in the absence of large hills. This range can be obtained by use of a balloon-borne antenna and amplifiers.

The principal electrical problems are to limit the weight of the cable from ground to balloon and to compensate for the cable loss.

Figure 14 is a curve showing attenuation vs. weight for 200 and 300 feet of typical coaxial cable at 75 mc. Coaxial cable is desirable since it is shielded and self-protected from the weather. A reasonable operating point is at 10 db loss. At this point the cable weight is 7-1/2 pounds. A

smaller, lighter cable could not be used since it might not support its own weight. A larger cable would require a larger balloon and more gas to fill it. The size chosen is equivalent to RG-55, -58, or-59, which are readily available. The loss of 300 feet is 10 db at 75 mc and 6 db at 30 mc.

The cable loss would seriously degrade the range obtainable. The usable range is proportional to the transmitted power and the receiver sensitivity (which is inversely proportional to the system noise temperature), when referred to the antenna terminals. The transmitter power is reduced by the loss in the cable. However, the reduction in receiver sensitivity is somewhat less than the cable loss, depending on the antenna noise temperature, and receiver noise figure. The system noise temperature, referred to the antenna terminals, can be written as:

$$T_S = T_A + (L-1) \, T_L + L \, (F-1) \, T_O$$

where:

T_S = system noise temperature, ^{O}K

T_A = antenna noise temperature, ^{O}K

T_L = temperature of the cable, ^{O}K

L = loss in the cable

F = receiver noise figure, power ratio

T_O = 290°K, reference temperature for the receiver.

Antenna noise temperature is determined by the antenna pattern and the amount of atmospheric and galactic noise recieved. Noise temperature due to pick-up of galactic noise, which predominates at these frequencies, was taken as 10,000^{O}K at 30 mc and 3,000^{O}K at 75 mc. (P. Strom, Proc. IRE, 46, p. 43; January 1958). Assuming a 5 to 10 db noise figure for a receiver, the system noise temperature for zero cable loss is 3600°

to 5600°K at 75 mc and 10,600 to 12,600°K at 30 mc. Substituting for 10 db cable loss, the system temperatures are 11,800 to 31,600°K at 75 mc and 17,070 to 36,870°K at 30 mc. This is equivalent to sensitivity loss of 5 to 7.5 db at 75 mc and 2 to 4.7 db at 30 mc.

The degradation in system performance discussed above is rather large. Much of this degradation (approximately 6 to 10 db) can be regained by installing a transistorized power amplifier in the balloon gondola to drive the antenna. Such amplifiers, with 10-db gain and 1.5-watts output over the 30 to 75 mc band, are well within the present state-of-the-art. The balance of the degradation (on receive – approximately 4 to 7 db) can be regained by also installing a low-noise transistorized preamplifier in the gondola. These types of amplifiers can be built to cover the entire band with 15 to 20 db gain, and with a noise figure of 5 to 6 db.

The proposed installation of these two amplifiers is as shown in Figure 15. Two ganged SPDT diode switches operated in synchronism by the mike button connect either the power or receive amplifiers in the antenna feed line. The outer coaxial shield provides the dc ground connection between the gondola and the ground station. Switch command pulses are sent up on the inner coaxial conductor, and amplifier power on a separate wire, which also may be used to support the coaxial line, if required. A table of weights and sizes of the gondola equipment is given in Table XVIII.

TABLE XVIII
WEIGHTS AND SIZES OF GONDOLA EQUIPMENT

Component	Weight #	Sizes
Pwr. Amp.	0.5	1.5 x 1.5 x 4.0 inches
Rec. Amp.	0.5	2 x 1-5/8 x 3-1/4 inches
Cable	7.5	300'
Switches (2)	0.5	1.5 x 1.5 x 3.0 inches
Wire	2.0	300'
Misc. (cable-conn.)	1.0	
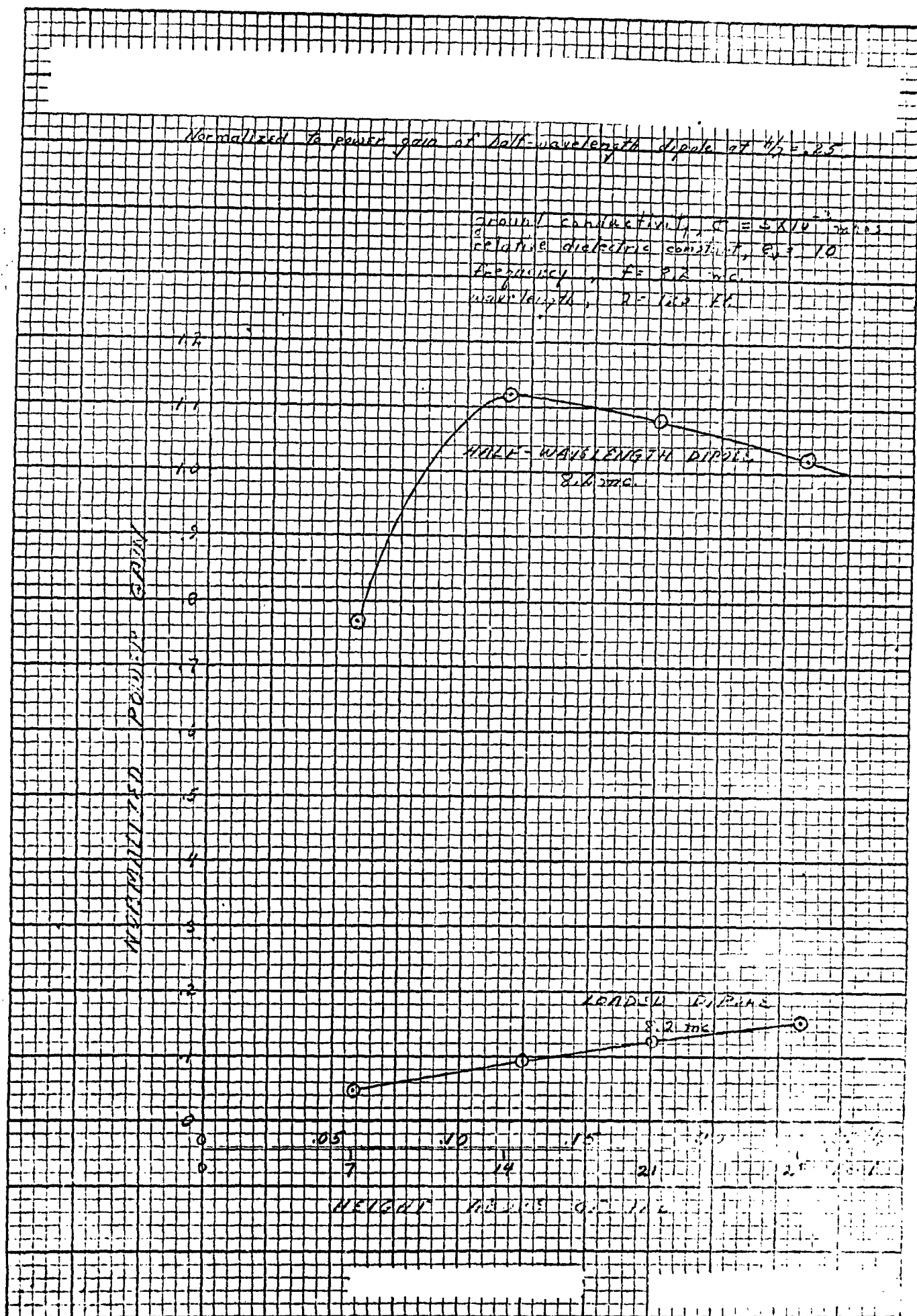
Figure 8. Computed Power Gain of Half-Wavelength Dipole and Loaded Dipole vs. Height

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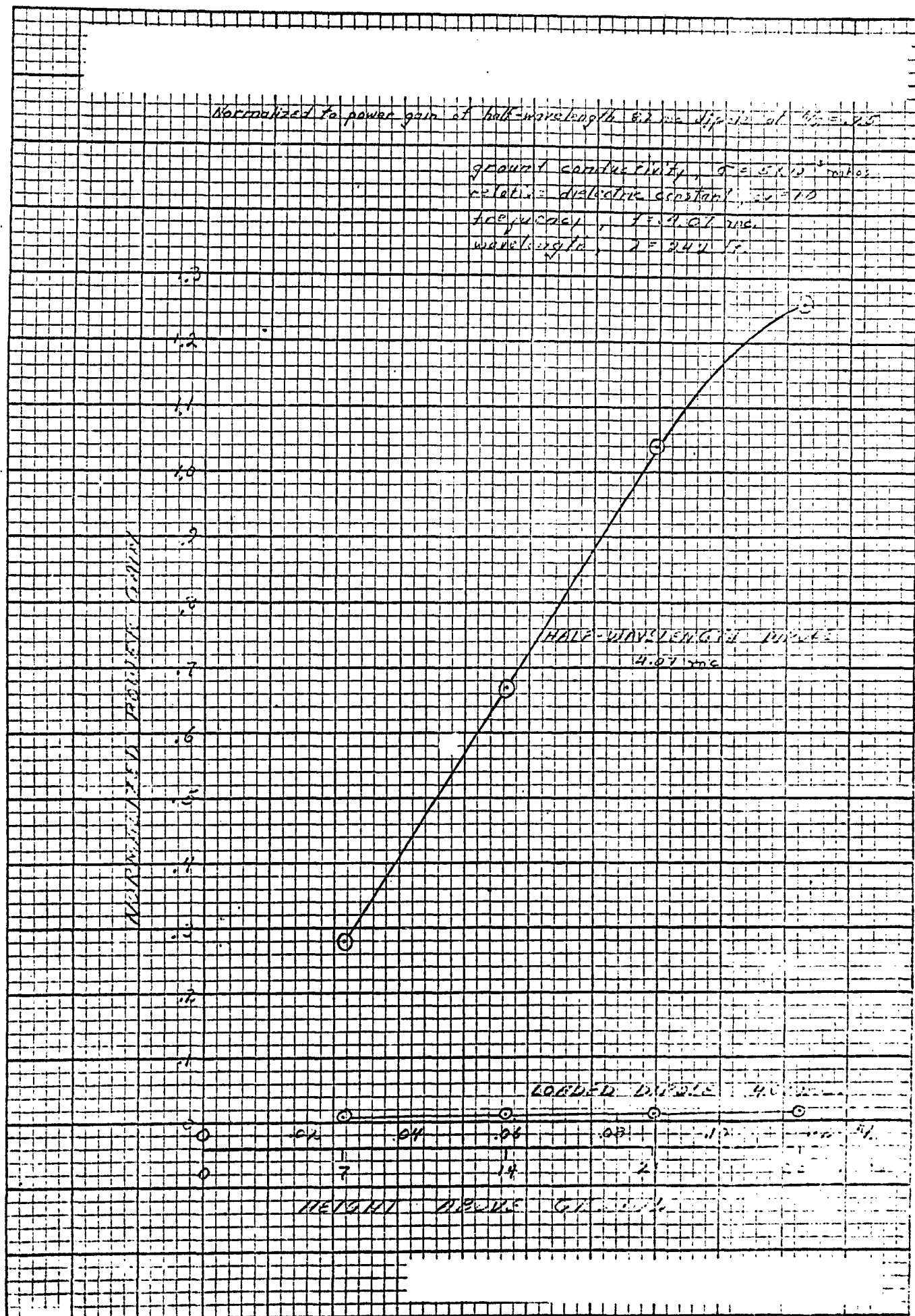
Figure 9. Computed Power Gain of Half-Wavelength Dipole and Loaded Dipole vs. Height

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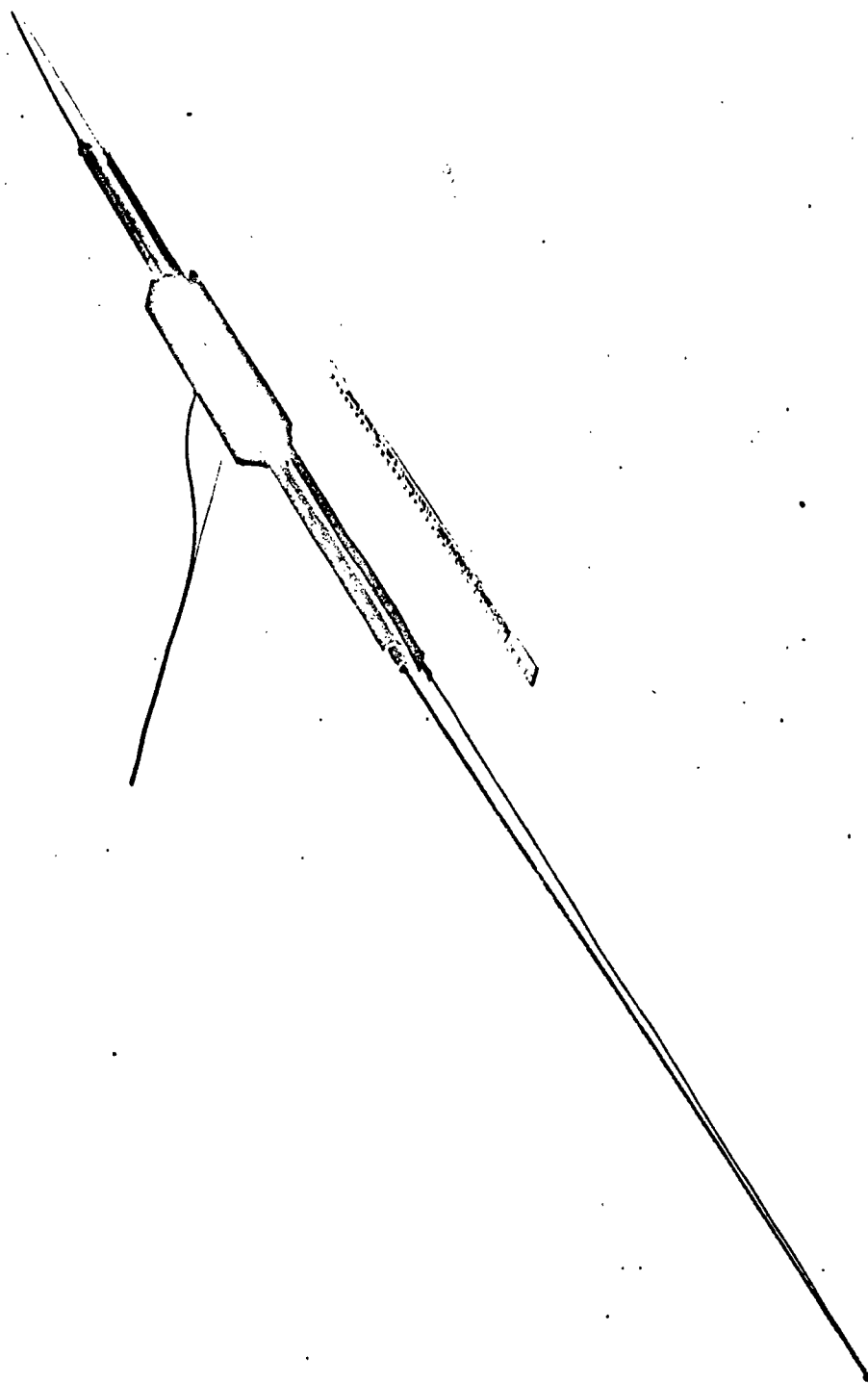
Figure 10. 4-MC Loaded Dipole Antenna
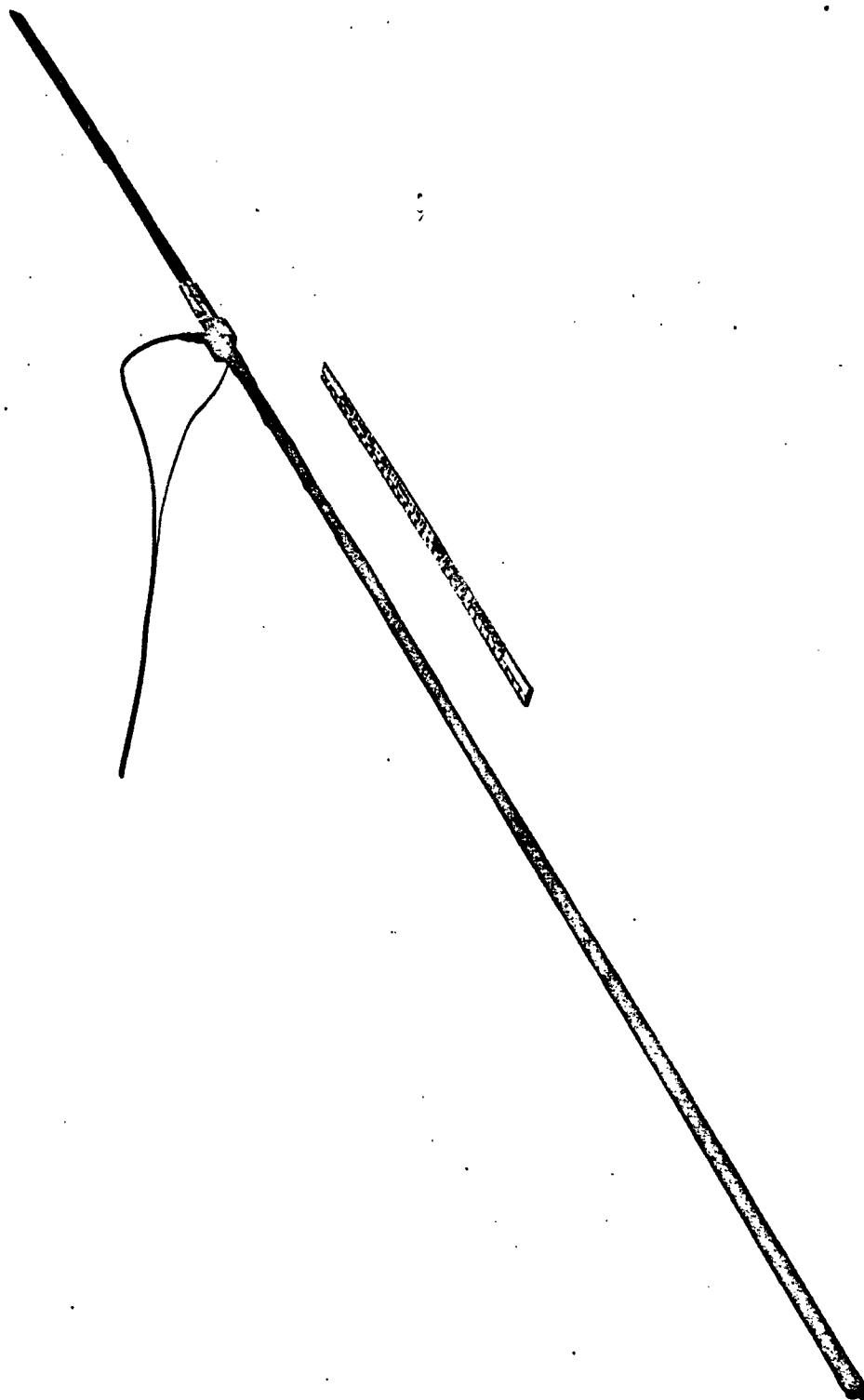
Figure 11. 7-MC Heliwhip Antenna
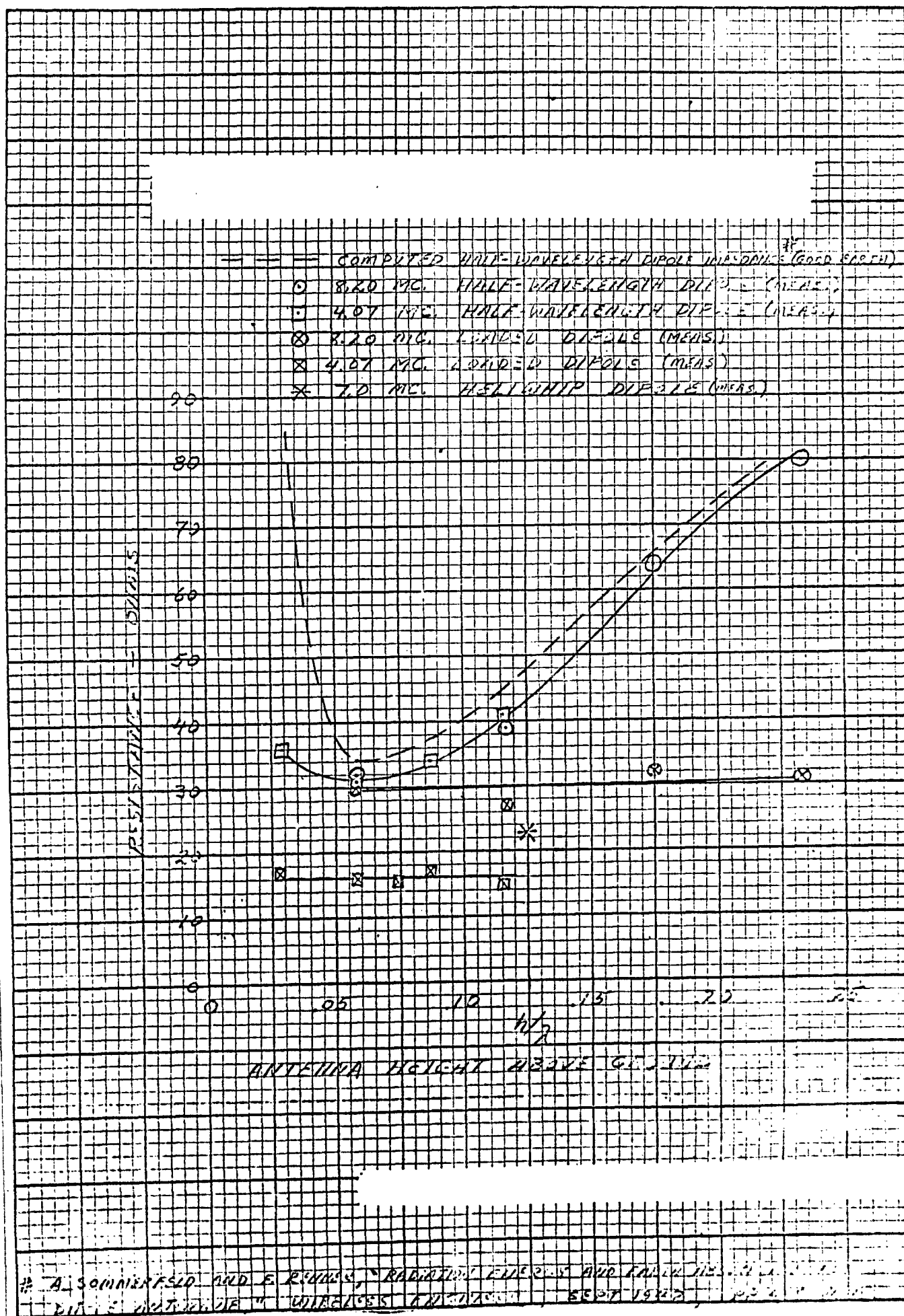
Figure 12. Antenna Resistance vs. Height

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17.5 FT.

2.5 FT

300 Ω TWIN LINE

150 FT.
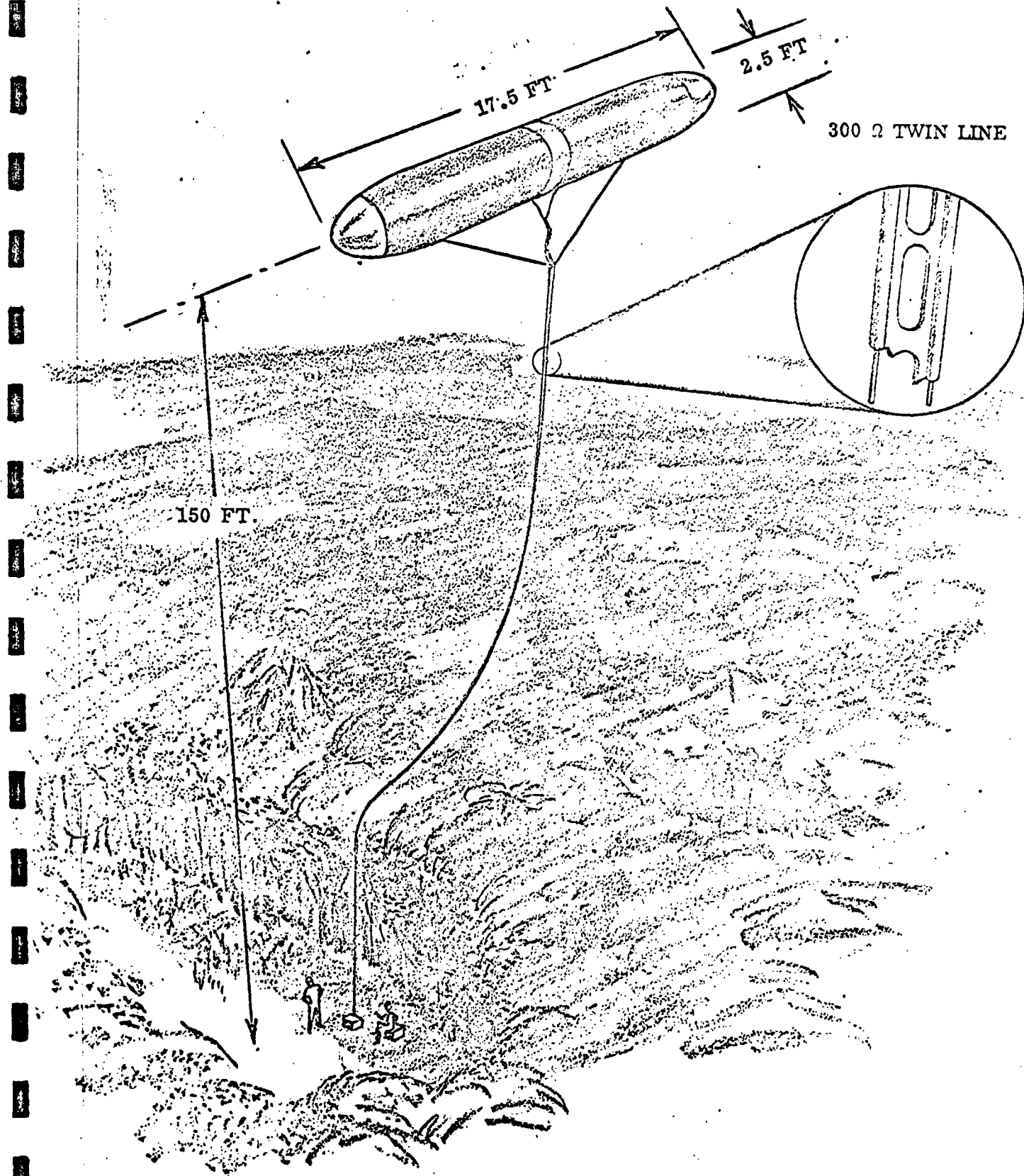
Figure 13. Fat Dipole VHF Antenna
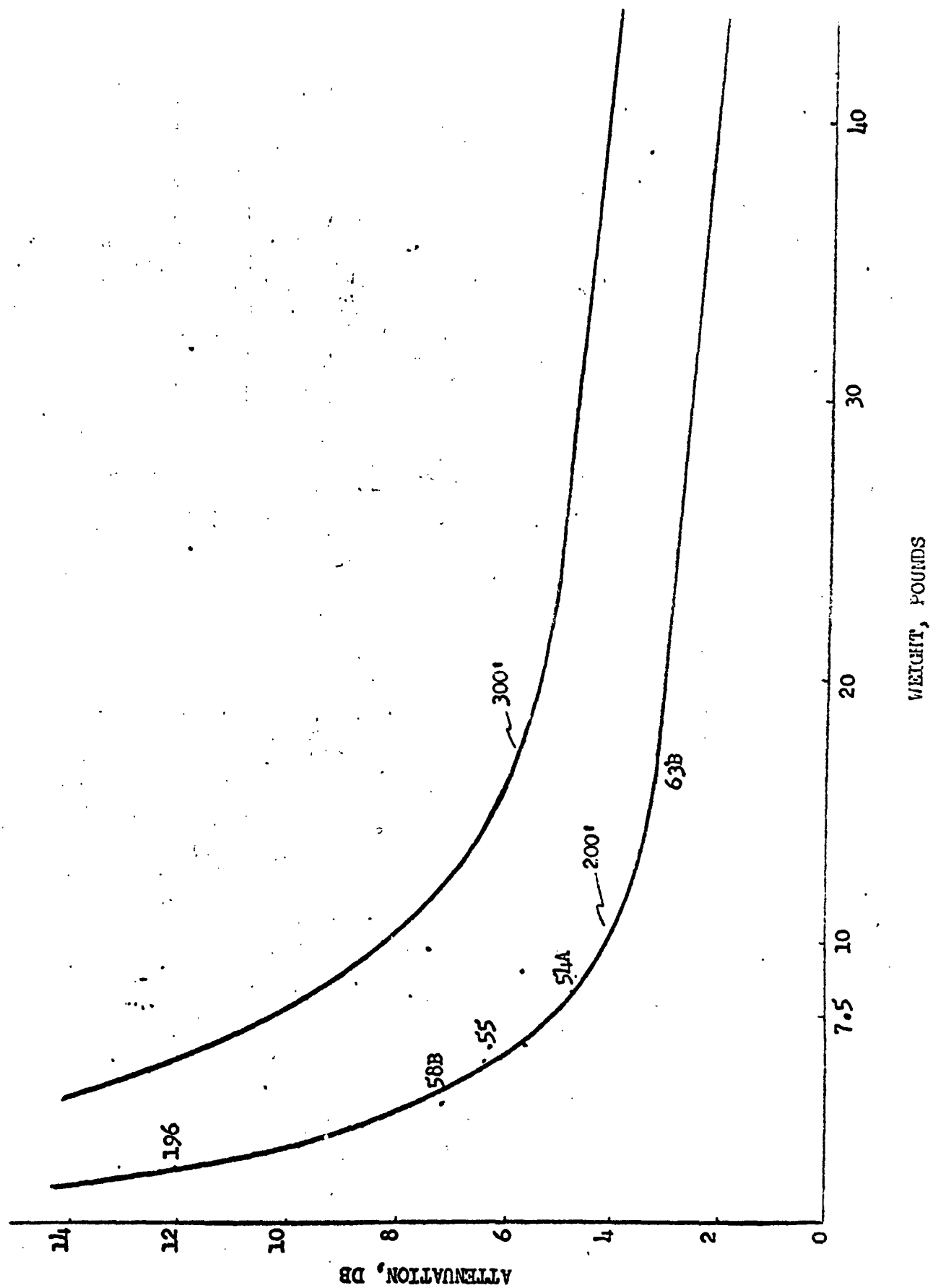
Figure 14. Attenuation vs. Weight at 75 Mc for
200' and 300' Typical Cable
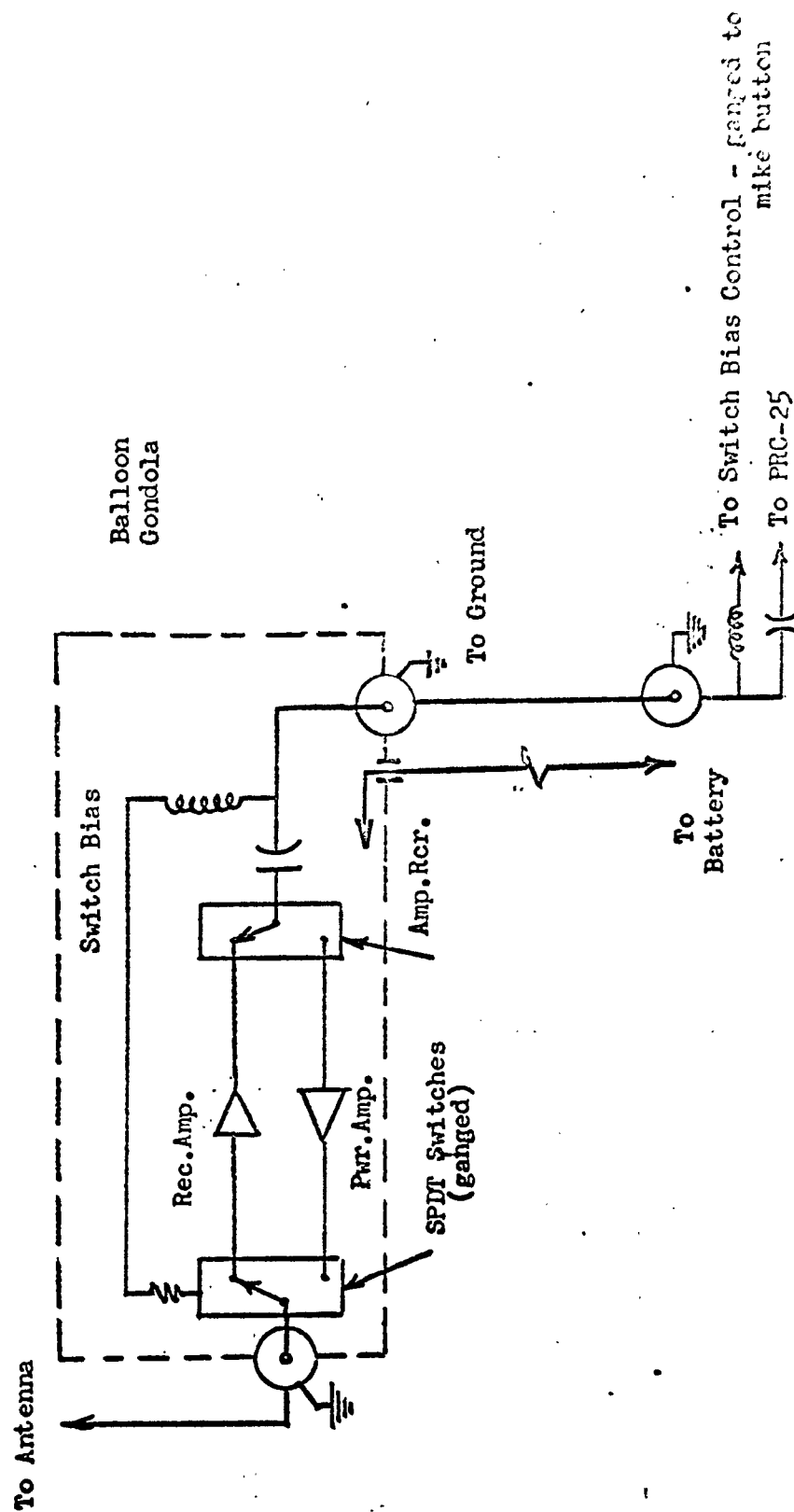
Figure 15. VHF Amplifier Schematic

SECTION IV
METHODS OF ANTENNA ERECTION IN THE JUNGLE

4.1 GENERAL

There are four levels of height to which an antenna might be raised in the jungle in an attempt to obtain satisfactory propagation with minimum efforts.

a. Near ground level

b. Below the tree tops

c. On the tree tops

d. Above the tree tops

Ground-level installations which rely on line-of-sight propagation need only readily-available equipment. Installations below the tree tops must depend on sky-wave propagation, due to the loss in the foliage. If the canopy is thick and continuous, or if concealment is important, a below-the-tree-tops installation is likely to be the only permissible level of installation. Antennas installed on the tree tops may simply be draped across the trees. Antennas installed above the tree tops must be supported in some manner. Solutions to this problem tend toward heavy equipment, difficult erection, and lack of concealment.

Various methods of antenna erection were studied. Some methods can be used in combination with others to obtain the most suitable technique for a given jungle environment. Methods having the most promise are the balloon, the bobbin for throwing a hoisting line over a tree, and the CO_2 gun or rocket for shooting out a wire. These methods and others are discussed in the following paragraphs.

4.2 BALLOONS

A balloon can be used to raise an antenna above the tree tops, or to any lower level. The height is limited by the amount of gas that can be carried, or generated, and by the size of the balloon. The size of the

opening in the canopy through which the balloon must pass, the strength of the wire or cable being lifted, and the amount of wind place additional limitations on balloon antenna design.

Erection is a silent process, but concealment may be jeopardized if the balloon is allowed to rise above the tree tops. The installation is not permanent due to gas leakage that would be encountered through the balloon membrane. The larger the balloon, with respect to its load, the longer the balloon will stay up. A small neoprene balloon will lose half its lift in 7 days. Sunlight will destroy a neoprene balloon in about the same amount of time, so no advantage is gained in using a neoprene balloon with more than twice the lift required to keep it up in a given wind.

Helium or hydrogen may be used as the gas. Although it is possible for one man to carry enough helium in cylinders to allow at least one antenna erection, the manpack would be relatively large and heavy. Hydrogen in a manpack would be too dangerous. If hydrogen generators are used, a source of water is required, and the time for inflation exceeds the 10-minute limit.

There are other difficulties associated with the use of a balloon. It is subject to puncture and tearing by the thorny vines, which are common in the jungle, and if the balloon is spherical its usefulness is limited to days when the wind velocity is less than 15 mph. (See Figure 16.) A stronger wind will cause excessive drift and a tendency to bounce.

Even though there are limitations to the use of a balloon, it seems to be a good way of raising a moderate load above the tree tops and holding it there.

A balloon which has aerodynamic lift is made by Dewey and Almy Chemical Co. and is called a Kytoon. A similar vehicle, made by Viron Div. of Geophysics Corp. of America, is called a Geokite. Both are blimp-shaped,

Aerodynamic lift obtained by this shape tends to reduce the drift caused by drag. A kytoon 10 feet long and 4 feet in diameter will drift 22° from vertical in a 20 mph wind. It will fly satisfactorily in winds up to 29 mph. A kytoon of this size can lift only 2 pounds, in still air, but in a 5 mph wind it will lift 5 pounds. As with other neoprene balloons, leakage is a problem. The kytoon leaks about 5 gms of gas per hour, and, therefore, requires recharging once a day in order to retain its air-foil shape. Its inflated volume is 82 cu. ft. A nyloncloth protects the neoprene bladder.

The short life of neoprene, its permeability, and its vulnerability to puncture leads one to explore the possibility of using plastics for the balloon skin. While this study did not include a comparison of the plastics in detail sufficient to choose or recommend one for the fabrication of balloons, the following plastics have some merit for our application: mylar tedlar, biaxially-oriented polypropylene, polyurethane sheets, and various laminates. A balloon made of any of these plastics would not be as elastic as neoprene, which means that a partially inflated balloon would not have a smooth shape and would probably be more subject to drift in a moderate wind. A plastic kytoon would not retain aerodynamic lift unless some means is provided to maintain pressure in the kytoon.

A balloon fabricated of 1-mil polyester (mylar) film, aluminized 1000 A thick, and coated with a urethane elastomer, one-half mil thick, would be a good compromise between light weight, and the other desirable characteristics. The urethane coating will have good abrasion resistance, and weathering resistance characteristics. For maximum performance the urethane layer should be pigmented white. The aluminized layer will reduce the gas permeability, probably by a factor of 10 or more, and the mylar film will provide good strength, and fair tear resistance. It is estimated that such a film would weigh about .01 lb./ft^2 and would leak at the rate of 0.56 cm^3/ft^2/24 hr. The loss of lift is negligible. This material is assumed to be used in all further discussions of balloons in this report.

A heavier but more rugged fabric would be a laminate of polyester film to polyester cloth, aluminized and coated with urethane elastomer. This composite will have good tear and abrasion resistance and will withstand more abuse than the first material. Either material can be packaged in a small closed container.

As shown in Appendix C, the lift provided by dry helium at sea level, at 90°F and 100 percent humidity, is .058 lb/ft^3. Under the same conditions the lift provided by wet hydrogen, that is, hydrogen produced by chemical reaction in water, is .062 lb/ft^3. This value of lift for hydrogen may be too high, since reaction temperature is higher than ambient temperature, and considerable vapor may be carried into the balloon, and condensed on the walls. A bleeding procedure is recommended to expel as much water as possible. The remaining water on the walls will reduce the lift by a small amount.

Spherical balloons made of a thin film have a net lift capability as shown in Figure 16.

A possible configuration for a manpack of helium cylinders is shown in Figure 17. Each cylinder is 4.24 inches outside diameter and 18-1/2 inches long. The ends are spherical. Two cylinders make up one manpack weighing approximately 20 pounds. Pressure in the cylinders would be 4,940 psi. Volume of helium at 1 atm in one manpack would be 81 cu. ft. The number of inflations vs. size of balloon is shown in Figure 16. Calculations for the cylinder are given in Appendix C.

Hydrogen can be generated for balloons at the inflation site. Various military generators are available. Table XIX gives information on some of these generators. All of these generators require several gallons of water for the chemical reaction, and to provide cooling for the exothermic reaction. The condensation appearing inside the balloon is very caustic and, needless to say, hydrogen is very flammable. Strict safety precautions must be taken.

TABLE XIX
HYDROGEN GENERATORS

Military Type	Capacity (cu. ft.)	Time to Generate Full Capacity	Size (inches)	Weight* lbs.	Water Req'd. (gallons)
ML-185-C or ML-49D/GM	120	120 min.	(see TM - 11 - 2400)		
M-315-B	45	30 min.	4. 3 dia x 11. 6 lng	2. 9	50
ML-303/TM with ML-305/TM	24	30 min.	5-1/8 dia x 15-1/2 lng 3-3/4 dia x 8 lng	1. 6 4	20

* Weights do not include packing case or manifolds

Metal Hydrides Inc. makes "Hydripill" pellets which, when mixed with water, produce hydrogen. Each 3/4-inch pellet produces .135 cu. ft. of hydrogen. These pellets are based on solium borohydride and cobalt chloride. Any advantage that Hydripills might have over the military generators probably lies in its packaging possibilities. The advantage is not clear at this time. Water is required, the reaction is exothermic, and the required volume is about the same as the military generators.

Summarizing the case for balloons to lift an antenna in the jungle, it would appear that in a situation where concealment of a balloon which rises above the trees is not important, a small spherical balloon is practical, providing the wind is less than 15 mph. A kytoon or similar device can be used in winds up to 29 mph. Manpack helium provides the most unrestricted and ready source of gas, although the weight of a helium manpack is greater than the equivalent hydrogen generator. If time for inflation is not critical and a water supply is available, the hydrogen generator should be used because of of its lighter weight. An excellent example of the proper use of the hydrogen generator is the antenna for the Gibson Girl radio supplied in the survival equipment for sea rescue.

4.3   BOBBINS

One of the simplest methods of hoisting an antenna in the jungle is to throw a line over a branch and by pulling on one end of the line, draw the antenna up on the other end.   The success of this operation is contingent upon several factors:

a.   The line must be thrown over the desired branch, then the end of the line must drop back to the jungle floor.

b.   The friction of the line over the branch must be low enough to allow hoisting up the antenna without breaking the line.

c.   The branch must be hard enough and the string large enough to prevent the line's cutting into the branch.

d.   The line must not twist on itself.

e.   The area under the branch must be clear enough so that the antenna does not foul on the way up.

There are several advantages associated with this method of hoisting an antenna:

a.   It is silent.

b.   The weight is low and the size is small.

c.   It is not affected by wind.

d.   It can lift a 4 pound antenna.

e.   It is semi-permanent

Some skill is required in throwing the bobbin over a suitable branch.

The purpose of the bobbin is to carry the throwing line in such a way as to lay it out as the bobbin is flying through the air and drops to the ground, thus eliminating the friction of dragging a line, and assuring that the end of the line returns to the ground.   There are two types of bobbins which might be considered, an expendable bobbin (see Figure 18) and a rewindable bobbin (see Figures 19 and 20).

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The expendable bobbin is fabricated of a tough plastic, and contains enough line (180 ft) to be used twice to raise antennas to 40 feet. The line used in the expendable bobbin is 72-lb. test dacron trolling line. Tests have shown that a 2-5/16 inch diameter bobbin weighing 6 oz. and wound with the above line can be thrown quite easily over a 40-ft. branch. In these tests, a 2-lb. weight was lifted with very little pull required on the line.

The rewindable bobbin is 3 inches in diameter and weighs 11 oz. (This weight can be reduced). It contains 120 feet of line which can be rewound on the bobbin. Rewind time is 1-1/2 minutes. There is some difficulty with line twist on this bobbin. Because of the size, the rewind time, the lift limitation, the twist problem, and the initial cost of this bobbin, it is recommended that it yield to the expendable bobbins in all but special situations.

The bobbins shown should not be considered final design. They were fabricated for experimental purposes only and, therefore, they utilize materials and parts which were readily available.

The height limitations imposed by the strength of the thrower's arm might be overcome by shaping the bobbin in such a way that it can be shot from a CO_2 gun. (A description of this gun appears later). A contained explosive or a spring might also be used to shoot a bobbin. By using these propelling devices there is every indication that an antenna wire can be wound on the bobbin and then shot in a slanting direction to form a sloping wire antenna. Tensolite Insulated Wire Company, Inc. makes a wire which is 21 strands of #40 wire with 0.015 inches insulation. It can be packaged in a bobbin 1-inch diameter by 5-inches long, weighing 0.5 lb. This is a practical size for shooting from a CO_2 gun.

Summarizing the possibilities of the bobbin, it seems to have the best combination of light weight, reliability, and silent operation of any method for raising an antenna to a height of 40 feet under the tree tops. When used with a propelling device, its possibilities for use at greater height

are also good when compared to other methods. A semi-permanent installation is limited only by the rate of deterioration of the line. Wind does not cause problems as serious as those encountered by a balloon. When wound with a wire, the bobbin can be used to extend a wire antenna into the tree tops or along their tops. A combination of a bobbin with other devices seems to be a practical method of antenna erection.

4.4 CO_2 GUN

The CO_2 gun (see Figure 21) provides a means to propel a wire or line without making excessive noise. The wire or line can be dragged by a projectile or a bobbin can be shot. The bobbin is recommended. The gun is a plastic enclosed assembly consisting of a telescoping 2-ft. firing tube and a 12-inch long x 2-inch diameter, 2-lb. cylinder containing 8 oz. of CO_2. The CO_2 cylinder contains enough gas to make 15 firings. The bobbin is a 1-inch diameter x 10-inches long cylinder containing 200 feet of 72-lb. test line or 160 feet of insulated antenna wire. Tests have demonstrated that this equipment will shoot the 72-lb. test line to a height of 100 feet.

Another approach to a CO_2 gun might be practical after a development program. A firing tube would be used again and this one could be clipped to a rifle barrel. The 180 feet of line would be packaged inside a charged CO_2 cartridge weighing 6 oz. The line would be tied to a relatively large plug in the end of the cartridge. The plug would be withdrawn rapidly by a suitable firing mechanism on the firing tube and the cartridge would be propelled by the pressure built up behind it as well as a short period reaction effect. A cartridge large enough to contain the 180 foot line could also contain 3 oz. of CO_2; however, according to very rough calculations this amount of CO_2 when rapidly expanded would cause freezing and prevent complete withdrawal of the line. 0.5 oz. of CO_2 should be sufficient to propel the cartridge to a useful height. Experimentation might prove that a cartridge 10-inches long x 1-inch diameter and only partially charged might be suitable for this application.

The CO_2 gun is a practical propelling device for use in the tropics, but would not work in the artic, because the CO_2 pressure drops off rapidly with decreasing temperature. For jungle use it is about the quietest gun with sufficient energy to be practical. Further effort should be applied in this direction to develop evaluation models.

4.5   ROCKETS

Rockets were considered for laying wire over the tree tops. If the wire is carried with the rocket and fed out as it flies, there is less danger of snagging in the foliage. There is also less of a problem from burning of the wire by the rocket blast. A rocket carrying 160 feet of wire might weigh a total of 1 lb. Such a rocket would need an impulse of about 3.5 ft.-sec. if drag is neglected. This is equivalent to 12 lbs. thrust for .3 sec. Based on Li'l Mike, which is a solid-fuel rocket for space applications, it would appear that a scaled-up version 5 inches long x 2 inches diameter would provide plenty of energy. There are several drawbacks in the use of rockets; a solid-fuel rocket such as this would make considerable noise, handling would have to be in accordance with the rules governing the handling of explosives, and a launching guide would be necessary to start the rocket on the proper course.

A rocket using water under pressure from a CO_2 cartridge was investigated. This approach is entirely impractical. When the rocket is compared to other launching methods, both noisy and silent, the rocket must be discarded. A rifle grenade will do the same thing with equivalent noise and less trouble. A CO_2 gun will do the same thing with less noise and equal trouble.

4.6   SPRING MAST

A study was made of a design for a lightweight mast which could support a 2-lb. antenna at the top, and which could be quickly erected from a manpack without assembly. Likewise, it could be restowed in the manpack by simply turning a crank. It could be erected to any height up to 25 feet when

simply supported at the base. The tower is 25 feet long and 1-3/4 inches in diameter when extended. When stored in a manpack it is 24-inches long x 12-inches wide x 5-inches thick and weighs approximately 20 lbs. (see Figure 22).

The proposed tower is similar to one invented by George J. Klein of Canada's National Research Council. A .010-thick strip of steel is formed to take a relaxed shape in the form of an overlapping cylinder. This cylinder is 1-3/4 inches in diameter and 25-feet long and has the overlap edge in the longitudinal direction. When the cylinder is forced open so that the steel strip is flat again, it can be rolled up from one end into a cylinder 3 inches in diameter and 11 inches long. It is carried in this position. The size of the pack includes the guides, the stand, and the crank required to stow the mast.

Design calculations are included in Appendix C. Additional calculations may show that this mast could be used on a vehicle to raise an antenna. In this case it would be motorized and could be designed either for a stationary or moving vehicle. The torque required to stow the mast is large enough that a motorized design is very desirable.

4.7 SPRING GUN

A "Negator" type spring gun which has a constant force of 82 lbs. has enough energy to throw a bobbin into the trees. It has a width of 4 inches and a drum size of 2.71 inches. A spring 2 ft. long could be cocked by one man giving an energy of 164 ft.-lbs. Compared to a CO_2 gun of comparable size, the CO_2 gun has roughly ten times more energy.

4.8 TELECARTRIDGE

"Telecartridges" can be supplied in various diameters from .38 to 2.8 inches with energies from 3 to 4000 ft-lbs. A cartridge 1 inch in diameter has a stroke of 4 inches and has an output of 400 ft.-lbs. This is sufficient to throw a bobbin over the tree tops. These cartridges can be supplied

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as a percussion fired device or an electrically fired device. Since the blast is contained there is no flash and very little noise (less than a rifle or rocket). An aiming and launching device is required to direct the bobbin in the desired direction. This might be a tube which is normally carried in a pack but can be attached to a rifle prior to firing. The size and ease of operation of this device is about the same as a CO_2 gun. It has good possibilities as a propulsion device.

4.9   HELEVATOR

Fairchild Stratos-Electronic Systems Division makes an unmanned rotary wing aircraft which lifts an antenna into the air. It is called a Helevator. This device might be used for base-camp installations. A VHF amplifier and antenna could be hoisted to 1000 feet with a 40 hp unit. The Helevator is said to be capable of staying aloft 1000 hours without maintenance. It can withstand icing conditions, electrical storms, and winds up to 60 mph.

A 40 hp Helevator has rotor blades 14 feet in diameter. The vehicle weight is 195 lbs. The payload at 1000 feet is 50 lbs. plus 160 lbs. of coax transmission line. The power required for the electric driving motor is 1100 volts, 400 cycles, 3 phase, 40 KVA. The power requirement appears to be prohibitive.

4.10   OTHER EMPLACEMENT DEVICES

Other devices were considered for throwing a wire or a line. Some are accepted and used by the military, others have serious practical limitations which render them virtually impractical for jungle operations.

4.10.1   Rifle Grenade

The rifle grenade is used to lay a wire. Instructions are given in TM11-2240. The advantages of using this method lie in the availability of the rifle and the grenade launcher, and in the accuracy and range which can be obtained. The greatest obstacle in its use in the jungle is the noise which it creates.

4.10.2 Spigot

The spigot is a bolt which drops into the end of a rifle barrel. A string or wire is attached to the spigot and shot out. It is reported that the Australians used this method successfully and prefer it to other methods because of its simplicity and small size. Noise is the problem again. If a bobbin is attached to the spigot, a line can be draped over a very high tree and be used as a hoist. This would be a special bobbin in which the spigot would be ejected or withdrawn from the bobbin shortly after leaving the barrel. The line would be free then to feed out from the center of the bobbin.

The energy in a MI rifle round is approximately 2700 ft.-lbs. If the same energy can be put into the spigot then a bobbin can be thrown far over the tree tops.

4.10.3 Crossbow

A crossbow with a bobbin was considered. The energy is very much lower than the rifle (being in the order of 35 ft.-lbs.), This is not enough energy to drag up a line. The awkward size and shape of the crossbow make it a difficult apparatus to carry under jungle conditions.

4.10.4 Bazooka

A new expendable bazooka is used to lay a wire as described in TM11-2240. It is reported to have a total weight of 3.4 lbs. and will propel a .5 lb. payload 600 yds. The noise and awkward shape are problems in the jungle.

4.10.5 Naval Line Throwing Gun

These guns could be used but, again, noise and size are problems.

4.10.6 Underwater Spear Guns

Not enough energy.

4.10.7 <u>Chemical Rockets</u>

Too large.

4.10.8 <u>Vacuum Gun</u>

Not enough energy.

4.10.9 <u>Catapult</u>

Too awkward and too large.

4.10.10 <u>Sling</u>

Too awkward.

4.10.11 <u>Casting Rod</u>

Too awkward.

There are also other ways of hoisting an antenna. The following were considered:

4.10.12 <u>Line Climber</u>

If it is found that foliage in a given jungle area is of such a nature that a bobbin becomes entangled in a tree top, an antenna could be hoisted up the snagged line by a battery-propelled line climber. This may be a solenoid-ratchet device or a motor-driven device. It would be small and quiet.

4.10.13 <u>Tree Climber</u>

A device was considered which hooks over successively-higher branches and pulls itself up on itself. The result is a heavy and cumbersome mechanism.

DIAMETER (ft)				
CAPACITY (ft³)	4.2	14.1	33.5	65.5
*** DRIFT IS 10 MPH WIND (degrees)	28°			13°
*** DRIFT IN 15 MPH WIND (degrees)	55°			31°
** NO. INFLATIONS/MANPACK	5		2	1
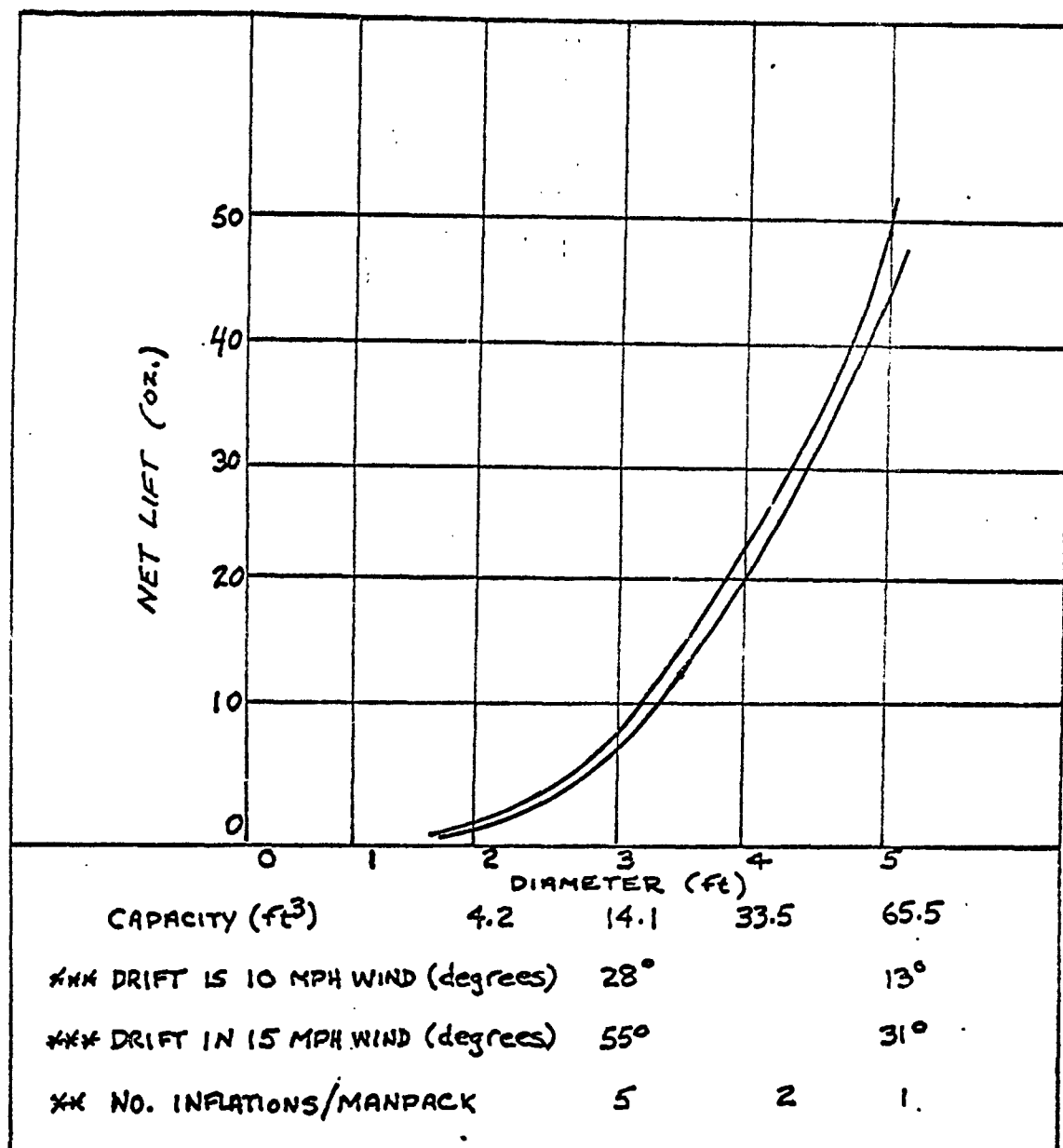
*   Lift is based on 90°F, 100% humidity and sea level.

**   Number of inflations includes at least 14% leakage.

*** Drift is measured in degrees from vertical. It is assumed that the wire being lifted is 80 feet long and weighs 2.8 oz. Drag on the wire is neglected. Drift was calculated for helium-filled balloons only.

Figure 16. Theoretical Data for Tethered Spherical Balloons Weighing .01 lb/ft²

18.5" x 4.24" TANKS

20"

10"

5"
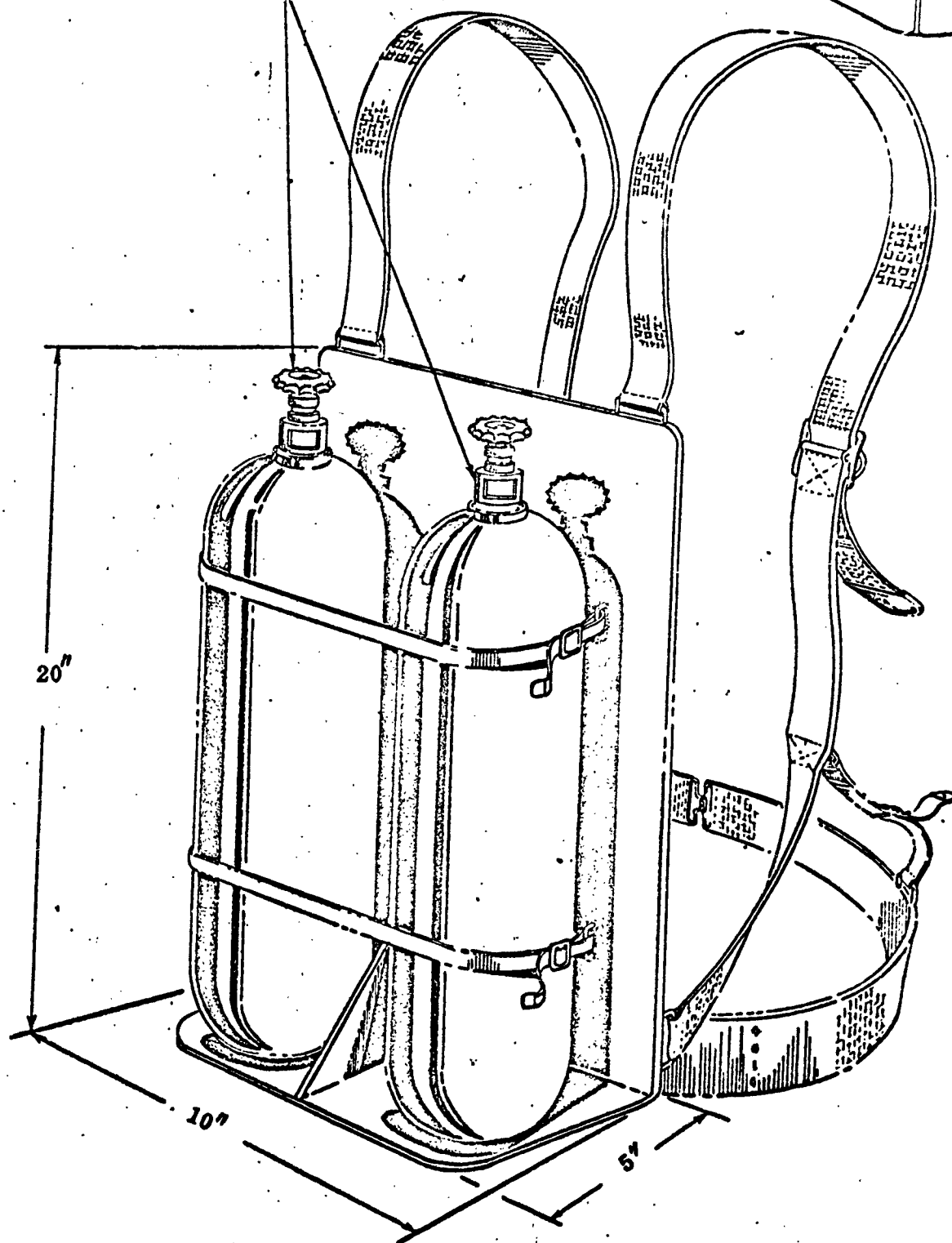
Figure 17. Helium Manpack
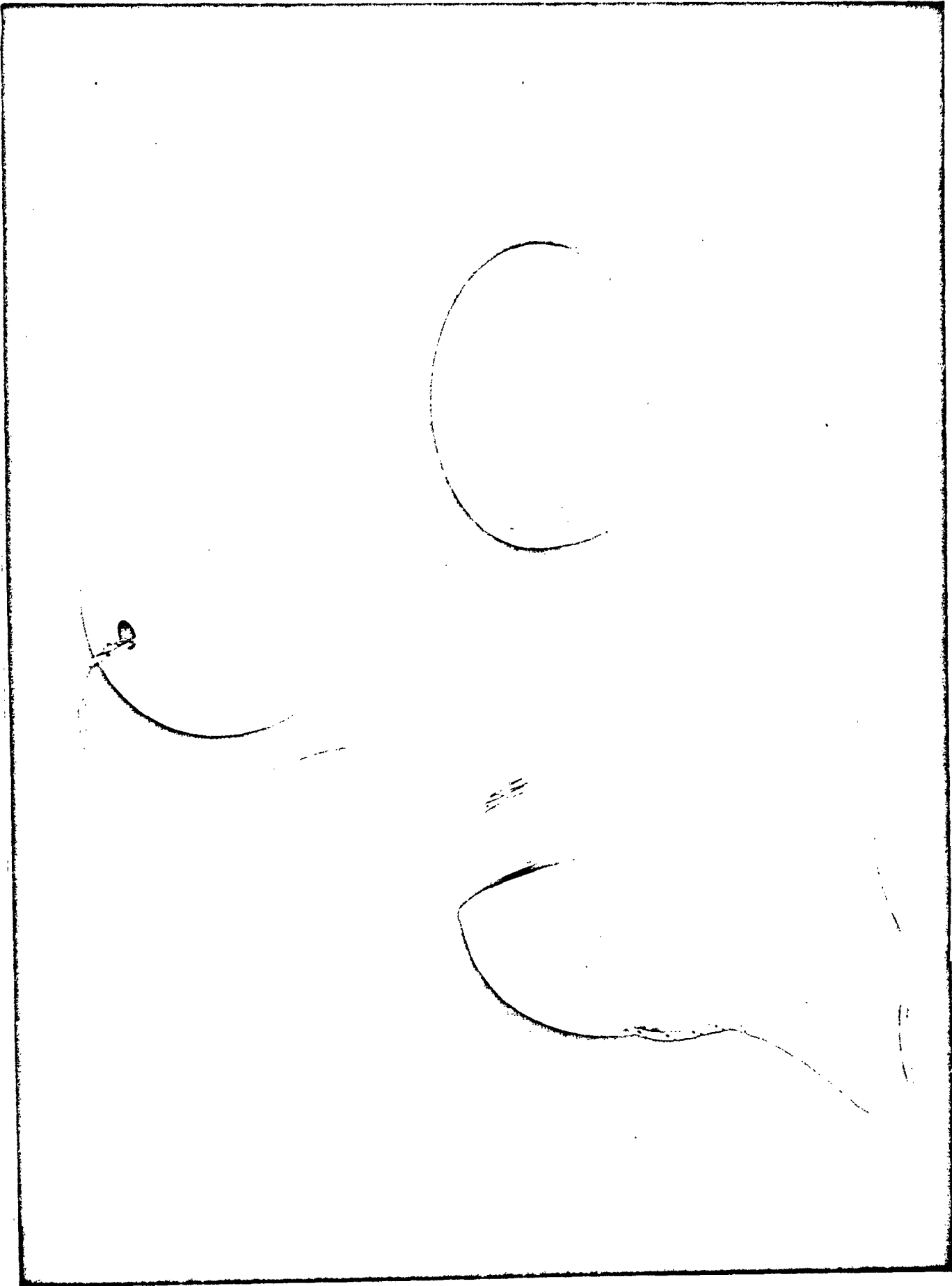
Figure 18. Expendable Bobbin

Figure 19. Bobbin
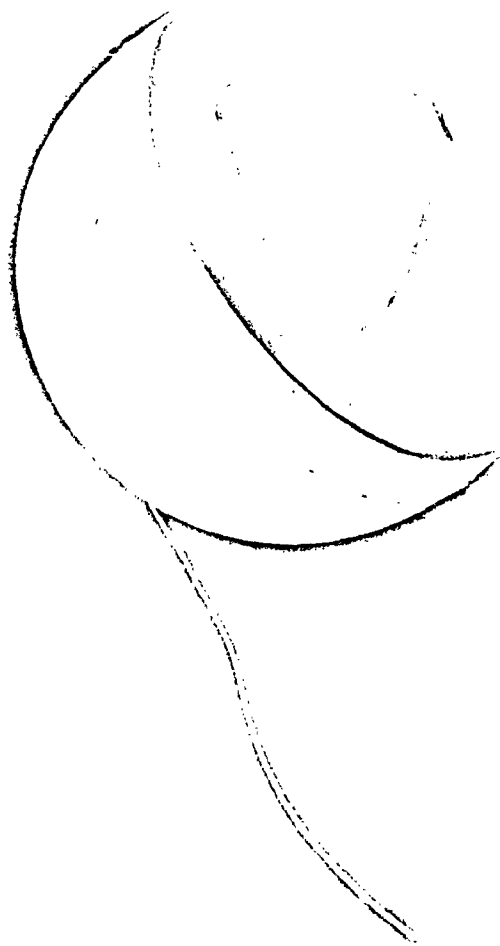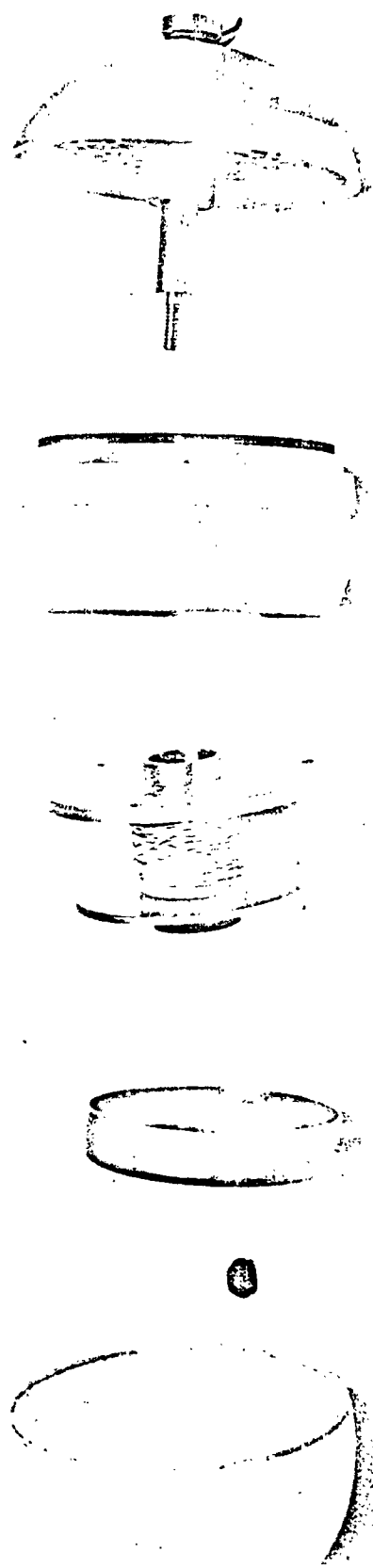
Figure 20. Bobbin, Exploded View

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Figure 21. CO_2 Gun

1-3/4" DIA.

24"

18"

12"

DETACHABLE STAND
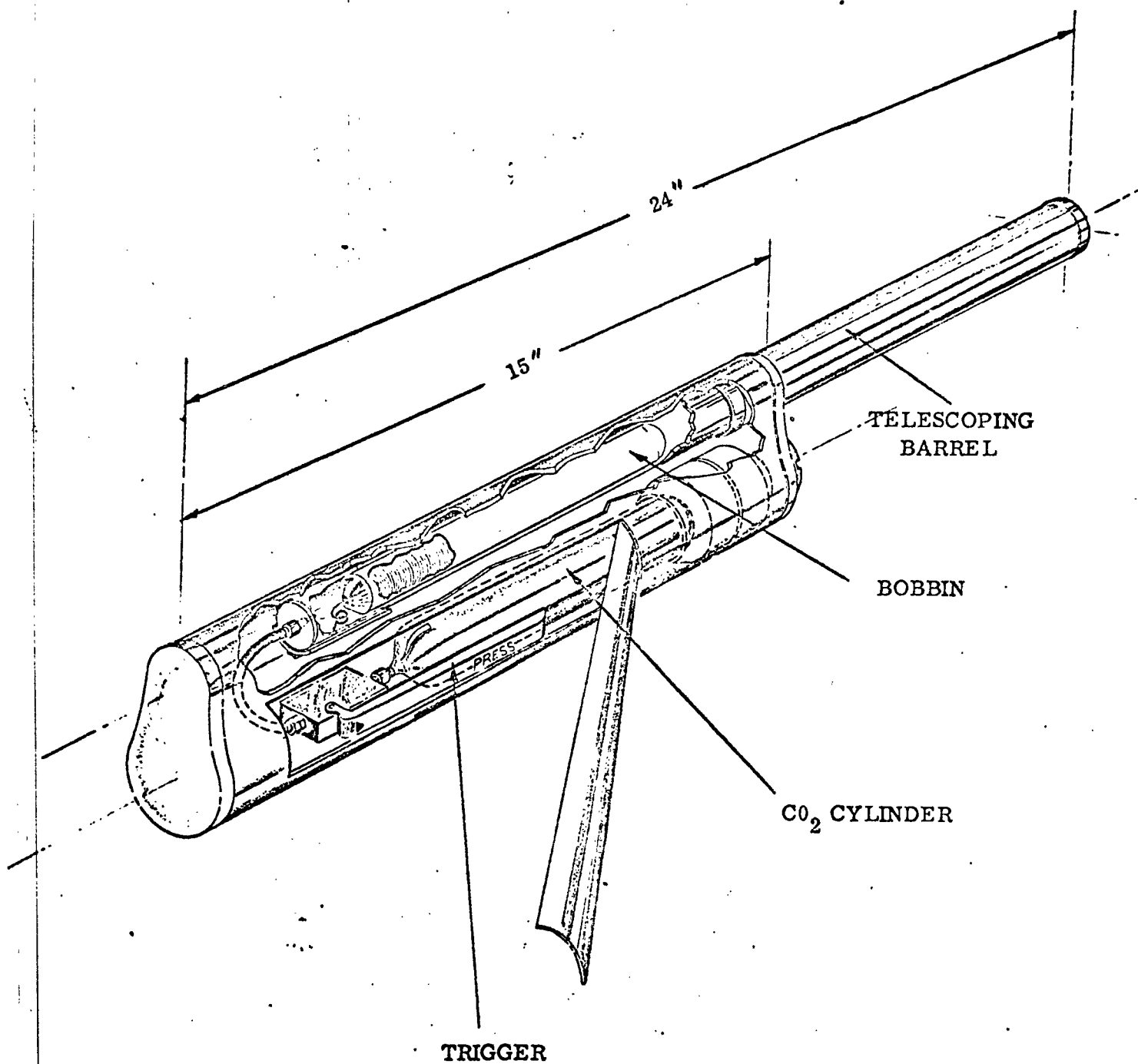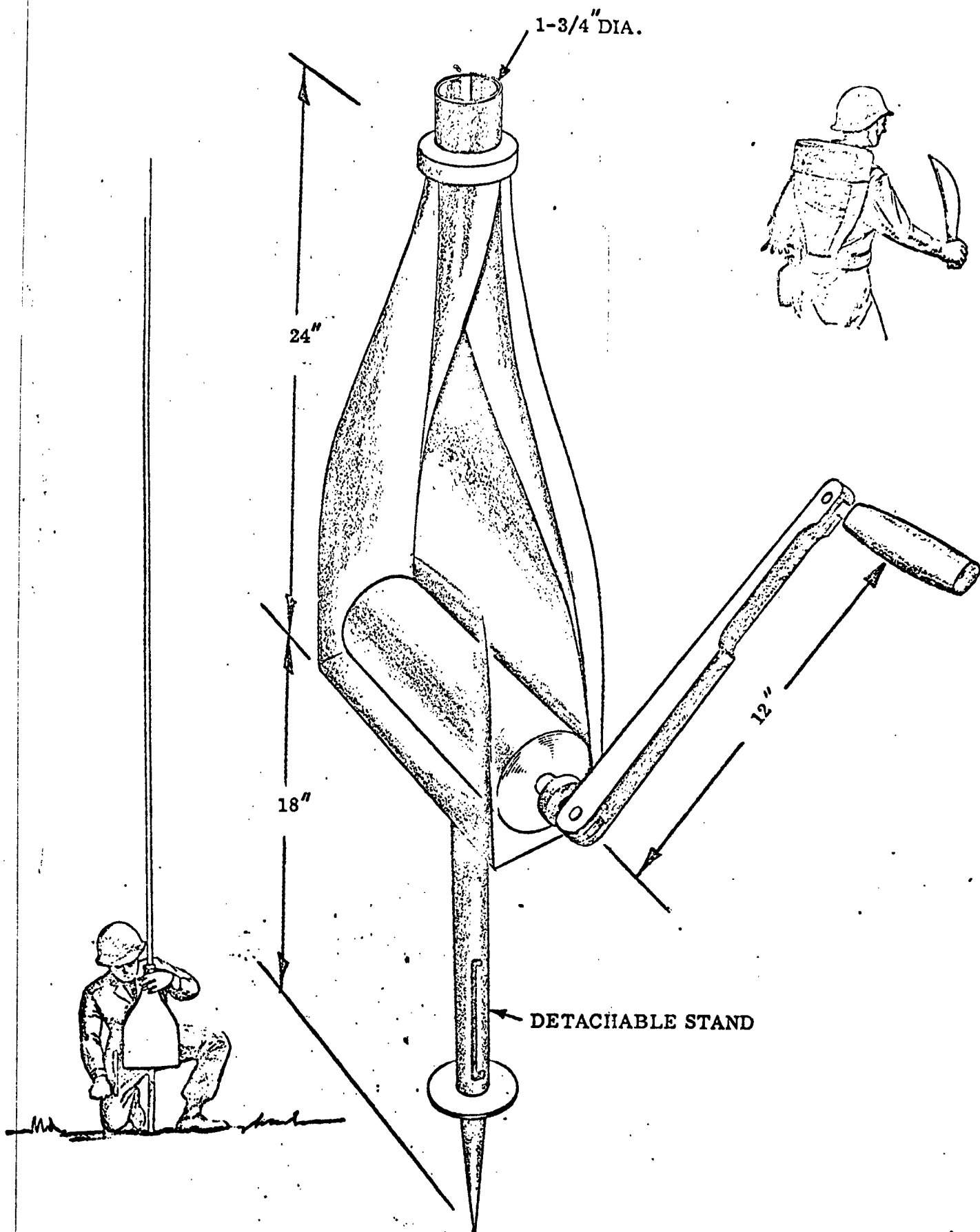
Figure 22. Spring Mast (25 Ft.)

SECTION V
CONCLUSIONS

5.1 JUNGLE PROPAGATION

5.1.1   Because the attenuation of the dense jungle foliage is so great, even at 3 mc, ground wave propagation is useless unless the antennas are raised above the foliage or are sited on hills with relatively clear line-of-sight.

5.1.2   Sky-wave transmission, with available Army HF Sets, using quarter to half-wave horizontal, or sloping wires below the canopy will perform for over 90 percent of the daylight hours and over 50 percent of the nighttime hours, provided broadside radiation to the ionosphere is used, and the predicted LUFs and MUFs are carefully observed.

5.2 ANTENNAS FOR SKY-WAVE PROPAGATION

5.2.1   The best practical antenna for sky-wave propagation by jungle patrols is a half-wave wire dipole at 1/8 wavelength height above ground.

5.2.2   Even at 1/20 wavelength height the antenna gain is still not worse than 50 percent of maximum obtainable gain. This is a practical compromise, where tree branches are dense at higher levels.

5.2.3   Loaded dipoles at any height are less efficient than a half-wave wire only a few feet above ground.

5.2.4   A simple bobbin, thrown over a branch, is the best way of elevating wire antennas to the described heights. See Figures 23 and 24.

5.3 ANTENNAS FOR LINE-OF-SIGHT PROPAGATION

5.3.1   An HF wire antenna can be shot up over the trees by a relatively-noiseless CO_2 gun, and excited from the end on the ground. This method may be a way of getting "ground-wave" propagation to an elevated base-camp antenna. Investigation of antenna efficiency for this condition must be made. Input impedance measurements are promising.

5.3.2   An alternate method of elevation is by means of a long, thin balloon raised just above tree-top level. This method is less attractive because of the weight of the gas tanks to be carried. An efficient broadband antenna can be printed on the balloon. The balloon antenna is more feasible at VHF because of the limitations on balloon size. A lightweight, low-loss, feed line is also feasible.

5.3.3   The free-space approach requires elevation of a base-camp antenna to heights of the order of 300 feet or more. This is feasible using a balloon and special lightweight amplifiers to compensate for cable losses. This method is limited by the environmental conditions and especially by wind-speed.
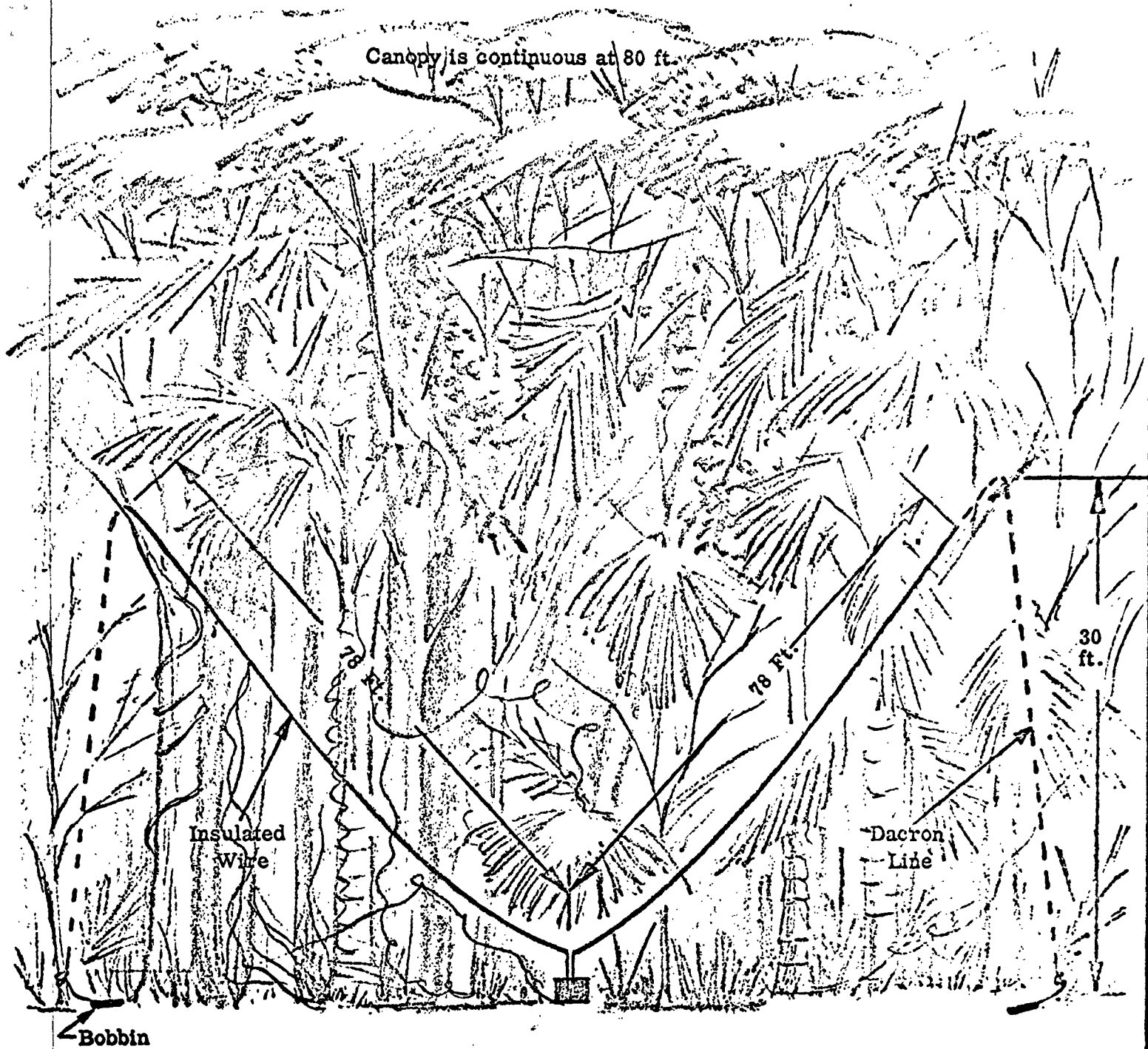
Figure 23. 1/2 λ Dipole Antenna

Sloping Wire Installation

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CANOPY IS CONTINUOUS AT 80 FT.

78 FT.

78 FT.

INSULATED
WIRE

RG-58/C →

← DACRON
LINE

30'
FT.

BOBBIN
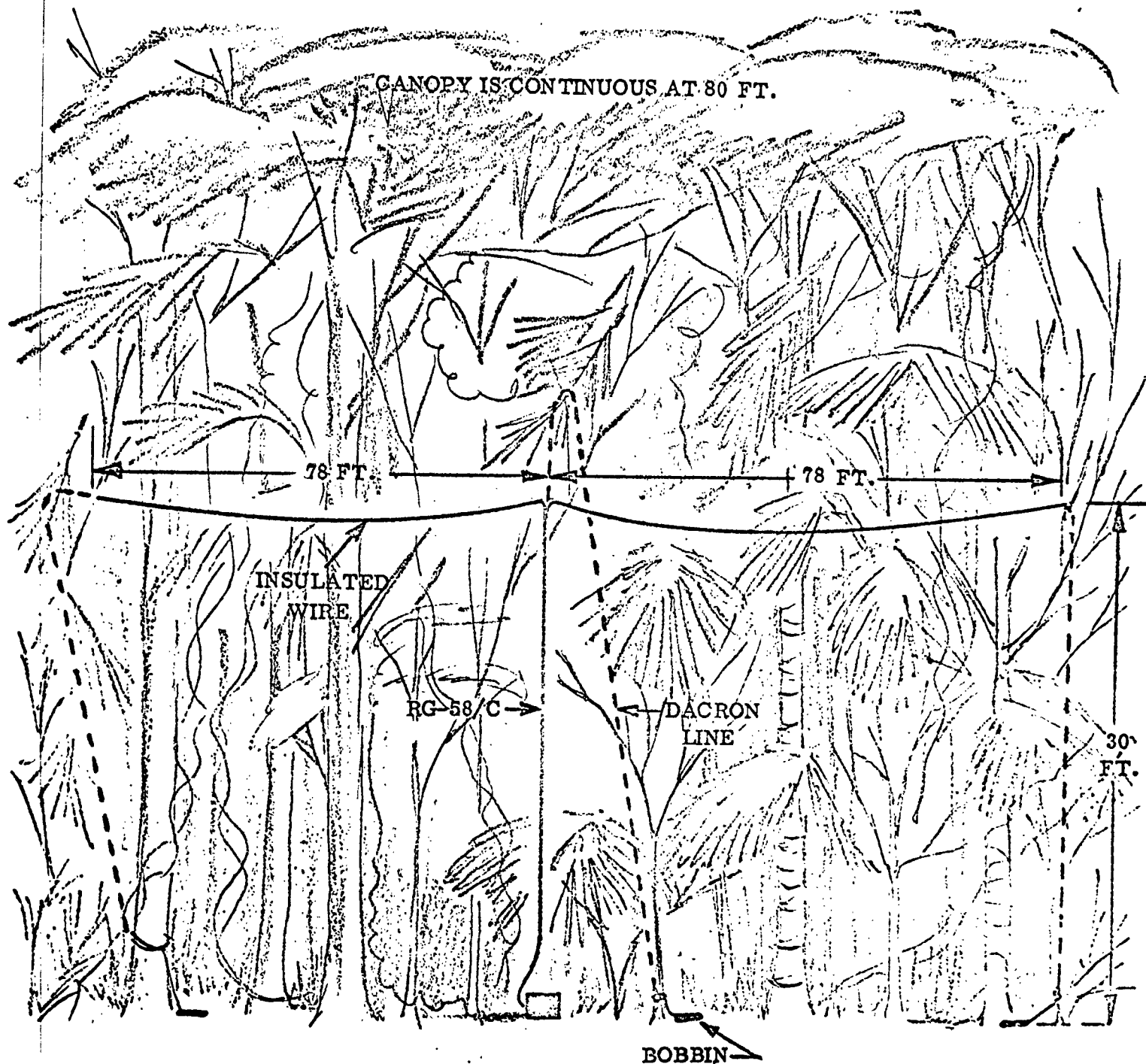
Figure 24. 1/2 λ Dipole Antenna
Horizontal Wire Installation

SECTION VI
RECOMMENDATIONS

6.1   ANTENNAS

The $\lambda/4$ to $\lambda/2$ horizontal wire below the canopy appears most economical, and best suited to tactical operations. However, the sky-wave propagation laws must be obeyed; that is, transmission must be by horizontally-polarized waves between the MUF and LUF.

6.2   TASKS RECOMMENDED FOR FUTURE EFFORT

6.2.1   Fabricate and field test normal and foreshortened HF half-wave wire antennas for efficient sky-wave transmission in the jungle.

6.2.2   Fabricate and field test a VHF antenna balloon and lightweight cable for patrol use.

6.2.3   Fabricate and field test a balloon and amplifiers for base-camp use.

6.2.4   Design, fabricate, and field test improved propulsion devices to throw a wire or cord at least 80 feet high, to be reused at least 3 times.

6.2.5   Determine jungle tactical communication system power balances and tradeoffs for the above antennas and devices.

APPENDIX A
HF SKY WAVE PROPAGATION OVER SHORT OR MODERATE DISTANCES USING HALF-WAVE HORIZONTAL OR SLOPING ANTENNAS*

Introduction

Difficulties have been encountered by the various armed forces in the use of tactical radio, sets and antennas for transmission over even short distances in jungle areas. Ground-wave attenuation in the jungle was found to be very high; and in the design of the antennas for most tactical sets, efficiency in short distance sky-wave transmission has been sacrificed for mobility. Difficulties have also been encountered in transmission over distances of about 50 to 200 miles in open country.

It has been appreciated for some time that the substitution of antennas which radiate well in an upward direction would give much better transmission in jungles, over high mountains, and over medium distances in the open where ground-wave transmission is too weak and sky-wave transmission must be used.

Tests undertaken under NDRC Project C-79 have been directed toward obtaining quantitative data on the relative performance of various antenna types for sky wave in the 2-8 mc range and methods for adapting such antennas for use with tactical radio sets. Some work was done in Florida by the U. S. Signal Corps and some by Bell Labs in New Jersey.

Conclusions

(1)   A solution for the above problem was found in the proper use of 1/2 wave horizontal antennas from 7 to 30 ft. above ground or half-wave sloping wires of the same general height at a small vertical angle to the ground.

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* Extract from Final Report on NDRC Project C-79, Part III, 7/15/44.

(2)   The attenuation of high-angle sky waves through jungles is small since the actual wave path through the jungle is short, being only the distance from the sending antenna to the tree tops and from the tree tops to the receiving antenna. In addition, the transmitting and receiving antennas are not appreciably affected by nearby jungle growth, which is not the case with vertical antennas.

(3)   Horizontal 1/2 wave or sloping half-wave antennas, with a relatively-low vertical angle of slope, radiate and receive well at high angles. In addition, as receiving antennas, they have a marked tendency to discriminate against low-angle noise due to atmospheric static and to interference from other radio stations. Likewise, they transmit poorly at low vertical angles and, therefore, cause little or no interference to other receivers employing vertical antennas at ground-wave distances or long distances away. These statements apply even to suitably-proportioned end-fed antennas, since the combination of down lead and half-wave top receives much less low-angle power than the down lead alone. Short vertical antennas and the usual 1/4 wave inverted antennas do not have the above properties, and are suitable mainly for ground-wave use or for low-angle long-distance work.

(4)   The received sky-wave signal with the horizontal antennas was nearly the same, for given ionosphere conditions, at distances out to 150 miles, which was the greatest distance tested.

(5)   Tests confirmed that such antennas provide a way of getting a good signal over a high mountain range.

(6)   Comparative tests at 75 miles (on 3 mc) indicated that approximately equal signal/noise ratios would be received under the following conditions:

(a)   Feeding 3 kw into a 15 ft. vertical whip with counterpoise.

(b)   Feeding 1 watt into 1/2 wave end-fed horizontal 7' above the ground.

(c)   Feeding 1/6 watt into a sloping 1/2 wave wire 5 to 30 ft. ht.

In each case the sending and receiving antennas were identical. Sloping wires were broadside to each other.

TABLE I
SKY-WAVE TRANSMISSION BETWEEN LIKE ANTENNAS
75 MILE RANGE   3 MC FLORIDA

Antenna Type	Relative Received Power. for Equal Trans. Powers			Rel. Trans. Pwr. for Equal S/N
	Ref. Signal	Noise	S/N	
Horiz. 1/2 Wave End Fed 7' Ht.	0	0	0	1
" " " " 30' Ht.	21	12	9	0. 13 (150 mi)
" " " Center Fed 30' Ht.	21	12	9	0. 13 (" ")
Sloping 1/2 Wave End Fed 5' to 30'	12	4	8	0. 16 (broadside)
Sloping 1/4 Wave End Fed 5' to 20' 82" Counterpoise	1	6	-5	3. 2 "
SCR-188A Antenna, 45' top, 35' Downlead, 80' Counterpoise at 5' Ht.	-2	14	-16	40
Tactical 15' Tuned Whip with Crow Foot Counterpoise	-38	-3	-35	3200

The horizontal 1/2 wave antennas radiate a short-distance sky-wave signal which does not vary much with azimuth in the 2-8 mc range. This was found by test (and also is indicated in reference (13), U. S. Army RPA Tech. 6, Figure 108 and 110).

It was found by test that the sloping half-wave was somewhat directional in azimuth, giving the best received sky-wave signal when the antennas were broadside (parallel) to each other, and the lowest when the antennas were in line with their high ends pointed toward each other. This moderate directivity may be of some advantage in point-to-point transmission.

Examination of Table I shows that the 1/2 wave antennas receive high-angle radiation more efficiently than they do the noise.

(The largest vertical static fields observed in February and March in Florida were of the same order of magnitude as those observed in Panama in September.)

In the tropics it may be necessary in some cases to orient sending and receiving 1/2 wave antennas approximately parallel; this is not necessary in the temperate zones. (Effect is due to earth's magnetic field in the ionosphere.)

The 1/2 wave sloping antenna showed good pickup of high angle waves when used broadside. (Sending and receiving antennas parallel.) Somewhat less end on with low ends pointing together, and still less with low ends pointing away from each other. The 1/4 wave sloping end fed was about 6 db weaker in transmitting or receiving, than the sloping 1/2 wave.

When using sloping 1/2 wave antennas, benefits can be obtained by placing sending and receiving antennas broadside to each other with their high ends pointing toward the direction of principal interference.

A slope of 1 in 6 is suitable. A very great slope would change their characteristics to those of a vertical antenna of the same length.

Transmission tests were made over Mt. Mitchell (16 mi. airline) a 4700 ft. peak in North Carolina. Tests showed 1/2 wave horizontal with only 7' ht. gave good results. 15' vertical whips were unusable. Tests showed base impedance of sloping antenna remained nearly the same in wet or dry weather.

APPENDIX B
MEASUREMENT OF FACTORS AFFECTING JUNGLE
RADIO COMMUNICATIONS*

I.   INTRODUCTION:

In a recent report ORG-2-1, entitled "Radio Communication in Jungles," it was pointed out that since a large part of this war with Japan will be fought in jungle territory, there is a definite need for engineering data on the performance of radio equipment in jungles. In the above mentioned report it was shown that the only information available was in the form of reports from the field. It was further shown that the information contained in these reports was vague, to a certain extent contradictory, not quantitative, and inadequate to serve as a basis of information by means of which suitable equipment can be procured.

In order to obtain information of the desired type, an expedition was sent to Panama. An attempt was made to measure separately all factors affecting jungle communication which were determined by the theater of operation and to translate the results in terms of the range of particular sets. This approach was considered vastly superior to the conventional "service tests" wherein one set is moved out to the point at which communication fails.

The measurements which were made, may be divided into two general classifications: first, Radio wave propagation (a) over flat open ground to determine the radiated power of the set and (b) through heavy jungle to determine attenuation; and second, Measurements of atmosphere noise levels to determine the signal strength required for communication.

II.   SUMMARY:

Field strength measurements were made on 2005 kc, 5975 kc, 44 mc, and 98.8 mc to determine the attenuation of radio waves through heavy jungle. The attenuation was found to be so great that for communication greater than approximately one mile, the ground wave which is normally employed for these ranges, is practically useless. It requires powers of the

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* Extract from Report No. ORB-2-3, Sept-Oct 1943
  OCSigO, P & O Division, OR Branch.

order of 200 times the power of the sets tested to give a ground wave range of 2 miles. It is shown that communications over greater distances than one mile necessitate either (1) tree top or hill to hill transmitter and receiver sites at very high frequencies so that the transmission path is mainly above the top of the jungle; or (2) use of sky wave transmission at high frequencies wherein the transmission path is up to the ionosphere and back to the ground. The use of ionosphere predictions as a guide in the selection of proper frequencies for sky wave transmission is urged.

Measurements of "atmospheric" noise level were made on the frequencies 2005, 2700, 4160 and 5975 kilocycles to obtain quantitative data on the signal intensity required for satisfactory communications for correlation with predictions of required signal intensity made on the basis of thunderstorm data. The method of measuring average atmospheric noise level is described in detail and it is recommended that further noise measurements of this type be made in areas in which future operations are contemplated.

III.   CONCLUSIONS:

A.   The attenuation due to dense jungle growth is so great that for communication of more than approximately one mile, the ground wave which is normally employed for these ranges is practically useless.

B.   Communications greater than one mile may be obtained by elevating the antennas of VHF sets either by raising them into trees or by using hilltop sites.

C.   Ranges greater than one mile with MF or HF sets require use of sky wave transmission. This involves the use of antennas radiating energy almost vertically and the employment of ionosphere predictions for optimum results.

D.   The method of measuring average atmospheric noise level for predicting the field intensity required for communications is relatively easy

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to accomplish with improvised equipment and readily lends' itself to analysis.

IV. RECOMMENDATIONS:

A.   In jungle situations requiring communication ranges of over one mile, it is recommended that the following means be employed:

(1) At the present time, high frequency equipment of the power and frequency range of the SCR 694 be used, taking due consideration in the signal plan for the use of optimum frequencies as determined by ionosphere predictions for the time of day and year, and geographical location involved. Antennas which radiate energy almost vertically upward (long wire horizontal antennas) should be provided to supplement the usual rod antennas. The signal plan should also take into account the fact that a large number of channels can be made available during the daytime but the number available at night will be reduced and the reliability of these channels will be decreased.

(2) Plans for future operations should include sets having a frequency range of 2 to 12 megacycles, since the optimum frequencies for sky wave transmission will have increased by 1949-50 the time of the sunspot maximum, and higher frequencies will be required.

(3) In those cases of mountain terrain where the terminal stations can be located at relatively high altitudes above the surrounding terrain so that radio signals will follow a path above the jungle growth, VHF relay equipment such as the AN/TRC-1 is recommended. This equipment will provide a very reliable circuit under these conditions. Provisions should be made for raising the antennas of portable manpack VHF equipment such as the SCR 300 up to the level of the top of the jungle to obtain increased jungle range.

B.   It is recommended that additional quantitative measurements of atmospheric noise level be made in areas in which future military operations are contemplated.   It is recommended that the method of measuring average rather than peak noise be used since this method does not require extremely critical adjustments of equipment and it provides easily analyzed data that can be correlated readily with other data made with different equipment in other parts of the world.

APPENDIX C
CALCULATIONS FOR LIFT DEVICES

C. 1 CALCULATION OF NET LIFT OR SPHERICAL BALLOON
      FILLED WITH HYDROGEN OR HELIUM

Assume balloon is fabricated of a Mylar-Alum-Urethane film weighing $.01$ lb/Ft^2.

Weight of a sphere $= \pi d^2 (.01)$

$= .032 d^2$

where

$d = $ diam. sphere (ft.)

Volume of sphere $= .5236 d^3$

Net lift of sphere
using hydrogen $= $ lift of hydrogen - weight of sphere

$= (.062)(.5236) d^3 - .01 d^2$ lbs.

$= \underline{\underline{.518 d^3 - .512 d^2 \text{ oz.}}}$

Lift of helium $= .058$ lb/ft^3

Net lift of sphere
using helium $= $ lift of helium - weight of sphere

$= (.058)(.5236) d^3 - .01 d^2$ lbs.

$= \underline{\underline{.485 d^3 - .512 d^2 \text{ oz.}}}$

DATA FOR PLOTTING LIFT

Dia. ft.	Lift (oz.)	
	Hydrogen	Helium
1.5	.6	.5
1.8	1.4	1.2
2.0	2.1	1.8
2.5	4.9	4.4
3.0	9.4	8.5
3.5	15.9	14.5
4.0	25.0	22.8
4.5	36.8	33.8
5.0	52.0	47.8

C.2 CALCULATION OF DRIFT ANGLE (ψ) OF BALLOON USING HELIUM

Assume balloon = 5 ft. diameter

Assume wind velocity = 10 mph

Assume that antenna wire weighs 2.8 oz. and is 80 feet long.

Neglect drag on wire.
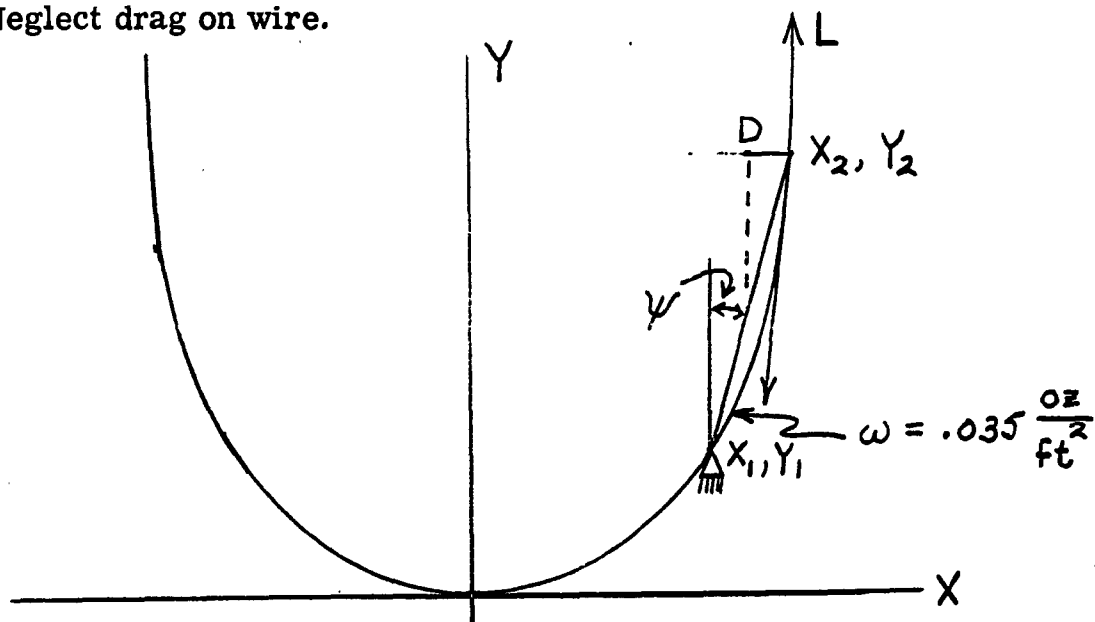
From Fig. I: Net lift (L) = 47.8 oz.

Drag = $.059 \, C_D \, d^2 \, v^2$

$\quad = (.059)(.07)(25)(100)$

$\quad = 10$ oz.

Slope of wire at X_1, Y_1 = $\dfrac{47.8 - 2.8}{10}$ = 4.5

Slope of wire at X_2, Y_2 = $\dfrac{47.8}{10}$ = 4.78

Formula for catenary curve referred to 0 is:

$$Y = a \left[\text{Cosh} \frac{X}{a} - 1 \right] \quad \text{where } a = \frac{D}{\omega} = 286$$

The slope of the curve $= \dfrac{dY}{dX} = \sinh \dfrac{X}{a}$

At X_1, Y_1: $\dfrac{dY}{dX} = 4.5 = \sinh \dfrac{X_1}{286}$

$$\dfrac{X_1}{286} = 2.21 \quad \text{From table of hyperbolic functions}$$

$$X_1 = 632 \text{ ft.}$$

$$Y_1 = a \left[\cosh \dfrac{X}{a} - 1 \right]$$

$$= 286 \left[\cosh \dfrac{632}{286} - 1 \right]$$

$$Y_1 = 1032 \text{ ft.}$$

At X_2, Y_2: $\dfrac{dY}{dX} = 4.78 = \sinh \dfrac{X_2}{286}$

$$\dfrac{X_2}{286} = 2.27$$

$$X_2 = 650 \text{ ft.}$$

$$Y_2 = 286 \left[\cosh \dfrac{650}{286} - 1 \right]$$

$$Y_2 = 1110$$

$$\psi = \tan^{-1} \dfrac{650-632}{1110-1032} = \tan^{-1} \dfrac{18}{78}$$

$$\psi = \underline{\underline{13^\circ}}$$

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C.3 CALCULATION OF DRAG (D) OF A SPHERE

$$D = \frac{C_D A_P v^2}{2}$$

where: C_D = .08 at 15 mph

  = .07 at 10 mph

  = .14 at 5 mph

A = projected area ft^2

P = mass density of air at $90^{\circ}F$
  and 100% humidity

  = $\frac{.0698}{32}$ slug/Ft^3

v = wind velocity   ft/sec

$$D = C_D \left(\frac{\pi d^2}{4}\ ft^2\right)\left(\frac{.0698}{32}\ \frac{lb\ sec^2}{ft^4}\right)\left(\frac{5280V}{3600}\ \frac{ft}{sec}\right)^2\left(16\ \frac{oz.}{lb.}\right)$$

where V = wind velocity mph

  = $.059\ C_D\ d^2\ V^2$ oz.

C.4 CALCULATING THE DENSITY OF SATURATED AIR AT 1 ATM
  AND 90° F

$$\rho_m = \frac{(B - .38\,p_v)}{R_T}$$

where B = atm pressure lb/in^2

  p_v = vapor pressure lb/in^2

  R = $.3704\ \dfrac{ft^3 - lb}{in^2 - lb\ ^{\circ}R}$

  T = 460 + 90 = 550 $^{\circ}R$

$$\rho_m = \left[14.5 - (.38)(1.422)\left(\frac{14.5}{29.53}\right)\right]\frac{1}{(.3704)(550)}$$

$$\rho_m = .0698 \ \text{lb/ft}^3 \ \text{(density of air)}$$

Lift of 1 ft^3 wet H_2 at 90°F:

    .0698 density of air

    .0081 density of H_2

Lift = .062   lb/ft^3

Lift of 1 ft^3 of dry H_e at 90°F:

$$\rho = \frac{P}{R_T}$$

$$= \frac{2500}{(386.3)(550)} = .0118 \ \text{lb/ft}^3 \ \text{(density of dry } H_e \text{ at 90}^\circ\text{F)}$$

Lift = $.0698 - .0118 = .058 \ \text{lb/ft}^3$

C.5   CALCULATING THE DENSITY (ρ_m) OF H_2 SATURATED WITH WATER VAPOR AT 1 ATM AND 90°F

p_v = Partial pressure of water vapor at 90°F = 1.422 in H_g

Atm pressure = sum of partial pressures

$B = p_v + p_h$

where B = atm pressure = 29.53 in H_g

= 14.5 lb/in^2

p_h = 29.53 - 1.42 = 28.11 in H_g (partial pressure of H_2)

Now $P_V = \omega RT$

and $\rho = \dfrac{\omega}{V}$

$$\therefore \rho_h = \frac{P_h}{RT}$$

where ρ_h = density of H_2 (lb/ft^3)

P_h = partial pressure of H_2 (lb/ft^2)

R = 766.8 $\frac{ft. \ lb}{lb \ ^\circ R}$

T = 460 + 90 = 550 $^\circ R$

$$\rho_h = (28.11 \text{ in Hg})(\frac{14.5}{29.53})\frac{lb}{in^2 \text{ in Hg}}(144)\frac{in^2}{ft^2}\left[\frac{1}{(766.8)(550)\frac{ft. \ lb \ ^\circ R}{16 \ ^\circ R}}\right]$$

$$\rho_h = .00472 \text{ lb/ft}^3 \quad \text{(density of } H_2\text{)}$$

$$\rho_v = \frac{P_v}{RT}$$

where: ρ_v = density of vapor lb/in^3

P_v = partial pressure vapor lb/in^2

R = .3704 $\frac{ft^3-lb}{in^2-lb \ ^\circ R}$

T = 460 + 90 = 550 $^\circ R$

$$\rho_v = 1.422 \text{ in Hg} \frac{14.5}{29.53} \text{ lb/in}^2 \text{ in Hg}\left[\frac{1}{(.3704)(550)\frac{ft^3-lb \ ^\circ R}{in^2-lb \ ^\circ R}}\right]$$

$$= .00343 \text{ lb/ft}^3 \text{ (density of vapor)}$$

Density of mixture = sum of densities of constituents.

$$\rho_m = \rho_v + \rho_h$$

$$= \begin{array}{r} .00343 \\ .00472 \\ \hline .00815 \end{array}$$

$$\rho_m = \underline{.00815 \text{ lb/ft}^3} \text{ (density of wet } H_2 \text{ at } 90^\circ F)$$

C.6 ROUGH CALCULATIONS FOR HELIUM PRESSURE VESSEL

Calculations are based on "Interstate Commerce Commission Regulations for Transportation of Explosives and Other Dangerous Articles by Land and Water in Rail Freight Service and by Motor Vehicle (Highway) and Water"; however, the results of these calculations should not be used as a design criteria for fabricating a pressure vessel in accordance with this code.

Para. 78.37 calls out spec. 3AA seamless steel cylinders which can be designed for stress (S) = 70,000 lb/in^2. Assume a cylinder 4.24 inches OD x 4.00 inches ID. The working pressure is given by:

$$P = \frac{S(D^2 - d^2)}{(1.3 D^2 + .4 d^2)} \times 3/5$$

where: D = outside diameter in inches

d = inside " " "

3/5 = factor allowed for testing above the working pressure

$$P = \frac{70,000 \left[(4.24)^2 - (4)^2\right]}{\left[1.3(4.24)^2 - 4(4)^2\right]} \times 3/5$$

$$= 4,940 \; lb/in^2$$

Assume that the ends of the cylinder are spherical and that the total inside length is 18 inches. The volume in the vessel is:

$$V = \frac{\pi d^2 \ell}{4} + .5236 \, d^3$$

$$V = \frac{4^2 \pi}{4}(14) + .5236(4)^3 = 209 \text{ cu. in.}$$

Volume at 1 atm = $\frac{(209)(4940)}{14.7}$ = 70200 cu. in. = 40.5 cu. ft.

Manpack volume = 81 cu. ft.

The weight of the vessel shell is:

W = Area x thickness x density

$$W = \left[4\pi(14) + \pi(4)^2\right] \times .12 \times .3 = 8.15 \text{ lbs.}$$

Manpack weight = 2 (8.15) + connection weight + canvas and straps.

= approx. 20 lbs.

C.7 CALCULATIONS FOR A SPRING MAST OF CROSS-SECTION SHOWN BELOW:
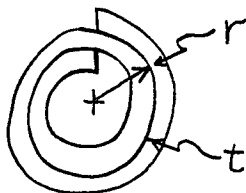
t = .01 inch

Assume mast will support a 2 lb. load at top. Assume the material is Maraging steel with a yield of 234,000 $lb/inch^2$ and E of 26.5×10^6 lb/in^2. Assume that only one thickness can be counted on for mechanical strength. Assume strip width to be limited by pack width = 11 inches. Max radius r:

$$r = \frac{\text{strip width}}{4\pi} = \frac{11}{4\pi}$$

r = .875 inches

$$I = \frac{\pi}{4}\left[r^4 - (r-t)^4\right] \quad \text{assume one thickness}$$

$$= \frac{\pi}{4}\left[.875^4 - (.875-.01)^4\right]$$

$$= .0204 \text{ in}^4$$

$$= 4\pi r \ p \ t$$

$$= 4\pi(.875)(.289)(.01)$$

$$= .0318 \text{ lb/in length}$$

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Checking stress in steel when tower is stored:

$$S = \frac{MC}{I}, \text{ where } M = \frac{EI}{r} \text{ and } C = \frac{t}{2}$$

$$S = \frac{Et}{2r}$$

$$= \frac{(26.5 \times 10^6)\,(.01)}{1.75}$$

$$S = 152,000 \text{ lb/in}^2 \quad \therefore \text{ Factor of safety is } 1.5$$

Checking elastic stability as fixed end vertical column:

$$P' = \frac{\pi^2 EI}{4\ell^2} = .3\omega\ell \quad \text{where } P' = \text{end load which will cause failure}$$

$$\text{(Roark pg. 306, Eq. 8)}$$

$$= \frac{\pi^2 (26.5 \times 10^6)\,(.0204)}{4\,(25 \times 12)^2} - .3\,(3.18 \times 10^{-2})\,(25 \times 12)$$

$$= 14.9 - 2.9$$

$$P' = 12 \text{ lbs} \quad \therefore \text{ column is stable}$$

Max. allowable stress in thin wall due to elastic buckling:

$$S' = \frac{.3Et}{r}, \text{ where } S' \text{ is stress which causes failure}$$

$$\text{(Roark pg. 316, Eq. M.)}$$

$$= \frac{.3\,(26.5 \times 10^4)}{.875}$$

$$S' = 90.800 \text{ lb/in}^2$$

Assuming that someone tries to lift the mast when it is extended in a horizontal position by grasping the base of the mast and swinging it up. The maximum length of unsupported mast which will withstand this abuse is calculated as follows:

$$S = \frac{MC}{I} \quad \text{where} \quad M = 2\ell + \frac{\omega\ell^2}{2}$$

$$S = 90,900 \text{ allowable}$$

$$C = r$$

$$\therefore \frac{\omega\ell^2}{2} + 2\ell = 90.900 \frac{I}{r}$$

$$\frac{.0318\ell^2}{2} + 2\ell = \frac{(90,900)(.0204)}{.875}$$

$$(1.59 \times 10^{-2})\ell^2 + 2\ell - 2120 = 0$$

$$\ell = \frac{-2 \pm \sqrt{4 + 4(1.59 \times 10^{-2})(2120)}}{2(1.59 \times 10^{-2})(12)}$$

$$\underline{\ell = 25.7 \text{ ft.}} \quad \text{This does not include allowance for acceleration forces.}$$

A larger diameter will not rapidly increase the allowable length as shown by the following equations and results.

$$S = \frac{Mc}{I} = \frac{.3Et}{r}$$

Substituting from previous equations and rearranging:

$$\ell = \frac{-1 \pm \sqrt{1 + \left\{\frac{1205}{r}\left[r^4 - (r-.01)^4\right]\right\}}}{.219\,r}$$

Results are:

r	ℓ
1 in	27.5 ft.
2 in	28.6 ft.
3 in	29.1 ft.
4 in	33.2 ft.

APPENDIX D
DERIVATION OF GAIN EQUATIONS FOR DIPOLES ABOVE GROUND
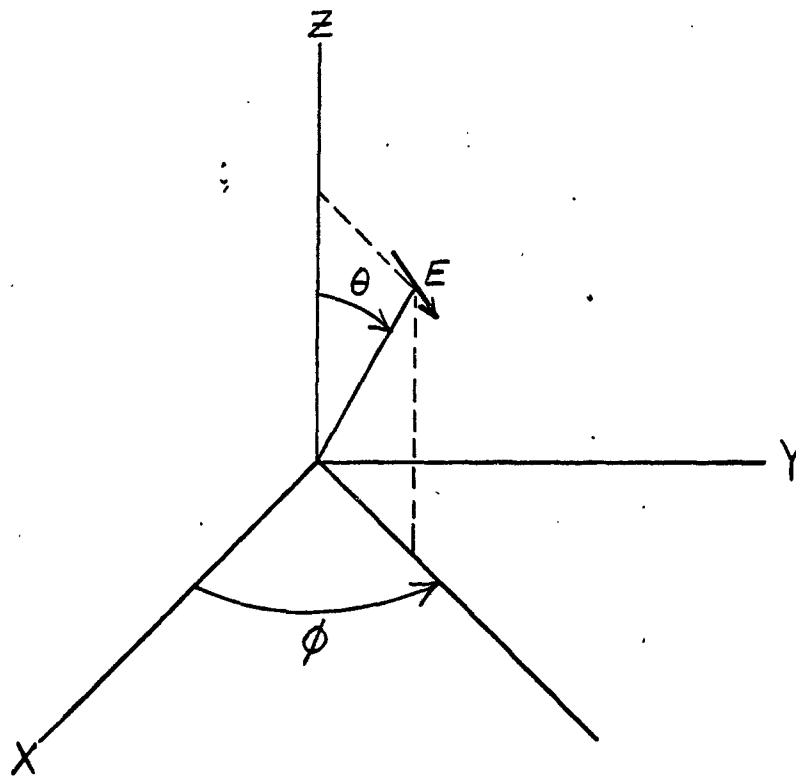
Coordinate System

The far field of any thin linear antenna in free space, is given by:

$$E = j \frac{60\pi \sin\theta}{r \lambda} \int_{-L/2}^{L/2} I_{(z)} \, dz \; e^{-j\beta r_{(z)}} \tag{1*}$$

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* Jasik - Antenna Engineering Handbook, p. 2-2, 2-3

where:

E = field strength in volts per meter

r = distance in meters to the observation point

λ = wavelength in meters

$\beta = 2\pi/\lambda$

$I_{(z)}$ = the rms current in amperes flowing through the differential element, dz

θ = the angle between the linear antenna and a straight line from the observation point to the center of the antenna

L = the length of the antenna in meters.

For a half-wave dipole the above expression reduces to

$$E_0 = j \frac{60 \, I_0}{r} e^{-j\beta r} \frac{\cos\left(\frac{\pi}{2} \cos \theta\right)}{\sin \theta} \qquad (2)*$$

where:

I_0 = current at the center of the half wave antenna.

For short antennas, (L less than $\lambda/4$), it becomes

$$E_1 = j \, 60\pi \frac{\sin \theta}{r} I_1 \, L_e \, e^{-j\beta r} \qquad (3)*$$

where:

I_1 = current at the center of the short antenna

L_e = effective length of the antenna defined as

$$L_e = \frac{1}{I_1} \int_{-L/2}^{L/2} I_{(z)} \, dz$$

* Jasik - Antenna Engineering Handbook, p. 2-2, 2-3

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For a constant distance, and in the plane perpendicular to the antennas ($\theta = 90^{\circ}$), these expressions become

$$E_O = j\ 60\ I_O\ K \tag{4}$$

and

$$E_1 = j\ 60\pi\ I_1\ K\ \frac{L_e}{\lambda} \tag{5}$$

$$\text{where } K = \frac{e^{-j\beta r}}{r}$$

D.1 VERTICAL GAIN RELATIVE TO A HALF-WAVE DIPOLE AT QUARTER-WAVE HEIGHT

When the short dipole is at a height (h) above ground, the field in the vertical direction is the sum of the direct wave from the antenna and the reflected wave from the ground. In the vertical direction:

$$E_1 = j\ 60\pi\ K\ I_1\ \frac{L_e}{\lambda}\ \left[1 + \Gamma\ e^{-j\frac{4\pi h}{\lambda}}\right] \tag{6}$$

where

Γ = the reflection coefficient of the ground at vertical incidence, and is a function of conductivity, dielectric constant and frequency.*

For a half-wave dipole at h = $\lambda/4$, the field in the vertical direction becomes

$$E_O = j\ 60\ K\ I_O\ \left[1 - \Gamma\right] \tag{7}$$

Thus, the power gain in the vertical direction of a short dipole at any height, relative to that of a half-wave dipole at quarter-wave height, is given by:

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* Ramo and Whinnery - Fields and Waves in Modern Radio - 2nd Edition, p. 307

$$G_o = \frac{|E_1|^2}{|E_o|^2} = \pi^2 \frac{I_1^2}{I_o^2} \left(\frac{L_e}{\lambda}\right)^2 \frac{\left|1 + \Gamma e^{-j\frac{4\pi h}{\lambda}}\right|^2}{|1 - \Gamma|^2} \tag{8}$$

But for constant power delivered to both antennas:

$$I_1^2 R_1 = I_o^2 R_o$$

where

R_o = Resistive component of input impedance at the center of the half-wave dipole,

R_1 = Equivalent value for short dipole.

Then:

$$G_o = \frac{R_o}{R_1} \pi^2 \left(\frac{L_e}{\lambda}\right)^2 \frac{\left|1 + \Gamma e^{-j\frac{4\pi h}{\lambda}}\right|^2}{|1 - \Gamma|^2} \tag{9}$$

Also, it can be shown that, for short dipoles –

$$R_{R_1} = \frac{80 \pi^2 (L_e)^2}{\lambda^2} \ *$$

where R_{R_1} = Radiation resistance of short dipole.

Thus,

$$G_o = \frac{R_{R_1}}{R_1} \frac{R_o}{80} \frac{\left|1 + \Gamma e^{-j\frac{4\pi h}{\lambda}}\right|^2}{|1 - \Gamma|^2} \tag{10}$$

---

* Jasik - Antenna Engineering Handbook - p. 2-11

But: $\dfrac{R_{R_1}}{R_1} = \dfrac{\text{Power radiated}}{\text{Power input}} = \eta = \text{efficiency}$

Finally, $\quad G_o = \eta \, \dfrac{R_o}{80} \, \dfrac{\left| 1 + \Gamma \, e^{-j\frac{4\pi h}{\lambda}} \right|^2}{\left| 1 - \Gamma \right|^2}$ (11)

D.2 GAIN OF SHORT DIPOLE ABOVE GROUND; RELATIVE TO A HALF-WAVE DIPOLE AT THE SAME HEIGHT

Using equations (4) and (5) above, the far field of the short dipole at any point in the equatorial plane, is given by:

$$E_1 = j \, 60 \, \pi \, K \, I_1 \, \frac{L_e}{\lambda} \left[1 + \Gamma(\phi) \, e^{-j\frac{4\pi h \sin \phi}{\lambda}} \right]$$ (12)

where

$\Gamma(\phi) = $ the reflection coefficient of the ground at incidence angle ϕ

The far field of the half-wave dipole at the same point is

$$E_o' = j \, 60 \, K \, I_o' \left[1 + \Gamma(\phi) \, e^{-j\frac{4\pi h \sin \phi}{\lambda}} \right]$$ (13)

where $I_o' = $ current at center of the half-wave dipole when elevated to a height h, above ground.

The relative gain is then

$$G_o' = \frac{|E_1|^2}{|E_o'|^2} = \pi^2 \, \frac{I_1^2}{I_o'^2} \left(\frac{L_e}{\lambda} \right)^2$$ (14)

Substituting for L_e, and again assuming constant power to both antennas,

$$G_0' = \eta \, \frac{R_0'}{80}$$

where R_0' = input resistance at center of half wave dipole at height h (15)

Note that this is an expression for the relative gain of the two antennas at any point in the equatorial plane. It is this fact which is the basis for the measurement procedure used.

APPENDIX E
PROCEDURE AND ARRANGEMENT FOR FIELD STRENGTH
MEASUREMENT
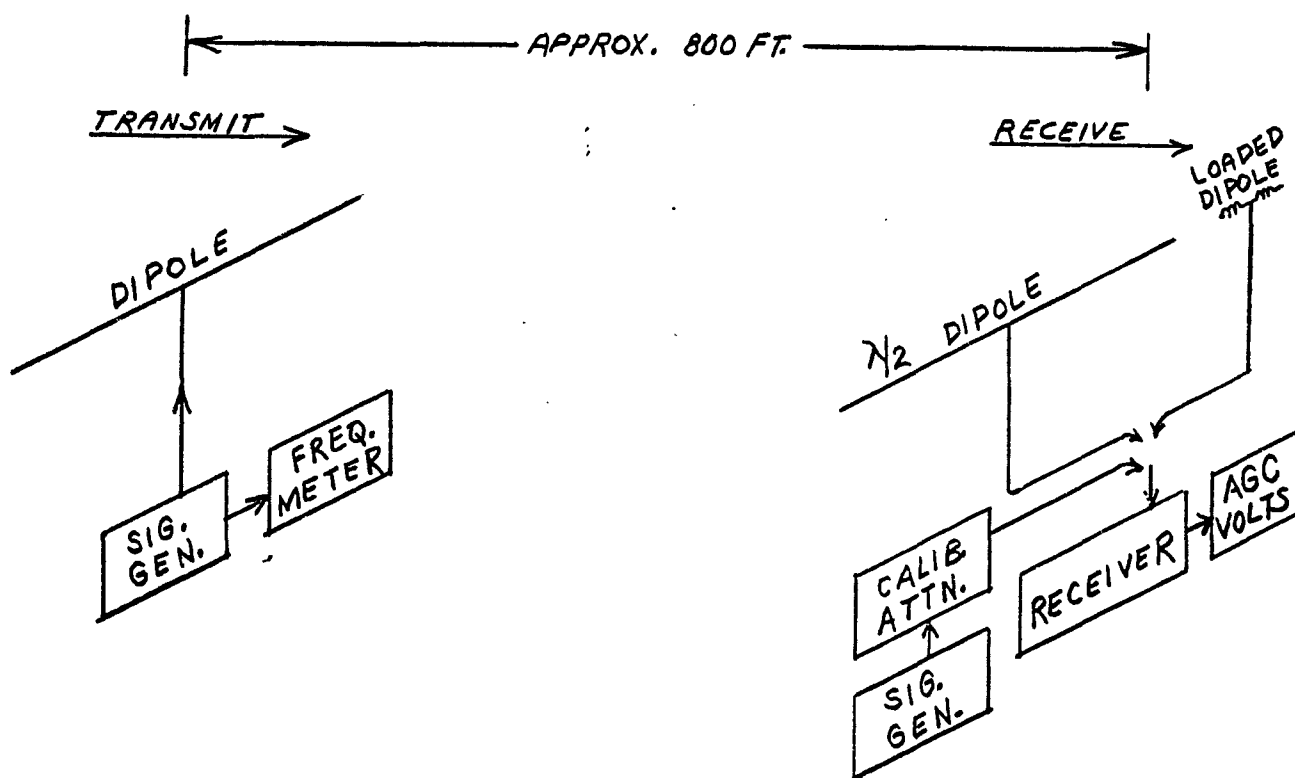
Test Arrangement Diagram

E. 1   TEST PROCEDURE

1. Transmitting and Receiving on same frequency.

2. Constant power delivered to the transmit antenna.

3. $\lambda/2$ dipole connected to Receiver - measured AGC volts.

4. Loaded dipole connected to Receiver - measured AGC volts.

5. No mutual coupling existed between $\lambda/2$ dipole and loaded dipole.

6. Measurements 3. & 4. done for 28', 21', 14', and 7' heights.

7. The calibrated attenuator provided the equivalent DB input differences corresponding to the measured AGC voltage differences.

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8. The following measurements were also taken:

    (a)   transmission line loss.

    (b)   transmission line length.

    (c)   antenna impedance measured thru transmission line

9. The differences of the maximum available powers between the $\lambda/2$ dipole and the loaded dipole were computed.

10. Appropriate corrections were applied in 9. to compensate for

    (a)   losses due to transmission line length

    (b)   losses due to VSWR on line

    (c)   losses due to impedance mismatch between antenna and transmission line.

REPORT ON FIELD TRIP TO REPUBLIC OF PANAMA
10/2/62 TO 10/18/62

F.1   PARTICIPANTS

N. Artuso - RCA M&SRD

F. Wezner - RCA M&SRD

J. Rabinowitz - RCA Surf Com   New York

Leroy Craig - USAERDL - Ft. Monmouth (Program Director)

M. Kaplan - USAERDL - Ft. Monmouth

W. Librizzi - USAERDL - Ft. Monmouth

F.2   PURPOSE AND SUMMARY

The purpose of the trip was to make preliminary evaluations of the effects of jungle growth on radio transmission, antenna efficiency and antenna erection techniques.   The work was done in a tropical rain forest near Chepo, Panama, in conjunction with Project Swamp Fox II, U. S. Army Corps of Transportation.

Horizontal and vertical HF and VHF antennas were erected on masts and in trees at a base camp and at a jungle site 15 miles distant.   The transmission path consisted of five miles of jungle and ten miles of hilly pasture land.   The hills were up to 300 feet high.   CW communication was established with base camp at HF using both vertical and horizontal antennas.   It is believed that transmission was via the ionosphere.   VHF communication was unsuccessful.   However, PRC-25 VHF radios and whip antennas were useful for transmission, as a pack set, up to one mile through dense jungle growth.

Insulated wires were draped over the tops of the trees using an M-1 rifle with grenade launcher.   The impedance of these wires were measured to determine if the foliage noticeably altered the impedance.   There were no noticeable effects on the resonant frequency of the wires.

Antennas can be supported in trees beginning at the 20 foot level, and it is possible to penetrate skyward with wire or masts.   Any mast design must

be lightweight, small, smooth contour and preferably not protrude from the contour of a man's body when carried on the back. This is important for effective mobility through the forest underbush.

A secondary purpose of the trip was to select a site for future, more extensive tests. A site in the Canal Zone was found which provides the necessary jungle environment within a few miles of desired base facilities. Accurate contour plots of the area are available, and local Army authorities have promised cooperation in making facilities available.

F.3 GENERAL DISCUSSION OF TEST SITES

The area visited is shown in Figure 1. Base Camp was a tent camp located approximately 45 miles from Panama City and served as a field headquarters for Swamp Fox II under the command of Col. Dawson. This operation was primarily set up for testing vehicles in severe jungle conditions. The camp was located in a meadow surrounded by hills approximately 200 to 300 feet high. A vehicle test course was located about five (5) miles from the base camp on higher ground and through dense jungle growth in a horseshoe-like shape, off a dirt road. Both of these sites were considered as possibilities for our tests and evaluation.

In general, the vehicle test course area was fairly dense jungle growth about 30 to 40 feet high. Lower undergrowth was sparse and penetration was possible with the aid of a machete. There were occasional small clearances, some of which extended skyward. Very large trunked trees 70 to 80 feet high dotted the area in random fashion. Palm type trees, 40 to 50 feet high, also populated the area. Some logging had been done in this area, and as a result, secondary growth existed in some sections where trees had fallen. Support for a vertical type antenna could be established at the 15 to 20 foot level.

Since this area did not have a higher primary canopy type growth and accessibility to the growth with equipment was difficult (the test equipment would have to be transported by tractor type truck over very difficult terrain

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for about three quarters of a mile), and interference from the vehicles was inevitable, it was decided to inspect other areas.

A forest reserve located within the Canal Zone looked like a possibility and was visited. This area is shown in Figure 1. It was similar to the vehicle test area except that it was populated with more tall trees, some of which were 100 feet high. Accessibility was by paved highway and the growth could be penetrated through already wide cut paths. Initial inquiries indicated a time consuming job of getting permission to use the area (too long for this trip) so it was decided not to run the test here.

A site originally selected for the base camp located about fifteen (15) miles from the present base camp and known as the Siligandi area was visited. Growth in this area was higher. The primary growth was about 40 to 50 feet high. Large trees 80 to 120 feet high populated the area in a random manner. They did not, however, form a canopy at this level. They could, however, be used to support a vertical mast section beginning at 15 to 20 feet. Other supports were also possible from lighter trees. The undergrowth was fairly dense and interwoven with vines and light foliage. Test equipment could be transported by helicopter and the brush immediately adjacent to the clearing could be used to set up equipment and run tests. The transmission path back to the base camp was observed by helicopter to be virgin hills up to 300 feet high covered at one end with five (5) miles of jungle and at the other end with 10 miles of grass and intermittent brush. Quarters could be established in a bohio (grass hut) located about a half mile from the clearing and near the Siligandi river. This area was chosen as one of the test sites.

F.4   BASE CAMP SITE

Test equipment shipped from Moorestown arrived on October 7. Arrangements were made for its release from Panama Customs through Canal Zone Customs and the equipment was delivered to the Base Camp by helicopter on October 9. For future trips, equipment should be sent to the Canal Zone rather than to a broker whose address is the Republic of Panama.

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Several antennas were erected at the Base Camp including an AT 791 vertical antenna, a 45 foot vertical mast for use as an HF monopole, a beacon, and a center fed horizontal heliwhip. Also, a center fed horizontal antenna (approximately 100 feet long and 30 feet off the ground) was erected for the Base Camp radio operator for communication with Fort Kobbe. He was not successful with a vertical whip. However, the horizontal antenna was successful. The AT 791 was erected using standard Signal Corps mast sections, each five feet long. The height was 45 feet to the antenna base and the mast was guyed at two levels at 120 degree ground positions. Six (6) men were used to erect this antenna. It was erected in a clearing about 80 feet in diameter near the Base Camp and adjacent to an orange grove. The growth around the antenna ranged in height to 30 feet and consisted of light foliage and orange trees.

Two heliwhips (each six feet long consisting of a wire wrapped in a helical fashion around a dielectric tube approximately 1/2" diameter) were mounted perpendicular to the axis of a fiberglass tube (2" OD x 30" long). This tube was attached to a standard Signal Corps mast section and using several five (5) foot sections was raised to a height of 40 feet. This antenna was directed toward the Siligandi area. It was guyed at one level to 120-degree ground positions. The growth around this antenna consisted of orange trees 30 feet high in the rear and very short foliage 2 to 4 feet high in front. This antenna was located approximately 300 feet from the AT 791 antenna.

F. 5   SILIGANDI SITE

The same type antennas were erected on this site that were erected at the Base Camp. In addition, wire 125 feet and 150 feet long were launched across the top of the trees.

The heliwhips were elevated to 40 feet using the standard mast sections, directed toward the Base Camp and guyed at one level at 120-degree ground positions. Using the TRC-77 and feeding the heliwhips as a dipole at 8.05 mc, code communication was established with the Base Camp. A 28 foot vertical wire was elevated into a tree and also used with the TRC-77. Code communications with the Base Camp was established at 8.05 mc. These antennas were located approximately 70 feet from each other. The 28 foot vertical antenna was inside the jungle brush and the heliwhips were located in a clearing about 20 feet from growth approximately 50 feet high.

An "80 pound" cross bow with a brass arrow was used to launch lacing cord into trees 20 to 40 feet high for the purpose of pulling up antennas. This method was satisfactory in clearings, but not satisfactory in any growth. The arrow became unstable when fired into even very sparse foliage. The M-1 rifle was used to launch practice grenades. Multi-conductor copper standard insulated wire attached to the grenades and fired over the trees draped lengths of 125 feet and 150 feet across the tree tops. These grenades were launched from a clearing and into light foliage at the canopy top. This light foliage did not affect the path of the grenade. The M-1 rifle and grenade were also used in an attempt to launch a 3/16" dacron rope into a tree approximately 75 feet high. The grenade, set at the top launcher position, carried the wire to the 75 foot height but was not heavy enough to fall to the ground bringing up the other end of the rope. Lacing cord was used for this purpose and an AT 791 elevated to this height.

The impedance of the 125 foot and 150 foot wires was measured as follows:

125 foot wire
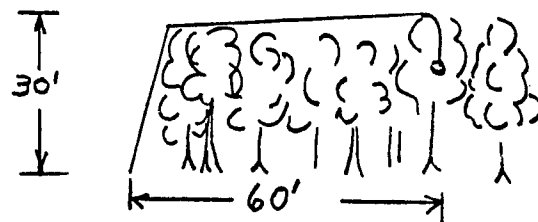
2.5 mc   130 + J300
3.0 mc   300 + J600
2.1 mc   100 + J90

150 foot wire

3.6 mc   210 - $\dfrac{J1900}{3.6}$

4.5 mc   160 - J83

5.0 mc   260 + J220

It is clear that the resonant frequency (zero reactance) of the 125' wire is near 2.0 mc and the 150' wire is near 4.6 mc. This corresponds to resonant lengths of 0.253 λ and 0.704 λ, respectively. Therefore, the reactive contributions of foliage made less than a ten percent shift in resonant frequency from theoretical values. This shift is within the limits of the equipment accuracy. It is tentatively concluded that an insulated wire laying on top of trees is not noticeably detuned.

F.6   FUTURE TEST SITE

Lt. Col. Larson, head of Caribbean R&D was contacted, and through his cooperation and recommendations, arrangements were made to visit Fort Sherman and Fort Davis located on the Atlantic side of the Canal Zone. Col. Olson, C.O. Fort Davis, assigned Lt. Meeks to guide us through the jungle

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125 foot wire

30'

60'

2.5 mc   130 + J300
3.0 mc   300 + J600
2.1 mc   100 + J90

150 foot wire

75'

75'

$$3.6 \text{ mc} \quad 210 - \frac{\text{J}1900}{3.6}$$

4.5 mc   160 - J83

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It is clear that the resonant frequency (zero reactance) of the 125' wire is near 2.0 mc and the 150' wire is near 4.6 mc. This corresponds to resonant lengths of 0.253 λ and 0.704 λ, respectively. Therefore, the reactive contributions of foliage made less than a ten percent shift in resonant frequency from theoretical values. This shift is within the limits of the equipment accuracy. It is tentatively concluded that an insulated wire laying on top of trees is not noticeably detuned.

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area near the Gatun Locks and Fort Davis. The type of jungle growth is similar to that in the Siligandi area. Undergrowth density is about the same. Very tall trees populate the area in a random manner. The Fort Sherman area is the same. Sharply rising hills 350 to 600 feet high make up the contour from Fort Sherman south to Escobal. The area is total jungle and very little has been cleared as between the Base Camp and Siligandi area. Access from Fort Davis to either Fort Sherman or Escobal is good. Sites could be located at each end - approximately eight (8) miles apart - and headquarters set up at Fort Davis. Contour maps of this area were given to us by Lt. Meeks. This area lends itself to future controlled tests.
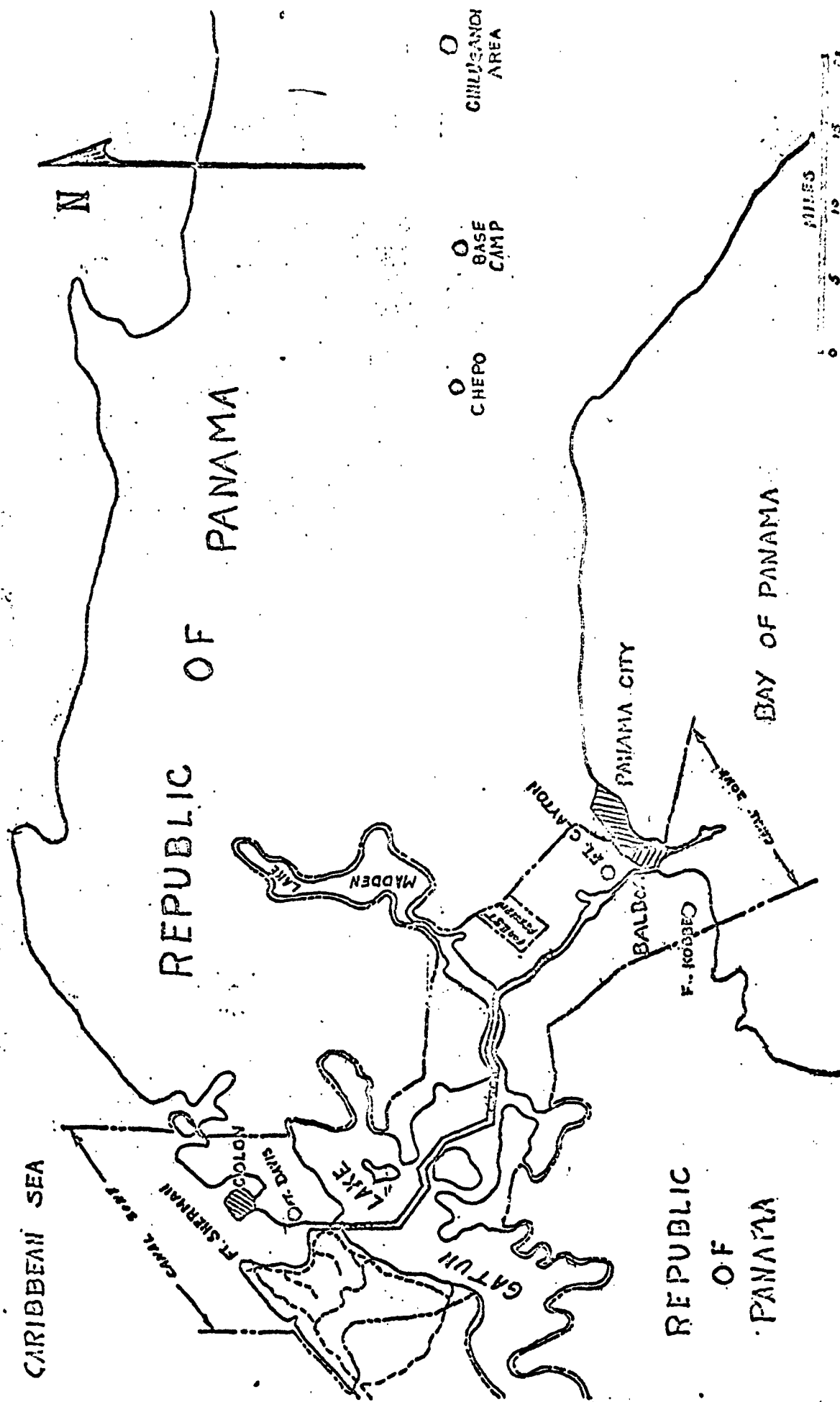
Figure 1. Site of Field Trip

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AD _____ Accession Number _____

Unclassified

Surface Communications Systems Laboratory
Radio Corporation of America, New York 13, N.Y.

TACTICAL JUNGLE COMMUNICATIONS STUDY-S. Krevsky.
N. Artuso, R. Mason, R. A. Thowless
Report for 21 March 1963 - p. incl. illustrations
Interim Report - DA-36-039-AMC-00011(E)
Unclassified Report

Present HF and VHF inter-troop communications equipment are unsatisfactory for operation in tropical rain forests. This is a direct result of excessive path losses for ground-wave and "line-of-sight" propagation, caused by dense jungle growth and tall trees. Purpose of the study was to devise antenna equipment that would improve the operational range of reliable communications, between/to "man-pack" equipment in dense jungle areas.

Results of the propagation study are presented, showing the utility of vertical-incidence, HF sky-wave transmission. Antenna design and antenna-erection methods particularly suited for jungle-patrol and base-camp operations using this mode of propagation are also presented.

Erection methods for HF dipoles at suitable heights were studied. Simultaneous estimates were made of efficiencies for various heights above ground. Foreshortening techniques for HF dipoles were studied.

Simple wire antennas, 10 to 30 feet above ground, were found to provide good efficiency and satisfactory low-power, HF sky-wave communications, potential for most severe jungle terrain circumstances.

Emphasis was also given to techniques, such as balloon-borne dipoles, for obtaining useful line-of-sight VHF transmissions.

1. Jungle Antennas
2. Jungle Radio Propagation
3. Antenna Erection Methods
I. Title: Tactical Jungle Communications
II. S. Krevsky, N. Artuso, R. Mason, R. A. Thowless
III. UAAELRDL
IV. Contract DA-36-039-AMC-00011(E)
Armed Services Technical Information Agency